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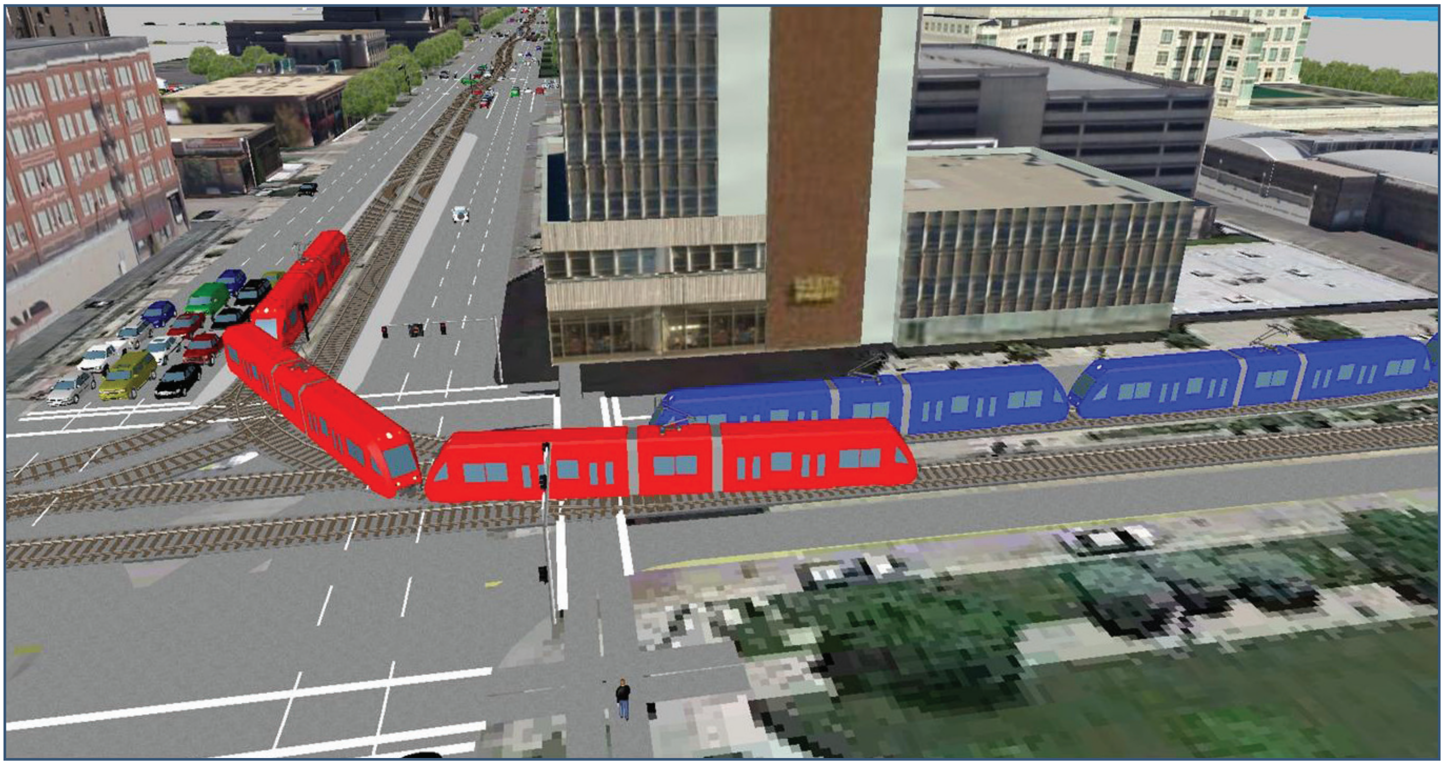
Traffic Modeling of Transit Oriented Development: Evaluation of Transit Friendly Strategies and Innovative Intersection Designs in West Valley City, UT



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TRAFFIC MODELING OF TRANSIT ORIENTED DEVELOPMENT: EVALUATION OF TRANSIT FRIENDLY STRATEGIES AND INNOVATIVE INTERSECTION DESIGNS IN WEST VALLEY CITY, UT

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ABSTRACT

Street networks designed to support Transit Oriented Development (TOD) increase accessibility for non-motorized traffic. However, the implications of TOD supportive networks for still dominant vehicular traffic are rarely addressed. Due to this lack of research, decision making in favor of TOD supportive street networks is often a difficult process. The goal of this project is to quantify the traffic impacts of TOD using a study network in West Valley City, Utah. In our methodology, the test network is modified using not only designs typical for TODs, but also some network designs that enhance traffic operations. Proposed network designs represent the alternatives to traditional street widening approaches that should increase traffic efficiency while not discouraging non-motorized modes. This approach would increase the potential of the test network to become a TOD in the future, with two Bus Rapid Transit (BRT) lines already in place. The results indicate that network designs that could be beneficial for TOD, such as enhanced street connectivity, innovative intersection designs, traffic calming measures and Transit Friendly Designs (TFD), do not necessarily decrease the efficiency of vehicular traffic for the most critical travel demand conditions. The major contributions of this study are the indications that TOD-supportive network designs are not necessarily associated with negative effects for vehicular traffic, even in conditions where mode shift does not occur and auto-mode travel demand remains the same. This is a significant finding that could be useful for metropolitan regions looking to retrofit the suburban neighborhoods into multimodal developments.

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EXECUTIVE SUMMARY

Transit Oriented Development (TOD) creates high density, mixed land use patterns with pedestrian friendly environment concentrated around transit stations. This enables people to walk to transit stops or to their daily destinations, and decreases the need for private vehicle use.

Throughout the Wasatch Front Metropolitan Region, the majority of land use development forces people to drive in order to access their destinations. This is due to low density and mostly single use developments built on poorly connected street networks with several cul-de-sacs and few routing options for transport system users. Even though the development of Wasatch Front has the legacy of transit supportive land uses in the region’s city centers and previous street car suburbs, the connection between them is still such that it encourages driving as the dominant mode of transportation. Designing streets and street networks that would support TOD environments is still considered with hesitation as the potential solution for traffic congestion and increasing travel demand. One of the reasons for this might be the need to evaluate the effects that TOD has on traffic operations.

This project aims to quantify the traffic impacts of TOD using a study network located in West Valley City, Utah, bordered by 3500 S and 4700 S (north-south), and 4800 W and 5600 W (east-west). This part of West Valley City will go through many development and land use changes in the next 15 years. The Mountain View Corridor is being built along 5600 W, and many other road and transit projects are planned in the vicinity. This area will be focused on transit use, so there is a need to design the best possible TOD features for the planned conditions.

The purpose of TOD is to motivate people to change their travel mode choices. Built environment could be the answer to this challenge. Changing the environment to accommodate walking and transit vehicles could increase the number of transit users. The main points and guidelines of the literature review have been adapted and applied to the project network. The design principles are given separately for each set of improvement measures. The improvement measure designs given in this document are:

- Enhanced street connectivity
- Traffic calming measures
- Innovative intersections
- Transit friendly designs

Once the designs were reviewed, edited, and approved by UTA, we created detailed design for each measure and applied them to the project network. Performance evaluation measures we used are related to traffic analysis, street connectivity, and transit accessibility. The report provides recommendations for future development of the observed network into a TOD-supportive environment.

1. INTRODUCTION

As our urban network traffic grows, we address congestion in a variety of ways. We increase the capacity of the network through improved traffic management, and we apply Intelligent Transportation Systems to optimize our resources. This capacity-based approach is overshadowed by the near default approach, which is simply to expand our roads with extra lanes and larger intersections. This serves to meet increasing traffic demand through increasing highway capacity. Collectors become distributors, which grow into arterials, which evolve into major highways. At a certain level, roads sever communities rendering pedestrian movements unfeasible.

So while this often repeated development has been shown to accommodate traffic growth, at least for a while, it does little to promote transit, bikes, and walking. We know that Transit Oriented Development (TOD) helps communities grow in a way that promotes accessibility and mobility, but we do not understand the traffic implications. This project takes a partially developed urban network in West Valley as its field case, and models the relationship between TOD and traffic impacts. Taking contemporary principles of urban design, the study will take an existing network as a control, and compare its traffic characteristics to a proposed network. This new network will embrace the best practices of TOD and livable streets.

The goal of the project is to quantify the traffic impacts of TOD using a study network. The network selected for this project is located in West Valley City, Utah, bordered by 3500 S and 4700 S (north-south), and 4800 W and 5600 W (east-west), as shown in Figure 1.1. The following objectives are identified for this project:

- Comprehensive literature review of TOD strategies and impacts
- Development of different design principles
- Creation, calibration, and validation of base network models
- Development of enhanced TOD networks and corresponding models
- Analysis of traffic impacts
- Synthesis of available transit performance measures
- Measuring transit accessibility of base and enhanced network models
- Recommendations for future TOD on the analyzed site

This part of West Valley City will go through many development and land use changes in the next 15 years. The Mountain View Corridor is being built along 5600 W, and many other road and transit projects are planned in the vicinity. This area will be focused on transit use, so there is a need to design the best possible TOD features for the planned conditions.

The first chapter of this report is the introductions with the problem statement. The second chapter is the literature review on the relationship between travel and the built environment, with the purpose to introduce the effects that environments such as TOD have on transportation outcomes and travelers' choices. The third chapter of the report elaborates on the proposed design principles for the selected case study network. After meeting with experts from the DOTs, transit authorities, consulting, and academia, four design approaches were established to be evaluated within this study, including innovative intersection designs, enhanced connectivity, traffic calming, and transit friendly designs. Modeling methods for evaluation of these principles that have the potential to be TOD-supportive are presented in chapter four. Results and discussion are provided in chapter five, while chapter six represents some additional tools for transit accessibility measurements that can be used as indicators for TOD implementation. The final chapter presents the conclusions of the study.

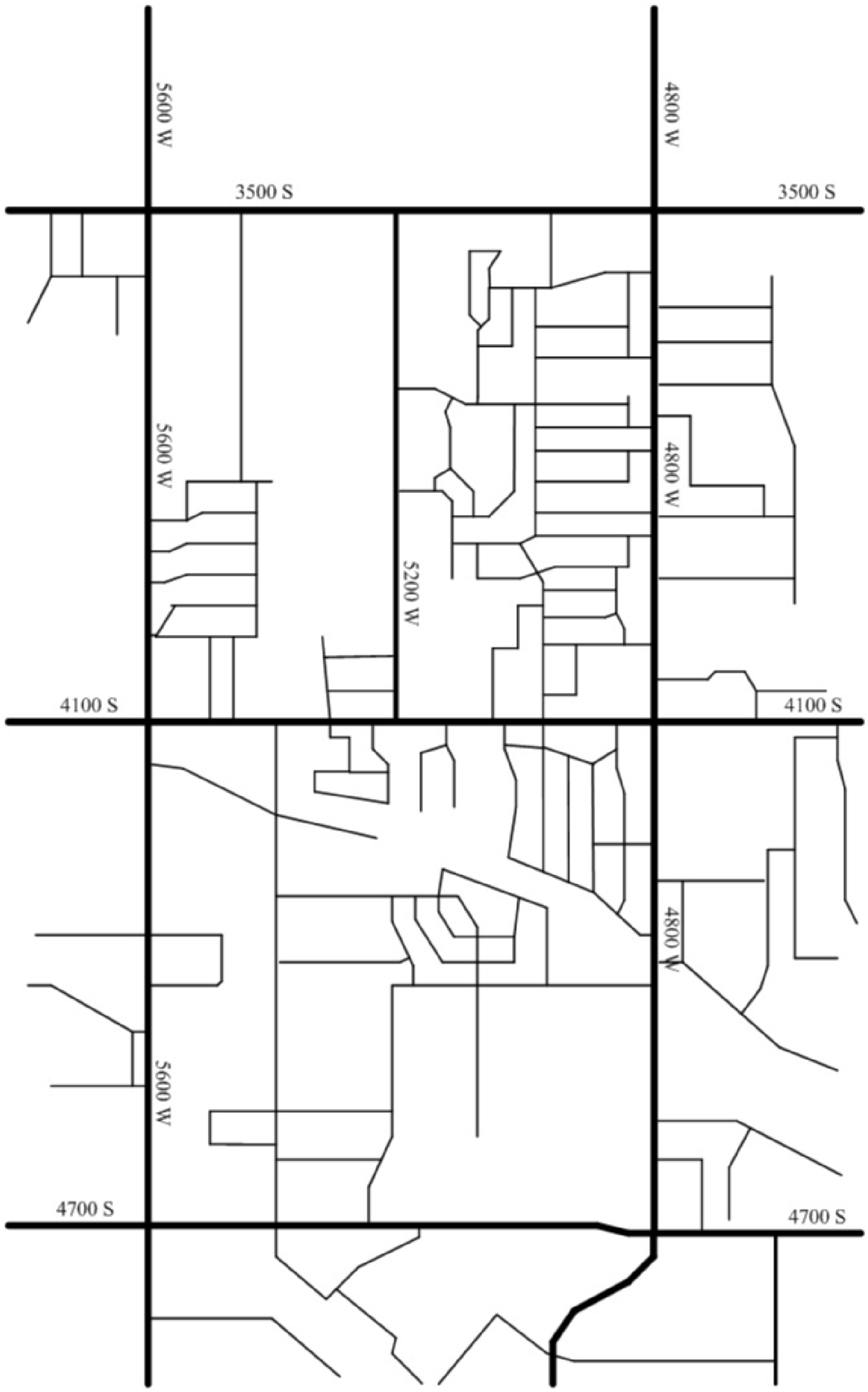


Figure 1.1 Project Network

2. LITERATURE REVIEW

2.1 Impact of Built Environment on Travel Choices

The purpose of TOD is to motivate people to change their travel mode choices. Built environment could be the answer to this challenge. Changing the environment to accommodate walking and transit vehicles could increase the number of transit users.

While TOD is defined as a strategy that concentrates housing, jobs and our daily needs around transit stations, creating a walkable environment and mixed land uses, the term TOD should not be confused with two other similar concepts. The first is a concept of Transit Friendly Design (TFD), focused on the design solutions that support transit and access to transit, explained in detail in chapter three of this report. The second is a concept of Transit Adjacent Development, which involves car-oriented environments near transit stations. These three concepts, TOD, TFD, and TAD, all represent different relationships between travel and built environment, addressed in the research reviewed in this chapter.

The first three papers, which are reviewed in this section, consider urban and land use planning as the solution for reducing automobile use. The first paper draws conclusions from many reviewed studies through meta-analysis. The second paper quantifies urban design principles that increase walkability. The third paper explains the impact of Mixed-Use Development on travel choices. This, in addition to the existing research on street connectivity, innovative intersection designs, traffic calming measures, and designs that support transit development in general.

This study (*2*) presents an effort to comprehensibly and objectively quantify subjective qualities of the urban street environment. Five qualities are the focus of the study: imageability, enclosure, human scale, transparency and complexity. The emphasis is on the subjective perception of the urban environment, rather than the mere physical characteristics, such as block length, street and sidewalk width, or building height. These physical characteristics do not tell much about the experience of walking down an urban street, and they do not capture people's perceptions of the street environment. The conceptual framework of the study is shown in Figure 2.1.

Travel and the Built Environment – A Meta-Analysis

Meta-analysis conducted by Ewing and Cervero (*1*) is the most extensive study on the relationships between the built environment and travel choices available to date. This study summarizes findings from 62 studies on associations between the built environment and travel. The authors looked for the characteristics of built environment that affect motorized and non-motorized trips. The purpose is to measure the magnitude of such relationships.

The authors started this research with their previous study from 2001, where they reviewed 14 studies in this area. This meta-analysis includes more studies. The authors used different web search tools, existing literature reviews, and Transportation Research Board papers. They contacted other researchers from this area and, finally, collected more than 200 studies that relate built environment to travel.

Meta-analysis is the summary of findings from the collected studies. This approach uses summary statistics from individual primary studies as the data points in the new analysis. The main advantage of meta-analysis is that it aggregates all previous research on a topic, allowing common threads to emerge. The drawback is combining stronger studies with weaker ones that may contaminate the results.

Meta-analysis requires a common measure of effect size to combine results from different studies. The common measure was the elasticity defined as the ratio of the percentage change in one variable with the percentage change of other variable. In this case, the authors measured the elasticity of some travel outcome with respect to one of the D variables:

- Density is the variable of interest (population, employment, vehicles) per unit of area
- Diversity is the number of different land uses in the given area and the degree to which they are represented in land area, floor area, or employment. Low diversity values indicate single-use environments. Higher diversity values indicate more varied land uses.
- Design includes block size, proportion of four-way intersections, number of intersections per square mile, sidewalk coverage, average building setbacks, average street width, number of pedestrian crossings, street trees, and other elements typical for pedestrian-oriented environments.
- Destination accessibility may be regional or local. Regional accessibility is the distance to the central business district. Local accessibility is the distance from home to the closest store.
- Distance to transit is an average of the shortest street routes from the residencies or workplaces in an area to the nearest rail station or bus stop. It can also be measured as transit route density, distance between transit stops, or the number of stations per unit area.

The authors found that the relationships between travel variables and built environment variables are inelastic. However, the combined effect of several built environment variables on travel could be quite large.

Table 2.1 Impacts of Built Environment D Variables on Travel Choices (*1*)

Travel Choice	Significant D Variable (Descending Significance)
Motorized Trips	1) Destination Accessibility 2) Distance to Downtown 3) Design (Intersection Density, Street Connectivity)
Non-Motorized Trips	1) Intersection Density 2) Jobs-Housing Balance 3) Distance to Stores 4) Distance to Transit Stops (less than 0.25 miles) 5) Street Connectivity 6) Land Use Mix

The approach of this study is to link specific physical features to urban design quality ratings. For this purpose, a panel of 10 urban design and planning experts from professional practice and academia has been assembled to participate in the study. The role of the panel members was to qualitatively define urban design qualities of streetscapes, rate different scenes according to these qualities, explain their ratings, discuss the ways of measuring urban design qualities, and review the field survey methodology. The panel members were shown dozens of video clips of different streetscapes from different cities across the United States. The investigators developed a filming technique to mimic the experience of pedestrians with motion, movements, peripheral vision, and scanning the environments. The panelists rated scenes and commented on the physical features that impacted their ratings with respect to each urban design quality.

The panel ratings were used as dependent, and the physical characteristics of the street environment as independent, variables in the estimation of statistical models. These models helped answer several questions: which physical characteristics are statistically associated with each perceptual quality; what is the direction of the association; what are the physical characteristics that impacted the variation in ratings of each quality; and what is the share of total variation in rating. These models helped select the five qualities: imageability, enclosure, human scale, transparency, and complexity. Coefficients that determine the level of significance of different features for each quality are calculated and used to sort those features.

Imageability can be defined as a quality of a physical environment that evokes a strong mental image in an observer. It is a quality of a place that makes it distinct, recognizable, and memorable. The study found that the following features have the most impacts on imageability (in order of significance):

- Number of people
- Proportion of historic buildings
- Number of courtyards, plazas, and parks
- Presence of outdoor dining
- Number of buildings with non-rectangular silhouettes
- Noise level (the only negative relation to perceptions)
- Number of major landscape features
- Number of buildings with identifiers

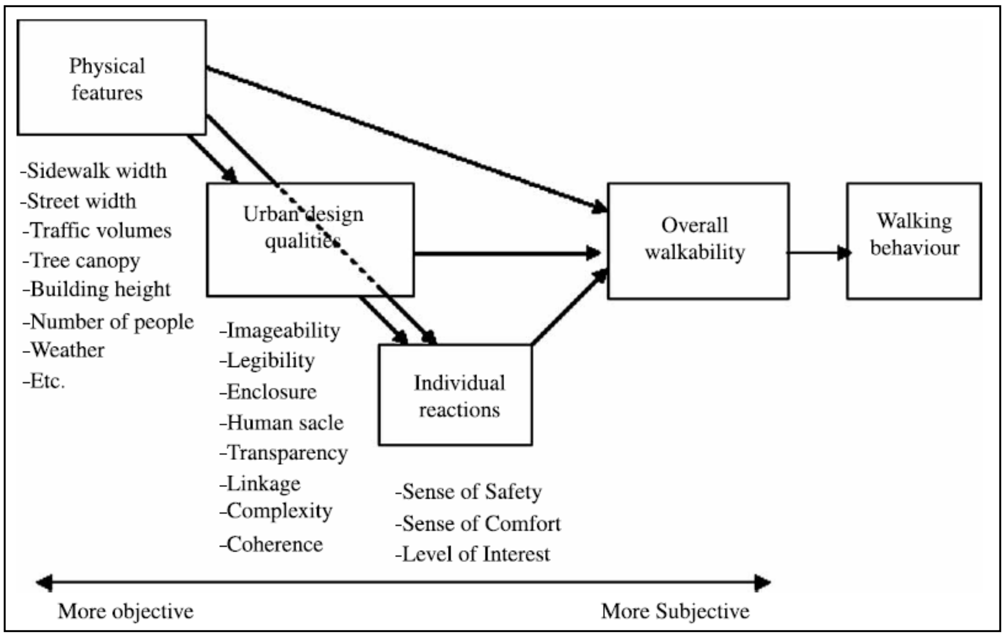


Figure 2.1 Conceptual Study Network (*2*)

Enclosure can be referred to as the degree to which streets and public spaces are visually defined by buildings, walls, trees, and other vertical elements. The study found the following features to significantly contribute to the perception of enclosure (in order of significance):

- Proportion of street wall (same and opposite side of street)
- Proportion of sky across street
- Number of long sight lines
- Proportion of sky ahead

Human scale refers to a size, texture, and articulation of physical elements that match the size and proportion of humans, and correspond to the speed of human walking. The most important features that contribute to the human scales found in the study are (in order of significance):

- Number of long sight lines
- Number of pieces of street furniture and other items

- Proportion of the first floor with windows
- Building height
- Number of small planters

Transparency refers to the degree to which people can see or perceive beyond the edge of a street. For the most part, it takes into account the degree of human activity that can be seen or perceived from the street. The study identified three features that significantly contribute to the perception of transparency (in order of significance):

- Proportion of the first floor with windows
- Proportion of active uses
- Proportion of street wall

Complexity refers to the visual richness of a place. It is related to the number of noticeable differences to which a viewer is exposed. The study identified six features that significantly contribute to the perception of complexity (in order of significance):

- Number of people
- Number of dominant building colors
- Number of buildings
- Presence of outdoor dining
- Number of accent colors
- Number of pieces of public art

The results of the study can be used in research, planning, and design of urban streets and public spaces. Researchers can measure urban design qualities in efforts to explain walking, use of public space, and other potential outcomes. Planners can assess physical characteristics of these qualities to identify problems and develop strategies for improving public spaces. Urban designers can give more attention to the features that are shown to be associated with each urban design quality. The findings of this study are of major importance when designing a TOD.

The purpose of this study (*3*) is to develop a methodology that would more accurately predict the traffic impacts of mixed-use developments (MXDs). It is estimated that the existing trip generation methodology does not capture the role of the MXDs the right way. The study uses data from six large and diverse metropolitan regions. Hierarchical modeling was used to estimate models for internal capture of trips within MXDs, walking and transit use on external trips, and trip length for external automobile trips. An accurate estimation of the proportion of internal trips within MXDs is important for an effective use of available land and developing master plans that would minimize traffic congestion.

Currently, the traffic impact analysis uses trip generation rates given in the Institute of Transportation Engineers (ITE) Trip Generation Manual. Although it provides a simple and straightforward methodology, it has certain weaknesses when dealing with MXDs. The following are defined as weaknesses of this methodology:

- It is based on a limited number of multi-use sites from Florida, so it needs a recalibration when used for different sites
- Only residential, retail, and office land uses are included in the methodology
- The scale of development is disregarded; the manual does not distinguish large and small sites
- The land use context of development is ignored
- The possibility of mode shift is not explicitly considered
- The length of external private vehicle trips is not considered

The study proposes a framework (also shown in Figure 2.2) in which travel to/from MXDs is conceived as a series of choices. Based on this, a methodology for adjusting ITE trip generation rates is proposed as follows:

- The first adjustment is made for trips that remain within the development; destination choice is conceived as dichotomous, where a traveler may choose a destination within or outside the development
- The second adjustment is made for walking or transit use for trips that leave the development; mode choices are conceived as dichotomous, where a traveler may choose to walk or not and to use transit or not
- The last adjustment is made for external personal vehicle trips, where the traveler chooses a destination that can be near or far

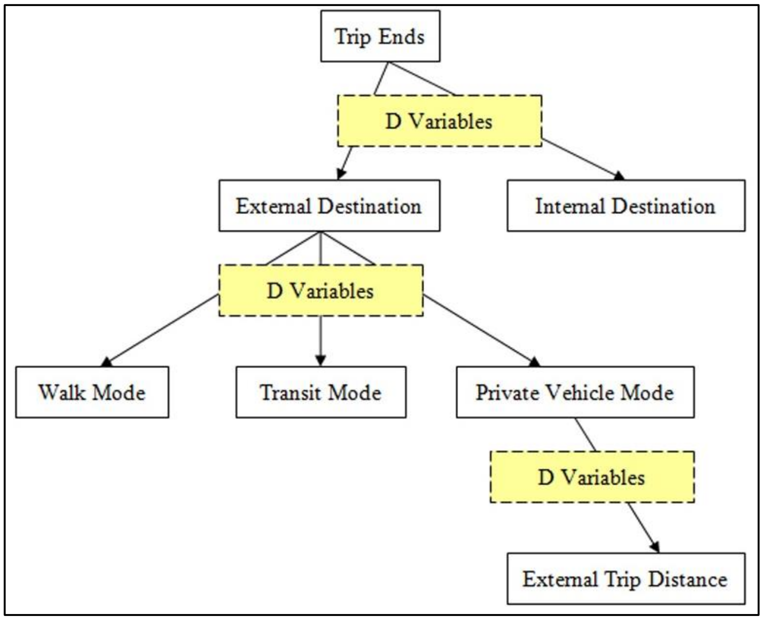


Figure 2.2 Framework and Traffic Impact Adjustments (*3*)

The researchers had to select a number of metropolitan regions to apply their methodology. The main criterion for selection was data availability. The data needed were on regional household travel surveys with XY coordinates for trip ends, and land use databases at the parcel level with detailed land use classification. Among the many metropolitan regions, six satisfied the criterion: Atlanta, Boston, Houston, Portland, Sacramento, and Seattle.

The proposed methodology defines data and model structure as hierarchical. The choices facing travelers are modeled in a three-level framework. Individual trips uniquely identified within MXDs form Level 1, MXDs form Level 2, and regions form Level 3. Models were estimated with HLM 6 software (Hierarchical Linear and Nonlinear Modeling). Linear models were used for the continuous variables (trip distance), while nonlinear models were used for the dichotomous variables (internal/external, walk/other, transit/other). Table 2 presents the list of variables that were used within this model.

Table 2.2 Model Variables (*3*)

Outcome Variables	Definition
INTERNAL	Dummy variable indicating that a trip remains internal to the MXD (1=internal, 0=external)
WALK	Dummy variable indicating that the travel mode on an external trip is walking (1=walk, 0=other)
TRANSIT	Dummy variable indicating that the travel mode on an external trip is public bus or rail (1=transit, 0=other)
TDIST	Network trip distance between origin and destination locations for an external private vehicle trip, in miles
Explanatory Variables	
	Level-1 Traveler/Household Level
CHILD	variable indicating that the traveler is under 16 years of age (1=child, 0=adult)
HHSIZE	Number of members of the household
VEHCAP	Number of motorized vehicles per person in the household
BUSSTOP	Dummy variable indicating that the household lives within ¼ mile of a bus stop (1=yes, 0=no)
	Level-2 MXD Level Variables
AREA	Gross land area of the MXD in square miles
POP	Resident population within the MXD
EMP	Employment within the MXD
ACTIVITY	Resident population plus employment within the MXD
ACTDEN	Activity density per square mile within the MXD
DEVLAND	Proportion of developed land within the MXD
JOBPOP	Index that measures balance between employment and resident population within MXD
LANDMIX	Diversity index that captures the variety of land uses within the MXD
STRDEN	Centerline miles of all streets per square mile of gross land area within the MXD
INTDEN	Number of intersections per square mile of gross land area within the MXD
EMPMILE	Total employment outside the MXD within one mile of the boundary
EMP30T	Total employment accessible within 30-minute travel time of the MXD using transit
EMP10A, EMP20A, EMP30A	Share of total employment accessible within 10-minutes, 20-minutes, and 30-minutes travel time of the MXD using an automobile at midday
STOPDEN	Number of transit stops within the MXD per square mile of land area
RAILSTOP	Rail station located within the MXD (1=yes, 0=no)
	Level 3 Regional Explanatory Variables
REGPOP	Population within the region
REGEMP	Employment within the region
REGACT	Activity within the region (population + employment)
SPRAWL	Measure of regional sprawl

Four outcomes are modeled in this study: choice of internal destination, choice of walking on external trips, choice of transit on external trips, and distance of external trips by private vehicle. Models apply to trips produced by and trips attracted to MXDs and are estimated separately by trip purpose: home-based work, home-based other, and non-home-based.

For internal capture of trips, coefficients and their significance levels (p-values) are calculated for home-based work, home-based other, and non-home-based trips. The coefficients are elasticities of the odds of internal capture with respect to the various independent variables. In the case of home-based work trips, the odds of an internal trip decline with household size and vehicle ownership, and increase with an MXD's job-population balance. Therefore, the internal capture is related to two D variables: diversity and demographics. For home-based other trips, the odds of internal capture decline with household size and vehicle ownership, and increase with an MXD's land area, job-population balance, and intersection density. Internal capture for trips from home to non-work destinations is therefore related to development scale, diversity, design, and demographics. For non-home-based trips, the odds of internal capture decline with household size and vehicle ownership, and increase with land area, employment, and intersection density of the MXD. In this case, the internal capture is related to design, development scale, and demographics.

The results for the walk mode choice on external trips are also given for home-based work, home-based other, and non-home based trips. The analysis is based on the same coefficients as in the previous case. For external home-based work trips, the odds of walking decline with household size and vehicle ownership. They increase with job-population balance within the MXD and number of jobs outside the MXD within a mile of the boundaries. Therefore, walking on external home-based work trips is related to three types of D variables: diversity, destination accessibility, and demographics. For external home-based other trips, the odds of walking decline with household size and vehicle ownership, and with the land area of the MXD. These odds increase with the activity density of the MXD, the job-population balance within the MXD, and number of jobs outside the MXD within a mile of the boundaries. So this choice is related to development scale, density, diversity, destination accessibility, and demographics. For external non-home-based trips, the odds of walking decline with household size and vehicle ownership, and increase with the activity density of the MXD, the intersection density of the MXD, and the number of jobs outside the MXD within a mile of the boundaries. Walking on these trips is therefore related to measures of density, design, destination accessibility, and demographics.

The same approach is used for predicting transit mode choice on external trips. For external home-based work trips, the odds of transit use decline with household size and vehicle ownership. They increase with the intersection density of the MXD and the number of jobs within a 30-minute trip by transit. Transit use on home-based work trips is therefore related to measures of design, destination accessibility, distance to transit, and demographics. For external home-based other trips, the odds of transit use decline with household size and vehicle ownership, and increase with the activity density within the MXD. Finally, the odds of transit use on external non-home-based trips decline with household size and vehicle ownership per capita, and increase with the number of jobs within a 30-minute trip by transit.

The last output from the model is related to the trip distance for external automobile trips. The same approach and coefficients were used as in the previous cases. For external home-based work trips, trip distance increases with household size, vehicle ownership per capita, and land area of the MXD. The distance declines with a project's job-population balance and the share of regional jobs reachable within 30 minutes by automobile. Trip distance for these trips is therefore related to four types of D variables: development scale, diversity, destination accessibility, and demographics. For external home-based other trips, trip distance increases with household size and vehicle ownership. It declines with the job-population balance within the MXD and the share of regional jobs reachable within 20 minutes by automobile. Trip distance in this case is related to measures of diversity, destination accessibility, and demographics. For external non-home-based trips, trip distance increases with household size and vehicle ownership. It declines with the job-population balance within the MXD, intersection density within the MXD, and the share of regional jobs reachable within 20 minutes by automobile. External trip length for these trips is therefore related to measures of diversity, design, destination accessibility, and demographics.

The models were validated by comparing model estimates to in-field traffic counts on a sample of 22 MXDs for which traffic counts of external vehicle trips were available. The results showed that the models were capable of predicting a wide range of internal capture rates and mode shares for external trips, taking into account development scale, site design, and regional context. The model was able to predict total vehicle counts within 20% of the actual number of trips observed for 13 of the 22 validation sites, within 30% for four sites, and within 40% for another four. Only one site was off by more than 40%. A strong association was also observed between predicted and measured external vehicle counts using the developed models.

This study developed models that can be used to predict trip productions plus attractions for three separate trip purposes. The results can be used to adjust the current trip generation rates given in the ITE Trip Generation Manual. This is the first national study of the traffic generation by mixed-use developments. The study found that an average of three out of 10 trips generated by MXDs put no strain on the external street network and generate relatively few vehicle miles traveled. It also revealed the primary factors affecting this reduction in automobile travel as:

- The total and the relative amounts of population and employment on the site
- The site size and activity density
- The size of households and their auto ownership
- The amount of employment within walking distance of the site
- The block size on the site
- The access to employment within a 30-minute transit ride of the site

The study is aimed to help guide planners and developers of mixed-use projects on design features that would minimize traffic generation and negative impacts associated with it. It could also help produce new analysis techniques for a more realistic quantification of impacts and infrastructure size for mixed-use development plans. Since TOD encourages mixed-use development, the findings of this study can be important for the project we are dealing with.

2.2 Street Connectivity

Developing a network that would be able to accommodate transit in the future requires adjustments for multi-modal transportations systems. This network would not only include cars, but also transit, biking and pedestrian routes. In order to encourage alternative modes of transport, a network needs to be denser, with frequent intersections, short walking distances, route choice options, and good access management. In short, streets in the TOD network need to be better connected. The term street "connectivity" brings us back to "the original purpose of streets," where streets should connect and enable movements between different parts of the network (*4*). The quality of connections or the "connectivity" of the street network influences the accessibility of potential destinations and has important implications for travel choices, emergency access, and, more generally, quality of life (*4*). Street connectivity is a measure of density of connections serving the same origins and destinations in the street network. It relates to how an entire area is connected by a street system, both internally and externally (*5*).

The motives for increasing street connectivity include: reducing traffic on arterial streets, providing continuous and more direct routes, providing greater emergency vehicle access, and improving the quality of utility connections. Figure 2.3 shows the benefits of street connectivity. The Congress for New Urbanism is also promoting the concept of connectivity as part of an effort to create more livable and sustainable communities (*6*). The design principles that New Urbanists suggest for street connectivity include:

- Interconnected street network to disperse traffic and ease walking
- A hierarchy of narrow streets, boulevards, and alleys
- High quality pedestrian network

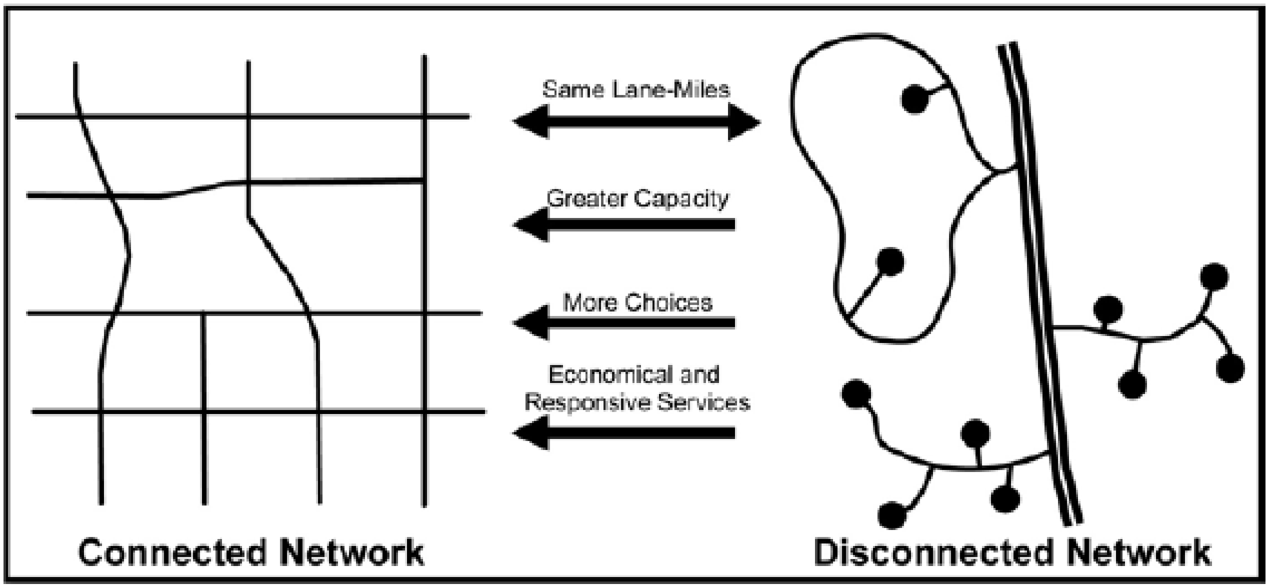


Figure 2.3 Benefits of Street Connectivity (*7*)

Street connectivity in the literature is usually presented in comparison to a "cul-de-sac" street pattern with dead-end streets. Here we examine connectivity versus expansion of arterial streets and present the existing measures of impacts that connectivity has on traffic. Increased connectivity will help (*8*):

- Decrease traffic on arterial streets
- Reduce travel time and VMT by creating shorter travel distances
- Provide continuous and more direct routes for walking and biking, and improve residents' health
- Provide better and redundant emergency vehicle access and reduce response time
- Provide improved utility connections, easier maintenance, and more efficient trash and recycling pick up
- Lower speeds and reduce accident severity
- Better accommodate transit use

Potential benefits of increased street connectivity are known; however, its traffic impacts are rarely quantified. It is certain that increased connectivity is more efficient than cul-de-sac patterns, although it raises some questions about community crime rates when compared to cul-de-sacs. But increasing connectivity and slowing down further development of arterial streets could lower the efficiency of the entire area network. Street connectivity in the existing literature will be reviewed from the cost-benefit perspective in comparison with arterial network expansion. The goal is to investigate potential parameters that could later be included in TOD modeling. Figure 2.4 shows the example of two neighborhoods with different levels of connectivity and explains the impacts on travel choices.

This image compares two typical suburban residential neighborhoods. The diameters of the circles are 1/4 mile, or about a 5 minute walk, which studies have shown to be the maximum distance most people are willing to walk to reach local destinations. Residents of the top neighborhood cannot walk to any nonresidential destinations within this radius. Thus, these residents are far more likely to use their cars for local trips than are those of the bottom neighborhood, who can easily walk to other houses, parks, and shops.

Figure 2.4 The example of two neighborhoods with different levels of connectivity (Source: New Jersey DOT)

U.S. Street Functional Hierarchy

Functional classification from the perspective of traffic engineers and community planners differs. Federal Highway Administration (FHWA) functional classification (*9*) is traffic oriented and recommends roadway design principles that relate to existing demand and requiring capacity. Planning oriented functional classification includes multi-modality, separates local from through traffic, and follows the concepts of sustainability and context sensitive design. While the definitions of freeways and expressways are similar, there are major differences between planners and traffic engineers related to street network design. Here we compare these two types of classification on the level of street network in order to establish the possible directions for future network development.

FHWA classification uses network density and functional class as inputs to the design process to control the basic size, speed, and accessibility of the roadway in the current design practice. Functional classification is the process by which streets and highways are grouped into classes, or systems, according to the character of service they are intended to provide. Defining the function that the roadway facility needs to serve is the first step in the design process. The level of service required for this function for the anticipated volume and composition of traffic is a basis for design speed and geometric criteria selection.

Functional classification of streets depends on the traffic and the degree of land access they allow (see Figure 2.5). Standard street classification includes arterial streets, collector streets, and local streets. There is a basic relationship between functionally classified highway systems in serving traffic mobility and land access. Arterials provide a high level of mobility and a greater degree of access control, while local roads provide a high level of access to adjacent properties but a low level of mobility. Collector roadways provide a balance between mobility and land access.

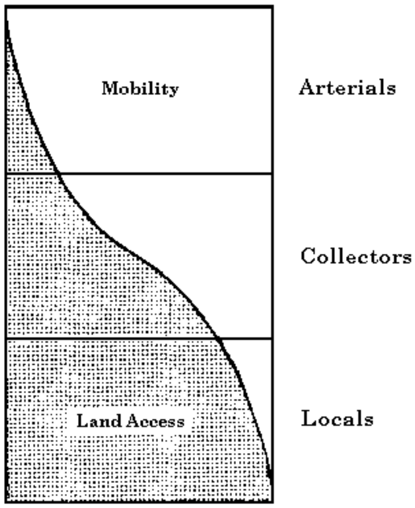


Figure 2.5 Relationship between Mobility and Land Access in FHWA Classification (source: FHWA)

Arterials provide the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control. They carry traffic between communities and connect communities to major intrastate and interstate highways.

Collectors provide a lower level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials. They convey traffic between arterials and from lower-order streets to arterials. They are the primary routes within residential and commercial areas.

Local streets primarily provide access to land with little or no through movement. Sub-collectors are local streets that provide frontage for individual lots and carry small amounts of through-traffic between collectors or from access streets to collectors. Access streets are local streets that provide frontage for individual lots and carry only traffic with an origin or destination on the streets themselves.

The joint ITE and the Congress for the New Urbanism project (*10*) proposed a functional classification that pairs existing design criteria with urban characteristics. Street connectivity is usually addressed as a part of context-sensitive design of street networks. It supports multi-modal transportation systems, walkability, and mixed use environments. Network density and functional class are used as inputs to the design process. They control the number of lanes, speed, and accessibility of the designed roadway. From the aspect of traffic engineering, street network development is focused on minimizing travel time and congestion. This approach tends to maintain network hierarchy and meet capacity-based needs. From the aspect of planning, streets' contribution to the community is also important. This approach is more open to various transport modes and promotes increased network density as an alternative to simple roadway expansion through lane addition. The goal of this classification system is to support diverse economic, social, and environmental needs of metropolitan communities.

The purpose of the joint ITE and New Urbanism project was to develop a street system concept that supports smart growth. The intent of this project was to encourage the practice of context-sensitive design. They introduced boulevards and avenues instead of major and minor arterials. Boulevards and avenues would accommodate local traffic to a greater extent than minor arterials. Collectors would no longer be used. Instead, connectors would link neighborhoods to town centers. The street system puts limits on the number of traffic lanes. It recommends reducing spacing between major streets rather than adding more lanes, in case more capacity is needed. Parking serves to shield and separate pedestrians from passing traffic. The purpose is to make walking as convenient as possible. The possible street typology is presented in Table 2.3.

Table 2.3 Possible Smart Growth Functional Classification (*10*)

Smart Growth	Conventional Equivalent	Max. Lanes	Max. Speed	Curb Parking	Adjacent Sidewalk	Functions under Smart Growth
Freeway	Freeway	6	55	No	No	Through, longer distance traffic
Expressway	Expressway	6	45	No	No	Through, longer distance traffic
Boulevard	Minor Arterial	6	35	Yes	Both Sides	Inter-neighborhood traffic and local circulation
Avenue	Minor Arterial	4	30	Yes	Both Sides	Inter-neighborhood traffic and local circulation
Connector	Collector	2	25	Yes	Both Sides	No collector function, connects to town, village centers
Local	Local	2	25	Yes	Both Sides	Local property access

The Federal Highway Function and Classification system contains the conventional classification system commonly accepted to define the functional and operational requirements for streets. Traffic volume, trip characteristics, speed and level of service, and other factors in the functional classification system relate to the mobility of motor vehicles, not bicyclists and pedestrians, and do not consider the context or land use of the surrounding environment. This approach, while appropriate for high speed rural and some suburban roadways, does not provide designers with guidance on how to design for living streets or in a context-sensitive manner. The street types described in Table 3 provide mobility for all modes of transportation with a greater focus on pedestrians. There is a need for greater flexibility in applying design criteria, based more on context and the need to create a safe environment for pedestrians. The Model Design Manual for Living Streets (*11*) describes the terms for street types that are more context-oriented and do not follow conventional classification so strictly. Table 4 below provides another list of possible street types.

Table 2.4 Possible Street Types according to Model Design Manual for Living Streets (*11*)

Street Type	Conventional Match	Description	Comment
Boulevard	Arterials	Traverses and connects districts and cities; primary a larger distance route for all vehicles including transit	Often has a planted median
Avenue	Collectors	Traverses and connects districts, links streets with boulevards, for all vehicles including transit	May or may not have a median
Street	Local Streets	Serves neighborhood, connects to adjoining neighborhoods, serves local function for vehicles and transit	
Alley (Lane)		Link between streets, allows access to garages	Narrow and without sidewalks

Well-planned street networks help create sustainable cities that support the environmental, social, and economic needs of their residents. Sustainable street networks improve traffic safety. Hierarchical street patterns with cul-de-sac subdivisions depending on arterials do not perform as well as sustainable street networks and cause more traffic crashes. Hierarchical street networks divert traffic to high-speed arterials that have large intersections. Most crashes occur at intersections. The speed on arterial streets increases the likelihood and severity of crashes. A 2011 study of 24 California cities found a 30% higher rate of severe injury and a 50% higher chance of fatality in cities dominated by sparsely connected cul-de-sacs compared with cities with dense, connected street networks (*12*). A 2009 study from Texas found that each mile of arterial is associated with a 10% increase in multiple-vehicle crashes, a 9.2% increase in pedestrian crashes, and a 6.6% increase in bicyclist crashes (*13*).

Sustainable street networks increase the number of people walking and bicycling and reduce vehicle miles traveled. Connectivity enables people to take shorter routes. It also enables them to travel on quieter streets, more conductive for bicycling and walking. These street networks allow more effective emergency response. Studies in Charlotte, North Carolina, found that when one connection was added between cul-de-sac subdivisions, the local fire station increased the number of addresses served by 17%. Emergency responders favor well-connected networks with a redundancy of routes to maximize access to emergencies.

These studies and others provide strong evidence that the benefits of a well-designed street network go beyond safety, and include environmental, social, and economic gains. Interconnected street networks can preserve habitat and important ecological areas by condensing development, reducing city edges, and reducing sprawl. A denser street network constrains traffic growth by limiting the number of lanes on each street while providing maximum travel options by collectively providing more lanes on more streets.

Street Connectivity Measures

There are many studies that deal with the problem of measuring street connectivity. One of the most common issues addressed in these studies is choosing the appropriate measure and method of measuring street connectivity. Each connectivity measure links travel behavior to urban forms. The purpose is to determine the standards and ranges of connectivity that would both benefit residential areas and increase regional traffic efficiency.

Dill (*14*) analyzes different connectivity measures for biking and pedestrian network development. The paper suggests the advantage of grid-like networks over cul-de-sacs and long blocks. Connectivity measures can be deployed as performance standards for new and/or existing development. Tresidder (*15*) uses GIS to measure network connectivity. He concluded that utilizing the connectivity measures requires a great amount of detail and explanation regarding the calculation of those measures. Scoppa et al. (*16*) analyzed the effects of street connectivity on the distribution of vehicular traffic in Metropolitan Atlanta. They used three measures of street connectivity: metric reach, directional reach, and global metric betweenness. Metric reach is a measure of street density and represents total street length, which is accessible from a street segment within a given network distance. Directional reach is a syntactic measure that represents total street length, which is accessible from a street segment within a given number of direction changes. Global metric betweenness expresses the extent to which a given road segment is a shortcut for all possible connections in the region. The study showed that street width has stronger association with traffic volumes than street connectivity. Yi (*17*) used GIS to compare the levels of connectivity and pedestrian accessibility of cul-de-sac and grid-like neighborhood networks. The paper was motivated by the debate between New Urbanists, the proponents for the grid pattern, and developers who want to continue cul-de-sac practice. The results showed that street connectivity is highest in the neighborhoods with grid street patterns. Cul-de-sacs had better overall pedestrian accessibility than the grid urban form. Creating pedestrian-friendly neighborhoods is more important than choosing between grids or cul-de-sacs. The study also finds GIS as an essential tool for measuring street connectivity and pedestrian accessibility. Table 2.5 is the summary of street connectivity measures most commonly addressed in the existing research.

Traffic Impacts of Street Connectivity

The published research on street connectivity tends to support the argument that greater connectivity will reduce traffic volumes on arterials. This reduction can be attributed to two factors: the dispersal of vehicle trips throughout the network and the decrease in total amount of vehicle travel. Connectivity might reduce vehicle trips by reducing trip distances, reducing the number of trips, or encouraging a shift to transit or non-motorized modes. Existing studies agree that average trip distance and congestion will be lower in areas with rectilinear street patterns than in areas with conventional suburban street patterns only if the number of trips made by car does not increase.

Table 2.4 Summary of Street Connectivity Measures from the Literature (*17*)

Measure	Definition	Standard	Research
Block Length	Length from the curve of one side of the block to the curb on the other side of the bloc. Can also be measured from intersection centerline.	330 ft preferred 528 ft maximum	Cervero et al. (1997) Handy et al. (2003)
Block Size	Area of block perimeter.	1000 ft preferred 1400 ft maximum	Hess et al. (1999) Reilly (2002) Song (2003) CNU et al. (2005)
Block Density	Mean number of blocks per mi^2	160 preferred 100 minimum	Cervero et al. (1995) Cervero et al. (1997) Frank et al. (2000)
Effective Walking Area	Number of parcels within ¼ mi walking distance from origin point/ Number of parcels within ¼ mi radius of origin point		
Pedestrian Catchment Area	Pedestrian network area/Total area		
Pedestrian Route Directedness	The ratio of route distance to straight line distance for two selected points	1.5 preferred 1.8 maximum	Hess (1997) Randall et al. (2001)
Intersection Density	Number of intersections per unit of area	160 preferred 100 minimum	Cervero et al. (1995) Cervero et al. (1997) Reilly (2002) Metro (2004)
Grid Pattern Percentage of Four-way Intersections	Percentage of area with four-way intersections	95% preferred 85% minimum	Boarnet et al. (2001) Greenwald et al. (2001)
Street Density	Number of linear miles of streets per square mile of land	26 mi preferred 18 mi minimum	Handy (1996) Mately et al. (2001)`
Percentage of Cul-de-Sacs	Number of cul-de-sacs/Number of nodes		
Connectivity Index	Number of links divided by the number of nodes in an area	1.4 preferred 1.2 minimum	Ewing (1996) Handy (2003)
Connected Node Ratio	Number of street intersections divided by the number of intersections plus cul-de-sacs	1 preferred 0.7 minimum	Allen (1997) Song (2003)
Link Node Ratio	Same as connectivity index		
Gamma Index	Number of existing links/Number of possible links		
Alpha Index	Number of actual circuits/ Number of possible circuits		

The results of several simulation efforts support the theory that greater street connectivity will reduce traffic volumes on arterials. McNally and Ryan (*18*) used a travel demand forecasting model to predict traffic in two hypothetical neighborhoods. One neighborhood was a conventional planned development with curvilinear network, and the other a traditional rectilinear grid. The simulation showed significant decreases in vehicle miles traveled, trip lengths, and travel time in the traditional grid. In a similar simulation study in Portland, Oregon, analysts found that total vehicle miles traveled were 43% less in a traditional neighborhood with highly connected street patterns than in a conventional neighborhood with hierarchical street patterns (*19*). Portland Metro's study results show that medium and high levels of connectivity improved traffic flow on arterials. Overall, vehicle hours of delay, vehicle miles traveled, and average trip lengths declined in each area when connectivity increased from low to medium levels. Traffic volumes approaching key intersections also declined. The results from Portland Metro also show that greater connectivity could have negative impacts on both residential streets and on arterials. The model showed some use of local streets to bypass congested intersections and/or arterial sections when doing so yielded better travel times. The researchers noticed that arterials might lose some capacity due to increased number of intersections. The results generally show that an optimal level of connectivity needs to be determined.

Some research studies examined the possibility that greater network connectivity could increase the frequency of trips. Crane (*20*) concluded that grids tend to increase car trips and, as a result, total vehicle travel would also increase even if trip lengths decreased. Handy (*21*) found evidence in a study of neighborhoods in the San Francisco Bay Area that improved accessibility can lead to greater trip frequencies. Ewing and Cervero (*1*) completed a comprehensive review of studies that tested the link between street networks and vehicle travel and concluded that the evidence is inconclusive.

The major benefit of street connectivity is traffic redistribution that provides network-wide capacity increase. Street connectivity takes local trips off the arterials and reduces the need for street widening. The question remains how much traffic local streets can take and preserve level livability.

Alba and Beimborn (*22*) explain how poor street connectivity leads to higher traffic concentration on arterials and creates the need for street widening. In other words, better connectivity could prevent the need for street widening. Their study further presents the relationship between connectivity of local streets and arterial traffic. There are many debates on whether increased connectivity reduces arterial traffic or stimulates further demand increase and congestion. The advantage of this study is that it provides a quantitative analysis of the subject. The study is based on a detailed travel demand analysis of local street networks. The test network was chosen in an area of mixed lane use, high activity levels, and poor connectivity. The authors used demographic and employment information to provide details on trip origins and destinations. They coded the local streets in greater detail to show the existing street pattern and then added new links to provide better connectivity. The network models had different combinations of speed to determine how speed affects flows. The study compared the existing network to the new network with increased connectivity. A method developed to assess the impacts of connectivity on arterial traffic shows that improved connectivity can reduce arterial traffic levels. The study compares traffic volume differences along the arterials for the existing and new network. The comparison almost always showed volume reduction for the new, better connected network. This reduction depends on relative speed on the arterial versus local roads and the extent to which arterials carry through traffic. Impacts are greatest when the speed differential is small and there is limited through traffic. Very few arterial segments experienced a traffic volume increase with increased connectivity. The results of this study show a contradiction in the role of local streets in the neighborhoods. Local streets are successful in serving internal traffic when speeds on the local streets are close to those on the arterials. However, traffic calming as a strategy shows opposite results and requires operating at lower speeds. So these two strategies have conflicting approaches to the same goal. This is why street network design in neighborhoods is a very complex process.

Increased street connectivity increases non-motorized travel due to shorter walking distances. The entire community benefits from this since walking means an increase in physical activity. The damaging environmental consequences of car dependence are also reduced if other travel modes are encouraged. Ewing and Cervero (*1*) concluded that it is hard to predict which modes will be dominant in grid-like networks. Handy et al. (*21*) found that the rates of walking are higher in traditional grid pattern areas. This shows that it is important to jointly plan land use and connectivity requirements.

The most appropriate way to measure street connectivity and how much connectivity is the sufficient amount are still questions (*21*). There is a need to quantify and compare higher connectivity impacts versus conventional solutions in order to answer these questions. Further research in this area would lead to an optimal street network design for achieving the desired level of connectivity.

2.3 Innovative Intersections

Innovative intersections (also known as unconventional intersections) are generally defined as any at-grade design concepts that are able to reduce the number of phases at the main intersection, thereby increasing the efficiency and capacity of the signal (*28*). In most cases, this is accomplished by rerouting left turns at a point well ahead of the main intersection, or accomplishing left turns through a combination of through, right, and U-turn movements. These designs are regarded to be "unconventional" because they incorporate geometric features or movement restrictions that would be permissible at standard at-grade intersections (*29*). Such elements include the elimination and/or relocation of various through and turning maneuvers, the use of indirect turning movements, and the inclusion of roundabout designs.

The general goal of innovative intersections is to improve the overall operation of the intersection by favoring heavy volume through movements on the arterial street. They often manage to relieve traffic congestion, and in most cases their cost is relatively modest. The ways that innovative intersections improve traffic conditions can be summarized as follows:

- Reducing the number of conflict points, or improving safety and capacity by spreading them out
- Restricting and/or rerouting movements
- Reducing the complexity of traffic signal phasing

One of the recognized problems with new implementations of innovative intersections is unusual driver expectancy. Perfect driver expectancy can only be achieved with conventional intersection design. Also, some "unusual" intersection designs are in use in some states (median U-turn in Michigan, or jughandle in New Jersey), making them familiar to the drivers in these states, but not in others. For that reason, a DOT agency must provide adequate education and guidance to cope with drivers' confusion during the initial period following the installation.

Different intersection designs have appeared during the last few decades that are considered "unconventional." These new designs for urban intersections are context sensitive, efficient, and often affordable, especially if such a design is envisioned when adjacent land uses are first established (*28*). In most cases, they can accommodate more traffic than grade-separated designs, with much lower construction and maintenance costs.

Median U-Turn Intersection

The main objective of the median U-turn intersection (a.k.a. Michigan U-turn, through-turn) is to remove all left-turn traffic from the main intersection. It redirects left turns through a combination of through, right, and U-turn movements (*28 - 31*). A schematic diagram of this intersection type is given in Figure 2.6.

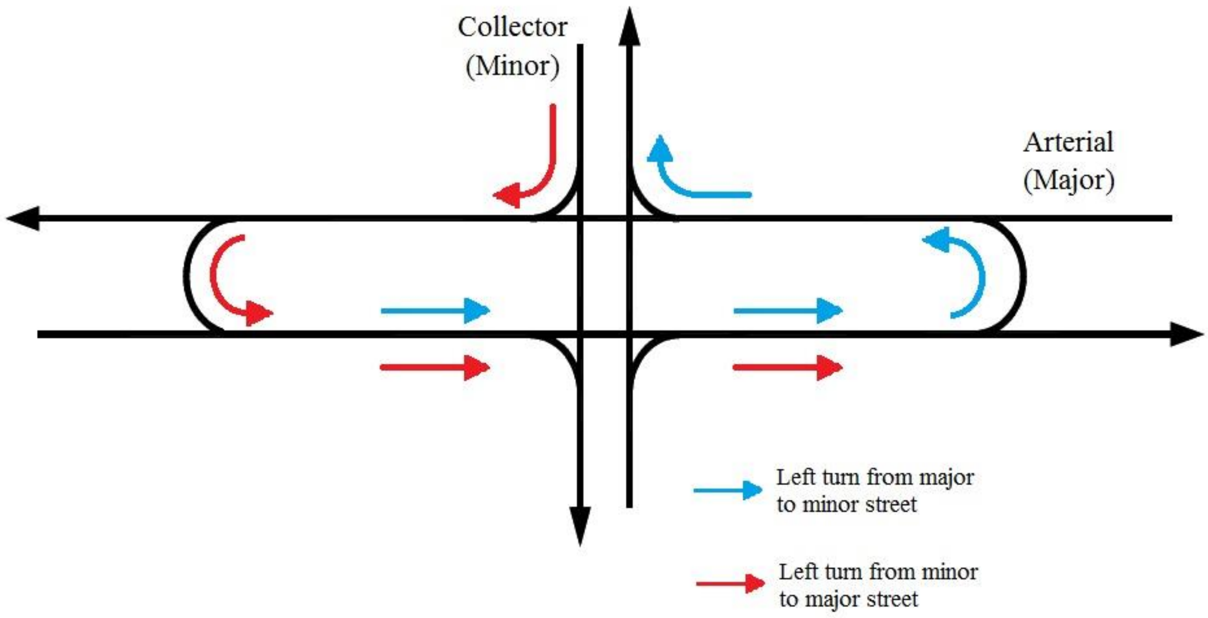


Figure 2.6 Median U-turn

Vehicles turning left from the major to minor street continue through the intersection, make a U-turn at the designated place on the major street, and then turn right at the intersection. Vehicles turning left from the minor to major street first turn right at the intersection, make a U-turn at the designated place on the major street and then continue straight through the intersection. The relocation of left turns at the intersection simplifies its signal phasing. The intersection can operate on a simple two-phase timing plan, increasing capacity, reducing delays, and improving intersection coordination. Safety at this intersection is also improved, since it eliminates conflicts between left-turning and through vehicles. For the same reason, it is more pedestrian-friendly, since there are no conflicts between pedestrians and left-turning vehicles. Studies on median U-turn intersections show an increase in capacity of about 50% when compared with double left turns, and a crash rate that is 20% lower (*28*).

The main disadvantage of the median U-turn is increased delay and travel distance for left-turning vehicles. In some cases, the U-turn may require a separate signal if the traffic volumes on the major street are too high. Also, sometimes it may be necessary to expand the roadway at the U-turn section, which takes up more space.

This type has been in use in Michigan since the 1960s (hence its name). The drivers in Michigan are used to this design type, so it does not conflict their expectancy. They are not so common in other states, which can cause unusual driver expectancy in the early stages of implementation.

Bowtie Intersection

The turning movements at Bowtie intersections are similar to median U-turn intersections. The difference is that Bowtie uses roundabouts located on the minor road, as shown in Figure 2.7 (*28*, *29*, *32*, *33*). The advantages are similar to those seen at median U-turns, with elimination of left-turn phases, increased capacity, and improved safety. Also, Bowties eliminate the necessity of having signalized U-turns, since roundabouts are used in this case. Having a roundabout on the minor street is also an advantage, because the turning movements face lower traffic volumes. The roundabouts in the Bowtie variation also provide unique opportunities for side-street tie-ins, improved aesthetics, and traffic calming, which are qualities attractive for livable corridors.

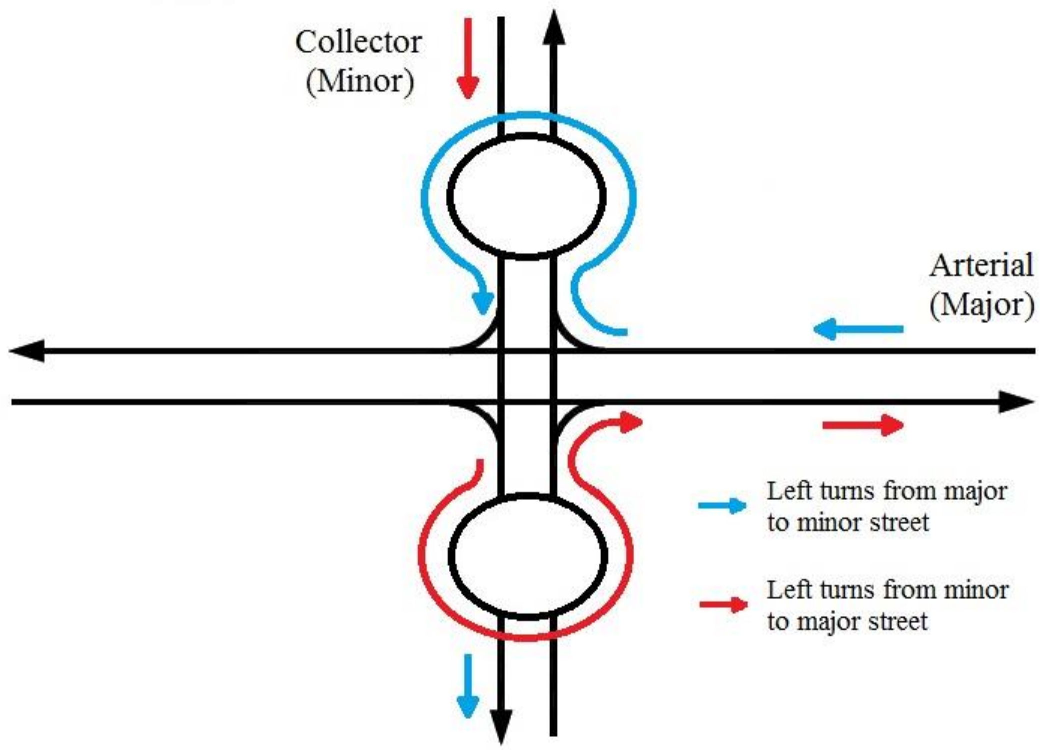


Figure 2.7 Bowtie Intersection

The distance between the main intersection and the roundabouts depends on the amount of storage space required for minor street approach queuing. The size of the roundabouts would depend on the design speed and design vehicles in a particular location.

Bowties increase delays and travel distances for left-turning vehicles, which is the major disadvantage. Also, the roundabouts in the Bowtie require additional space for construction. Unusual driver expectancy should also be considered with this intersection type.

Quadrant Intersections

At a Quadrant intersection, left turns are redirected onto an adjacent roadway that connects two legs of the intersection at locations that could allow traffic to bypass the main intersection. This decomposes the main large intersection into three smaller signalized intersections. All left-turn movements from both roads are completed prior to or after the main intersection on a bypass road (*28*, *29*, *32*). The diagram of a single Quadrant intersection is given in Figure 2.8. It is possible to achieve all left turns with a single quadrant, although it is not recommended.

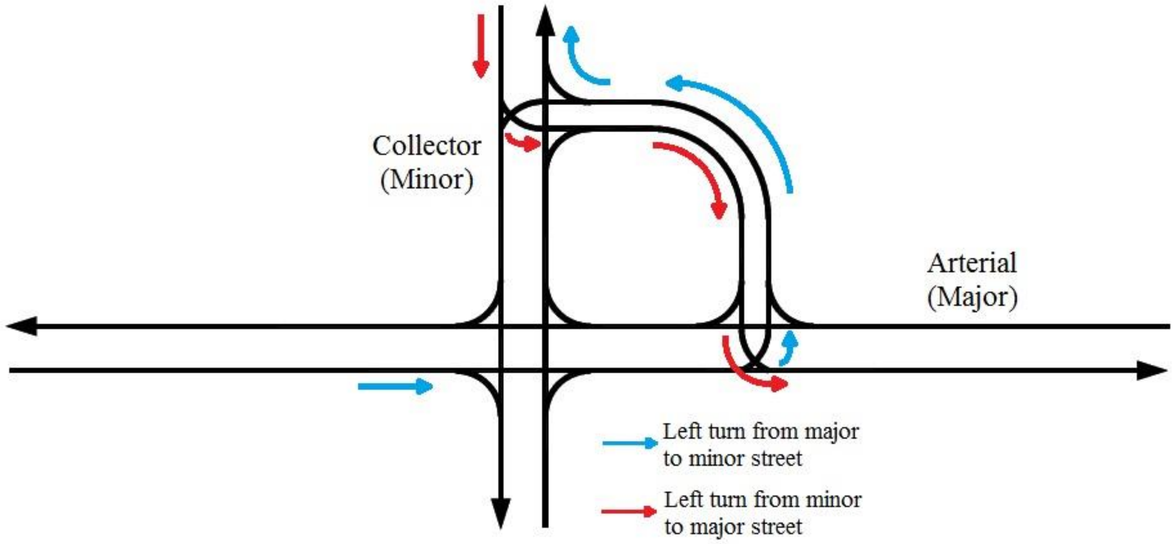


Figure 2.8 Single Quadrant Intersection

Eliminating left-turn movements at the main intersection increases the intersection capacity and efficiency by eliminating left-turn signal phases, which in turn provides more green time to through traffic. Without left-turn movements, a simple two-phase signal can be used, which may increase corridor capacity by as much as 50%. Eliminating the left-turn movements also improves intersection safety by decreasing the number of vehicular and pedestrian conflict points, therefore reducing the opportunity for collisions. In the case of a single Quadrant intersection, a key component is the coordination of the three signals. The left-turning movements into and out of the quadrant roadway occur during the phase that overlaps the coinciding movement at the main intersection, which minimizes (or even eliminates) the number of stops required to complete the left turn. The length of the quadrant roadway and the locations of its accompanying intersections are dictated by a trade-off between the amount of storage required for left-turn queuing and distance and time required to travel to the intended direction. Although building a Quadrant intersection is more costly, it provides access to and from developments within the selected quadrant. A Quadrant intersection can also provide opportunity for additional storefront opportunities. A higher number of vehicles on the connector roadway will provide a unique and potentially profitable location for businesses. Aesthetic improvements can also be made to the quadrant to help improve its appeal. Some other advantages of this design include a reduction in conflict points at the main intersection, and reduced intersection widths that benefit pedestrians.

The main disadvantage of this intersection type is increased delay and travel distance for left-turning vehicles. This configuration could also be more confusing for drivers, because the left-turn movements are not the same for different directions. Left turns for two of the approach directions would be made prior to the main intersection and the other two approaches would initiate their left-turn maneuvers after the main intersection. Some of these problems can be solved by introducing two or four Quadrant intersections.

Jughandle Intersection

The Jughandle intersection introduces a design similar to quadrant intersections. The principle of the jughandle design is to remove all turning traffic (including right turns) from the main intersection by shifting them from the major street approaches and onto an adjacent ramp (*28*, *29*). A diagram of the Jughandle intersection is given in Figure 2.9.

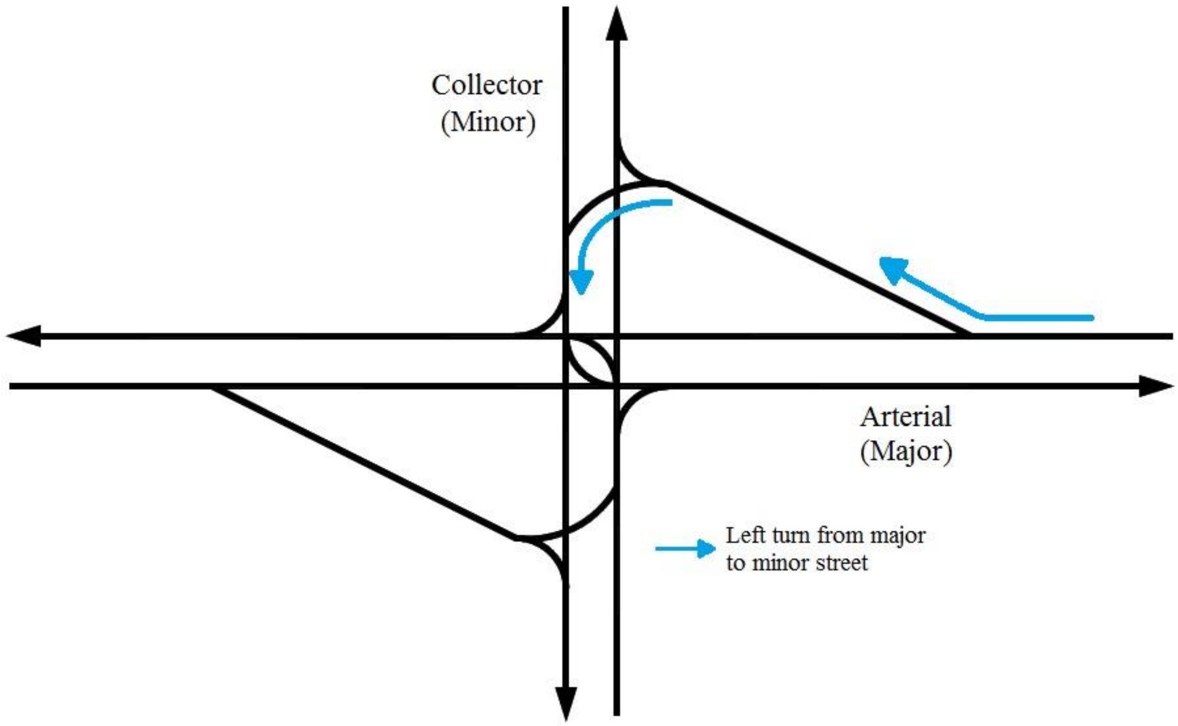


Figure 2.9 Jughandle Intersection

The turning maneuvers are completed at an intersection created between the ramp and the minor highway, and then proceed through the main intersection, similar to the Quadrant intersection. However, a difference is that left turns from the minor street are permitted onto the major roadway. This design type is best suited for high volume arterial roadways with moderate to low left-turn volumes. It eliminates the need for a left-turn phase on the major roadway (although it may be needed for the minor road, depending on the volumes). Other advantages and disadvantages are the same as for the Quadrant intersection.

Split Intersection

The Split intersection separates directional traffic flows into two offset one-way roads. This configuration is similar to an at-grade diamond interchange without a separate bypass for through traffic (*29*). A diagram of this intersection is given in Figure 2.10.

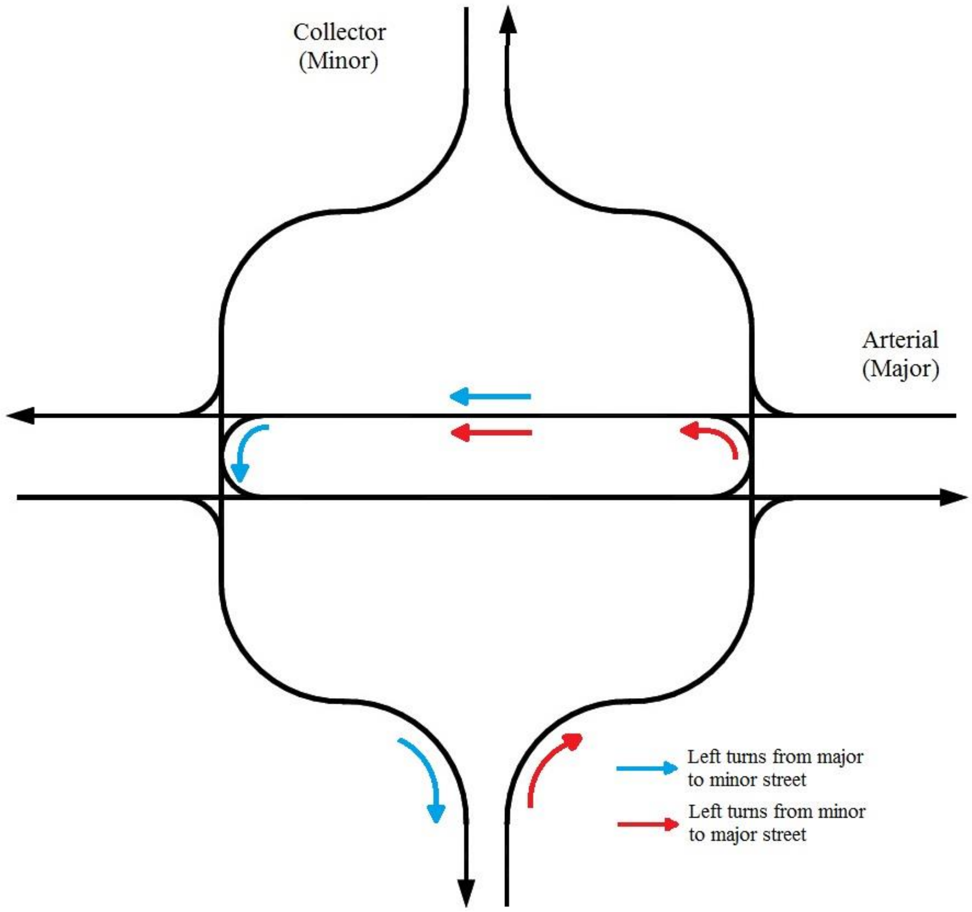


Figure 2.10 Split Intersection

The separation of flows reduces delay and eliminates turning conflicts compared with a conventional four-legged intersection. The majority of the delay reduction results from the elimination of one of the four traffic-signal phases of the intersections. This adds more green time to the cycle for left-turning vehicles. Reducing the number of conflicts between left-turning and through vehicles has been shown to increase safety. The main disadvantages of the Split intersection are the high initial cost, right-of-way acquisition, and possible wrong-way movements by unfamiliar drivers. Split intersections can also be achieved by separating flows for the major and minor roadway (or two roadways of the same class). In that case, it is known as the Town Center Intersection or the Square-about. The Split intersection is a common design in New Jersey.

Superstreet Intersection

The Superstreet intersection has many similarities with the Median U-turn intersection. In this case, the main intersection is closed for both through and left movements from the minor street. They are achieved through a combination of a right and U-turn movement. The effect of this configuration is that it allows a four-approach intersection to operate as two separate three-approach intersections, and allows each direction of the major street to operate on an independent timing pattern (*28, 29*). In this case, left turns from the major roadway on to the minor street are allowed at the main intersection. This configuration is shown in Figure 2.11.

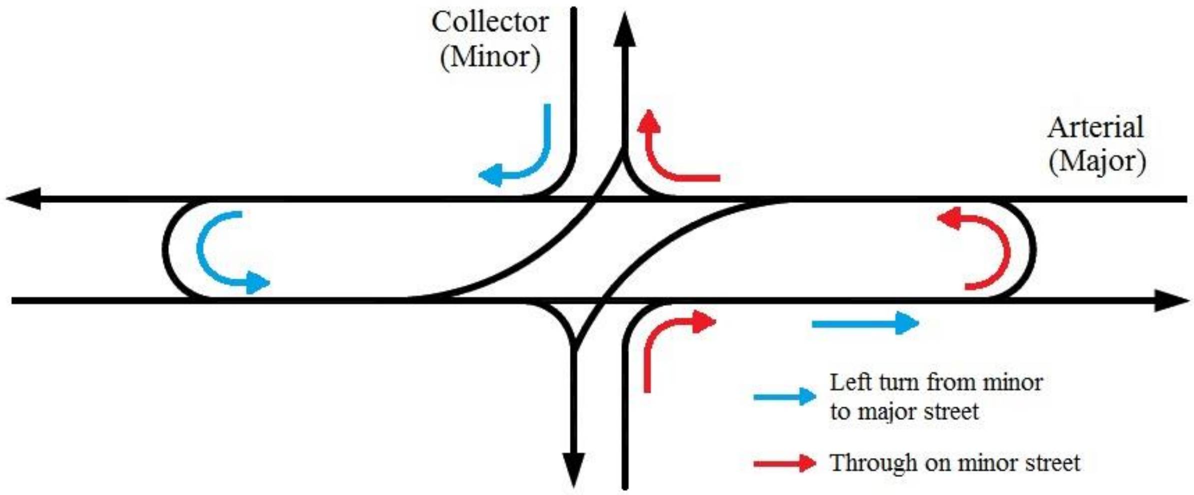


Figure 2.11 Superstreet Intersection

Because of the ability to independently control the major street directions, the superstreet design permits coordinated progression for the major street regardless of its spacing relative to upstream and downstream intersections. This significantly reduces delays on the major roadway. The most significant disadvantage is that it does not permit through or direct left-turn movements from the minor roadway. This increases delays and travel distances for those movements. The driver expectancy can also be a problem. Pedestrians are required to cross the main intersection at an angle, parallel to the left-turn crossovers, requiring a longer pedestrian phase.

Continuous Flow Intersection

The Continuous Flow Intersection (CFI) is another complex unconventional intersection design in terms of the amount and proximity of channelizing and control features. The basic concept of the CFI is to move left-turn traffic from all approaches of the main intersection across the opposing traffic lanes prior to the main intersection (*28, 29, 34*). Left-turn maneuvers are then completed simultaneously and unopposed with their accompanying and opposing through movements, allowing the intersection to operate on a two-phase signal. For comparison, a standard signal with protected left-turn arrows must serve eight major movements, four left turns and four through movements, but only two movements can occur at a time, which demands a four-phase signal. The left turns prior to the intersection are also signalized, but they are coordinated with the main signal allowing the left-turning vehicles to cross the main intersection without stopping. The diagram of a CFI intersection is given in Figure 2.12. It shows only the CFI design on the major roadway, although it can be implemented on all approaches.

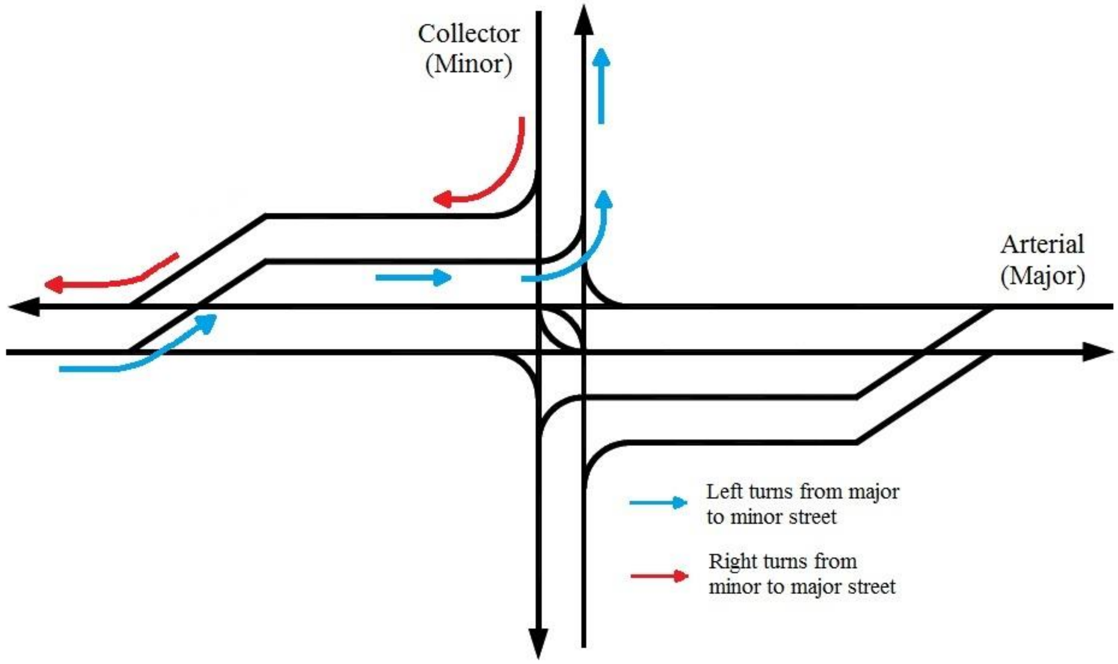


Figure 2.12 Continuous Flow Intersection (CFI)

It has proven to be simple for drivers to get used to, and in some cases can fit within existing rights-of-way (*28*). A full four-approach CFI with two to three lanes per approach can handle about 10,000-14,000 vehicles per hour at LOS E. A standard intersection with the same number of through lanes and with dual left-turn lanes on all approaches can handle about 6,000-8,000 per hour at the same level of service. The CFI design can greatly increase capacity and reduce delays.

The CFI also has some disadvantages. Drivers need to be aware of the need to make left turns prior to the intersection, so clear guidance must be given to warn them of the impending roadway and guide them into the appropriate lanes. Because of the multiple lane crossings within the intersection, pedestrian would also need to be guided and informed of the vehicle approach direction. Other disadvantages include the need for U-turn opportunities because access to and egress from intersections' quadrant developments would be difficult for most approach movements. The CFI would be most appropriate for high volume arterials with few needs for U-turns. Another important consideration is the level of development near the intersection. Because of the locations of the left- and right-turn lanes, the CFI does not provide easy access to and from adjacent properties.

Evaluations of Innovative Intersection Designs

One of the most widely used designs is the median U-turn. A comparative evaluation of conventional two-way left turn, median U-turn, and super-street median geometric designs was compared to assess the performance of these designs (*30*). Models of a typical suburban arterial corridor near Detroit, Michigan, were created in CORSIM simulation software. The modeled corridor was 2.5 miles long and included five signalized intersections, with varied intersection spacing (1,600 to 3,500 feet). Separate models were created for each design, where all the signalized intersections were modeled according to the specific design (two-way left turn, median U-turn, and super-street median). Each model scenario was repeated for four different levels of traffic volumes obtained from the field for the AM peak, noon-period, midday off-peak, and PM peak.

The analysis of variance (ANOVA) focused on the total system-wide travel time, average stops per vehicle, and average speed. The ANOVA results indicated that the arterial geometry was a significant factor at a 99.99% level of confidence for each dependent variable. The median U-turn scenario yielded the lowest travel times and highest speeds for all levels of traffic volumes. Super-street median provided lower travel times and higher speeds than the conventional design for peak period traffic volumes. Median U-turn and super-street median have experienced higher numbers of stops per vehicle than the conventional design for all volume levels. Because of their ability to reduce peak period delays without the need of additional capacity, the authors recommended considering these unconventional designs for implementation in the field.

A continuation of this study performed by the same authors looked into the performances of seven types of unconventional intersection designs (*31*). They analyzed the quadrant roadway intersection, median U-turn, superstreet median, bowtie, jughandle, split intersection, and CFI designs. Simulation experiments in CORSIM were conducted using turning movement data from seven existing intersections in Virginia and North Carolina to compare the travel time of conventional and unconventional designs. The volume levels used in experiments were the off-peak, PM peak, and a volume 15% greater than the PM peak period.

A combination of different designs at different volume levels was simulated for each intersection. The analysis focused on total system travel time rather than intersection delays (to adequately capture the effects of these designs on left-turn movements). The results from these experiments yielded several conclusions:

- The conventional design never produced the lowest average total time. At least one of the unconventional designs always had a lower average total time.
- The conventional design usually produced the lowest number of stops per vehicle.
- The quadrant roadway intersection and median U-turn designs usually vied for the lowest average total time.
- The quadrant roadway and median U-turn designs produced the most miles driven at each intersection.
- The split intersection competed well with all designs tested at off-peak volume levels and had lower average total times than the conventional design at most intersections.
- The CFI always had the highest move-to-total-time ratio of all designs, keeping traffic moving as its name implies.
- The superstreet median and bowtie designs were only competitive with the conventional design at intersections with two-lane cross streets.
- The jughandle design never performed better than the conventional design in average travel time.

Among all the designs, the quadrant intersection and median U-turn are viewed as the most effective designs. The authors recommended considering these unconventional designs for implementation in the field where traffic conditions are similar to the studied intersections and where the extra right-of-way can be reasonably procured.

There have been several implementations of innovative intersection designs. Despite the disadvantages, in most cases it was proven that these designs perform better than conventional intersections. Some of the designs can have a great impact on land use development and business opportunities, mainly the quadrant and town-center (split) intersections. Some potential locations can use the existing roadways, which can be easily transformed into innovative designs. Within the project network, there are several locations that are potential candidates for some of the innovative designs. The project will look into some options and recommend the best solutions. With the help of micro simulation, a comparison of different alternatives can be easily performed. We will develop several simulation models that will include some of the innovative solutions (with UTA's approval), identify advantages and disadvantages of each of them, perform traffic analyses, and recommend the solution that would be best for the observed network.

2.4 Traffic Calming Measures

Traffic Calming Measures (TCM) are developed to reduce congestion and increase safety in residential environments. They have been around for more than 40 years. Many researchers have examined their impact on traffic. The general conclusion is that the implementation of TCM improves the quality of residential environment.

This literature review is related to the project that examines the impact of Transit Oriented Development (TOD) on traffic. The street network needs to be adjusted to TOD. Speeds and traffic volumes need to be reduced; street design needs to be changed to accommodate transit vehicle movements; pedestrians and transit users' requirements need to be considered. TCM have an important role in all these adjustments. Engineers use TCM as a tool to develop a transit-friendly environment. TCM affect both traffic and environment livability.

History and Definition of TCM

The idea of traffic calming started in Europe in the 1960s. Angry residents of the Dutch City of Delft fought cut-through traffic by turning their streets into "woonerven," or "living yards." This was followed by the development of European slow streets (designed for 30 kph [or 20 mph]) in the late 1970s. The application of traffic calming principles to intercity highways through small Danish and German towns and urban arterials in Germany and France followed in the 1980s (*35*).

In the United States, a version of traffic calming was practiced as early as the late 1960s and early 1970s in such places as Berkeley, CA, Seattle, WA, and Eugene, OR. The first national study of traffic calming was completed in 1980. It explored residential preferences related to traffic, collected performance data on speed humps, and reviewed legal issues. Almost 20 years later, with a track record in place, the Federal Highway Administration (FHWA) funded another study in 1998 that led to the ITE report, "Traffic Calming: State of the Practice," by Reid Ewing. As compared with the 1980 study, this report goes beyond residential streets to major thoroughfares, beyond speed humps to a toolbox of calming measures, and beyond legal issues to policy, procedural, and political challenges.

Definitions of traffic calming vary, but they all share the goal of reducing vehicle speeds, improving safety, and enhancing quality of life. Some include all three "Es," traffic education, enforcement, and engineering. Most definitions focus on engineering measures to change driver behavior. Some focus on engineering measures that compel drivers to slow down, excluding those that use barriers to divert traffic. The following are some example definitions.

- Institute of Transportation Engineers (ITE) – Traffic calming involves changes in street alignment, installation of barriers, and other physical measures to reduce traffic speeds and/or cut-through volumes in the interest of street safety, livability, and other public purposes.
- Federal Highway Administration (FHWA) – The term "traffic calming" is often described as the combination of mainly physical measures that reduce the negative effects of motor vehicle use and improve conditions for non-motorized street users. However, the term "traffic calming" also applies to a number of transportation techniques developed to educate the public and provide awareness to unsafe driver behavior.

According to the FHWA, general objectives of traffic calming are:

- To encourage citizen involvement in the traffic calming process by incorporating preferences and requirements of the citizens
- To reduce vehicular speeds
- To promote safe and pleasant conditions for motorists, bicyclists, pedestrians, and residents
- To improve the environment and livability of neighborhood streets
- To improve real and perceived safety for non-motorized street users
- To discourage use of residential streets by non-citizens cutting through vehicular traffic

Traffic calming is a way to design streets to improve safety, reduce the amount of cut-through traffic traveling on residential streets, and generally encourage people to drive more slowly. It relies on physical and visual cues in the roadway to induce drivers to travel at slower speeds. Traffic calming is self-enforcing. The design of the roadways results in the desired effect. It does not rely on complying with traffic control devices such as signals and signs. Street trees and lighting complement traffic calming devices and are often used to provide the visual cues that encourage people to drive more slowly. Traffic calming is such a powerful tool because it is effective. Some of the effects of traffic calming, such as fewer and less severe crashes, are clearly measurable. Others, such as supporting community livability, are less tangible, but equally important. Experience through Europe, Australia, and North America has shown that traffic calming, if done correctly, reduces traffic speeds, the number and severity of crashes, and noise level. Research on traffic calming projects in the United States supports their effectiveness at decreasing automobile speeds, reducing the number of crashes, and reducing noise levels in certain locations.

Traffic Calming Devices and Techniques

Traffic calming schemes generally incorporate a wide range of measures designed to complement each other in both speed reduction and environmental terms. Schemes are designed to be self-enforcing, although the effectiveness of this varies according to the measures employed. The Institute of Traffic Engineers defines four categories of TCM techniques:

- Vertical deflections
- Horizontal deflections
- Road narrowing
- Closures

The following descriptions of different TCM techniques and devices are based on a study conducted by Ewing (*36*). The study emphasizes the importance of the design principles for TCM. These measures must abide the standards for dimensions and horizontal and vertical curvature. Some of the principles for signs and markings are defined in the Manual on Uniform Traffic Control Devices (MUTCD), but there are no clear standards. Some of the principles are adopted from standards used by different DOTs in the United States, or in Europe and Australia. However, it should be noted that during the time this report was written and published (in 1999), the actual MUTCD edition was from 1988. The latest MUTCD edition (December 2009) includes standards and guidelines for signs and markings for TCM. The other important feature of TCM is the aesthetic appearance. For that reason, the use of landscaping is recommended in TCM areas.

Vertical deflections

Speed humps are rounded raised areas placed across the roadway. ITE guidelines specify that a speed hump should be 12 feet long (in the direction of travel), 3 to 4 inches high, and parabolic in shape, with the design speed of 15 to 20 mph. The profile of a speed hump can be circular, parabolic, or sinusoidal.

They are often tapered as they reach the curb on each end to allow unimpeded drainage. Speed humps are good for locations where very low speeds are desired and reasonable, and noise and fumes are not a major concern. In a survey by the Urban Transportation Monitor, speed humps were rated both the best and the worst traffic calming technique. They were rated best for their relatively low cost and their effectiveness in reducing vehicle speed. They were rated worst for various reasons, including appearance, liability, and "rough ride" because of their height.

Speed tables are flat-topped speed humps often constructed with brick or other textured materials on the flat section. Speed tables are typically long enough for the entire wheelbase of a passenger car to rest on the flat section. Their long flat fields give speed tables higher design speeds than speed humps. The brick or other textured materials improve the appearance of speed tables, draw attention to them, and may enhance safety and speed-reduction. Speed tables are good for locations where low speeds are desired but a somewhat smooth ride is needed for larger vehicles.

Raised crosswalks are speed tables outfitted with crosswalk markings and signage to channelize pedestrian crossings, providing pedestrians with a level street crossing. Also, by raising the level of the crossing, pedestrians are more visible to approaching motorists. Raised crosswalks are good for locations where pedestrian crossings occur at haphazard locations and vehicle speeds are excessive.

Raised intersections are flat raised areas covering an entire intersection, with ramps on all approaches and often with brick or other textured materials on the flat section. They are usually raised to the level of the sidewalk, or slightly below to provide a "lip" that is detectable by the visually impaired. By modifying the level of the intersection, the crosswalks are more readily perceived by motorists to be "pedestrian territory." Raised intersections are good for intersections with substantial pedestrian activity, and areas where other TCM would be unacceptable because they take away scarce parking spaces.

Textured and colored pavement includes the use of stamped pavement or alternate paving materials to create an uneven surface for vehicles to traverse. They may be used to emphasize either an entire intersection or a pedestrian crossing, and are sometimes used along entire street blocks. Textured pavements are good for "main street" areas where there is substantial pedestrian activity and noise is not a major concern.

Horizontal deflections

Traffic circles are raised islands, placed in intersections, around which traffic circulates. They are good for calming intersections, especially within neighborhoods, where large vehicle traffic is not a major concern but speeds, volumes, and safety are problems.

Roundabouts require traffic to circulate counterclockwise around a center island. Unlike traffic circles, roundabouts are used on higher volume streets to allocate right-of-way between competing movements.

Chicanes are curb extensions that alternate from one side of the street to the other, forming S-shaped curves. Chicanes can also be created by alternating on-street parking, either diagonal or parallel, between one side of the street and the other. Each parking bay can be created either by restriping the roadway or by installing raised, landscaping islands at the ends of each parking bay. Good for locations where speeds are a problem but noise associated with speed humps and related measures would be unacceptable.

Lateral shifts are curb extensions on otherwise straight streets that cause travel lanes to bend one way and then bend back the other way to the original direction of travel. They are one of the few measures that have been used on collectors or even arterials, where high traffic volumes and high posted speeds preclude more abrupt measures.

Realigned intersections are changes in alignment that convert T-intersections with straight approaches into curving streets that meet at right angles. A former "straight-through" movement along the top of the T becomes a turning movement. While not commonly used, they are one of the few TCM for T-intersections, because the straight top of the T makes deflection difficult to achieve, as needed for traffic circles. They are good for T-intersections.

Narrowings

Neckdowns are curb extensions at intersections that reduce the roadway width from curb to curb. They "pedestrianize" intersections by shortening crossing distances for pedestrians and drawing attention to pedestrians via raised peninsulas. They also tighten the curb radii at the corners, reducing the speeds of turning vehicles. They are good for intersections with substantial pedestrian activity and areas where vertical TCM would be unacceptable because of noise considerations.

Center island narrowing is a raised island located along the centerline of a street that narrows the travel lanes at that location. Center island narrowings are often landscaped to provide a visual amenity. Placed at the entrance to a neighborhood, and often combined with textured pavement, they are often called "gateway islands." Fitted with a gap to allow pedestrians to walks through at a crosswalk, they are often called "pedestrian refuges." Center island narrowings are good for entrances to residential areas, and wide streets where pedestrians need to cross.

Chokers are curb extensions at midblock locations that narrow a street by widening the sidewalk or planting strip. If marked as crosswalks, they are also known as safe crosses. Two-lane chokers leave the street cross section with two lanes that are narrower than the normal cross section. One-lane chokers narrow the width to allow travel in only one direction at a time, operating similarly to one-lane bridges. They are good for areas with substantial speed problems and no on-street parking shortage.

Closures

Full street closures are barriers placed across a street to completely close the street to through-traffic, usually leaving only sidewalks open. They are good for locations with extreme traffic volume problems and several other measures have been unsuccessful.

Half closures are barriers that block travel in one direction for a short distance on otherwise two-way streets. They are good for locations with extreme traffic volume problems and non-restrictive measures have been unsuccessful.

Diagonal diverters are barriers placed diagonally across an intersection, blocking through movements and creating two separate, L-shaped streets. Like half closures, diagonal diverters are often staggered to create circuitous routes through the neighborhood as a whole, discouraging non-local traffic while maintaining access for local residents. They are good for inner-neighborhood locations with non-local traffic volume problems.

Median barriers are islands located along the centerline of a street and continuing through an intersection so as to block through movement at a cross street.

Summary of TCM techniques

The ITE report by Reid Ewing (*36*) also classifies TCM according to their dominant effect on traffic volume or traffic speed. All closure measures are classified as *volume control measures*. Their primary purpose is to discourage or eliminate through traffic. Vertical deflections, horizontal deflections, and narrowings are classified as *speed control measures*. Their purpose is to slow traffic.

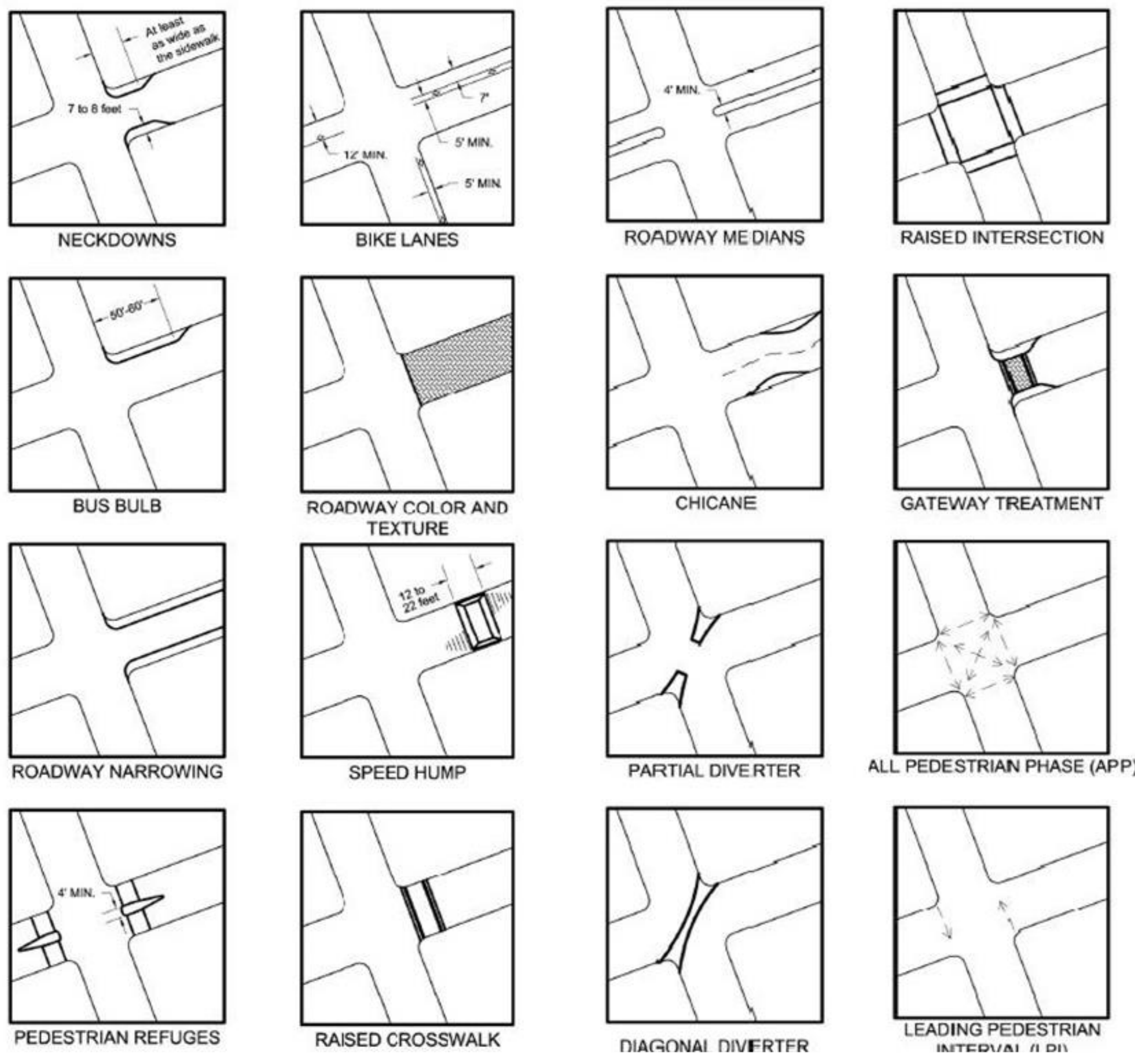


Figure 2.13 Traffic Calming Measures (*36*)

Traffic Impacts

The study conducted by Ewing (*37*) quantifies the kinds of impacts from various types of TCM. The main conclusion is that the TCM generally have the desired impacts on reducing speeds, volumes, and collisions. The practical value of this impact analysis is demonstrated in Portland, Oregon's North Ida Avenue project. TCM resulted with 85th percentile speed decline and lower daily traffic volumes.

Impact on Traffic Speed

The impact of TCM on traffic speed is examined using many before-and-after studies. Three measures of impact were used in this study:

- Average 85th percentile speed after the treatment
- Average absolute change in 85th percentile speed from before to after treatment
- Average percentage change in the 85th percentile speed from before to after treatment

Of all TCM, speed humps impacted 85th percentile speed the most, reducing it by 7 mph or 20%. Among speed control measures, raised intersections and narrowings have the least impact. Interestingly, half closures, a volume control measure, have an impact on speeds comparable to speed tables.

Speed impacts of TCM depend primarily on geometrics and spacing. Geometrics determine the speeds at which motorists travel through slow points. Spacing determines the extent to which motorists speed up between slow points.

The study uses a sample of 58 streets in 10 communities to measure 85th percentile speeds before traffic calming, 85th percentile speeds at midpoints after traffic calming, and spacing between slow points. These data were combined with known crossing speeds at slow points and used to estimate speed models. The relation between speeds before and after the treatment is obtained through partial correlation. Midpoint speeds are related to all other variables. The authors used nonlinear regression to model the midpoint speeds. It is assumed that midpoint speed equals 85th percentile speed when slow points are closely spaced. Midpoint speeds would rise asymptotically toward 85th percentile speed as slow points become widely spaced. The model of midpoint speeds was based on these assumptions. This model calculates the midpoint speed for different values of other variables.

The results showed that speed humps (14-foot length, 3-inch height) reduced 85th percentile speed from 32 mph to about 25 mph. Speed tables deployed on higher order streets (22-foot length, 3-inch height) reduced 85th percentile speed from 40 mph to about 32 mph. Traffic speed at the humps was reduced by 30% in both cases. The speed 100 feet upstream and downstream from the humps was 3-6 mph greater than the speed at the installed hump.

Impact on Traffic Volume

Volume impacts depend on the entire network, not just the characteristics of the street itself. The availability of alternate routes and the application of other measures in area-wide treatments may have large impact on traffic volumes.

In particular, volume impacts depend fundamentally on the split between local and through traffic. TCM will not affect the amount of locally bound traffic unless they are so severe or restrictive as to “degenerate” motor vehicle trips. The concept of suppressing motor vehicle travel with increased costs is still new and it is unlikely to succeed in the United States. TCM may reroute non-local traffic instead of dealing with local.

The statistics on volume impacts are based on before-and-after studies. The author chose two measures of impacts: average absolute change in daily traffic from before to after treatment, and average percentage change in daily traffic from before to after treatment. The type of TCM was independent variable. As expected, the largest volume reductions occur with street closures and other volume control measures. However, significant reductions also occur with speed humps and other speed control measures.

Volume impacts of TCM prediction was based on given origin-destination data for trips on the local street network, and estimates of link speeds after treatment. The author used a traffic assignment program that seeks the path with the minimum travel time for each trip. The statistical model was estimated through multiple classification analysis.

Volume controls reduce traffic volumes by about 39%, disregarding the type of TCM. Full closures reduce traffic volumes by an additional 5%. Speed control measures reduce traffic volumes by 15%. Speed humps reduce volumes by an additional 5%. The percentage of traffic volume reduction is weakly related to the percentage of speed reduction.

The results also depend on the location where the measurements are taken. Volume impacts of traffic calming measures depend on the availability and quality of alternate routes. Impacts for streets calmed with street closures, diverters, and other volume control measures would also be expected to depend on which movements are blocked. Volume impacts would be expected to vary with the degree of speed reduction for streets calmed with speed control measures. TCM also impact travel time and thus route choice, increasing traffic volumes on the routes with shorter travel times.

Impact on Traffic Safety

TCM may result in fewer collisions by slowing traffic, eliminating conflicting movements, and/or sharpening drivers' attention. Collisions may be less severe when they occur, due to lower speeds. According to Ewing's study (*37*) traffic circles and chicanes have the most favorable impact on safety, reducing collision frequency by an average of 82%. Circles have this effect because they are located at intersections, where a great number of collisions occur. Chicanes might have this effect due to heightened attention. Speed humps were almost as effective as circles and chicanes, reducing collision frequency by an average of 75%. This is counterintuitive, because humps create wide speed variations in the traffic stream.

A meta-analysis of 33 studies also showed that TCM can increase safety level (*37*). It included the results from studies conducted in eight countries (Australia, Denmark, Finland, Germany, Great Britain, Netherlands, Norway, and Sweden) between 1971 and 1994. These studies include different TCM measures for volume and speed control, mostly implemented in residential areas. The analysis mainly focused on studies that were non-experimental, reported the number of different types of accidents before and after TCM implementation, and used tested and comparison groups in their analyses. The method used in this paper is the log odds method of meta-analysis and it included a 95% confidence interval for the weighted mean estimate of effects.

Four characteristics of the evaluated studies were used in the analysis: study design, data on traffic volumes, accident severity, and the type of road. For study design, a distinction was made between studies using a matched comparison group, studies using a general comparison group, and studies not using a comparison group. For accident severity, the studies were classified for injury accidents, property damage only accidents, and studies that did not report the severity. For the type of road, the analysis included the whole area, main roads, and local roads.

The analysis of the evaluation studies shows that area-wide traffic calming reduces the number of accidents by about 15% in the whole area affected by the measures (main roads and local roads combined). The greatest reduction was recorded in studies where the accident severity was not reported. A greater reduction in the number of accidents is observed on local roads (about 25%) than on main roads (about 10%). Also, the results of the evaluation studies are quite robust with respect to study design. Studies were classified in five groups, depending on the confounding factors. There is a tendency for weakly controlled studies to find greater effects of TCM than well-controlled studies. The results are stable over time and of similar magnitude in these eight countries.

Confidence in safety impacts of TCM is limited. TCM are mostly implemented in low-volume residential areas, where collisions occur infrequently. This makes the statistical significance of TCM safety impacts lower. TCM safety effects in the United States are less favorable than elsewhere. One possible explanation is that European TCM are more intensive and more integrated with their surroundings than the U.S. treatments.

Impact on Transit Vehicles

TCM raise a number of special issues for the operation of buses. Several considerations should be taken into account when TCM are being designed and installed (*38*).
Buses have firmer suspension systems, similar to most other large vehicles carrying heavy loads. They are less maneuverable than cars. TCM can lead to increased wear and tear to buses. If buses are driven along a traffic calmed road many times a day, they can be damaged and maintenance costs can increase.

Bus operators have a duty of care to their passengers, particularly senior citizens and disabled, who may be standing or moving around the bus. In some situations, traffic calming can cause great discomfort, especially if the bus service has numerous vertical deflections.

Bus services operate by a timetable. Reliability is important if customer confidence is to be maintained. It is important that TCM do not cause excessively increased travel times to buses by requiring diversions or slowing down significantly more than other vehicles.

Speed cushions are the preferred vertical deflection measure for bus routes, as they have less impact on buses than speed tables, but slow vehicles to a desirable speed. It is important that there are no parked cars in the running lanes. This would prevent the bus from having to go “two wheels up” over cushions, which can be uncomfortable for bus passengers and cause delay.

Speed tables should only be used on bus routes at key locations, such as schools or shopping centers. They should not be closely spaced. The bus operators would prefer no more than five speed tables on any bus route.

Round-top speed humps are not acceptable on bus routes in London as passengers experience a double discomfort when a bus is traversing the hump, one for each set of wheels.

Suitable design schemes for TCM on bus routes should be discussed with the bus operators early in their development. Development of TCM on bus routes is often assisted by first testing bus operation on the various layouts. TCM on bus routes in London use innovative designs to achieve the required level of traffic calming without adversely affecting bus operation.

Negative Impacts of TCM

TCM could have negative effects on emergency response, slowing down the emergency vehicles. Some of the measures, especially vertical obstacles and closures, can have significant impacts on emergency response vehicles. Surveys found that fire truck engines are the most prone to be impacted by TCM measures. They are followed by ambulances carrying patients, ladder trucks, and ambulances without patients. The 12-foot hump has the most significant impact on those vehicles. Different measures have been taken to overcome these problems. TCM measures should not be applied on streets in the vicinity of fire stations, since those are the routes fire trucks use the most. Some design changes, such as speed cushions, split humps, or sealed down deflector islands are implemented to reduce the impact on emergency vehicles. The most important part is the communication between traffic management and emergency services. TCM measures have not been shown to impact police vehicles, mainly because of the special design of those vehicles. Public works, mainly snow removal, had big theoretical concerns in some areas. However, this was not a problem in practice, and TCM measures did not impact these operations. The research conducted by the Insurance Corporation of British Columbia summarizes 43 case studies of TCM impacts. Each of these studies showed that TCM decreases collision frequencies from 8% up to 100%.

Hidas et al. (*40*) conducted a study that analyzes the effects of TCM that can potentially have negative impacts on certain aspects of traffic. The analysis focused on vehicle headways, delay for vehicles entering from driveways, absorption capacity, and pedestrian crossing opportunity.

The data for the study were collected at eight sites in Sidney, Australia, where raised platforms, speed humps, or median islands were implemented. Two VDAS 3000 Vehicle Detection Data Acquisition Systems, with four detectors each, were used for the surveys. These systems collected data on traffic flows, delays, and headways 100 m (300 ft) before and after the TCM device.

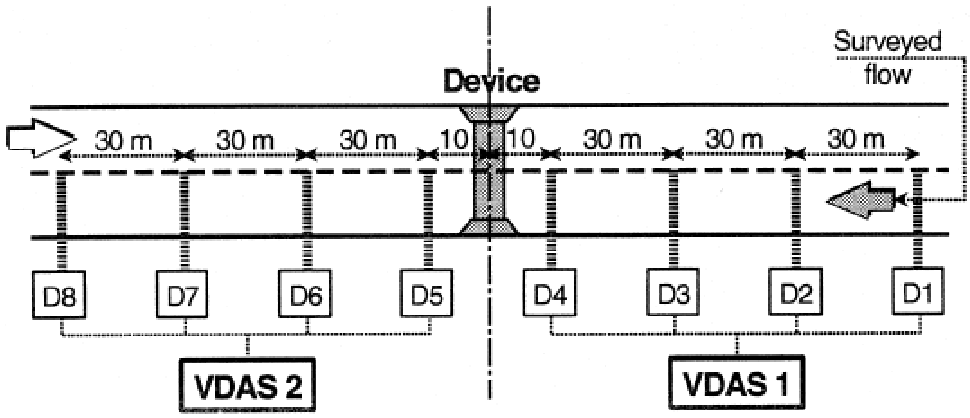


Figure 2.14 Typical Site Layout for Data Collection (*40*)

The results on headway distributions showed a disturbance in headways just before and after the device. However, at the points where vehicles left the detection zone, the headway distribution normalized. Average delays for vehicles entering from driveways were calculated at each observation point for each traffic flow level separately. At flows over 600 vph there is a noticeable increase in the average delays near the device, and that the increase is more pronounced at higher flows. However, the differences in average delays to vehicles were statistically significant only in the medium to high flow ranges (mostly between 500 and 900 vph) and at locations close to the device. Absorption capacity shows the maximum possible flow that can enter or cross a major flow from a minor approach such as at a T-intersection or a driveway under steady-state conditions. The maximum recorded decrease in the absorption capacity was less than 50 vph in absolute terms, which is less than 10% at all traffic flow levels at all survey sites. Statistically significant differences in the absorption capacities occurred only occasionally at traffic flows between 400 and 800 vph and close to the device. The majority of survey sites had implemented raised platforms. They were designed specifically for pedestrian crossing, but not as a dedicated “zebra crossing,” meaning that pedestrians do not have the right of way. In this case, there was a statistically significant decrease for almost all traffic flows between 200 and 1000 vph at locations just before and after the devices, and this impact gradually reduced with the distance from the device. Crossing opportunities at lower crossing speeds were less influenced by the devices than at normal and higher crossing speeds.

The study also looked at the desired effects of the implemented TCM measures at analyzed sites. Speed profiles in the vicinity of the devices were constructed from the headway data. An effective reduction of average speed from around 50 km/h (31 mph) to around 35km/h (22 mph) is achieved in the vicinity of the devices at all flow levels. Accident data were collected for three years before and three years after these devices were installed. The analysis focused on accidents within 100 m (300 ft) on either side of the device. All the sites except one had a percentage drop of over 50% in the number of accidents. The reduction is even more significant in terms of injury accidents.

The study concluded that physical speed control devices do have some negative side effects, but their magnitudes are below the level that would conceivably influence traffic patterns. These minor impacts are confined to the immediate vicinity of the devices. However, they are far outweighed by the benefits in terms of accident savings as a consequence of the speed reductions.
This paper shows another aspect of TCM. The findings are important for our project, since it clearly shows that the benefits of having TCM in residential areas would be greater than the expected negative impacts.

Public Opinions on TCM

Many of the described TOD programs faced concerns, complaints, and lawsuits. However, most of them were not proven to be significant or even related to implemented measures. Still, this is an aspect that needs to be considered during the planning process. Several parties are directly impacted by TCM. For that reason, TCM become a social issue rather than just a set of technical solutions. Cruise (*41*) sees TCM more as people calming than traffic calming.

The social implications of TCM implementation are focused on freedom and liberty, interaction and exchange, severance and segregation, and rights and priority. Freedom and liberty mostly refer to the freedom of people to enjoy the streets. Some reviewed studies saw the presence of a large amount of traffic as a "caging effect" on residential neighborhoods. Some researchers argue that transportation should be a means and not an end in accomplishing social interactions and exchange. Too much emphasis is placed on "getting there instead of the exchange itself." The reviewed studies also argue that the automobile-based societies cause severance and segregation between social communities. According to some authors, this reduces relationships, ideas, and cultural experiences. Traffic calming can help mitigate the negative factors that residential traffic has on social interactions. The study concludes that TCM is not about applying techniques, but rather a mindset. It should be focused on changing people's perception and behavior.

The conclusion of this study can be very useful for our project. It reminds us to have a broader perspective when analyzing TCM, and not to focus only on the technical aspects. Traffic itself is a big social issue, and traffic calming is just a part of it.

TCM – Best Practices

Implementation of TCM as traffic safety countermeasures decreased crash fatality rates in NYC significantly. The study reviewed here (*42*) shows that TCM have the intended effect on severe crashes. NYC has the lowest fatality rates among all U. S. cities with the population over 250,000. This is why NYC needs to be considered as one of the best examples of TCM application.

Despite the great number of TCM projects in the United States, little is known about their impact on traffic safety. The study conducted by Zein et al. in 1996 summarized 43 international traffic calming case studies. It showed that collision frequency is reduced in each case. The most safety-effective TCM were traffic circles and chicanes (82%); less effective were speed humps and narrowings (75%); and the least

effective speed reductions and engineering measures. Ewing (1999) compared 85th percentile speeds and traffic collision frequencies before and after TCM were implemented in United States. Of all TCM, speed humps and bumps had the greatest impact on 85th percentile speeds, reducing them by an average of more than 7 mph, or 20%. Among speed reducers, raised intersections and narrowings had the least impact. All measures reduced the average number of collisions on treated streets. Traffic circles caused the largest collision reduction of 73%, while speed humps caused the smallest collision reduction of 14%. A study conducted in Oakland (Tester et al., 2004) showed that the presence of speed humps on a street was associated with lower odds of child pedestrians being injured within their neighborhoods or being struck in front of their homes. Improved street safety is a stated objective of many programs, and many programs prioritize projects based in part on crash statistics (Ewing and Brown, 2009).
The paper reviewed here is focused on TCM implemented in NYC to reduce crashes. Traffic fatalities are the sixth leading preventable cause of death in the United States. According to NHTSA, 12% of traffic fatalities in 2009 involved pedestrians. In cities with populations over 250,000 the percentage of pedestrian crashes is even higher.

NYC maintained its low pedestrian fatality rate despite a high percentage of trips involving walking. Nearly 57% of workers in NYC used public or non-motorized transportation to travel to work in 2007. The city has accomplished this by identifying the locations where safety countermeasures need to be implemented and invested a lot to implement them.

NYC uses vertical deflection measures referred to as speed humps or speed tables to calm traffic. Speed tables are flat-topped speed humps usually constructed of asphalt, with brick or other textured materials on the flat section. They are typically long enough for the wheelbase of passenger car to rest on top of them. Longer ones may even accommodate trucks and buses. Speed tables enable higher design speeds and smother rides due to their lengths and flat fields.

The authors use a quasi-experimental before-after study design with a comparison group to examine the effect of speed tables. The goal is to assess the impact of speed tables on the frequency of various types of crashes. The study compares crashes before and after TCM treatment and refers to matched comparison streets. This design is called "an untreated control group design with pretest and posttest samples."

The comparison of crashes before and after TCM treatment shows the effect of speed tables on crash reduction. The comparison between treated and untreated streets is conducted to capture whether the crash reduction would occur without the treatment. This makes the study more valid than the previous studies in this area. T-test is used to show how significant the effect of the treatment is.

The sample used for this study consists of NYC streets treated with speed tables between 1996 and 2006. Two years of crash data before the treatment were compared to two years of crash data after the treatment. The sample of untreated streets was drawn from the same years. The treated and untreated streets with similar characteristics were matched for the comparison.

The outcome variable was the difference in police-reported crashes that occur on roadway segment before and after installation of speed tables. The authors computed the difference in crash frequency after treatment relative to before the treatment, less the equivalent difference for untreated streets. This is how they determined whether the relative change in crashes is significant.

The results showed that the treated and untreated streets comparability is weak. This is because treated streets had significantly higher crash frequencies before the treatment than the untreated streets. However, the expectation of reduction in crashes due to implementation of speed tables proved to be correct. The reduction was more significant for pedestrian crashes than crashes as a whole. This suggests that TCM reduce severity of crashes.

This study has several major contributions. It shows the need for more tests to establish the TCM effects, since NYC had a decreasing trend in crashes with each passing year. TCM reduce the severity of crashes, although the impact on reduction in crashes as a whole is marginal. The major limitation of the study is that only one type of TCM is examined. The study also does not consider inconsistency in traffic volumes in NYC. The authors conclude that although the effect on crash frequency is barely significant, TCM improve the quality of residential environment while being cost-effective.

2.5 Toward Successful TOD

A report done by Nelson et al. (*43*) develops planning methodology for TOD. This methodology involves increasing the density of housing, offices, retail, and services around mass transit stations in an urban region. It makes pedestrian access very easy and encourages more use of transit and a reduction in automobile driving. TOD is intended to influence all travel purposes. The report mostly focuses on non-work travel and its implications on TOD. The objectives of the study described in the report were:

Analyze non-work travel demand as influenced by retail market dynamics on a national and regional level

- Review the state-of-the-art in regional transportation planning by metropolitan planning organizations (MPOs) with respect to non-work travel
- Create a planning template for regional transportation and land use planners for TOD that encompasses non-work travel

TOD Planning

Nelson et al. (*43*) explains the change of thinking that lead to TOD planning. Low density, separated use developments that were predominant in the United States stimulated travel by automobile. This caused an increase in congestions, delays, air and noise pollution, and a deteriorated life quality. One of the solutions to these problems was encouraging TODs. During the 1990s, TODs became one of the leading urban planning concepts. Proponents of TODs envision dense, mixed-use activity centers connected by high quality transit systems. MPOs, local governments, and public transit agencies have launched major efforts to direct growth of the TODs.

TOD is defined as a center with a mix of high-density residential, retail, office, public and open space uses. Retail shops and services are in a commercial core within an easy walk of homes (a walking radius of about 10 minutes). A transit station is at the center of the core. Uses in the core are “vertically integrated,” where apartments and offices rise above ground-floor stores. Secondary areas for lower intensity uses surround the core to a distance of about a mile. These areas might be locations for single-family housing in a range of sizes, small parks, schools, and light industry. Streets largely conform to a grid pattern and provide direct walking and biking access to the core.

Factors that determine the success of a TOD can be viewed on a station area and regional aspects. The main factors that determine the success of a TOD are following:

Number and siting of TODs	Employment and housing density	Travel behavior
Transit quality	Commercial mix	Zoning flexibility
Transit technology	Retail siting area	Resident reactions
Street pattern	Regional market structure	Housing type preference
Station area parking	Consumer activity patterns	Residential self-selection
		Government policies

Another indicator of the success is the cost/benefit ratio.

Table 2.5 Costs and Benefits of TOD

Cost	Benefit
Transit system construction	Congestion reduction
Transit system operations	Air quality improvement
Mitigation of traffic congestion caused by compact development	Reduced infrastructure
TOD planning and development incentives	Personal travel time, vehicle operation savings
	Personal vehicle ownership reduction

Since the 1970s, there has been a big increase in personal travel. It has largely resulted from increased frequencies of non-work trips, especially for shopping and other family and personal business activities. Retail activities account for more than half of all person trips, and most are made to locations where the traveler has more than one choice of destination. Many retail trips are linked in tours that involve several stops for a variety of purposes. Several studies found that private vehicles dominate in the mode share for these trips. The goal of a TOD is to change the mode share distribution and facilitate non-motorized and transit mode for non-work trips.

Changes in the retail marketplace are observed as the predominant factor of the increase in non-work trips. It is characterized by a great variety and opportunity. For that reason, it plays a major role in the TOD planning and design process.

Finally, the TOD planning process has to account for a large number of non-work trips. The main steps that have to be taken are as follows:

- Emphasizing non-work trips in urban transportation planning
- Assembling data to describe these trips and the activities and destinations that cause them
- Assessing the complexity, risk and uncertainty that these data reveal for transportation in the future
- Adjusting the direction of public policy in response to the revealed data and the assessment of what they mean for the future

This study describes the most important factors that have to be considered for a TOD planning process. TODs insist on mixed land-use developments, which increase the number of non-work-related trips. The study focuses on those types of trips and describes the main elements that have to be considered from this aspect. The findings can be very useful for our project.

TOD Design Issues

TOD dimensions considered from the design aspect are regional context, land use mix, and primary transit mode (*44*).

There are two perspectives for the regional context dimension: city center TODs and suburban TODs. A city center's TOD emphasizes a transit-accessible urban development to increase transit ridership and to encourage pedestrian activity. Some aspects of the city center, such as grid street patterns and ground-level retail uses, are attributes usually shared with TODs. Most TOD implementations reported an increased transit ridership, encouraged pedestrian activity, and required less parking than more traditional projects. Suburban TODs are generally built on or around park-and-ride lots. TOD has become viable on these sites in part because metropolitan areas have expanded outward beyond the ends of the transit lines. However, balancing TOD and parking provisions have shown to be among the greatest challenges in planning suburban TODs. Transit mode share for suburban TOD is higher than for traditional suburban development, but the automobile still plays a predominant role in providing mobility.

	City Center Context	Suburban Context
Transit Markets	Urban sites are often directly accessible to and from multiple transit markets. For example, Gallery Place Metro station in Washington, DC, is fed by three rail lines originating from five different suburban areas and passing through different downtown areas, all offering one-seat rides to the station.	Markets served by high-quality transit service may be limited. For example, Ballston Metro station in Arlington, Virginia, is fed by a single east-west rail line originating from two suburban areas. Other transit riders from around the metropolitan area must transfer to arrive at the station and/or use bus service.
Drive Markets	Highway accessibility remains important to the urban real-estate market. Automobile-oriented commuting is prominent even in the most transit accessible locations.	Mode of access to suburban transit station developments tends to remain dominated by the automobile and therefore automobile accessibility is of substantial importance.
Parking Management	It may be more acceptable to constrain and manage parking in downtown areas, especially by using pricing. Constrained parking leads to higher transit attractiveness. People may own fewer cars in central areas due in part to good transit service availability and easy walking access to utility retail.	It may be difficult to manage parking; the suburban real estate market may dictate parking space ratios that are higher-than-optimal for transit. Examples abound where developers build more parking than is required. Also, higher rates of automobile ownership among residents are present.
Phasing Effects	Existing nearby land uses may support a TOD project in reducing single-occupant vehicle usage for midday trips. Alternatively, nearby legacy development may retain automobile orientation and dampen the behavior impacts of adjacent TOD.	Neighborhood services supportive of non-automobile, non-work travel may not pre-exist. Thus, until such uses are part of the TOD, the early phases of a new TOD may exhibit higher automobile mode share than the later phases of a more mature TOD.

Figure 2.15 Perspectives of TOD as Differentiated by Regional Context (*44*)

In general, more diverse TODs from the aspect of land use generate more non-motorized and transit trips. The analysis of different TOD sites showed that a TOD that enables its occupants to address daily needs within the site would result in fewer automobile trips per person.

The traveler response can further be analyzed by the specific land use type. The most common land use types are residential, office, and retail. TODs that are focused on residential use offer enhanced opportunity for residents to accomplish commuter trips and off-peak activities using transit. Off-peak and other non-work activities in particular may also be met by walking, especially if convenience retail is located nearby. Office development has strong peak-period travel demand as workers arrive and depart the facilities at similar times. It also generates midday travel demand. Transit-oriented office centers enable building-to-building travel by walking and easy connections to other activity centers via transit, reducing the number of automobile trips. TODs that focus on retail also showed an increased number of non-automobile trips. Longer trips are usually accomplished by transit, while walking was predominant for short trips.

Almost 90% of the TODs analyzed in this report are built at rail transit stations, most of it around heavy rail transit (HRT) and light rail transit (LRT). Other modes, sorted by the level of influence on TODs, are commuter rail, bus rapid transit (BRT), and traditional bus.

	Less-Diverse TOD Project	More-Diverse TOD Project
Transit Markets	Unless the TOD is a shopping complex, it is likely that peak-period (commuter) transit travel, mainly in one direction, will predominate.	Peak-period travel is likely to be oriented around commuter trips, but possibly more balanced by direction, and some land uses, such as shopping and entertainment, may generate off-peak transit trips.
Travel Needs	Tenants are more likely to require vehicle travel to satisfy daily needs.	Tenants are more likely to find at least some of their needs can be met without requiring out-of-project travel. Substitution of walk trips is thus facilitated.
Parking Requirements	Proximity to transit may lead to higher project transit mode shares than for non-TOD development and correspondingly lower development parking requirements.	Possibility for higher project transit mode shares and walk mode of access to transit shares, coupled with potential for shared parking among uses, may lead to lower overall parking requirements than for less-diverse TOD or non-TOD centers.
Auto Ownership	Need/desire to own and use a car may be higher in a less diverse context than in a more diverse context.	Walking is a likely mode for the short distance travel allowed by a more diverse context. This may lead to a reduced requirement for automobile ownership.

Figure 2.16 Perspectives of TOD as Differentiated by Degree of Land Use Mix (*44*)

The most important underlying traveler response factors that influence mode share are recognized as follows:

- Land use and site design
- Automobile ownership
- Transit service characteristics
- Highway access and congestion
- Parking supply
- Parking pricing and transit support
- Self-selection of residents

Mode	Typical Attributes	Considerations	Examples
Heavy Rail Transit (HRT)	Motorized cars draw power from a third rail and operate on exclusive right-of-way with no at-grade crossings. Off-board fare payment at or verified by fare gates.	Large investment in HRT leads to very extensive station-area planning. High service levels and traffic-free operation attract substantial proportions of transit-using TOD residents. Special challenge with HRT suburban stations is finding balance with vast numbers of park-and-ride spaces.	Atlanta, GA Chicago, IL San Francisco, CA Washington, DC
Light Rail Transit (LRT)	Motorized cars draw power from overhead wires and operate on some or all non-exclusive right-of-way with at-grade crossings. Off-board fare payment verified by random ticket inspection.	LRT stations tend to be smaller scale and more closely spaced than HRT. Park-and-ride use can be a challenge. Substantial investment is required to build LRT, sparking similar levels of planning attention as HRT.	Dallas, TX Denver, CO Portland, OR San Diego, CA
Commuter Railroad (CRR)	Railroad cars motorized or pushed/pulled by a locomotive. Often share tracks or corridor with freight trains. Ticket purchase verified by on-board conductor.	Not all systems offer off-peak service or weekend service. Notable TOD projects are most associated with seven-day service and peak period headways of 20 minutes or so. Park-and-ride is an important CRR rider market.	San Francisco, CA Chicago, IL New York - New Jersey
Bus Rapid Transit (BRT)	Premium bus service including: special vehicles, exclusive right-of-way segments, signal priority, upgraded waiting areas. Various fare payment methods employed including off-board.	BRT systems involving special vehicles, dedicated lanes, and frequent seven-day service can logically have the same TOD possibilities as LRT. Park-and-ride can be a significant land use near berthing areas.	Boston, MA Pittsburgh, PA Ottawa, Canada
Traditional Bus	Scheduled, fixed-route local and express bus services. Predominantly on-street running; may operate on special facilities. On-board fare payment.	High-frequency traditional bus services (at least four vehicles per hour) can offer the potential to support TOD. Also, bus lines play a supportive role at most rail TODs.	Boulder, CO Renton, WA

Figure 2.17 Perspectives of TOD as Differentiated by Primary Transit Mode (*44*)

The most important underlying traveler response factors that influence mode share are recognized as follows:

- Land use and site design
- Automobile ownership
- Transit service characteristics
- Highway access and congestion
- Parking supply
- Parking pricing and transit support
- Self-selection of residents

Land use and site design are focused on density, diversity, and design from a TOD-supportive perspective. Higher development and trip densities go hand-in-hand with TOD. Increased development density places more housing, jobs, and activities within the same land area. This creates a higher number of trips starting and ending within the TOD, creating high trip densities. The added ridership potential of TOD-supportive densities facilitates a cost effective, higher-quality transit service. More diverse TOD projects offer the possibility of a greater proportion of activities being conducted within the center and a corresponding reduction in motorized travel generation. Diverse land use enables more needs to be satisfied on a single visit and allow internal walking trips to serve for visiting more destinations. The compact, pedestrian-friendly design of a TOD leads to higher transit usage and walking because of the underlying traveler responses to this environment. The shorter walking distances encourage transit usage and walking for transit access, and the pedestrian-friendly design encourages more walking overall.

Many studies recognize automobile ownership to be a key factor in mode choice. Individuals living in households without an automobile, or with fewer automobiles than licensed drivers, are more likely to use transit, walk, or rideshare. Automobile ownership levels among station-area residents have been seen to be lower as compared with non-station-area residents.

The traveler response to TOD is influenced by the service characteristics of the one or more transit modes providing access to and from the location. TODs with better transit service characteristics have higher transit ridership levels. Also, some studies suggest that such TODs are more likely to attract residents interested in making use of transit. The most important service characteristics are service coverage, hours of operation, frequency, travel time, fares, and perceptions of safety and security.

Highway access is very important to TOD, especially in the suburban context. A significant number of residents, employees, and customers still travels to and from a TOD using private vehicles. The higher densities associated with the typical TOD may contribute to localized congestion. When such congestion causes automobile travel times to decline relative to transit operating on an exclusive right-of-way or in reserved lanes, it tends to encourage transit use at the TOD. Similarly, walking rather than driving may be encouraged for short trips to the extent that good pedestrian connections are available.

Parking supply within a TOD has a major role in travel mode selection. It must be held at a reasonable level and carefully planned, since a significant number of vehicles still need to access the TOD by automobile. Insufficient parking supply near transit stations can reduce transit ridership by limiting the auto access ridership component. On the other hand, excessive parking can create a hostile environment for pedestrians and transit. There are two components of the parking supply within a TOD: parking for the development at the station and parking for transit users. Both components are equally important for a carefully planned TOD.

Parking pricing offers a mechanism to manage demand and maintain availability of constrained parking in TODs. Transit support is aimed to encourage transit use. Two demand management programs exist within the studied TOD implementations: employer-based programs and transit pass programs. These programs impact both parking and transit support.

Studies showed that residents who live near transit stations almost always have higher transit mode shares than residents outside these areas. A certain number of people choose to live near transit stations because of the easier access to transit. This process has been labeled as “self-selection of residents.”

A certain number of related impacts and information that impacts TOD development was also studied in this report. Related information and impacts are grouped as:

- Household characteristics
- Trip characteristics and congestion
- Pre- and post-TOD travel modes
- Vehicle trip, VMT, energy, and environmental relationships
- Health and safety benefits
- Economic benefits
- Transit-oriented development index

Households in TODs have exhibited different demographic and socioeconomic attributes than non-TOD households in several surveys. Some of this difference is explained by common attributes of individual households that choose to live in TOD housing rather than being an effect of the TOD on households. In general, smaller-than-average households appear to have been attracted to TOD projects.

A high-density development of a TOD leads to a greater concentration of residents, workers, or shoppers in a localized area. Since a significant number of those people uses automobiles to access the TOD, congestion may appear. Higher transit ridership associated with the TOD can help mitigate the congestion. Also, some trips that would otherwise require an automobile may be replaced with internal walking trips. The most important aspects of these TOD characteristics are trip generation, trip chaining, midday trip making, and congestion.

A few studies looked into the travel modes of TOD residents or workers before and after relocating to a TOD. The travel mode shifts upon relocation into TODs range from 2% to 16% in transit commute mode share gain.

Reductions in automotive trips and VMT come primarily from either mode shifts or reductions in trip length. These reductions lead to further energy savings, air and noise pollution reductions, and an overall improvement in the quality of life.

A TOD has many health and safety benefits. Three main categories are most recognized: health benefits attributable to increased walking opportunities, health benefits from improved regional air quality, and safety benefits derived from an improved pedestrian environment.

Certain economic benefits are also associated with a TOD. The most attention is given to property values. Some studies showed a correlation between the proximity of a transit station and an increased property value. Apartments and offices near stations also tend to rent for more. This, on the other hand, brings more property tax revenue for government agencies.

The “TOD Index” was imagined as a way to characterize the degree to which a project functions as a TOD. It is a preliminary design planning guidance tool. A national survey of 30 professionals highlighted 15 success measures of a TOD. All the indicators are related to travel behavior, built environment, and economics.

2.6 Transit Friendly Designs

TOD and Transit Friendly Designs (TFD) are often seen as the same concept. However, after reviewing literature on different transit practices, we were able to draw a line between the two concepts. TOD is a comprehensive planning approach toward creating dense, diverse, mixed land-use communities concentrated in the vicinity of major transit stations. It focuses on massive transit systems, such as heavy, commuter, and light rail, or, in some cases, BRT or enhanced bus service lines. TFD is an engineering approach that facilitates transit on an area-wide scale. It considers all transit modes, but is more focused on bus transit that is more flexible and can cover a wider service area. TFD is an integral part of TOD, but it also can be implemented as a stand-alone concept. In the second case, TFD can be one of the first steps toward creating TOD. This section provides the most important concepts of TFD, current state of practice, and lessons learned from its implementations.

What is Transit Friendly Design?

TFD can be defined as a set of techniques for improved integration of transit into residential and non-residential areas (*46*). It can be incorporated into the planning process for new developments, or can be applied to existing ones.

Transit friendly streets make transit use more efficient and convenient. It also makes the street less convenient for automobiles while still accommodating them. At the same time, other functions of a street are recognized so that transit does not overwhelm the street. Transit friendly streets accomplish the following four goals (*47*):

- Establish a clear priority for transit vehicle operations with convenient, accessible transit stops
- Reduce conflicts between cars and other private vehicles, including reduction of vehicle speeds
- Create a strong pedestrian orientation, including adequate circulation space, ease in crossing streets, and appropriate amenities, all of which contribute to comfort and convenience
- Integrate the whole process of planning shared transit streets into a larger community development or livability-enhancing strategy, working closely with the communities impacted by the program

Transit friendliness applies to shopping, industrial and office park developments, as well as residential areas. There is mutual gain when transit and enterprise support each other. Transit can provide employees and customers easy access to commercial enterprises and business activities. These activities generate trips on transit and help support quality transit options (*46*). TFD provides transportation options and improves access to employment, supporting economic development. It also reduces dependence on the private automobile, resulting in reduced traffic congestion, reduced fuel consumption, improved air quality, and a decrease in demand for new roads (*48*).

Transit Friendly Design Principles

There are several engineering techniques that help define transit friendly designs. Some of them overlap with the principles of TOD, which are incorporated into the community development plans. Others can be achieved as stand-alone implementations that help improve existing communities and bring transit to a higher level. The set of applicable techniques can be classified into the following eight principles (*46*):

1) Provide appropriate community densities
2) Minimize walking distance
3) Provide mixed land uses
4) Organize density, land use, and buildings to benefit from transit
5) Create a pedestrian friendly environment

6) Route transit into the community
7) Reduce transit travel time
8) Build quality, user friendly transit facilities

Provide Appropriate Community Densities

To be cost-effective, transit must reach a sufficiently sized pool of potential riders and must reach a minimum threshold population (*46, 48, 49*). Development of population or jobs above minimum levels should be encouraged. Population and employment densities affect the quality (frequency of service), range (service choices), and duration (hours of operation) of transit service that can be provided in an area. Low densities provide an insufficient pool of potential riders and cannot support desirable service options. Table 7 provides the requirements of density (given as dwellings per hectare) for different transit services obtained through research of transit properties across North America (*49*).

Table 2.6 Transit Service Related to Density (*49*)

Transit Service Description	Density (dwellings/ha)
Local bus, daytime hourly service	9.88
Local bus, extended hours and 60 min service, or 30 min daytime service	17.29
Frequent bus service, some express	22.23
Very frequent service (5 – 10 min)	37.05

Minimize Walking Distance

A commonly accepted walking distance is about one-quarter mile, or five minutes of walking time. This distance is adopted as the gauge to locate distance to transit from the majority of dwelling units in transit friendly communities (*46, 48*). Pedestrians are discouraged by a long, indirect walk to transit, especially in inclement weather. They are more likely to use transit services if the beginning and the end of their trip is close to a transit stop or station. Efficient community design that addresses both walking distance and the need to minimize transit travel distance will reduce the costs associated with providing and operating transit service. Block lengths and street pattern are the main features that affect the walking distance (*46, 49, 50*). For a high degree of walkability, block lengths of about 300 feet are desirable. Blocks of 400 to 500 feet are still acceptable. However, as blocks grow to 600 to 800 feet or to superblock dimensions, adjacent blocks become isolated from each other. If blocks are scaled to the automobile (more than 600 to 800 feet), lighted pedestrian pathways, midblock crosswalks, and pass-throughs are recommended.

Also, narrower streets on a grid pattern with more intersections to slow local traffic down are recommended to minimize walking distance and make walking trips more interesting and safe. The grid network should be designed for convenient, direct pedestrian access to services, shops, and transit that are located on the arterial road. This convenience results in more pedestrian activity and higher transit ridership. Figure 2.18, adapted from (*46*), shows some undesirable and desirable designs from the aspect of walking distance.

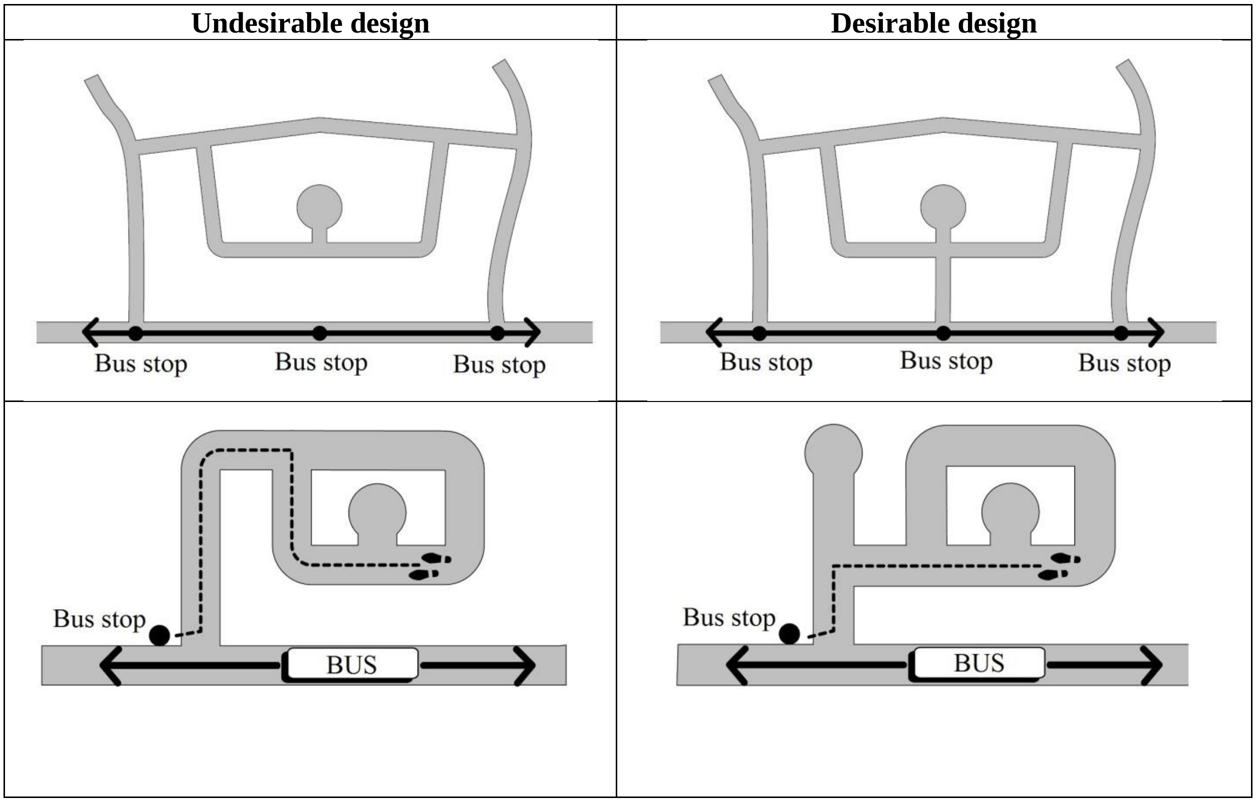


Figure 2.18 Undesirable and Desirable Designs for Walking Access (*46*)

Provide Mixed Land Uses

As a part of TOD, TFD promotes development that includes residential, commercial, employment, institutional, and recreational uses (*46, 48, 49*). Mixed land uses (or activities) contribute to enhanced transit operation by accommodating a range of travel options or trip purposes. Transit riders gain the ability to undertake multi-purpose trips on the way to or from work. Diverse uses along a street also create activity and a greater sense of personal security for those walking or waiting for transit service. Mixing land uses means combining commercial uses of various types, permitting personal services and restaurants to be located near industry or commerce. Most importantly, residential subdivisions should include convenience services within walking distance. The opportunity to walk to and from bus stops and accomplish errands conveniently is further motivation to use transit rather than drive. Retail facilities can become independent transit destinations if they are located on transit routes.

TFD should feature pedestrian oriented streetscapes, with building entrances directly at the sidewalk within a few steps of transit, and with sidewalks that have amenities such as trees, benches, and some border between the sidewalk and the street. People living in this type of development are more inclined to use public transit because their familiarity of the area is not dependent on automobile use. Many places are easily accessible from the sidewalk as opposed to being hidden inside an enclosed space like a mall. A mix of land uses in close proximity to each other makes it easy for people to accomplish several trip purposes by walking, a single transit trip, or a single automobile trip, rather than several destinations. The key to reducing single automobile trips with mixed land uses is to incorporate road designs and pathways that allow direct pedestrian access.

Organize Density, Land Use and Buildings to Benefit from Transit

The developments should be organized in such a way to take the most advantage of transit service (*46*, *48*, *49*, *50*). Bringing transit closer to people makes travel much easier and encourages transit use. The highest density uses should be closest to transit. Commercial sites that are transit supportive usually face the street and provide ease of access for patrons who are approaching by foot, not by automobile. A transit supportive streetscape provides the majority of parking behind buildings, rather than having angle parking or large lots in front. Some retail businesses are automobile oriented, resulting in heavy traffic on streets where they are located. Typically, these businesses have parking directly off the street. Some examples, adapted from (*46*) and (*50*) and given in Figures 2.19 and 2.20, show the undesirable and desirable site organization. The undesirable organization is automobile oriented, while desirable is transit oriented.

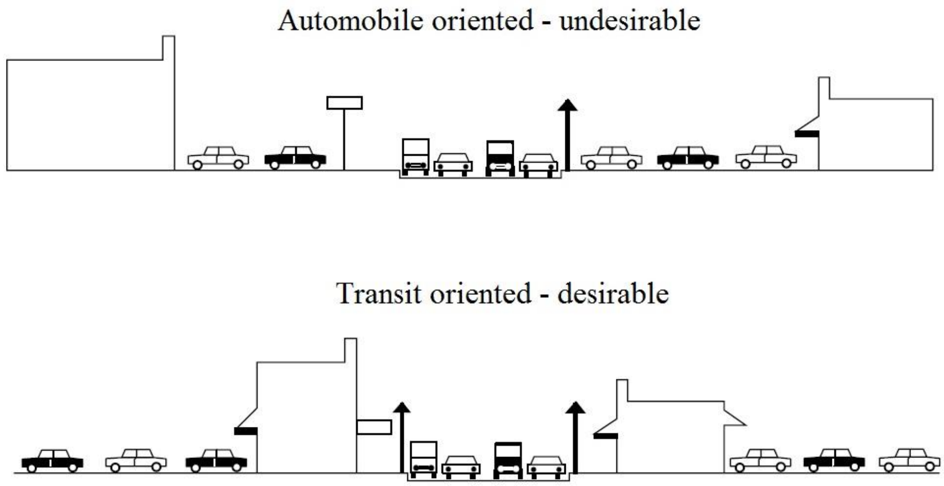


Figure 2.19 Automobile and Transit Street Organization

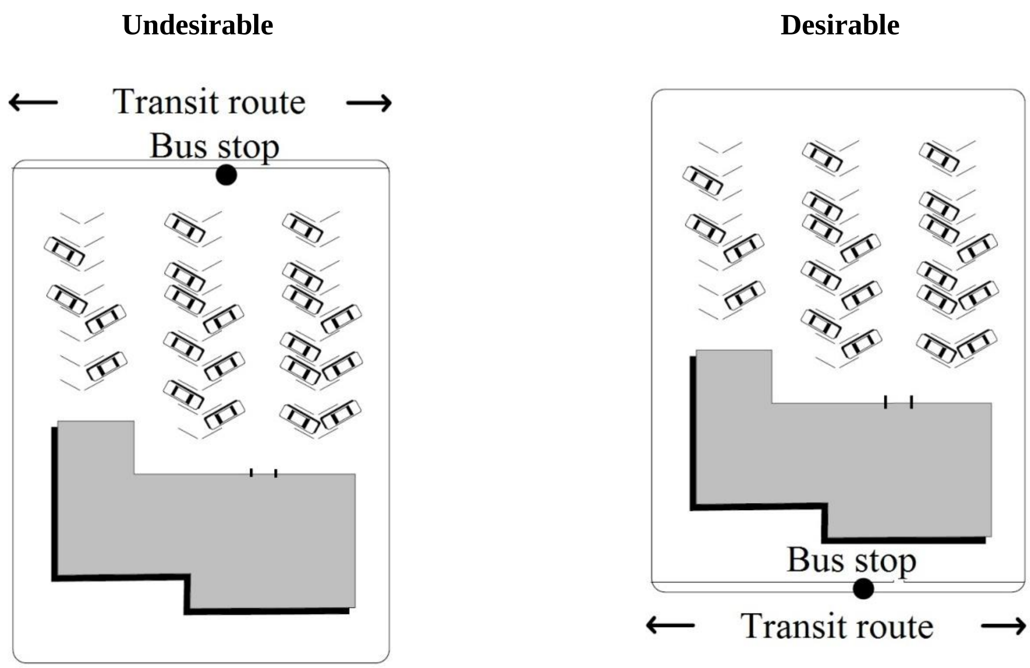


Figure 2.20 Undesirable and Desirable Access (*46*, *50*)

Buildings should be clustered at intersections close to the street to make them convenient to bus stops and to organize street crossing. Developments or single sites that cluster the buildings close to the street should incorporate a street level design that encourages pedestrian activities. To be more convenient for pedestrian access, buildings should be set back no farther than 25 feet from the street edge. Ideally, buildings should be flush with the sidewalk or set back just far enough for a modest yard, forecourt, or landscaped area in front. Surface parking will be to the side or rear of buildings. Parked cars should not dominate the streetscape by projecting beyond adjacent building fronts. If any off-street parking is allowed in front, and it is best not to allow any, it should be no deeper than a row or two. An example of a desirable design, adapted from (*46*), is shown in Figure 21.

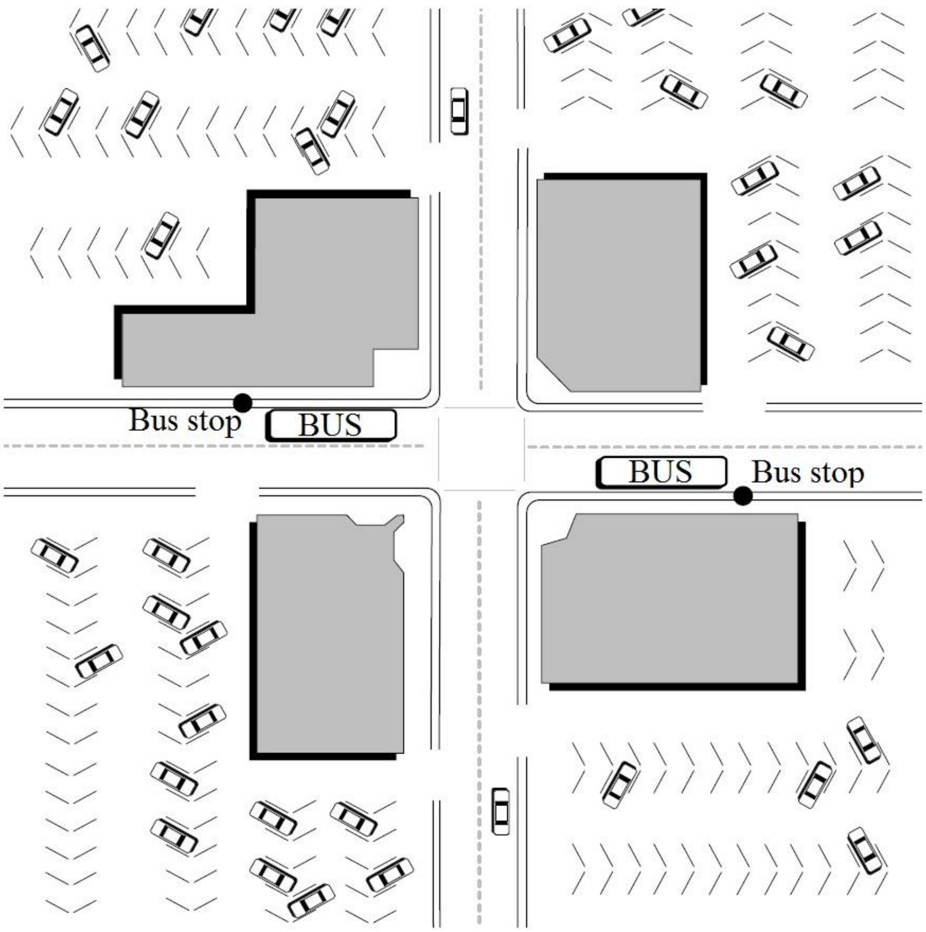


Figure 2.21 Desirable Corner Development (*46*)

Landscaped setbacks should be carefully designed to avoid long walking distances for transit users and to avoid isolating those waiting for buses. Pedestrian connections linking the building and transit services should be provided. Where the normal sidewalk system is inadequate, dedicated pedestrian walkways should be used to provide access to transit services.

Create a Pedestrian Friendly Environment

Transit and pedestrian friendly designs are two inseparable parts for successful developments that do not rely on automobile. Since the majority of transit trips begin and end with walking, special attention should be given to this mode to make it more beneficial for transit use (*46, 50*). For that reason, pedestrian facilities are required in all areas of a development. The pedestrian system should provide for a continuous high-quality barrier-free walking surface and be directly linked to transit stops or rail stations. Barrier-free sidewalks and pathways to transit service are necessary for all transit customers, especially for those with reduced mobility. Manuals of traffic engineering establish minimum sidewalk widths of 4 to 8 feet, depending on the functional class of road and the abutting land use (*50*). For example, a 5-foot sidewalk is wide enough for two people to walk comfortably abreast, and may represent a good dimension where pedestrian traffic is light, street furniture is limited, and buildings are set back from the sidewalk. Where these conditions are not met, as in any respectable downtown, wider sidewalks are warranted.

Pathways should be used to supplement the normal street network. Pathways that provide transit access should be short, direct, and lighted. They would serve regular transit customers making trips after dark. Every effort should be made to maximize opportunities for community surveillance of the pedestrian network that provides transit access.

Another important pedestrian feature is marked and lighted crosswalks. Crosswalks provide easier access to and from transit service, but are also an important safety feature. Some pedestrian facilities' design manuals recommend marked crosswalks every 100 feet on pedestrian streets (*50*). This would mean more mid-block pedestrian crossings, which can serve as a traffic calming measure. Pedestrian crossings can be simplified, and pedestrian safety improved, by designing street corners to be sharp rather than rounded. This means using lower street corner radii, up to 10 feet according to the aforementioned manuals. Traffic calming measures, such as neckdowns, chockers, raised crossings, and textured pavement, can be successfully used in pedestrian facility design (*47*).

Route Transit into the Community

The most desirable option for transit is to integrate transit service into the heart of the community or development. The quarter-mile walking standard should be incorporated wherever possible. This means a careful routing of transit and bus stop location selections. The optimal spacing of routes is about half a mile for parallel transit lines. This assumes that transit stops are closely spaced along routes, and that local streets lead directly to stops. If stops are infrequent or local streets are curvilinear, parallel routes must be even closer together. Many TOD manuals recommend transit routes every half mile, and collectors or arterials spaced accordingly. Collectors and arterials are favored for transit use over local streets because of their wider lanes and greater distances end to end. Half-mile spacing of higher-order streets and transit routes is a recommended value for network density.

Transit friendly street networks are interconnected street patterns that provide direct pedestrian access through neighborhoods to a centrally located bus stop (*48*). Street networks with curvilinear characteristics and grid networks may be considered transit friendly as long as shared use paths creating short, direct connections are provided.

For a public transit agency to provide service that is fast and convenient, road design should take into consideration two factors:

- Pedestrian access to the transit route should be safe, comfortable, barrier free, and direct
- Roadways should be designed to allow transit movements that are competitive with automobile travel time

Important activity sites like shopping centers, and educational and medical facilities should be designed to provide convenient on-site transit facilities. On-site facilities provide reduced walking distances for riders and may promote transit use because they are highly visible to new or occasional riders.

Surroundings of a mass transit stations (such as light rail) offer a great opportunity to link high-quality transit facilities with adjacent land uses for long-term mutual gain. This is especially important for the planning process, where this type of development should be planned well ahead.

Reduce Transit Travel Time

Transit travel time can be considered the single attribute of a transit system that customers care the most about, especially for trips made for work purposes. Travel time for transit riders has several parts: the time spent walking to transit, waiting for the bus or train, and time spent travelling on transit. Community design can help reduce walking and vehicle travel distances. These measures contribute to a shorter and more direct transit trip. The street system within a community must provide for the efficient circulation of transit vehicles in a manner that effectively links the activities and residents. The walking distance guideline of 400 meters should be used to develop an appropriate transit route, and within this guideline, directness of travel should be emphasized.

The routing of transit lines can help lower the transit vehicle travel times. The transit routes should be as direct as possible. Some examples of undesirable and desirable transit routings are given in Figure 2.22, adapted from (*46*).

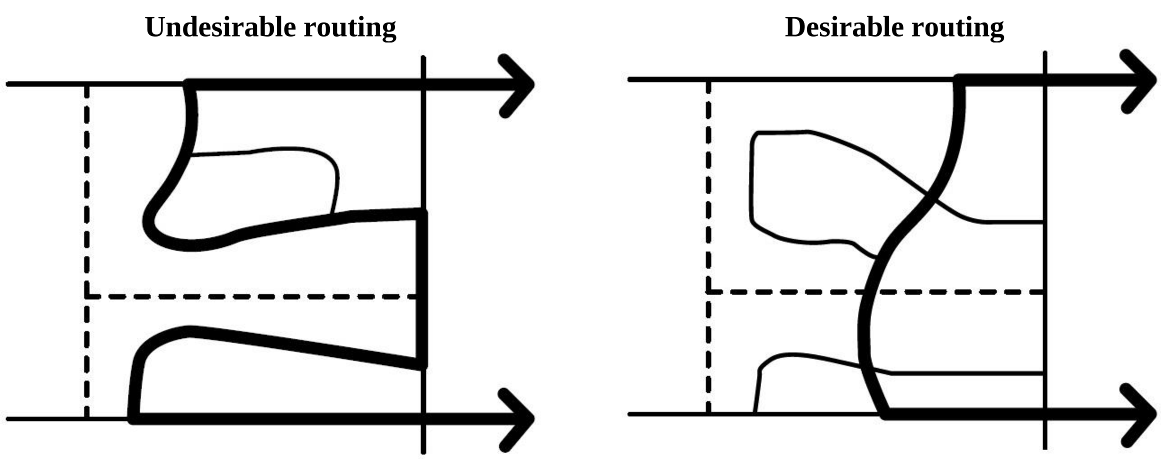


Figure 2.22 Undesirable and Desirable Transit Routing (*46*)

There are several strategies that are used to reduce transit travel times. The most common used are transit-only links, transit-only lanes, transit signal priority and preemption, and queue jump lanes. A transit-only lane is a strategy used to improve transit efficiency on a commercial street, either as part of larger projects (such as a transit mall) or separately (*47*). However, their implementation can sometimes be limited by the available resources. Transit signal priority and preemption are operational strategies that prioritize transit vehicles at signalized intersections, reducing their delays and therefore lowering the travel time. These operational strategies improve schedule reliability, make transit more competitive to private cars, and have a potential to increase market share of trips (*49*). Queue jump lanes are separate lanes at intersection approaches that allow transit vehicles to “jump” ahead of waiting vehicles. These lanes are sometimes integrated with right-turn-only lanes. The use of queue jump lanes can also be limited by the available resources. A schematic diagram of a queue jump lane is shown in Figure 2.23.

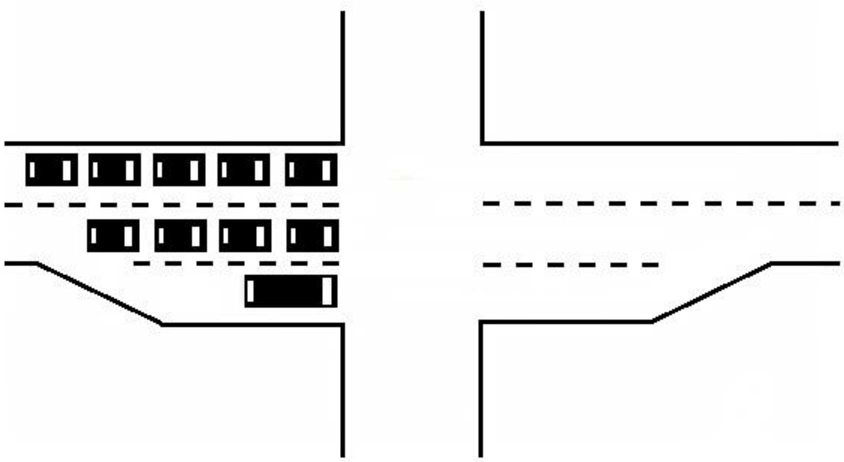


Figure 2.23 Bus Queue Jump Lane (*49*)

Build Quality, User Friendly Transit Facilities

Transit facilities should be planned and designed to provide a quality and safe environment for transit users. In general, transit facilities should be considered a long-term project that is designed to accommodate modifications as new circumstances and service options develop (*46*). Facilities should be managed to ensure constant effort toward expanding activities and enhancing the market and community potential of the site. Ease of maintenance and adaptability are important factors to consider in the initial design.

The enhancement of transit-friendly streets should include the design of the curb and the sidewalk space (*47*). Bus stops spaced along a street are the most common transit amenities. Bus stop and passenger shelter locations should be based on the level of ridership activity. Developments along transit routes should include appropriate locations for bus stops with paved passenger boarding areas and passenger shelters for stops with higher activity. Stops should be located where it is safe for passengers to wait and board. Transit stops at large commercial and office developments should be centrally located, or located on streets and not within the development. This would maximize the use of stops and minimize transit distances and travel times. Passenger shelters should be included at stops with higher ridership activity. Shelters protect passengers from inclement weather and provide a safe place to wait for transit. They should be enclosed at three sides and located at least five feet from the curb. They also must comply with ADA requirements. A commonly used design of a bus stop with shelter is given in Figure 2.24, which is adapted from (*48*).

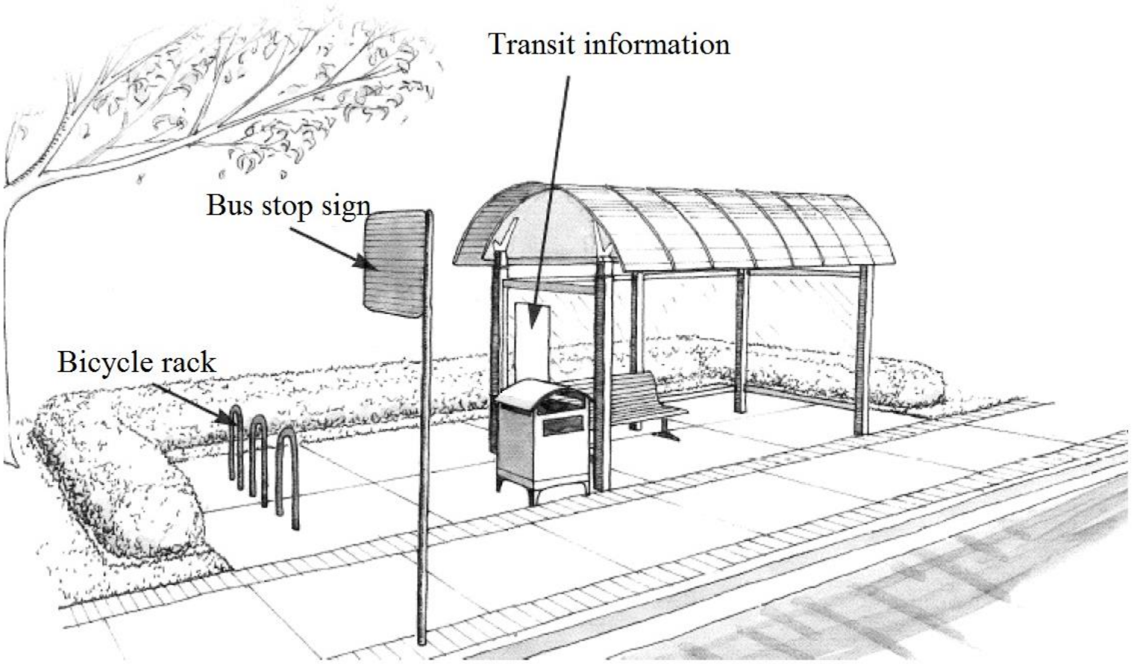


Figure 2.24 Typical Design of a Bus Stop with Shelter (*48*)

When transit amenities are located on sidewalks, they are usually part of a range of "street furniture," making a street more pleasant and comfortable to use (*47*). In addition to bus shelters, amenities can include seating (on benches or planter ledges), trees, telephones, light fixtures, trash receptacles, and information kiosks; clocks, fountains, sculptures, drinking fountains, banners, and flags are sometimes provided as well. Well-maintained bus stops and passenger shelters encourage transit use and enhance the aesthetics of the surrounding area.

TFD is an engineering approach that facilitates transit on an area-wide scale. Effective TFD standards are implemented through comprehensive plan policies, inclusion in development regulations, and through consideration during the development review process. TFD benefits the entire community through fundamental elements of design that can be included in existing development regulations and adopted as development policy.

TFD is an integral part of TOD, but it can also be implemented as a stand-alone concept to improve transit use and efficiency in existing and developing communities. This review offers some guidelines of achieving TFD through engineering measures, which is a good first step toward TOD. The guidelines are summarized from the best practices of TFD implementations. TFD guidelines can be successfully combined with other practices presented in this document to the project network. All these measures combined can create a transit and pedestrian oriented development that can improve the quality of life of its patrons.

2.7 Summary of the Literature Review

Within the last two decades, the concept of urban planning has changed its focus toward managing travel demands and encouraging the use of alternative transportation modes. Diverse and mixed land-use designs have started to replace separated, single use and automobile friendly developments. The emphasis is on livability, walkability, safety, and overall improvements in the quality of residential life.

These new planning concepts use different traffic management strategies and measures. Every implemented measure has certain effects on traffic and travel choices. However, it is more important to assess the effects of combinations of measures, since these effects can be quite large. In order to affect people's travel choices, the planners must be able to recognize the qualities of urban design that have the greatest effect and plan accordingly. Mixed used developments offer big possibilities for implementing quality urban designs that emphasize walking and non-motorized travel modes.

Street connectivity is another important aspect of urban design, whether it is aimed toward motorized or non-motorized users. Destination accessibility largely depends on street connectivity. A measure that can help relieve congestion and, to some degree, affect business opportunities and transit operations is the implementation of innovative intersection designs. Indirectly, these designs help to redefine the quality of urban design and also affect non-motorized users.

Traffic calming measures and TOD planning concepts work together in changing people's travel and driving behavior. TOD emphasizes non-motorized travel modes, especially the use of public transit for meeting daily needs. It also insists on diverse, dense, mixed land-use developments where many trips within a zone can be accomplished by walking. Traffic calming aims to discourage motorized trips that cut through residential areas, and/or to reduce their negative impacts by lowering speeds and creating a safer environment. Traffic calming can be implemented independently, while TOD always incorporates some traffic calming measures. That way the benefits of both concepts are combined to create developments with improved walkability and safety for all users. TFD concepts are another part of TOD, although they can be implemented separately. TFD creates developments with strong transit orientation, and it insists on non-motorized travel modes. Good connectivity and destination accessibility are the most important underlying principles of TFD.

The set of design principles described in this document are recognized as the principles with the highest impacts for creating livable, safe transit and pedestrian friendly developments. Although some of these principles discourage the use of private automobiles, they do not ban it altogether. All these principles are highly applicable to the project network. The developments within this network are suitable for implementations of designs that support transit and walking. The network is bordered by major arterials that carry a lot of traffic and provide good connections to other networks. Some of the designs can be applied to these arterials, improving the traffic flow efficiency and creating better connections with the observed network. This project will look into the different combinations of measures and recommend the most suitable designs for creating a livable, safe, and traffic-efficient development.

3. DESIGN PRINCIPLES

The main points and guidelines of the literature review have been adapted and applied to the project network. The design principles are given separately for each set of improvement measures. The improvement measure designs given in this document are:

- Enhanced street connectivity
- Traffic calming measures
- Innovative intersections
- Transit friendly designs

Once the designs have been reviewed, edited, and approved by UTA, we created detailed designs for each measure and applied them to the project network.

3.1 Design Principles of Street Connectivity

In order to accommodate transit in the future, this study explores the effects of both increasing street network connectivity and the traditional street widening approach on the network traffic operations. Design principles for improving the way streets are connected are adapted from the reviewed literature and presented in Table 2.5. The approach used in this study increases the connectivity between the streets in the study network gradually, until the recommended level of network connectedness is achieved.

Since this study is not focused on land use but on modifying the street network for the purpose of future land use development, street connectivity is deployed as one of the ways of facilitating the future TOD on the site. It should be considered that for this purpose, the street network consists of densely spaced streets rather than wide streets in order to accommodate not only transit and private vehicles, but to enable walking and biking, too. Keeping the streets narrow and increasing the number of intersections will help pedestrians access to transit stops.

The advantage of this test network is that it is in fact a grid-like network; however, the spacing between the streets does not encourage alternative modes. This simplifies the task of testing various connectivity levels on the network. The literature shows that denser street networks decrease the need for private vehicle use, but this study does not consider any mode shifts in order to account for the worst-case travel demand scenario. The design principles are focused on street spacing and traffic speeds on the existing and newly added corridors. Based on the recommendations from the literature (*51*), the intersection spacing goes as low as 400 feet, while speeds, even on arterials, go up to 35 mph.

It should be noted that the goal of the proposed network modifications/connectivity improvements is not to eliminate driving or force people to use other modes of transportation. The purpose is to actually enable alternative modes of transport and to make them part of the choice, especially for those who cannot or choose not to drive. The streets in a TOD are balanced to accommodate all users, and while the space for cars is still there, the right of way is shared with other modes. Table 2.5 gives an overview of the most widely used street connectivity measures. It is based on the definitions and existing standards obtained from the literature. The recommendations and guidelines obtained from the literature are applied to the study network. Figure 3.1 shows a possible new network with enhanced street connectivity.

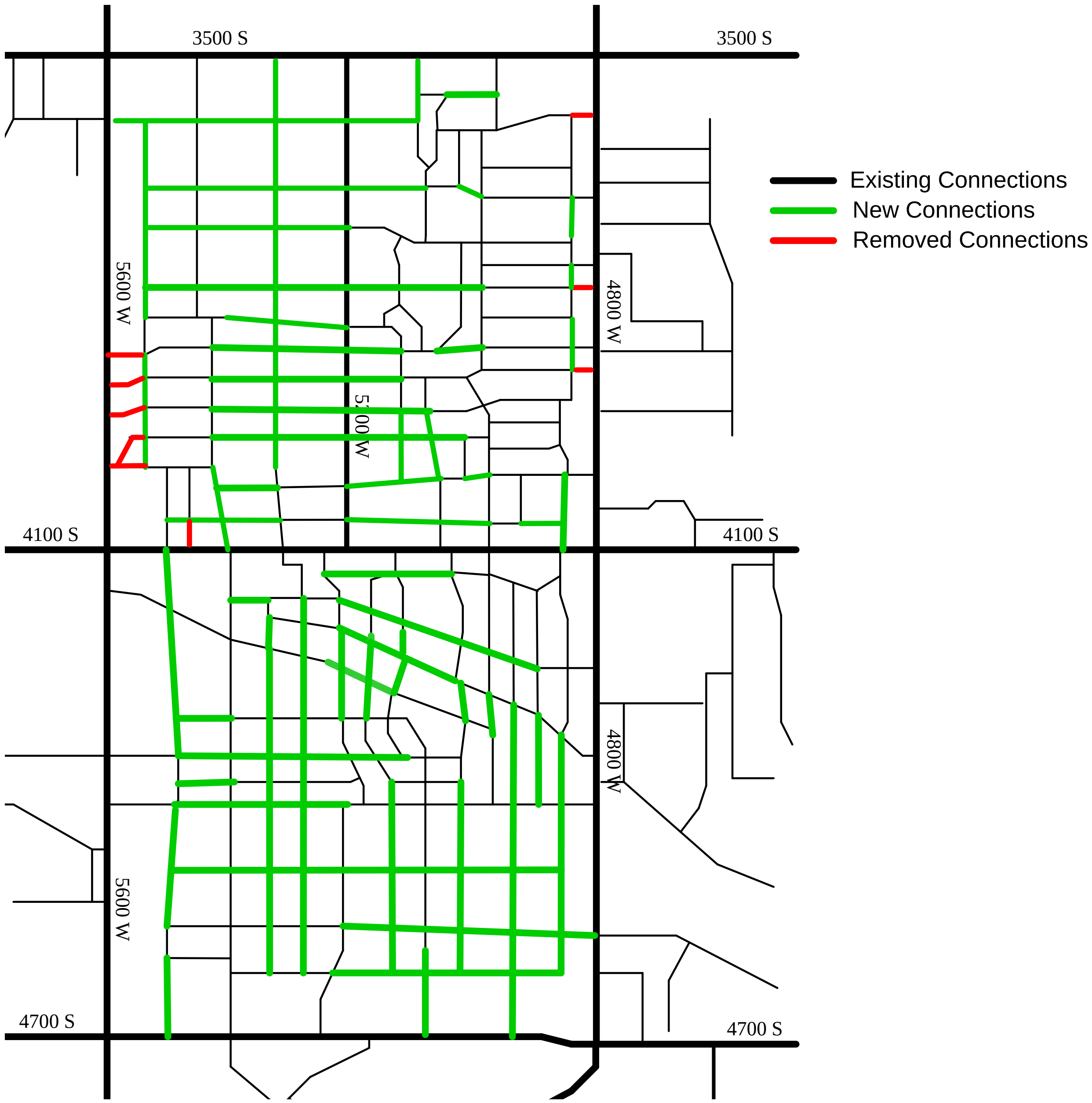


Figure 3.1 Possible New Network with Increased Connectivity

3.2 Design Principles of Traffic Calming Measures

The literature provides several results on traffic calming implementations. The most significant impacts of traffic calming are observed on traffic volumes, vehicle speeds and traffic safety. Although traffic calming measures are divided into volume and speed control, both categories have higher or lower impacts on both traffic parameters. Some studies also explored negative impacts of traffic calming, but in general they are outweighed by positive implications. A significant variable in traffic calming measure selection can be the cost of each particular device. The costs can be relatively low for some devices, such as speed humps and tables, or much higher for neckdowns, roundabouts, or full closures.

Table 3.2 shows the most important effects of traffic calming measures, along with the actual costs of implementation, summarized from the literature. For the project network, the researchers recommend some of the low cost effective measures, such as speed humps and tables, raised crosswalks, and textured pavement. Some traffic calming measures can be combined with the innovative intersection designs, where the roundabout in a bowtie intersection also serves as a traffic calming device. Traffic calming devices that benefit pedestrians, such as raised crosswalks and textured pavement, are recommended in this case, since the future network will be transit oriented with high pedestrian activity.

Figure 3.2 provides a set of possible locations for traffic calming implementation. These locations are mostly in the vicinity of pedestrian activity centers, such as schools, churches, daycare centers, and parks. Some locations are selected based on anticipated traffic volumes. They are considered to be more attractive for drivers to use them as shortcuts through the network, and the traffic calming implementation should divert those drivers. The simulation models will be able to capture the effects of traffic calming measures on traffic volume and distributions.

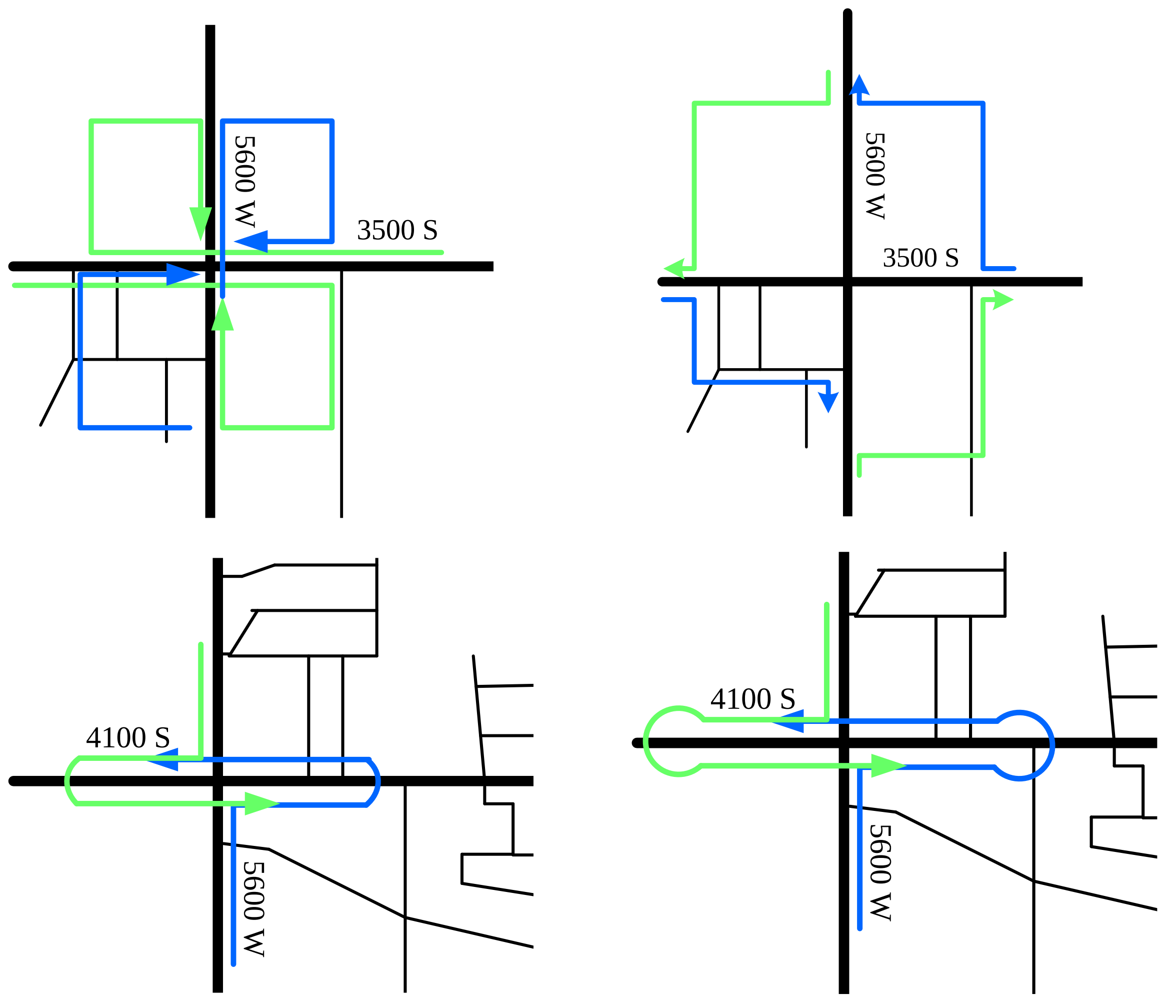
Table 3.1 Traffic Calming Measures

Traffic Calming Measure	Impact on Speed	Impact on Volumes	Impact on Safety (Crash Frequency)	Disadvantages	Cost Estimates
Speed Humps	22% decrease (12ft hump) 23% decrease (14ft hump)	18% decrease (12ft hump) 22% decrease (14ft hump)	13% decrease (12ft hump) 40% decrease (14ft hump)	Slowing down emergency vehicles; Increasing noise and pollution	$ 2,000
Speed Tables	18% decrease		45% decrease	Increasing noise and air pollution; Costs and aesthetics	$ 2,000
Raised Crosswalks	18% decrease	12% decrease	45% decrease	Increasing noise and air pollution; Impact on drainage	$ 4,000
Raised Intersections	1% decrease			Costs; Impact on drainage; Less effective in reducing speeds	$ 12,500
Textured Pavement	No data	No data	No data	Costs; Impact on people with disabilities	Varies by the area covered
Traffic Circles	11% decrease	5% decrease	29% - 73% decrease	Difficult for large vehicles maneuvering; On-street parking elimination; Maintenance	Varies by the area covered
Roundabouts			29% decrease	Difficult for large vehicles maneuvering; On-street parking elimination; Maintenance	Varies by the area covered
Chicanes	No data	No data	No data	Maintenance, Impact on drainage; On-street parking elimination; Could cause deviation out of the appropriate lane	$ 14,000
Re-aligned Intersections	No data	No data	No data	Costs; Additional right of way	Varies by the area covered
Neckdowns	7% decrease	20% decrease		Slowing down emergency vehicles; On-street parking elimination; Merging bicycles with vehicular traffic	$40,000 – $80,000
Center – Island Narrowings	7% decrease	10% decrease		On-street parking elimination	$8,000 - $15,000
Chokers	7% decrease			Merging bicycles with vehicular traffic; on-street parking elimination	$7,000 - $10,000
Full Closures		44% decrease		Require legal procedures; Difficulties for emergency vehicles; Costs; Limiting access to businesses	$120,000
Half Closures		42% decrease		Difficulties for emergency vehicles; Costs; Limiting access to businesses; Drivers might be able to circumvent the barrier	$40,000
Diagonal Diverters		35% decrease		Difficulties for emergency vehicles; Costs; Costs; Require the reconstruction of corner curbs	$85,000
Median Barriers		31% decrease		Require available street width on the major street; Limit turns to and from the side street; Difficulties for emergency vehicles	$15,000 - $20,000 per 100 ft

Figure 3.2 Possible Traffic Calming Locations

3.3 Design Principles of Innovative intersections

The project network is very convenient for the implementation of innovative intersections. Avenue Consultants already developed a set of design scenarios for innovative intersections along the 5600 W corridor. It is estimated that this type of design brings more benefits to the overall traffic than simple road widening, and they are very convenient for the inclusion of center running transit lines (whether BRT or LRT). The 5600 W corridor offers opportunities for innovative intersections at all three intersections within the project network (3500 S, 4100 S and 4700 S). Another possible location is the intersection of 3500 S and 4800 W. Based on the traffic volumes at other intersections along 4800 W, the implementation of innovative intersections cannot be justified at this point. Figure 3.3 provides a set of designs for innovative intersections within the project network.



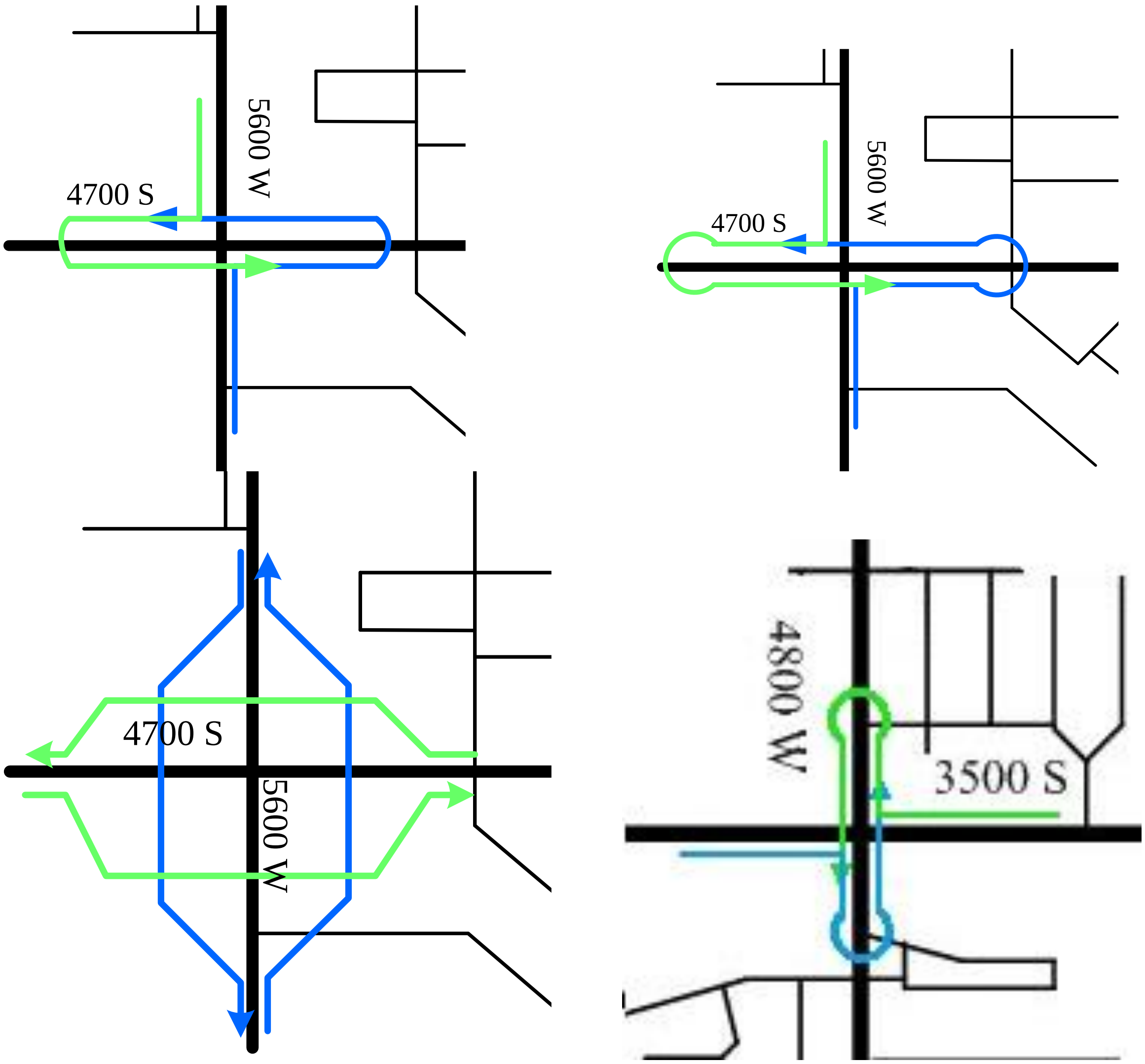


Figure 3.3 Innovative Intersections Implementation

3.4 Design Principles of Transit Friendly Designs (TFD)

TFD can be defined as a set of techniques for improved integration of transit into residential and non-residential areas. It can be incorporated into the planning process for new developments, or can be applied to existing ones.

Transit-friendly streets make transit use more efficient and convenient. It also makes the street less convenient for automobiles while still accommodating them. At the same time, other functions of a street are recognized so that transit does not overwhelm the street. TFD is a very important step toward achieving a functional TOD.

The main guidelines for TFD can be summarized as follows:

- Provide appropriate community densities
- Minimize walking distance: 0.25 miles maximum walking distance to stop
- Provide mixed land uses
- Organize density, land use, and buildings to benefit from transit
- Create a pedestrian friendly environment
- Route transit into the community: 0.50 miles maximum spacing between parallel lines
- Reduce transit travel time
- Increase transit frequency: up to 15-minute headways
- Build quality, user friendly transit facilities

Figure 3.4 provides a version of TFD applied to the project network. In general, frequencies on the existing transit lines within the area should be increased according to the guidelines. Also, an addition of three transit lines will increase the transit spatial coverage and satisfy the TFD recommendations. These lines should run along 5200 W, 3780 S, and 4400 S. Street connections should be added into this network to accommodate the new transit lines. Transit stops should be redistributed to minimize the walking distance and serve high activity centers.

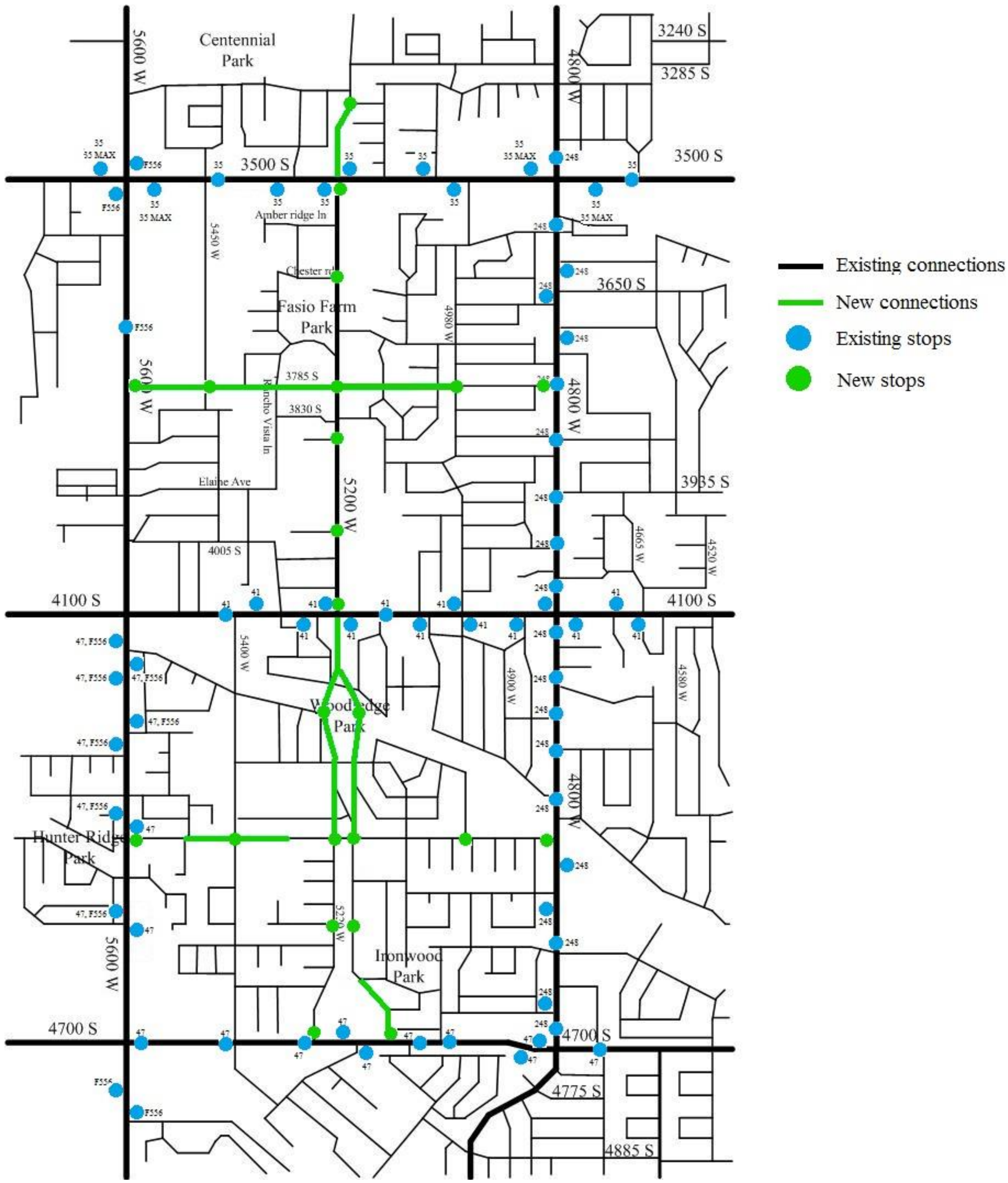


Figure 3.4 Enhanced Transit Network

4. MODELING METHODOLOGY

The effects of the implemented design principles will be assessed through combined macro and micro traffic simulations. The models are being developed simultaneously in VISUM (macro) and VISSIM (micro) simulation software. The main inputs used in the state of development and calibration of models are network geometry, traffic analysis zone (TAZ) data, origin-destination (OD) trip distribution, link volumes (AM, midday, and PM peak), signal timing data, and transit ridership data. The network geometry data are obtained through aerial and street view maps and used for coding the network. TAZ data, along with OD trip distribution and link volumes, are obtained from the Wasatch Front Regional Council, and these data exist for the years 2009 (existing) and 2040 (forecasted). Signal timing data for signalized intersections are downloaded using UDOT's i2 software, which allows a direct communication link to the field traffic controllers and control program databases. Traffic signals are coded simultaneously in VISUM and VISSIM. Transit ridership data, that also include boarding and alighting information for transit stops within the network, are obtained from UTA. These data are used for transit assignment projections in the simulation models.

VISUM macrosimulation is a tool for traffic planning, travel demand modeling, and traffic and transit assignments. VISSIM microsimulation is a tool for traffic performance analysis and provides detailed measure of effectiveness (MOE) data for many parameters. These two tools are used simultaneously throughout this project to exploit the benefits that both can offer. The fact that they are mutually interchangeable (macrosimulation can be exported to microsimulation and vice versa) simplifies their use and creates additional benefits. Figure 4.1 shows how each model based on the proposed methodology is developed. The main steps for creating each simulation scenario are defined as follows:

1) Build the base network in VISUM using the aerial maps
2) Input traffic and transit data (TAZ data, OD matrices, targeted link volumes, signal timing data, and transit ridership)
3) Perform Dynamic Traffic Assignment (DTA) in VISUM
4) Perform OD matrix correction and calibration
5) Export the calibrated network to VISSIM
6) Fine tune the network and perform model validation
7) Optimize signal timing using available data and Synchro software where needed
8) Perform traffic analysis using VISSIM

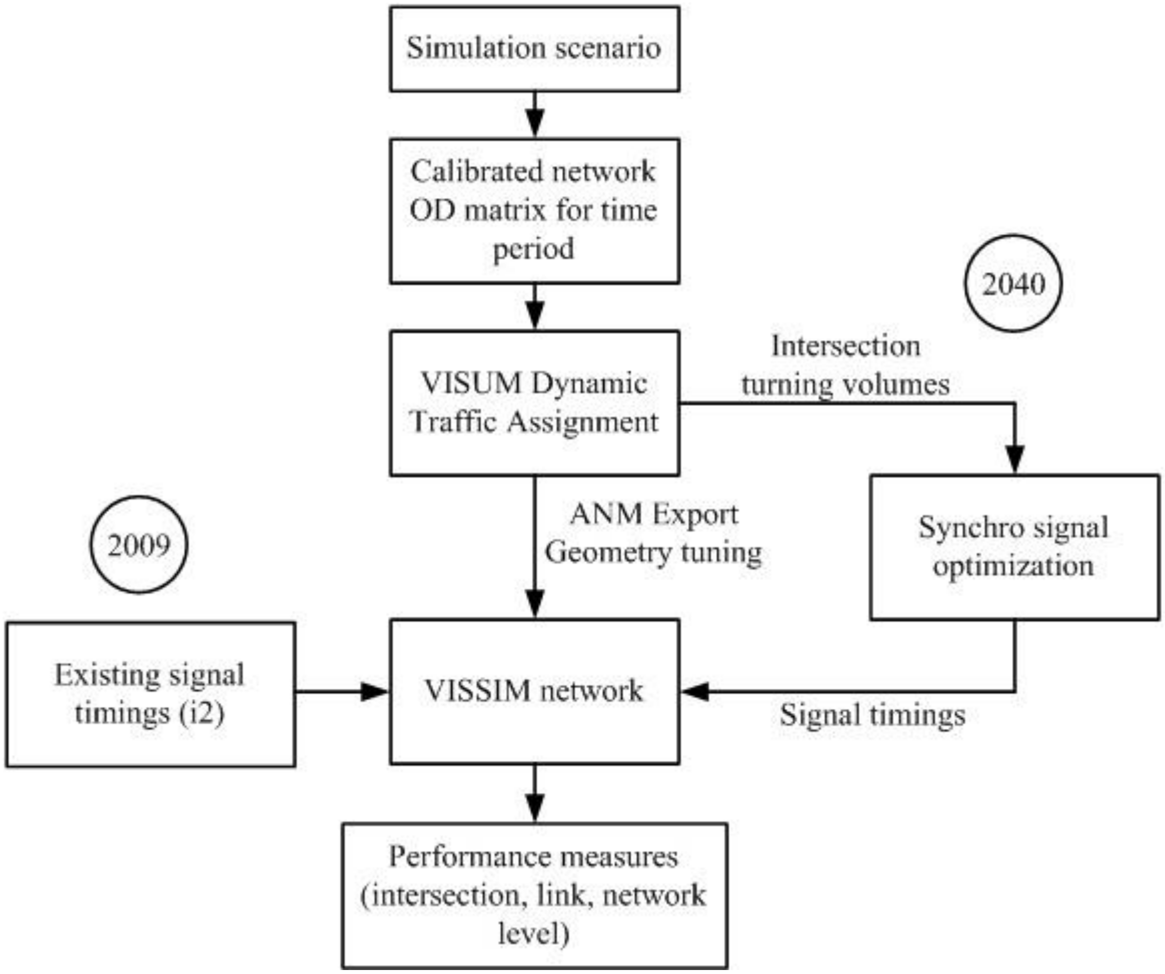


Figure 4.1 Modeling Methodology

4.1 Base VISUM/VISSIM Network Model

The choice of base network for this project is based on the fact that two BRT lines are already in place on 5600 West and 3500 South Streets. The Wasatch Choice for 2040 emphasizes future main activity centers in the Salt Lake Valley, locating a town center at 3500 South & 5600 West intersection. According to the Wasatch Front Regional Council (WFRC) plan for 2040, town centers have a strong sense of community identity and are well served by transit and streets. The current state of our test network indicates that network design changes, other than traditional street widening, are needed in order to accommodate for non-motorized modes in the future.

The first step in our methodology is building the test network in VISUM with the help of aerial and street view maps used in this process. The network model consists of the arterials, collectors, and local streets in the area, and it also includes links that represent big traffic generators. Each link is modeled to represent the length, number of lanes, location of intersections, speed limits, and the type of intersection control from the field. Transit lines and stops located within the area are also included in the model. Figure 4.2 shows the completed and interchangeable VISUM/VISSIM models of the existing conditions.

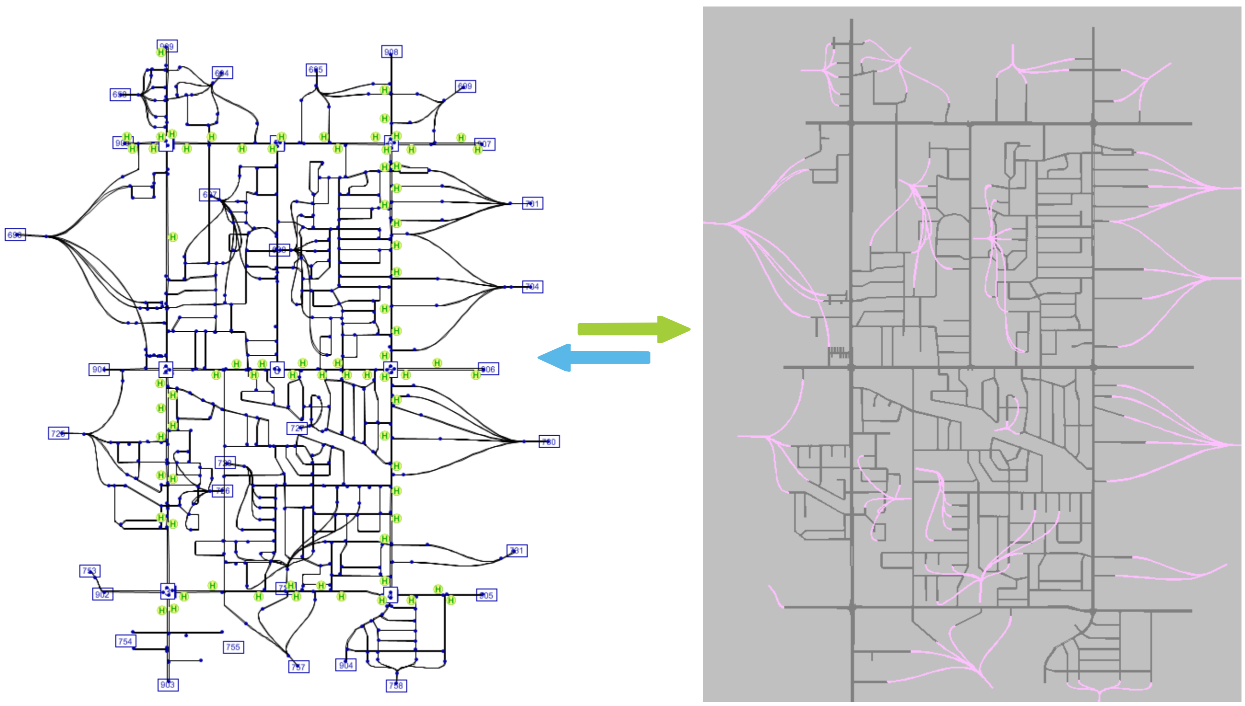


Figure 4.2 VISUM/VISSIM Network of Existing Conditions

4.2 Traffic and Transit Data

The next step in the modeling process is to input the traffic and transit data (TAZ data, OD matrices, targeted link volumes, signal timing data, and transit ridership). The TAZ data are obtained from the WFRC, and they include zone numbering, socio-economic data, trip data (generation attraction for different trip modes) for each zone, as well as zone-to-zone travel data (OD matrices). There are 21 actual TAZs within the project network. Since this network is a cut of the overall Salt Lake Valley transportation network, the model includes 10 dummy zones to account for the traffic that traverses the project network. These zones are located on arterials at the borders of the network. The locations of the TAZs incorporated in the modes are shown in Figure 4.3.

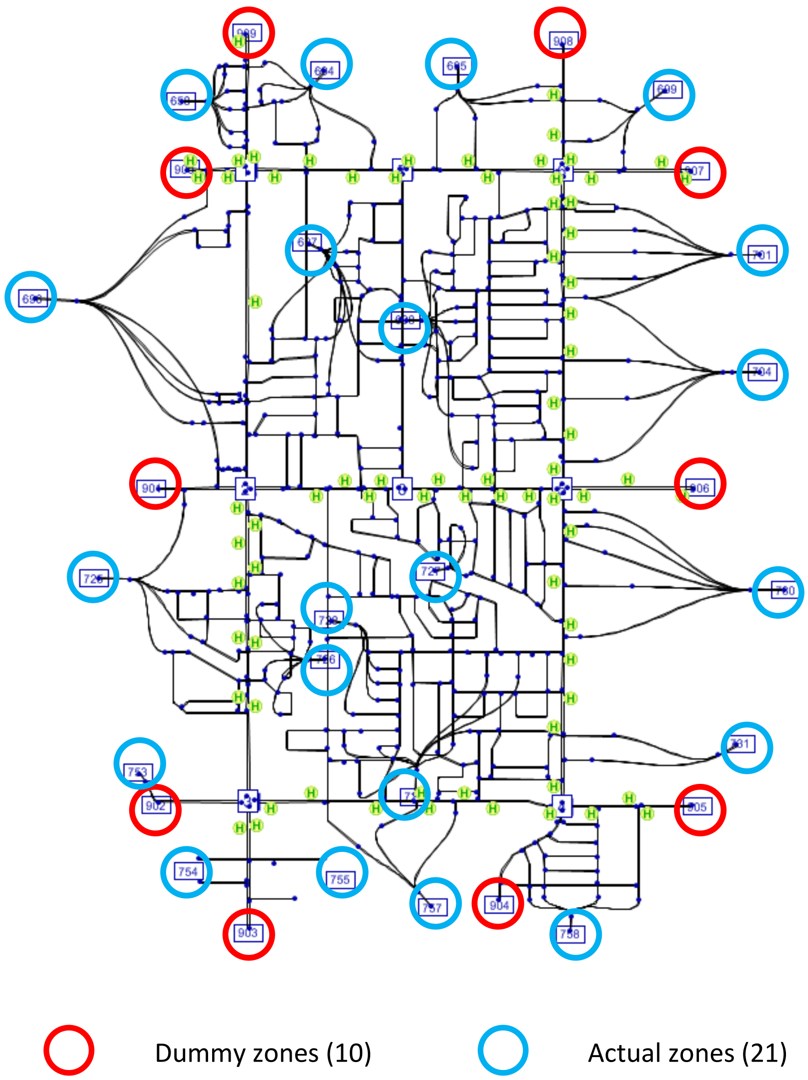


Figure 4.3 Network TAZs

An OD matrix of traffic demand is created for the simulation models for the 31 zones based on the available data. The OD demand for the actual zones is based on the WFRC trip data, while for the dummy zones the OD demand is developed based on the link volumes and the differences in trip data for the actual zones. These data are also used for network calibration.

There are eight signalized intersections within the network, and they are modeled based on the signal timing data obtained from UDOT. These intersections are coded into the simulation networks using VISUM's junction editor, as given in Figure 4.4. The model also includes transit lines and transit stops located or traversing the network.

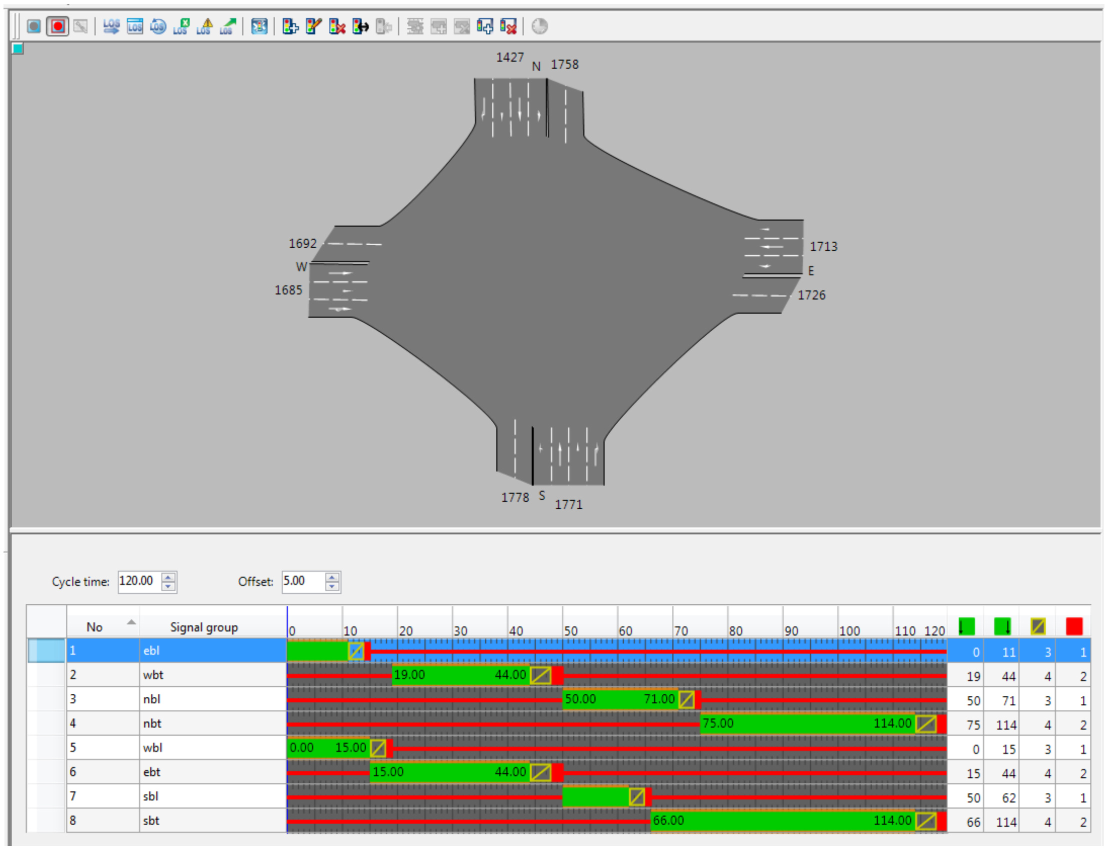


Figure 4.4 Junction Editor for Signalized Intersections

Six current transit lines with 120 stops are allocated on the network according to available public transit stops data from the Utah Transit Authority (UTA) and Google maps. Timetables for each line and transit route are also based on data available from the UTA. Transit ridership for each line and each transit stop is based on the transit boarding data for this are for the year 2011, and transit OD demand for the years 2009 and 2040.

4.3 Traffic Assignment in VISUM

VISUM is a useful tool for fast and accurate DTA. The DTA for the project network is performed based on the OD matrices created for the network from the available data. The OD matrices are coded in VISUM, along with the data on current link volumes, which are also used for model calibration.

The first step toward DTA was to input link volume data from WFRC into the VISUM network. Data are available for the years 2009 and 2040, for the main links on the VISUM network. VISUM links option “Add Value 1” is used for link volume inputs. Each link in VISUM also has data about link capacity, so the volume/capacity ratio can be computed.

The fact that links in VISUM have some volume data assigned does not indicate what volume of the links will be after the DTA. The link volume depends on the OD matrix. So the second step in DTA was to build the OD matrix for the existing and dummy zones. The total attractions and distributions for the existing zones are part of the WFRC trip data for the West Valley City network. Data are available for auto, transit, and non-motorized trips. The data for OD trips are available on a daily level, while we have link volumes for AM peak, PM peak, and evening periods. This allows the calculation of coefficients that will narrow daily OD data to period OD data for these four periods. For example, if we need OD trips for

PM peak period, we use the relationship between link volumes for PM peak and OD trips on the daily level from the corresponding TAZ to obtain the OD trips for PM peak period.

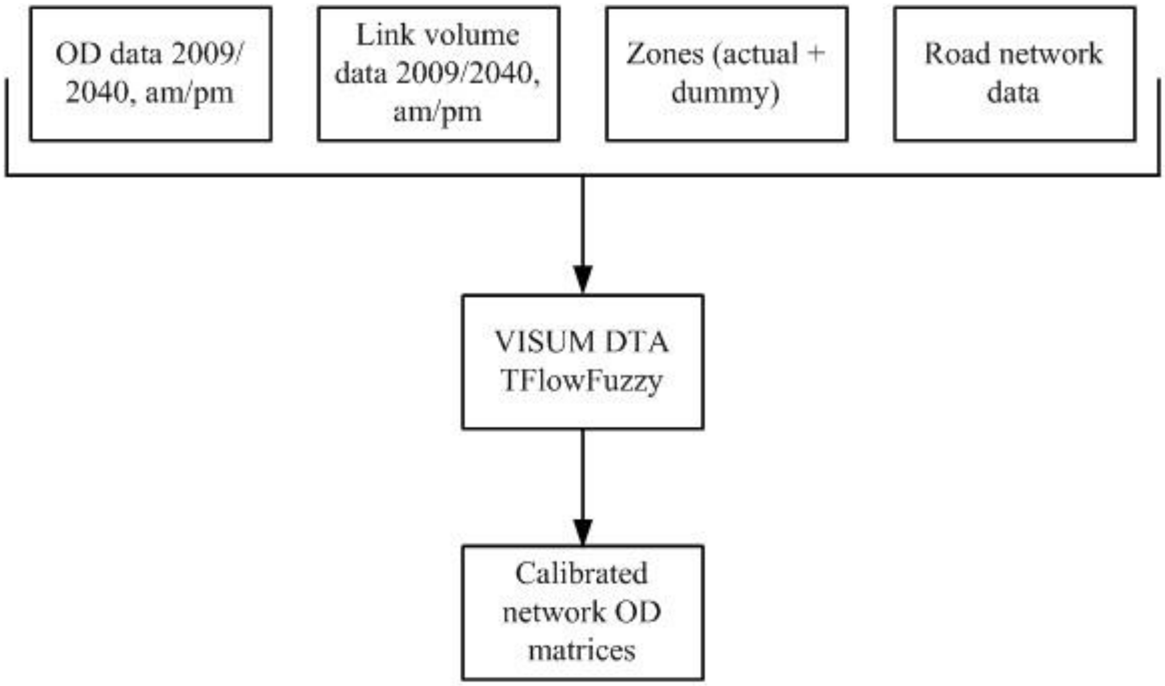


Figure 4.5 Calibration Process

An OD matrix, built in the described manner for AM peak, midday, and PM peak period, for auto mode is the basis for DTA in VISUM. We use "Calculate/Procedures/PrT Assignment" from the VISUM main menu to perform the assignment. Figure 3.4 presents the assignment results demonstration from VISUM.

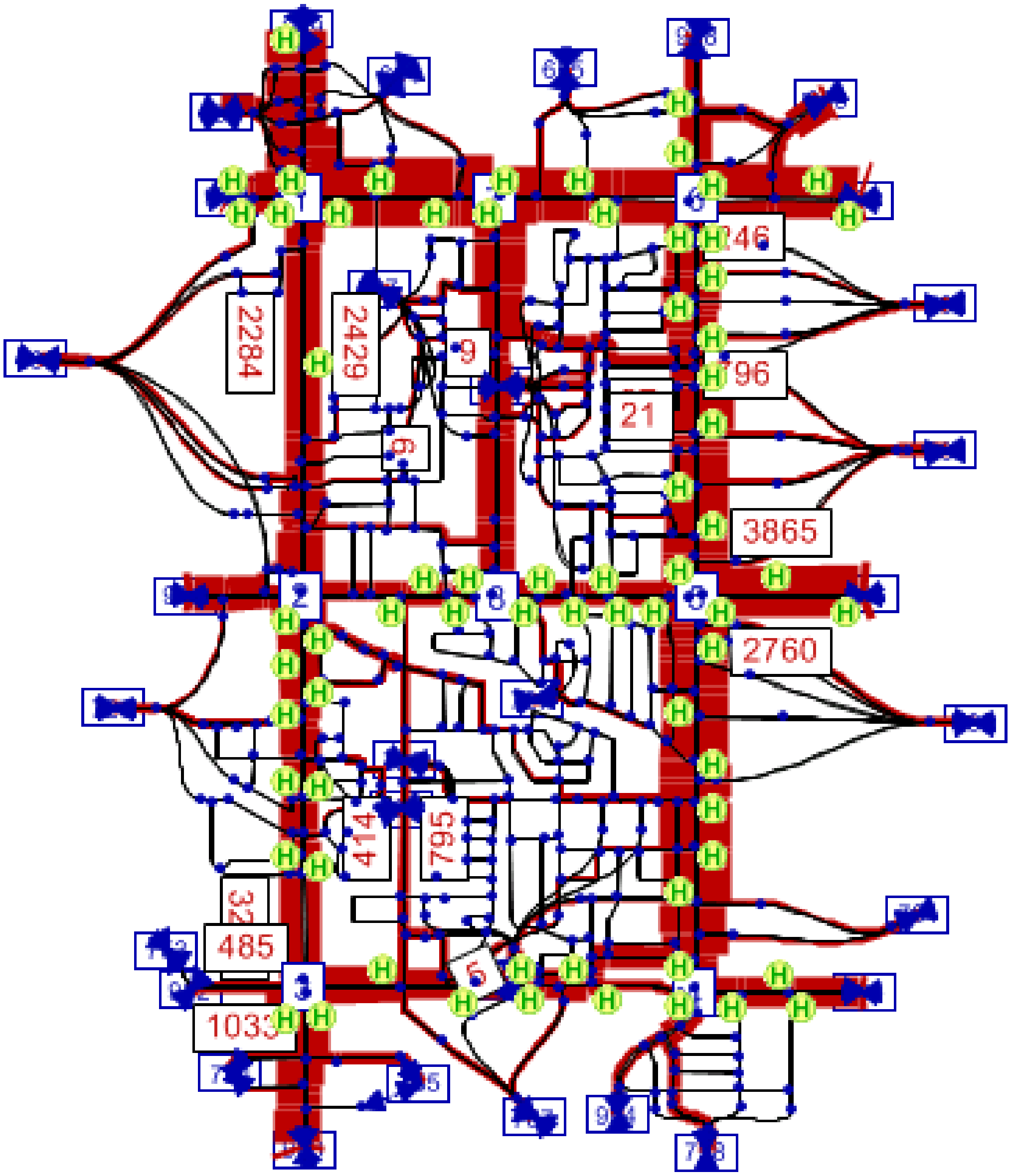


Figure 4.6 VISUM PrT Assignment for the Base OD Matrix, Auto Mode, PM Peak, 2009

There is an option in VISUM main menu, “Calculate/Procedures/Assignment Analysis,” that allows us to evaluate the assignment from Figure 3.4. This evaluation is in Figure 3.5 and shows how low the correlation is between OD auto trips data for PM peak period and link volume data for PM period for 2009. This requires further matrix correction until the assignment evaluation shows satisfying results.

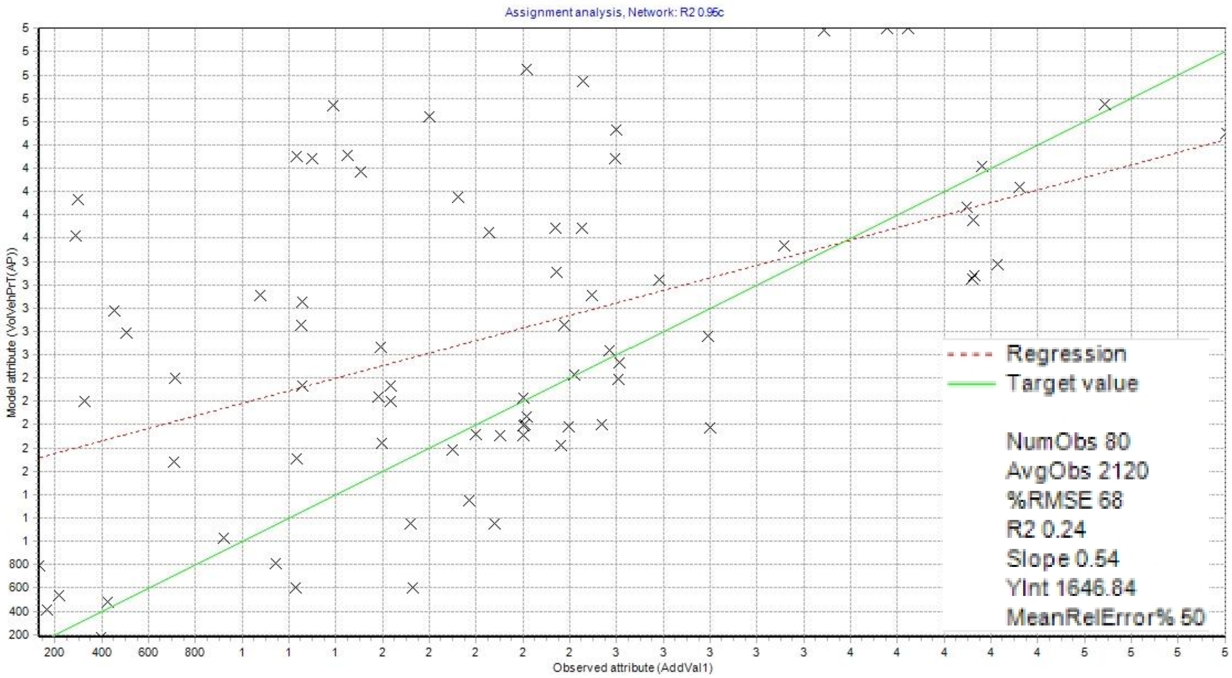


Figure 4. 7 VISUM PrT Assignment Analysis for the Base OD Matrix, Auto Mode, PM Peak, 2009

4.4 OD Matrix Correction and Model Calibration

The option of performing "TFlowFuzzy" matrix correction in VISUM until the assignment analysis shows high data correlation enables the changes in the base matrix. After applying TFlowFuzzy, the base matrix in VISUM is corrected and the new matrix can be used to repeat the assignment and the assignment analysis. The assignment results based on the corrected matrix in VISUM for PM peak period in 2009, for auto mode are in Figure 4.8.

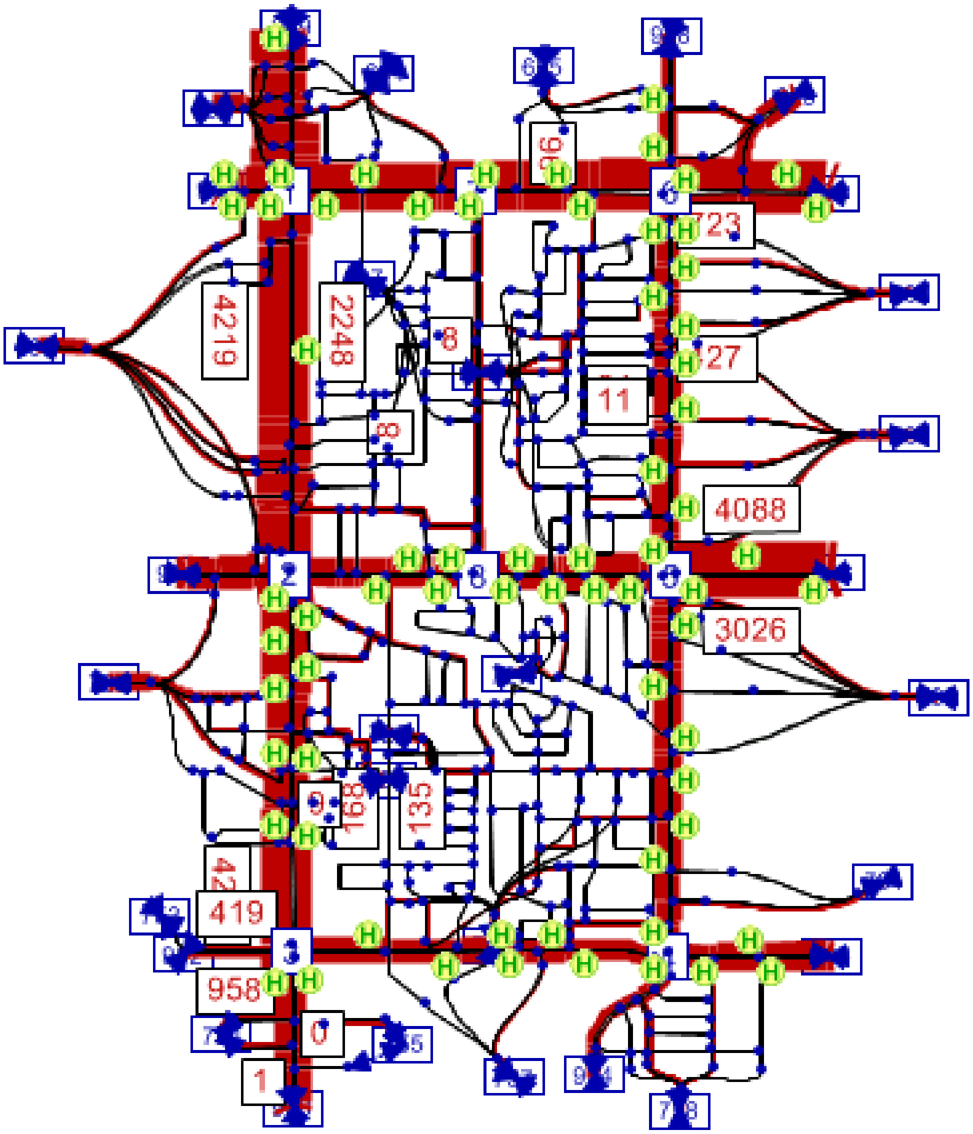


Figure 4.8 VISUM PrT Assignment for the TFlowFuzzy Corrected OD Matrix, Auto Mode, PM Peak, 2009

The assignment analysis of corrected matrix from Figure 4.8 shows a satisfying correlation between link volume data from WFRC and the assigned volumes in VISUM. Figure 4.9 presents the results of this evaluation. Transit assignment is performed and evaluated in a similar manner as PrT assignment in VISUM, but the data for assignment analysis come from a different source. The data about transit ridership for the three periods AM peak, midday, and PM peak are available from the UTA. The OD transit trips on the daily level from the WFRC are narrowed down to these three periods in the same way as they were for auto trips. The assignment after the matrix correction evaluated, as shown in Figure 4.8, can be exported to VISSIM for further evaluation of this project network.

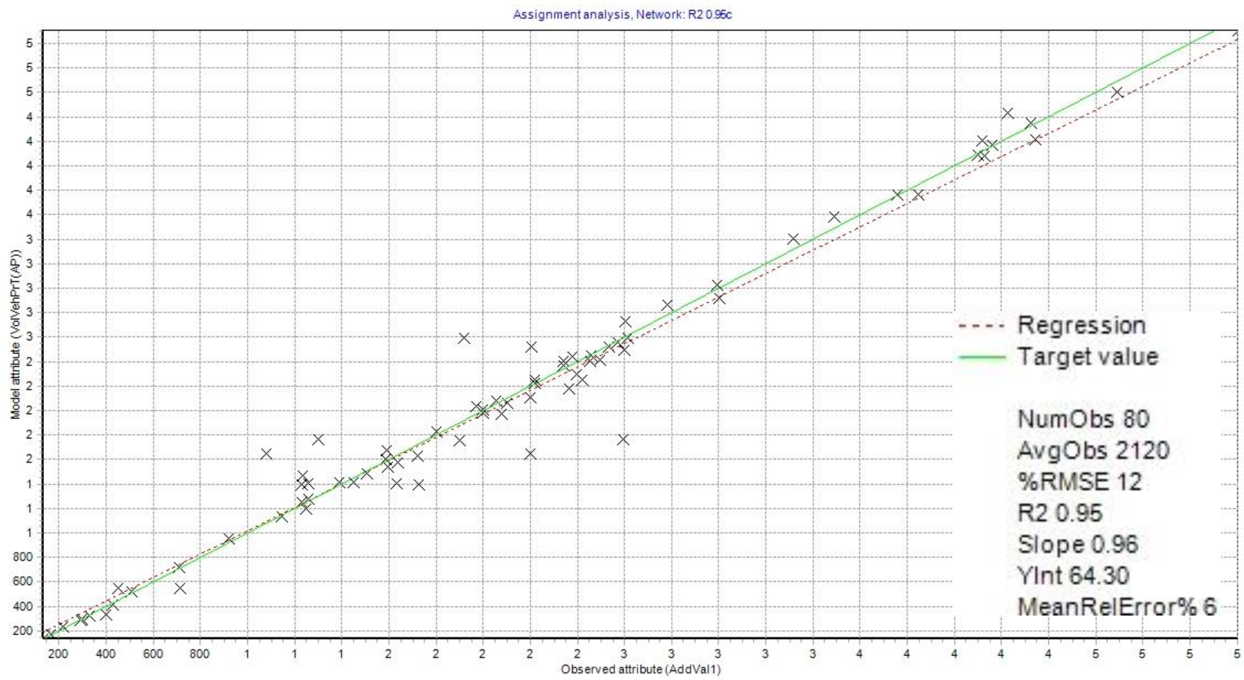


Figure 4.9 VISUM PrT Assignment Analysis for the TFLowFuzzy Corrected OD Matrix, Auto Mode, PM Peak, 2009

4.5 Performance Measures

Calibrated matrix with auto and transit assignment is exported from VISUM to VISSIM. The microsimulation environment will allow for a very detailed evaluation of performance measures related to traffic efficiency:

- Level of Service for intersections based on intersection delay
- Travel time and trip distance for a few representative trips
- Number of left turn movements
- Network performance through average speed, average number of stops, total delay

Since the imported network includes both auto and transit mode, VISSIM could measure average speed for both modes as an indicator of mobility. The additional performance measures that could serve to compare this base network with new network designs are the increase in trip redundancy and the number of cars rerouted from 5600 West. The goal is to meet the demand on 5600 West by introducing the optimal intersection design, rather than by rerouting the vehicles to the local network.

5. TRAFFIC ANALYSIS RESULTS AND DISCUSSION

The results presented in this chapter show the existing traffic conditions on our test network, expected traffic conditions in “no build case,” and traffic implications of proposed network designs. The measures of effectiveness are analyzed on intersection, corridor, and network-wide level. For the analysis on the intersection level, we defined nodes at the most important intersections. Travel time sections defined in VISSIM evaluate performance along the corridors. Finally, network performance evaluations in VISSIM provides the results on the network wide level. The results are given for 2009 AM, 2009 PM, 2040 AM, and 2040 PM peak hours.

5.1 Base Case Scenarios

Base case results (Table 5.1) show measures of effectiveness for AM and PM peak hour for the year 2009, compared to measurements for 2040, based on forecasted OD demand. The results are given in the following order: intersection analysis, corridor travel times, network performance, and 2009/2040 comparison.

From the results shown in Table 5.1, the intersection LOS values are D or higher for the year 2009, AM and PM peak periods, which is in agreement with UDOT recommendations for this area. However, the results based on travel forecasts for 2040 show that LOS for two intersections along 5600 W corridor and one intersection on 4800 W are F for PM peak hour, which becomes the critical focus of further analysis in this study.

Further results of intersection delay (Figure 5.1) show that delays increase for all intersections along 5600 W street, when compared between the 2009 and 2040 forecasts. Increase in delay for individual intersections is greater during the PM peak period. The 5600 W corridor is important to observe in this network because of its proximity to the new freeway that will take place on the west side of the corridor. This is the reason why volumes will increase and intersection delay will be more than double compared with the existing state for the PM peak period. This corridor will also have a BRT line implemented by 2015, and other transit improvements will follow. Transit service changes will surely bring some mode shift changes; however, current MPO forecasts for 2040 show that transit service alone will not suffice the travel demand, which is why both network/corridor/intersection design and traffic operations’ modifications should be considered.

Network performance results (Table 5.2) also show the highest average and total delay values for 2040 PM peak period. Corridor related performance measures (Table 5.3) show satisfying LOS for most all corridors in the network except for 4700 South Bound direction, which means that the critical points and causes of congestion will be intersections, which is why the study is expanded beyond the typical TOD measures to examine the performance of innovative intersection designs.

Using results from the base case scenario, this study is focused on the PM peak periods, and introduces transit, traffic operations, and street network alterations that are TOD supportive in order to examine the impacts they have on vehicular traffic. Traffic analyses of enhanced networks are presented in the following sections of this chapter.

Table 5.1 Intersection Level of Service for 2009 AM, 2009 PM, 2040 AM, and 2040 PM

Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	8349	7431	5609	2980	2934	5761	6835	4744
Delay (s)	26.6	26.9	22.2	3.0	2.1	24.8	40.5	12.9
Stop delay (s)	16.4	19.4	14.6	1.1	0.5	13.7	28.6	6.5
Stops	0.7	0.6	0.6	0.2	0.1	0.7	1.1	0.6
Avg Queue (ft)	46.7	48.2	28.7	1.5	0.4	48.8	111.9	12.8
Max Queue (ft)	269.5	291.3	220.5	117.3	54.1	371.2	512.8	167.5
LOS	C	C	C	A	A	C	D	B
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	9560	8592	7099	4853	4414	7891	9971	5439
Delay (s)	29.8	28.3	19.4	3.7	5.8	15.5	30.3	13.4
Stop delay (s)	20.8	19.8	12.0	1.2	2.9	8.9	19.3	6.5
Stops	0.7	0.7	0.6	0.2	0.2	0.5	0.9	0.6
Avg Queue (ft)	60.1	61.6	28.8	2.9	3.4	23.9	94.5	14.0
Max Queue (ft)	336.7	343.2	299.9	108.8	123.9	228.5	568.6	168.6
LOS	C	C	B	A	A	B	C	B
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	6148	7849	9425	4526	5203	6826	8138	7031
Delay (s)	29.4	34.1	69.1	3.2	6.7	31.1	21.1	12.3
Stop delay (s)	21.2	26.0	21.8	0.9	2.3	18.7	11.4	4.9
Stops	0.6	0.7	1.0	0.1	0.3	0.8	0.8	0.5
Avg Queue (ft)	43.3	67.2	97.7	1.3	6.9	93.7	41.3	17.6
Max Queue (ft)	249.8	343.3	555.0	125.6	345.5	598.9	339.5	191.9
LOS	C	C	E	A	A	C	C	B
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	11872	11028	12067	8634	7600	11511	11256	9515
Delay (s)	149.8	29.7	129.6	5.9	10.8	15.9	37.5	95.9
Stop delay (s)	80.4	19.7	49.3	1.6	3.7	7.9	25.9	47.0
Stops	2.7	0.8	2.4	0.2	0.4	0.6	0.9	2.7
Avg Queue (ft)	653.9	73.4	685.6	8.1	18.5	31.0	119.4	381.6
Max Queue (ft)	1106.7	426.2	1210.5	220.3	390.6	287.8	635.4	1077.2
LOS	F	C	F	A	B	B	D	F

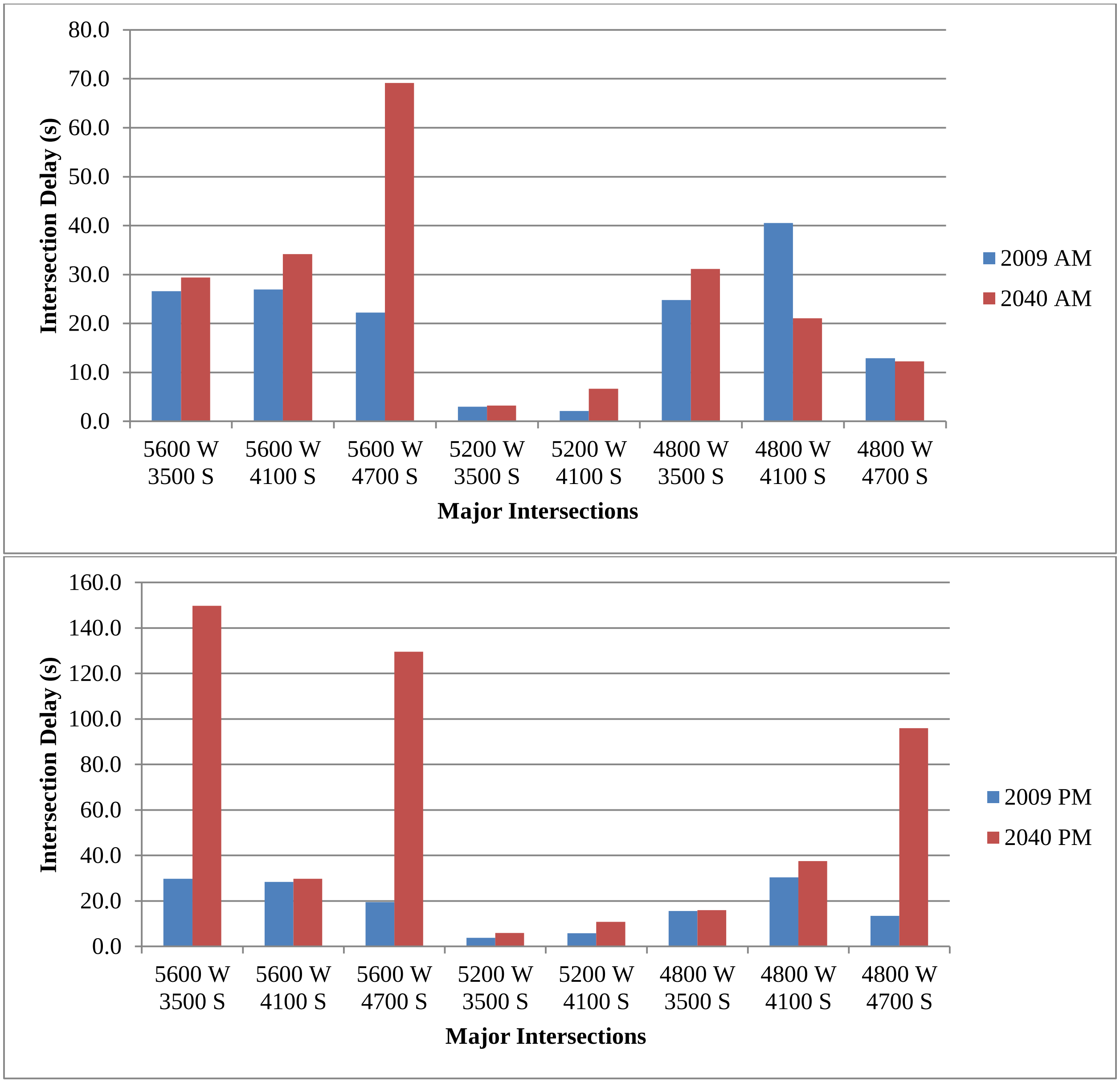


Figure 5.1 Intersection Delay Comparisons for 2009 and 2040, for AM and PM Peak Periods

Table 5.2 Network Performance for Base case Scenarios

Parameter	2009 AM	2009 PM	2040 AM	2040 PM
Number of vehicles in the network	546	719	655	1493
Number of vehicles that have left the network	23504	32839	27213	37576
Total number of vehicles	24050	33558	27868	39069
Average delay time per vehicle (s)	51	44.79	67.446	201.423
Average stopped delay per vehicle (s)	28	23.196	29.459	101.017
Average number of stops per vehicles	1.2	1.09	1.333	3.764
Total delay time (h)	339.6	417.514	522.11	2185.938
Total stopped delay (h)	190.1	216.229	228.049	1096.285
Total number of stops	30013	36573	37160	147067
Average speed (mph)	26.141	26.429	23.931	16.379
Total travel time (h)	1569.8	2156.765	2035.068	4320.68
Total distance traveled (mi)	41037.6	57000.92	48701.431	70769.321

Table 5.3 Travel Times and LOS for Test Network Corridors

		2009 AM			2040 AM		
Segment	Section (mi)	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	275.2	37.0	A	323.7	31.5	B
5600 W NB	2.830	288.4	35.3	A	321.9	31.7	B
5200 W SB	0.987	108.0	32.9	B	102.0	34.8	B
5200 W NB	0.983	96.1	36.8	A	96.3	36.7	A
4800 W SB	2.802	396.4	25.5	C	361.1	27.9	C
4800 W NB	2.802	450.4	22.4	C	407.6	24.7	C
3500 S EB	1.592	208.9	27.4	C	244.1	23.5	C
3500 S WB	1.592	200.8	28.5	B	201.7	28.4	B
4100 S EB	1.692	270.7	22.5	C	254.5	23.9	C
4100 S WB	1.692	255.8	23.8	C	232.9	26.1	C
4700 S EB	1.802	265.9	24.4	C	292.4	22.2	C
4700 S WB	1.796	276.9	23.3	C	264.6	24.4	C
		2009 PM			**2040 PM**		
Segment	Section (mi)	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	281.346	36.2	A	551.5	18.5	D
5600 W NB	2.830	309.920	32.9	B	412.9	24.7	C
5200 W SB	0.987	121.813	29.2	B	109.3	32.5	B
5200 W NB	0.983	97.559	36.3	A	99.4	35.6	A
4800 W SB	2.802	395.502	25.5	C	394.4	25.6	C
4800 W NB	2.802	401.576	25.1	C	517.0	19.5	D
3500 S EB	1.592	212.856	26.9	C	210.4	27.2	C
3500 S WB	1.592	213.796	26.8	C	221.8	25.8	C
4100 S EB	1.692	251.723	24.2	C	251.3	24.2	C
4100 S WB	1.692	234.671	26.0	C	268.4	22.7	C
4700 S EB	1.802	295.026	22.0	D	343.4	18.9	D
4700 S WB	1.796	276.204	23.4	C	700.1	9.2	F

5.2 Street Connectivity Scenarios

We tested five new network design scenarios with different connectivity levels, versus five street widening scenarios, making sure the length of new connections and additional lanes is equivalent for each of five scenario pairs. We also compared the impact of different levels of network connectivity on traffic operations, including the existing conditions and enhanced connectivity, with the presence of traffic calming measures. Each scenario and approach rendered a different traffic assignment in VISUM, and thus different vehicle inputs and routing decisions in VISSIM models. The results are shown on the intersection, corridor, and network-wide level. Figure 5.2 shows the street connectivity scenarios we modeled and tested.

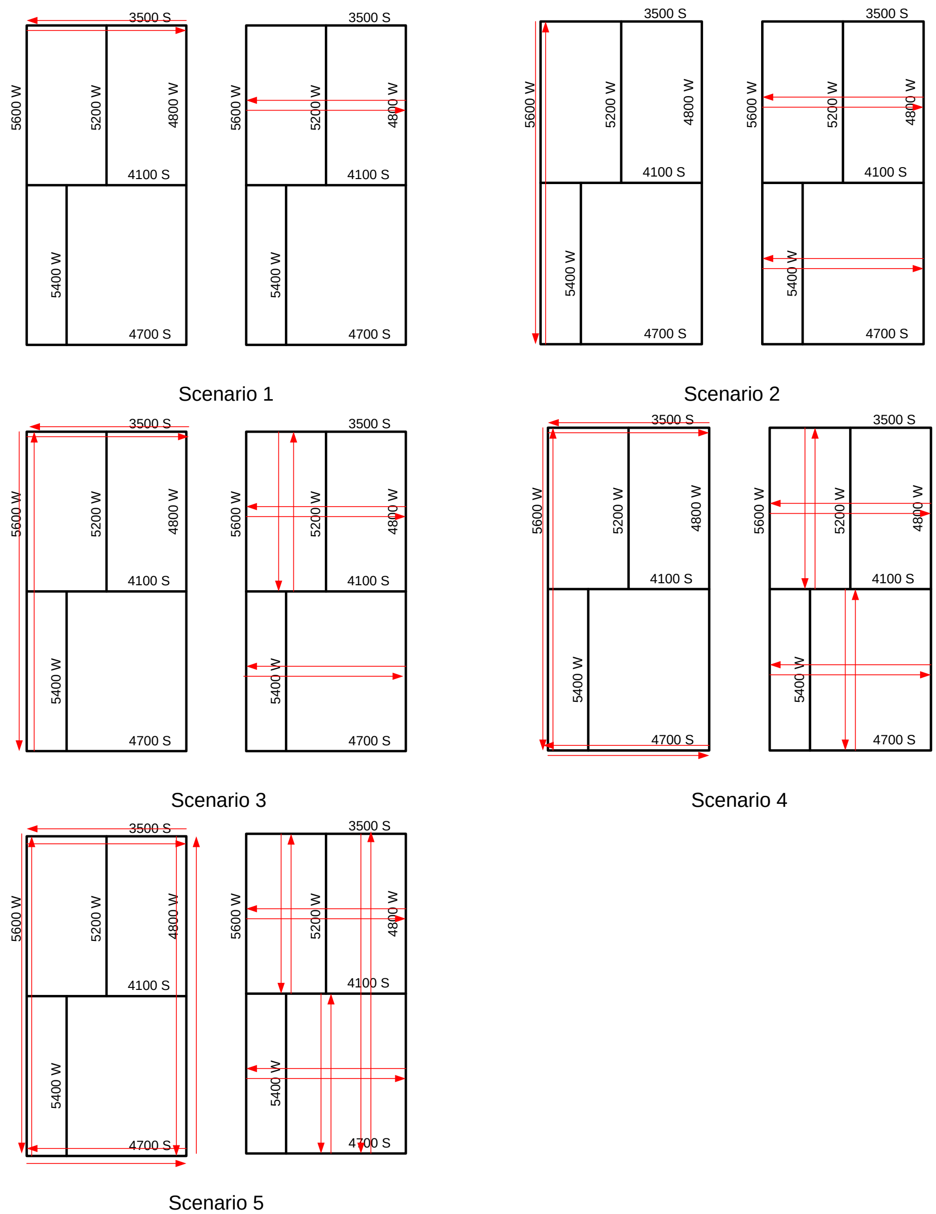


Figure 5.2 Street Connectivity Scenarios

Highly connected street networks increase accessibility for multimodal transport, but their effects on the efficiency of still dominant vehicular traffic is rarely addressed. This section discusses the implications of connectivity on traffic operations on part of the West Valley City network in Utah. Our test network has two Bus Rapid Transit (BRT) lines in place with the potential Transit Oriented Development (TOD) site according to regional plans for 2040. Since predicted traffic demand for 2040 requires modifications of this network, the question is if enhanced connectivity, as a TOD supportive approach, can accommodate that demand and replace the traditional street widening solution.

Intersection analysis (Table 5.4) shows that increased street connectivity does not improve intersection performance, and that critical intersections along the future BRT corridor retain low LOS. Street widening and increased connectivity even tend to increase intersection delay for PM peak period (Figures 5.3 and 5.4). As street connectivity increases (Figures 5.5 and 5.6) intersection delays also increase for the year 2040 for all intersections except those on 3500 S and 5600 W corridors.

Travel times, speeds, and LOS on the corridor level for street widening and connectivity scenarios are given in Tables 5.5 – 5.9. Additional connections to 5600 W do not cause the traffic to detour from this corridor and use other streets as alternatives in the southbound direction. The decrease in LOS and speeds, and increase in travel time along this corridor, with even only one additional street connection to the parallel arterial shows that more drivers would choose this corridor if more connections were provided. The LOS decreases on 5200 W corridor, too, as an alternative approach to 5600 W and 35 S intersection.

Additional street connections to the 5600 W corridor decreases its LOS in both southbound and northbound directions. Since the LOS does not change on the parallel 4800 W arterial, the traffic is coming to 5600 W from other directions, and not rerouting from 4800 W. This implies that simple street widening or adding connections that feed into this corridor will not improve its performance. As additional connections are added parallel to the corridor, travel time on 5600 W starts to decrease (Scenarios 3, 4, and 5). In these cases, improved connectivity proves to be a better alternative than street widening from the operational standpoint.

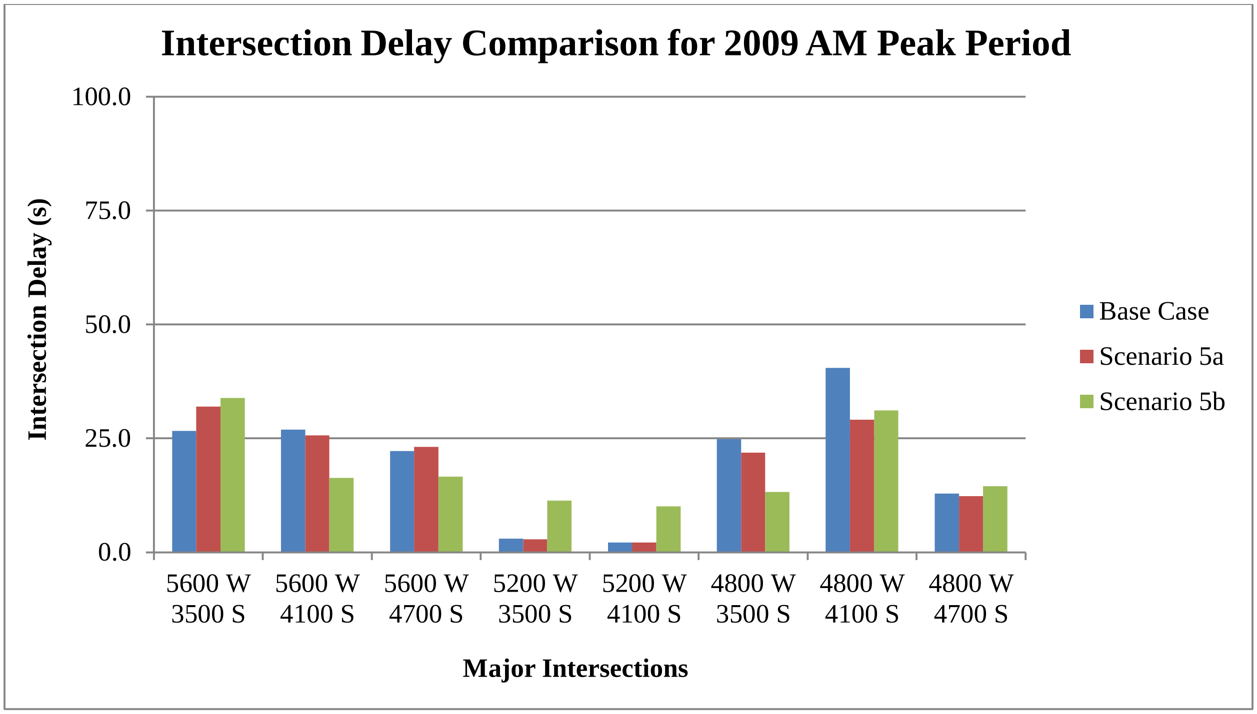
Traffic analysis of street connectivity scenarios on the network-wide level is given in Table 5.11. Enhanced street connectivity increases the overall network delay when compared with street widening and base case scenarios. The complete network analysis shows that networks with enhanced connectivity accommodate more vehicles during the same period of time. So it is a trade-off between capacity and delay whether the existing state of the network will be kept or connectivity will be increased for the current traffic conditions.

Considering the travel forecasts for 2040 AM and PM peak periods, however, enhanced connectivity contributes up to 30 seconds to average delay per vehicle, while it accommodates about 2,000 vehicles more than the base case or street widening scenarios. So for future network modifications, street connectivity with additional intersection design and operations might be the network development that could address the demand.

Our results show that enhanced connectivity opens new routes and provides better dispersion of intra-zonal traffic, without rerouting external-external trips from the major arterial. As connectivity increases, network designs with enhanced connectivity accommodate more traffic than designs with street widening. However, none of the proposed solutions will meet the 2040 traffic demand unless mode shift occurs.

Table 5.4 Intersection LOS for Street Connectivity Scenarios

Scenario		Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Scenario 1	2009 AM	1a	B	C	C	A	A	C	D	B
		1b	C	C	B	B	A	B	C	B
	2009 PM	1a	C	C	B	A	A	B	C	B
		1b	C	B	B	A	A	B	D	B
	2040 AM	1a	C	C	E	A	A	C	C	B
		1b	C	C	E	B	A	B	C	B
	2040 PM	1a	E	C	F	A	B	B	D	F
		1b	F	C	F	B	A	B	F	F
Scenario 2	2009 AM	2a	C	C	C	A	A	C	D	B
		2b	C	C	B	B	A	B	C	B
	2009 PM	2a	C	C	C	A	A	B	D	B
		2b	C	B	B	A	A	B	D	B
	2040 AM	2a	C	C	E	A	A	C	C	B
		2b	C	C	F	B	B	B	C	B
	2040 PM	2a	F	C	F	A	B	B	D	F
		2b	F	C	F	C	B	B	F	F
Scenario 3	2009 AM	3a	C	C	C	A	A	C	D	B
		3b	C	B	B	B	B	B	C	B
	2009 PM	3a	C	C	C	A	A	B	C	B
		3b	C	B	B	A	A	B	C	B
	2040 AM	3a	C	C	E	A	A	C	C	B
		3b	C	C	E	B	B	B	C	B
	2040 PM	3a	F	C	F	A	B	B	D	F
		3b	F	C	F	C	B	B	F	F
Scenario 4	2009 AM	4a	C	C	C	A	A	C	D	B
		4b	C	B	B	B	B	B	C	B
	2009 PM	4a	C	C	B	A	A	B	C	B
		4b	C	B	B	A	A	B	C	B
	2040 AM	4a	C	C	E	A	A	C	C	B
		4b	C	C	E	B	B	B	C	B
	2040 PM	4a	F	C	F	A	B	B	D	E
		4b	F	C	F	C	B	B	F	F
Scenario 5	2009 AM	5a	C	C	C	A	A	C	C	B
		5b	C	B	B	B	A	B	C	B
	2009 PM	5a	C	C	B	A	A	B	C	B
		5b	C	B	B	A	A	B	C	B
	2040 AM	5a	C	C	E	A	A	B	B	B
		5b	C	C	E	B	B	B	C	C
	2040 PM	5a	F	C	F	A	B	B	C	E
		5b	F	C	F	B	B	B	F	F



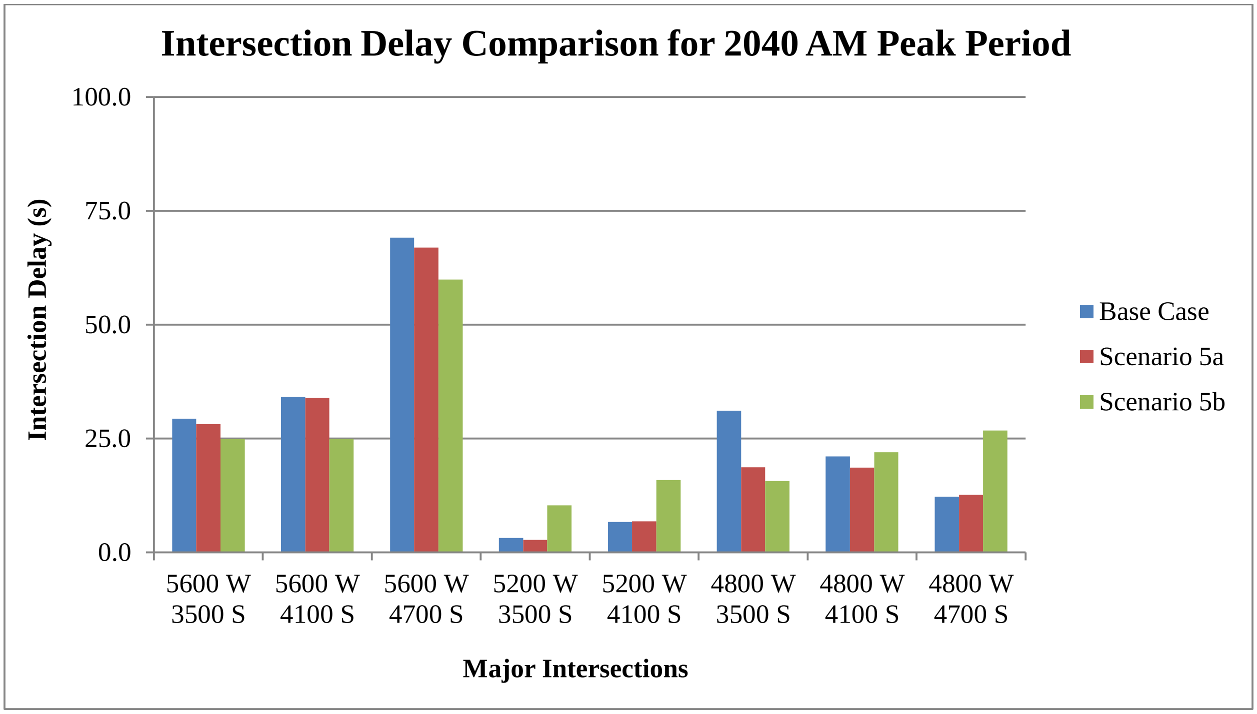


Figure 5.3 Comparisons of Intersection Delays for Base Case, Street Widening (a) and Increased Connectivity (b) Scenarios for AM Peak Period

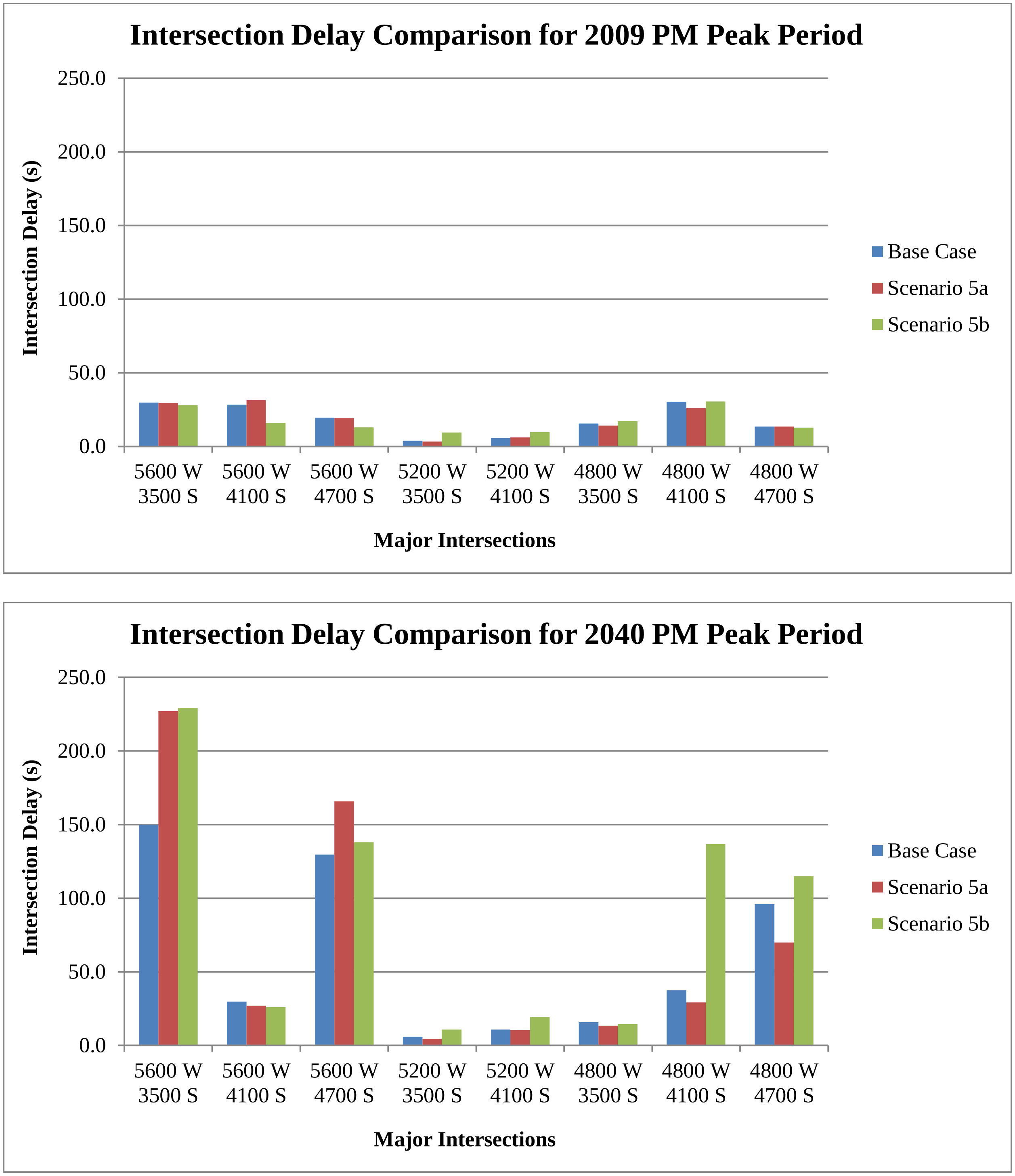
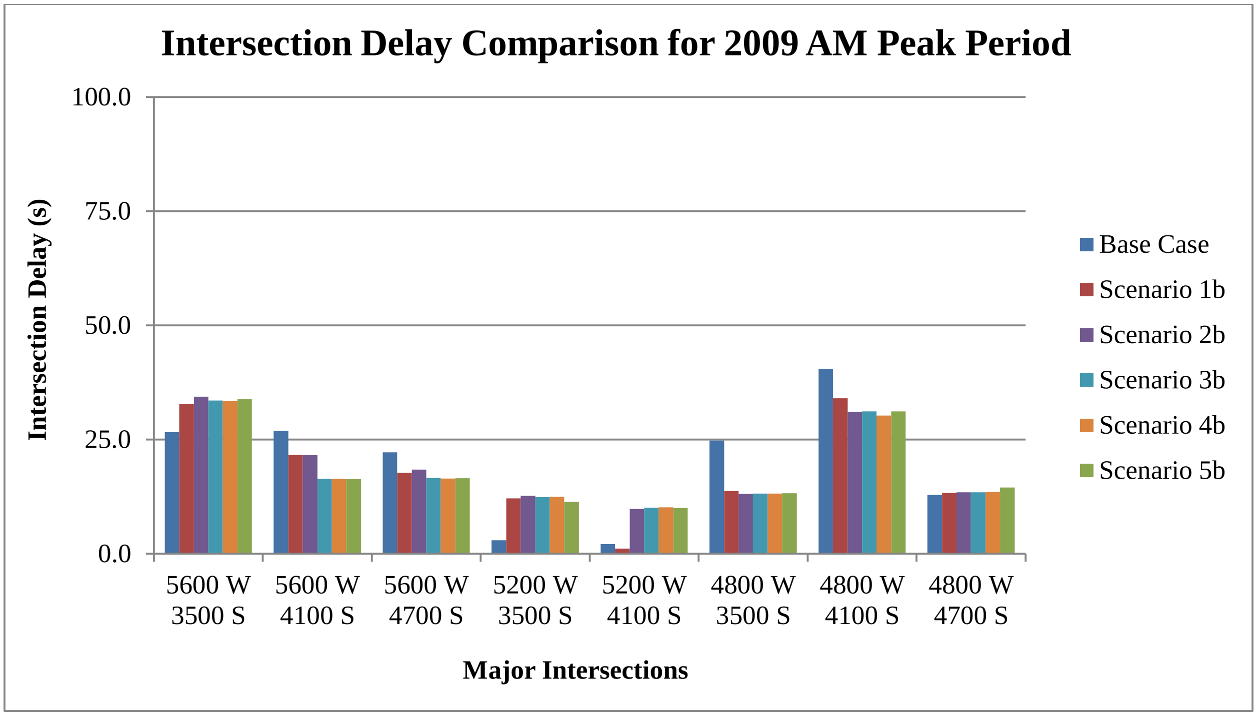


Figure 5.4 Comparisons of Intersection Delays for Base Case, Street Widening (a) and Increased Connectivity (b) Scenarios for PM Peak Period



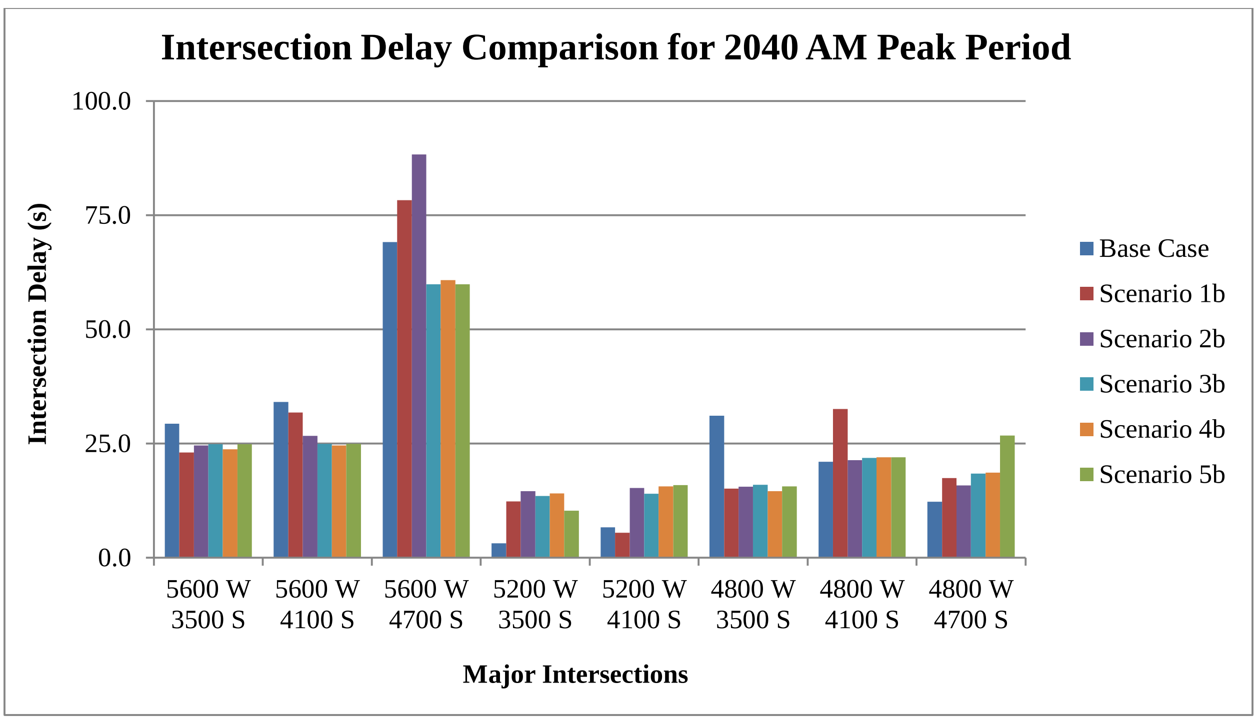
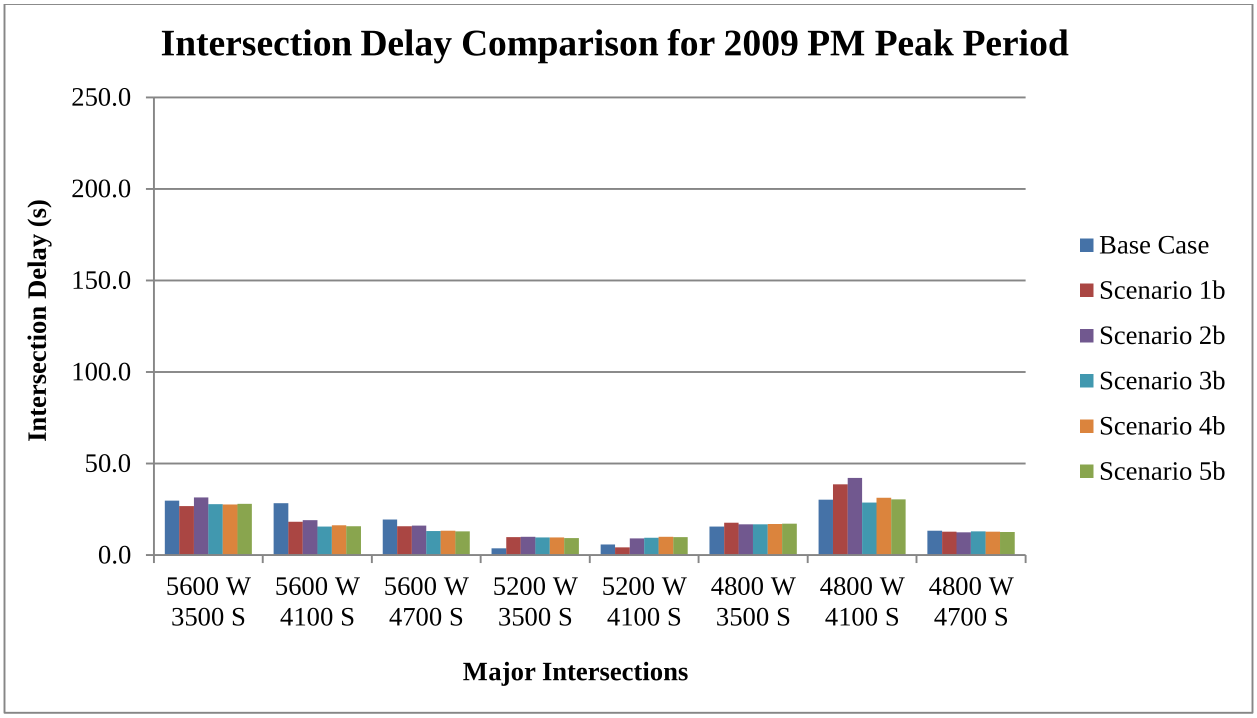


Figure 5.5 Comparisons of Intersection Delays for Base Case, and Increased Connectivity Scenarios for AM Peak Period



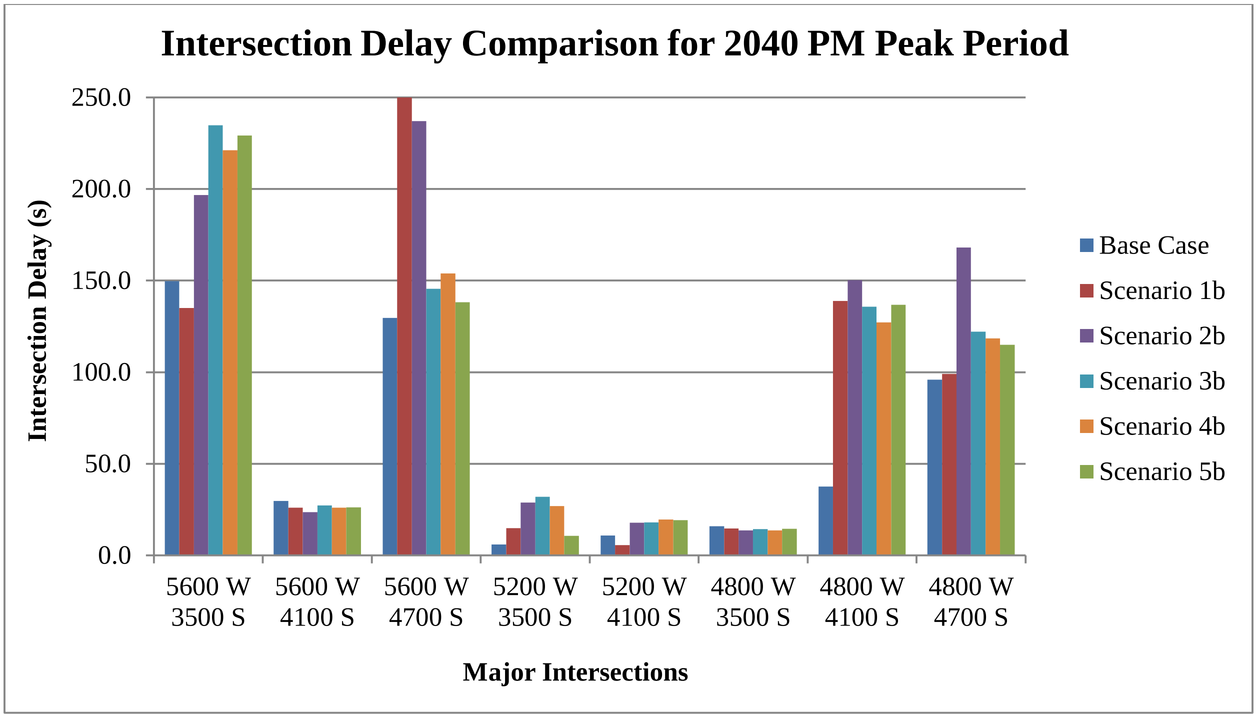


Figure 5.6 Comparisons of Intersection Delays for Base Case, and Increased Connectivity Scenarios for PM Peak Period

Table 5.5 Travel Times and Corridor LOS for Street Connectivity Scenario 1

Segment	Section (mi)	Base Case			Scenario 1					
					Street Widening			Street Connectivity		
		Avg TT (s	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	551.5	18.5	D	408.8	24.9	C	533.6	19.1	D
5600 W NB	2.830	412.9	24.7	C	400.9	25.4	C	823.2	12.4	F
5200 W SB	0.987	109.3	32.5	B	108.7	32.7	B	95.6	37.2	A
5200 W NB	0.983	99.4	35.6	A	99.3	35.6	A	151.7	23.3	C
4800 W SB	2.802	394.4	25.6	C	400.9	25.2	C	410.6	24.6	C
4800 W NB	2.802	517.0	19.5	D	523.6	19.3	D	535.5	18.8	D
3500 S EB	1.592	210.4	27.2	C	214.6	26.7	C	210.2	27.3	C
3500 S WB	1.592	221.8	25.8	C	203.6	28.2	B	217.6	26.3	C
4100 S EB	1.692	251.3	24.2	C	252.8	24.1	C	242.1	25.2	C
4100 S WB	1.692	268.4	22.7	C	270.8	22.5	C	520.0	11.7	F
4700 S EB	1.802	343.4	18.9	D	344.6	18.8	D	318.9	20.3	D
4700 S WB	1.796	700.1	9.2	F	714.6	9.0	F	586.2	11.0	F

Table 5.6 Travel Times and Corridor LOS for Street Connectivity Scenario 2

Segment	Section (mi)	Base Case			Scenario 2					
					Street Widening			Street Connectivity		
		Avg TT (s	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	551.5	18.5	D	790.4	12.9	F	608.1	16.8	E
5600 W NB	2.830	412.9	24.7	C	384.7	26.5	C	902.7	11.3	F
5200 W SB	0.987	109.3	32.5	B	108.8	32.7	B	97.9	36.3	A
5200 W NB	0.983	99.4	35.6	A	99.7	35.5	A	207.1	17.1	D
4800 W SB	2.802	394.4	25.6	C	402.4	25.1	C	439.1	23.0	C
4800 W NB	2.802	517.0	19.5	D	519.6	19.4	D	586.1	17.2	D
3500 S EB	1.592	210.4	27.2	C	211.3	27.1	C	209.4	27.4	C
3500 S WB	1.592	221.8	25.8	C	225.3	25.4	C	234.0	24.5	C
4100 S EB	1.692	251.3	24.2	C	252.4	24.1	C	254.4	23.9	C
4100 S WB	1.692	268.4	22.7	C	268.9	22.7	C	594.1	10.3	F
4700 S EB	1.802	343.4	18.9	D	334.8	19.4	D	323.7	20.0	D
4700 S WB	1.796	700.1	9.2	F	758.2	8.5	F	770.9	8.4	F

Table 5.7 Travel Times and Corridor LOS for Street Connectivity Scenario 3

Segment	Section (mi)	Base Case			Scenario 3					
					Street Widening			Street Connectivity		
		Avg TT (s	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	551.5	18.5	D	771.4	13.2	E	582.4	17.5	D
5600 W NB	2.830	412.9	24.7	C	382.5	26.6	C	692.3	14.7	E
5200 W SB	0.987	109.3	32.5	B	109.4	32.5	B	97.4	36.5	A
5200 W NB	0.983	99.4	35.6	A	99.3	35.6	A	246.5	14.4	E
4800 W SB	2.802	394.4	25.6	C	399.1	25.3	C	403.4	25.0	C
4800 W NB	2.802	517.0	19.5	D	528.3	19.1	D	513.2	19.7	D
3500 S EB	1.592	210.4	27.2	C	211.8	27.1	C	215.1	26.7	C
3500 S WB	1.592	221.8	25.8	C	206.8	27.7	C	227.7	25.2	C
4100 S EB	1.692	251.3	24.2	C	252.7	24.1	C	260.8	23.4	C
4100 S WB	1.692	268.4	22.7	C	266.2	22.9	C	515.7	11.8	F
4700 S EB	1.802	343.4	18.9	D	334.0	19.4	D	312.7	20.8	D
4700 S WB	1.796	700.1	9.2	F	756.3	8.5	F	643.1	10.1	F

Table 5.8 Travel Times and Corridor LOS for Street Connectivity Scenario 4

Segment	Section (mi)	Base Case			Scenario 4					
					Street Widening			Street Connectivity		
		Avg TT (s	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	551.5	18.5	D	714.5	14.3	E	564.3	18.1	D
5600 W NB	2.830	412.9	24.7	C	372.8	27.3	C	614.0	16.6	E
5200 W SB	0.987	109.3	32.5	B	109.6	32.4	B	98.1	36.2	A
5200 W NB	0.983	99.4	35.6	A	100.0	35.4	A	202.2	17.5	D
4800 W SB	2.802	394.4	25.6	C	391.6	25.8	C	394.5	25.6	C
4800 W NB	2.802	517.0	19.5	D	478.2	21.1	D	538.8	18.7	D
3500 S EB	1.592	210.4	27.2	C	212.9	26.9	C	209.1	27.4	C
3500 S WB	1.592	221.8	25.8	C	208.4	27.5	C	215.0	26.7	C
4100 S EB	1.692	251.3	24.2	C	251.7	24.2	C	262.1	23.2	C
4100 S WB	1.692	268.4	22.7	C	269.1	22.6	C	499.3	12.2	F
4700 S EB	1.802	343.4	18.9	D	313.2	20.7	D	322.9	20.1	D
4700 S WB	1.796	700.1	9.2	F	915.7	7.1	F	628.0	10.3	F

Table 5.9 Travel Times and Corridor LOS for Street Connectivity Scenario 5

Segment	Section (mi)	Base Case			Scenario 5					
					Street Widening			Street Connectivity		
		Avg TT (s	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
5600 W SB	2.830	551.5	18.5	D	827.4	12.3	F	608.1	16.8	E
5600 W NB	2.830	412.9	24.7	C	376.5	27.1	C	598.3	17.0	D
5200 W SB	0.987	109.3	32.5	B	109.2	32.5	B	97.9	36.3	A
5200 W NB	0.983	99.4	35.6	A	99.4	35.6	A	111.9	31.6	B
4800 W SB	2.802	394.4	25.6	C	361.4	27.9	C	392.8	25.7	C
4800 W NB	2.802	517.0	19.5	D	477.9	21.1	D	528.3	19.1	D
3500 S EB	1.592	210.4	27.2	C	210.3	27.3	C	207.9	27.6	C
3500 S WB	1.592	221.8	25.8	C	203.6	28.1	B	231.0	24.8	C
4100 S EB	1.692	251.3	24.2	C	246.6	24.7	C	261.9	23.3	C
4100 S WB	1.692	268.4	22.7	C	261.9	23.3	C	531.3	11.5	F
4700 S EB	1.802	343.4	18.9	D	314.1	20.7	D	318.7	20.4	D
4700 S WB	1.796	700.1	9.2	F	795.8	8.1	F	657.3	9.8	F

Table 5.10 Network-Wide Performance: Street Widening vs. Enhanced Connectivity

2009 AM	Base	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
Total number of vehicles	24,050	24,051	24,692	24,063	25,904	24,073	26,245	24,056	26,172	24,060	26,616
Average delay time per vehicle (s)	51	49	50	54	49	53	45	53	45	47	45
Average number of stops per vehicles	1.2	1.2	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.3
Total delay time (h)	339.6	325.4	344.8	358.4	349.6	352.0	329.8	355.7	326.2	316.9	329.7
Average speed (mph)	26.1	26.4	26.3	25.3	26.6	25.4	27.0	25.3	27.0	25.7	26.9
Total travel time (h)	1,569.8	1,555.9	1,575.1	1,617.6	1,655.4	1,615.2	1,643.4	1,619.4	1,635.5	1,595.4	1,658.4
Total distance traveled (mi)	41,037.6	41,042.0	41,445.1	41,003.6	44,024.8	40,995.0	44,393.8	40,990.9	44,231.3	41,013.9	44,672.2
2009 PM	Base	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
Total number of vehicles	33,558	33,555	33,846	33,583	35,081	33,572	35,142	33,568	34,991	33,561	35,349
Average delay time per vehicle (s)	45	47	46	49	48	46	44	46	43	43	42
Average number of stops per vehicles	1.1	1.1	1.3	1.2	1.4	1.1	1.2	1.1	1.3	1.1	1.2
Total delay time (h)	417.5	433.9	432.0	455.8	468.1	428.8	425.2	425.7	414.7	401.5	410.3
Average speed (mph)	26.4	26.2	26.5	25.7	26.4	26.0	26.8	26.1	27.1	26.2	27.1
Total travel time (h)	2,156.8	2,170.0	2,156.4	2,214.7	2,280.4	2,192.3	2,197.7	2,188.5	2,210.1	2,175.4	2,221.8
Total distance traveled (mi)	57,000.9	56,938.6	57,125.5	56,941.4	60,239.0	57,015.3	58,830.3	57,033.0	59,889.5	57,031.2	60,283.2
2040 AM	Base	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
Total number of vehicles	27,868	27,873	24,692	27,824	30,184	27,832	31,006	27,830	30,901	27,795	31,195
Average delay time per vehicle (s)	67	67	50	67	71	67	62	67	62	62	63
Average number of stops per vehicles	1.3	1.4	1.4	1.3	1.7	1.3	1.5	1.3	1.5	1.2	1.5
Total delay time (h)	522.1	519.0	344.8	518.3	593.7	516.5	532.4	515.0	531.0	476.7	545.7
Average speed (mph)	23.9	24.0	26.3	23.7	23.9	23.6	24.9	23.6	24.8	23.9	24.6
Total travel time (h)	2,035.1	2,032.4	1,575.1	2,051.8	2,215.1	2,058.1	2,201.1	2,057.1	2,194.3	2,028.9	2,221.0
Total distance traveled (mi)	48,701.4	48,719.1	41,445.1	48,602.0	53,027.4	48,605.7	54,701.9	48,604.1	54,494.4	48,546.6	54,738.0
2040 PM	Base	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
Total number of vehicles	39,069	39,796	37,597	38,501	38,978	38,518	41,521	39,087	41,391	38,894	41,335
Average delay time per vehicle (s)	201	179	269	231	280	231	255	224	247	219	241
Average number of stops per vehicles	3.8	3.4	5.2	4.4	5.9	4.5	5.1	4.4	4.9	4.3	4.8
Total delay time (h)	2,185.9	1,973.8	2,810.0	2,466.7	3,028.9	2,470.0	2,937.5	2,430.8	2,838.2	2,364.1	2,766.0
Average speed (mph)	16.4	17.4	14.0	15.2	13.7	15.1	14.5	15.4	14.8	15.5	14.9
Total travel time (h)	4,320.7	4,149.6	4,828.4	4,586.5	5,131.6	4,593.9	5,182.8	4,581.8	5,078.4	4,517.2	5,003.1
Total distance traveled (mi)	70,769.3	72,247.5	67,361.6	69,491.1	70,314.0	69,509.1	75,212.9	70,501.3	74,975.2	70,226.5	74,755.5

5.3 Traffic Calming Scenarios

Traffic analysis of different street connectivity scenarios from the previous section shows the need to balance the level of connectivity, at least from the traffic operations standpoint. One of the ways to do that is through traffic calming that helps to avoid high traffic volumes on local streets.

Traffic calming studies are usually based on the empirical evidence and analyzed for their safety effects. While previous studies found that traffic calming has positive effects on safety, their operational effects are rarely tested. This is because traffic calming is installed in neighborhoods to lower traffic speeds. It is, however, important to examine the effects of these measures on the network-wide level, especially in TOD environments.

We used the equation from the U.S. Traffic Calming Manual to calculate the optimal spacing of traffic calming measures, depending on the midpoint speed, street speed, and low point speed. The 85^{th} midpoint speed represents the speed 5 mph over the posted speed limit. Street speed is the posted speed limit, while low point speed is the target speed that should be achieved through traffic calming installation.

$$Spacing^{0.08} = \frac{85th\ midpoint\ speed}{1.86 \cdot (85th\ street\ speed)^{0.42} \cdot (85th\ slow\ point\ speed)^{0.23}}$$

Before using these calculations to allocate traffic calming effects in the form of decreased link speeds, we compared posted speed limits with assigned traffic speeds on the base case network and network with increased connectivity. This is how we identified potential network areas where speeding might occur as the network density increases.

Tables 5.14 - 5.16 show intersection, corridor, and network analysis of scenarios that include traffic calming with the highest level of street connectivity applied in the previous section. Traffic calming measures modeled in this way reduce the level of service for intersections, considering the forecasted demand for 2040.

When we compare travel times and LOS for base case scenario, improved connectivity scenario, and traffic calming scenario, the LOS for 2040 AM peak period on the corridors becomes lower as traffic calming is introduced. Except for that period, traffic calming does not increase delays or decrease average speeds significantly along the corridors. The network analysis shows that traffic calming affects 2040 PM peak period the most, with the highest delay values.

Further research needs to be done with various combinations of street connectivity and traffic calming implementation to determine the optimal network density and speeds. Our results show that traffic calming has influence on the entire network, even though it is only applied to local streets. TOD does not necessarily require traffic calming, but in the case where network is not dense enough and intersection density alone does not decrease traffic speeds to encourage alternate modes, calming traffic is both an efficient and non-expensive way of preventing high speeds in the environment that should be pedestrian-friendly.

Table 5.11 Intersection LOS with Traffic Calming for 2009 AM, 2009 PM, 2040 AM, and 2040 PM peak periods

Node number	1	2	3	4	5	6	7	8
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	8934	6943	4689	3392	3234	5773	6532	5100
Delay (s)	33.5	16.2	16.8	11.8	9.5	13.1	33.1	14.5
Stop delay (s)	22.8	9.5	11.1	6.7	4.8	6.4	22.3	6.9
Stops	0.8	0.5	0.6	0.4	0.4	0.5	1.0	0.7
Avg Queue (ft)	65.3	27.0	19.2	10.9	9.4	18.2	64.8	16.0
Max Queue (ft)	404.9	242.3	183.5	141.9	159.4	211.8	448.9	170.5
LOS	C	B	B	B	A	B	C	B

Node number	1	2	3	4	5	6	7	8
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	10321	8060	5691	5295	4739	7620	9183	5618
Delay (s)	27.4	15.6	14.0	9.7	9.4	17.3	31.0	13.6
Stop delay (s)	16.4	8.1	7.4	4.9	3.6	11.6	17.9	5.0
Stops	0.8	0.6	0.6	0.4	0.4	0.5	1.0	0.6
Avg Queue (ft)	66.8	27.9	18.5	10.0	6.5	29.6	91.2	16.1
Max Queue (ft)	509.5	304.2	181.4	131.4	145.5	250.0	713.3	190.1
LOS	C	B	B	A	A	B	C	B

Node number	1	2	3	4	5	6	7	8
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	12236	8982	9697	7958	3883	10606	6704	7857
Delay (s)	315.7	308.1	228.2	154.0	289.5	89.7	287.3	230.8
Stop delay (s)	175.8	152.9	92.7	72.6	213.3	27.9	187.3	130.9
Stops	5.4	6.7	5.3	2.3	3.4	1.9	4.6	4.9
Avg Queue (ft)	1205.9	868.2	760.9	674.9	631.4	391.2	560.4	783.0
Max Queue (ft)	1438.4	1452.0	1144.8	1570.9	1008.4	1129.9	1182.3	1656.0
LOS	F	F	F	F	F	F	F	F

Node number	1	2	3	4	5	6	7	8
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S
Vehicles	11890	10019	10996	8491	6857	10723	9745	9389
Delay (s)	339.2	36.3	145.9	126.1	13.8	85.0	136.3	121.8
Stop delay (s)	185.3	23.7	46.7	22.8	6.5	21.7	47.8	55.7
Stops	5.1	0.9	3.3	2.5	0.5	2.1	2.6	3.1
Avg Queue (ft)	1214.6	114.1	848.1	612.0	21.2	419.8	583.7	532.0
Max Queue (ft)	1435.0	553.3	1161.1	996.4	284.9	1163.7	898.2	1388.8
LOS	F	D	F	F	B	F	F	F

Table 5.12 Travel Times and Corridor LOS with and without Traffic Calming

Period	Segment	Section (mi)	Base Case			Street Connectivity			Traffic Calming		
			Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS	Avg TT (s)	Speed (mph)	LOS
2009 AM	5600 W SB	2.830	275.2	37.0	A	284.0	35.9	A	284.5	35.8	A
	5600 W NE	2.830	288.4	35.3	A	308.3	33.0	B	304.4	33.5	B
	5200 W SB	0.987	108.0	32.9	B	91.6	38.8	A	91.6	38.8	A
	5200 W NE	0.983	96.1	36.8	A	98.7	35.8	A	98.8	35.8	A
	4800 W SB	2.802	396.4	25.5	C	359.0	28.1	B	348.5	28.9	B
	4800 W NE	2.802	450.4	22.4	C	371.7	27.1	C	369.8	27.3	C
	3500 S EB	1.592	208.9	27.4	C	218.2	26.3	C	217.8	26.3	C
	3500 S WB	1.592	200.8	28.5	B	219.8	26.1	C	219.9	26.1	C
	4100 S EB	1.692	270.7	22.5	C	232.9	26.2	C	232.8	26.2	C
	4100 S WB	1.692	255.8	23.8	C	229.4	26.5	C	228.3	26.7	C
	4700 S EB	1.802	265.9	24.4	C	272.0	23.9	C	274.4	23.6	C
	4700 S WB	1.796	276.9	23.3	C	270.5	23.9	C	276.1	23.4	C
2009 PM	5600 W SB	2.830	281.346	36.2	A	309.5	32.9	B	313.033	32.5	B
	5600 W NE	2.830	309.920	32.9	B	297.3	34.3	B	299.326	34.0	B
	5200 W SB	0.987	121.813	29.2	B	96.8	36.7	A	95.972	37.0	A
	5200 W NE	0.983	97.559	36.3	A	98.8	35.8	A	98.715	35.8	A
	4800 W SB	2.802	395.502	25.5	C	376.0	26.8	C	386.164	26.1	C
	4800 W NE	2.802	401.576	25.1	C	382.8	26.3	C	391.817	25.7	C
	3500 S EB	1.592	212.856	26.9	C	203.1	28.2	B	202.694	28.3	B
	3500 S WB	1.592	213.796	26.8	C	195.0	29.4	B	195.847	29.3	B
	4100 S EB	1.692	251.723	24.2	C	231.5	26.3	C	232.614	26.2	C
	4100 S WB	1.692	234.671	26.0	C	244.3	24.9	C	246.713	24.7	C
	4700 S EB	1.802	295.026	22.0	D	267.0	24.3	C	267.692	24.2	C
	4700 S WB	1.796	276.204	23.4	C	258.9	25.0	C	257.132	25.1	C
2040 AM	5600 W SB	2.830	323.7	31.5	B	329.7	30.9	B	495.1	20.6	D
	5600 W NE	2.830	321.9	31.7	B	323.6	31.5	B	2636.7	3.9	F
	5200 W SB	0.987	102.0	34.8	B	93.9	37.9	A	325.7	10.9	F
	5200 W NE	0.983	96.3	36.7	A	98.9	35.8	A	114.1	31.0	B
	4800 W SB	2.802	361.1	27.9	C	354.8	28.4	B	924.3	10.9	F
	4800 W NE	2.802	407.6	24.7	C	383.8	26.3	C	968.1	10.4	F
	3500 S EB	1.592	244.1	23.5	C	212.7	26.9	C	233.2	24.6	C
	3500 S WB	1.592	201.7	28.4	B	191.4	29.9	B	690.0	8.3	F
	4100 S EB	1.692	254.5	23.9	C	250.7	24.3	C	632.1	9.6	F
	4100 S WB	1.692	232.9	26.1	C	246.9	24.7	C	917.5	6.6	F
	4700 S EB	1.802	292.4	22.2	C	310.0	20.9	D	372.2	17.4	D
	4700 S WB	1.796	264.6	24.4	C	268.0	24.1	C	886.9	7.3	F
2040 PM	5600 W SB	2.830	551.5	18.5	D	608.1	16.8	E	619.5	16.4	E
	5600 W NE	2.830	412.9	24.7	C	598.3	17.0	D	702.7	14.5	E
	5200 W SB	0.987	109.3	32.5	B	97.9	36.3	A	96.9	36.7	A
	5200 W NE	0.983	99.4	35.6	A	111.9	31.6	B	125.7	28.2	B
	4800 W SB	2.802	394.4	25.6	C	392.8	25.7	C	420.0	24.0	C
	4800 W NE	2.802	517.0	19.5	D	528.3	19.1	D	528.7	19.1	D
	3500 S EB	1.592	210.4	27.2	C	207.9	27.6	C	207.9	27.6	C
	3500 S WB	1.592	221.8	25.8	C	231.0	24.8	C	684.4	8.4	F
	4100 S EB	1.692	251.3	24.2	C	261.9	23.3	C	262.7	23.2	C
	4100 S WB	1.692	268.4	22.7	C	531.3	11.5	F	530.5	11.5	F
	4700 S EB	1.802	343.4	18.9	D	318.7	20.4	D	313.3	20.7	D
	4700 S WB	1.796	700.1	9.2	F	657.3	9.8	F	688.5	9.4	F

Table 5.13 Network Performance for Traffic Calming Scenario

Parameter	2009 AM	2009 PM	2040 AM	2040 PM
Number of vehicles in the network	548	686	4561	2512
Number of vehicles that have left the network	25963	34619	34719	38510
Total number of vehicles	26511	35305	39280	41022
Average delay time per vehicle (s)	45	42	809	324
Average stopped delay per vehicle (s)	23	18	506	131
Average number of stops per vehicles	1.3	1.2	13.1	6.4
Total delay time (h)	331.1	413.7	8829.4	3694.8
Total stopped delay (h)	169.0	176.3	5519.6	1490.9
Total number of stops	33263	43955	516448	261536
Average speed (mph)	26.861	27.068	6.001	12.481
Total travel time (h)	1651.3	2221.8	10774.8	5900.3
Total distance traveled (mi)	44353.9	60139.8	64658.5	73639.3

5.4 Innovative Intersections Scenarios

Innovative intersections are intersections designed with removed left turns and reduced number of traffic signal phases in order to increase capacity and reduce the number of conflict points. These intersections require unexpected vehicle movements, such as rerouting left well ahead of the main intersection or going through the intersection and making a U-turn and a right turn in order to turn left. For the purpose of this project, only at-grade intersection design concepts are analyzed. The performance of innovative intersections within the studied network is compared to the performance of the base scenario to assess the effects that these designs have on the overall network. Innovative intersection designs for the intersection of 5600 W @ 3500 S are given in the Figure 5.8.

Overall intersection delays are the highest for 2040 PM peak period, as expected (Figure 5.9). Among the different intersection designs, innovative intersections perform better than the simple expansion of intersection capacity by adding extra lanes on all approaches. The best LOS and delay values result from the quadrant intersection design.

We used proposed intersection re-designs to measure travel times along the 5600 W corridor (Figure 5.10). While simple intersection widening improves travel times along the corridor when compared with the base case scenario, designs like Michigan U Turn or Bowtie intersection do not perform as well. Just as in the intersection analysis, best corridor travel times are achieved with quadrant intersection.

Network-wide analysis (Table 5.17) consistently shows lowest delays for quadrant intersection design, when compared with base case and other innovative designs, for the PM peak period. Results for the AM period show some inconsistencies and extremely high delay for this design in the year 2040. Quadrant intersections should, however, be considered as the future design for the intersection of two BRT lines in this network, since it is both pedestrian friendly and provides opportunity for land uses typical for town centers.

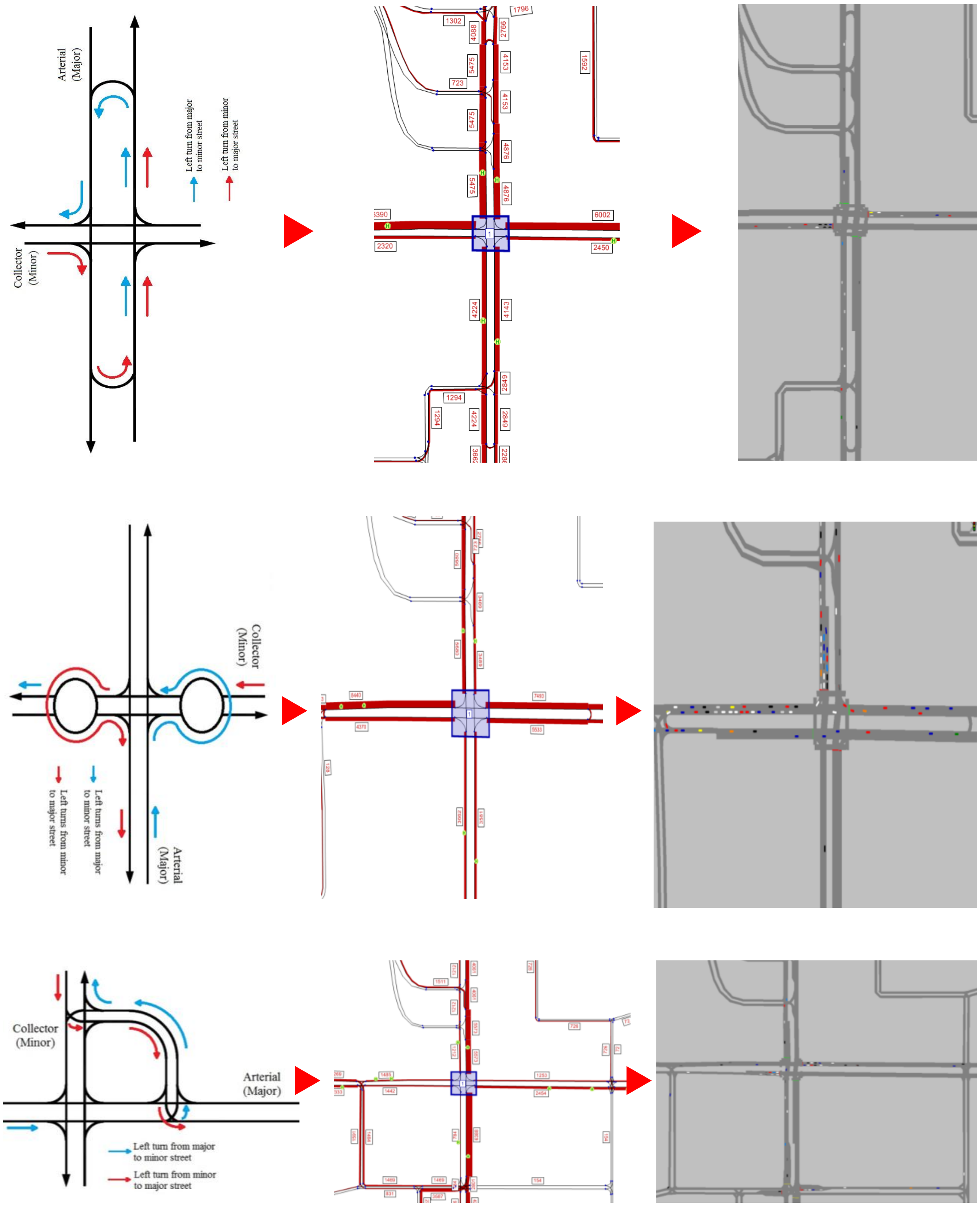


Figure 5.7 Innovative Intersections Design, Traffic Volume Assignment and Delay Analysis

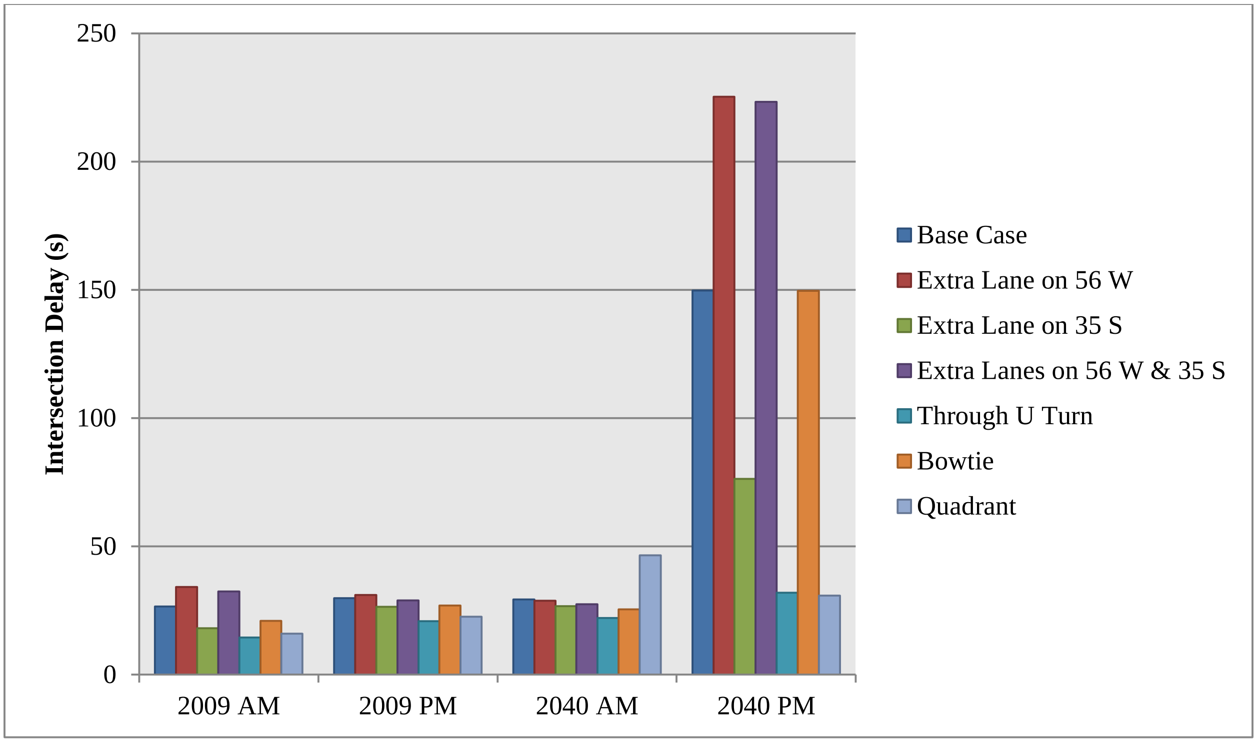


Figure 5.8 Intersection Delay Analysis for Different Intersection Designs

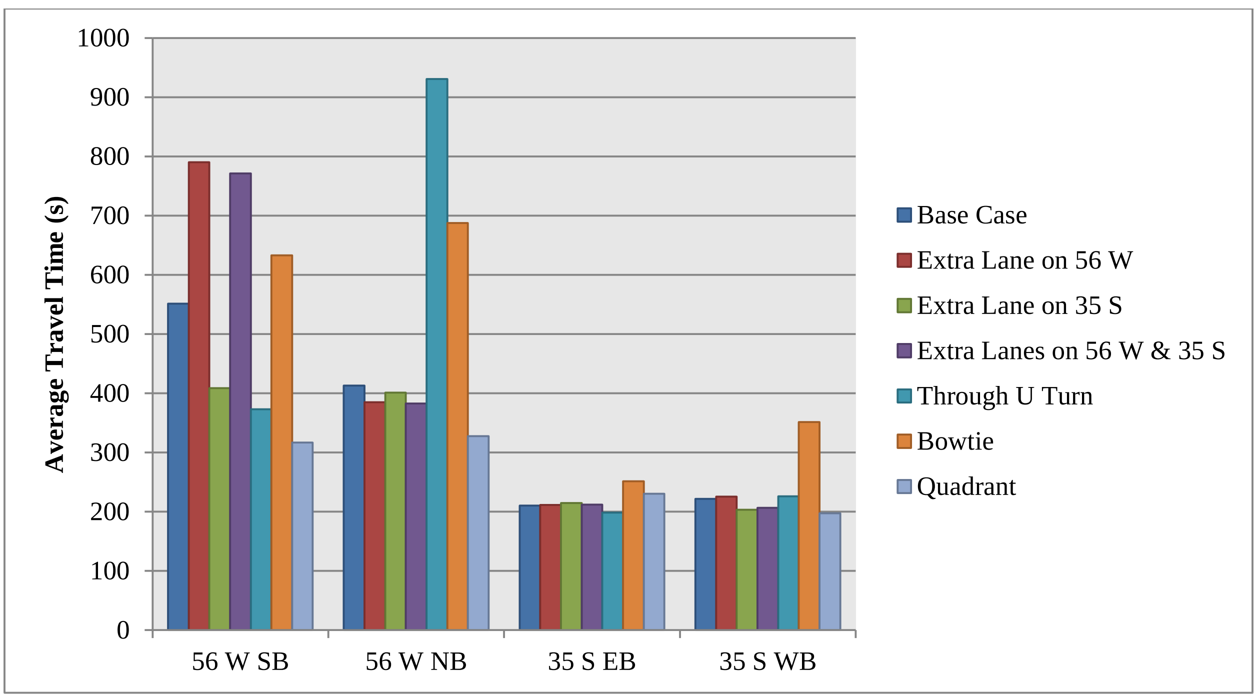


Figure 5.9 Average Corridor Travel Time for Different Intersection Designs

Table 5.14 Network-Wide Performance: Base Case vs. Innovative Intersections

	2009 AM			
Parameter	Base	Bowtie	MUT	Quadrant
Total number of vehicles	24050	24137	23665	23392
Average delay time per vehicle (s)	51	53	65	52
Average number of stops per vehicles	1.2	1.2	1.2	1.2
Total delay time (h)	339.6	354.4	426.5	339.8
Average speed (mph)	26.1	25.9	24.7	25.8
Total travel time (h)	1569.8	1608.6	1653.2	1545.3
Total distance traveled (mi)	41037.6	41659.2	40913.4	39912.5
	2009 PM			
Parameter	Base	Bowtie	MUT	Quadrant
Total number of vehicles	33558	33797	32512	32389
Average delay time per vehicle (s)	45	61	48	43
Average number of stops per vehicles	1.1	1.3	1.1	1.0
Total delay time (h)	417.5	572.4	437.7	389.8
Average speed (mph)	26.4	39.6	25.9	26.3
Total travel time (h)	2156.8	2341.2	2119.6	2074.8
Total distance traveled (mi)	57000.9	92598.5	54967.2	54572.1
	2040 AM			
Parameter	Base	Bowtie	MUT	Quadrant
Total number of vehicles	27868	28497	28016	24657
Average delay time per vehicle (s)	67	77	135	670
Average number of stops per vehicles	1.3	1.6	1.6	8.5
Total delay time (h)	522.1	606.9	1050.5	4588.8
Average speed (mph)	23.9	37.2	19.0	8.1
Total travel time (h)	2035.1	2167.1	2565.7	6047.3
Total distance traveled (mi)	48701.4	80643.8	48691.6	49131.4
	2040 PM			
Parameter	Base	Bowtie	MUT	Quadrant
Total number of vehicles	39069	37951	37523	37115
Average delay time per vehicle (s)	201	293	207	196
Average number of stops per vehicles	3.8	6.6	4.2	4.7
Total delay time (h)	2185.9	3086.6	2159.5	2024.6
Average speed (mph)	16.4	21.3	16.2	16.5
Total travel time (h)	4320.7	5162.5	4223.8	4063.8
Total distance traveled (mi)	70769.3	109985.9	68284.2	67032.5

5.5 Overall Performance Comparison

Tables 5.12 and 5.13 show the comparison of intersection and corridor level performances between the base case scenario, innovative intersections, and connectivity scenarios for the critical 2040 PM peak period. Although quadrant and Michigan U-Turn intersection designs are the only alternatives that result in the acceptable LOS C, combining these intersection designs with network alterations in terms of connectivity is still recommended in order to accommodate alternative transportation modes on future TOD sites.

Table 5.15 5600 W @ 3500 S Intersections Performance Comparison for 2040 PM

2040 PM 5600 W @ 3500 S Intersection Performance					
Scenario	Vehicles	Delay (s)	Stops	Avg Queue (ft)	LOS
Base	11,872	150	2.7	654	F
Bowtie	13,295	154	3.1	212	F
MUT	11,899	32	0.7	113	C
Quadrant	9,698	31	0.6	90	C
1a	12,630	76	1.5	468	E
1b	11,554	135	2.1	652	F
2a	11,379	225	4.3	634	F
2b	12,326	197	3.0	778	F
3a	11,406	223	4.2	594	F
3b	12,547	235	3.5	827	F
4a	11,517	206	4.0	590	F
4b	12,503	221	3.3	810	F
5a	11,423	227	4.3	589	F
5b	12,448	229	3.4	812	F

Table 5.16 Arterial Travel Times Comparison for 2040 PM

	2040 PM Arterial Travel Times (s) Comparison													
Section	Base	Bowtie	MUT	Quadrant	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b
5600 W SB	551	637	373	375	409	534	790	608	771	582	715	564	827	608
5600 W NB	413	734	931	637	401	823	385	903	382	692	373	614	377	598
5200 W SB	109	107	107	109	109	96	109	98	109	97	110	98	109	98
5200 W NB	99	94	92	92	99	152	100	207	99	247	100	202	99	112
4800 W SB	394	389	403	392	401	411	402	439	399	403	392	394	361	393
4800 W NB	517	786	501	751	524	536	520	586	528	513	478	539	478	528
3500 S EB	210	260	198	204	215	210	211	209	212	215	213	209	210	208
3500 S WB	222	405	226	209	204	218	225	234	207	228	208	215	204	231
4100 S EB	251	241	253	249	253	242	252	254	253	261	252	262	247	262
4100 S WB	268	329	315	264	271	520	269	594	266	516	269	499	262	531
4700 S EB	343	325	334	333	345	319	335	324	334	313	313	323	314	319
4700 S WB	700	854	598	857	715	586	758	771	756	643	916	628	796	657
Total Arterial TT (s)	4,080	5,162	4,330	4,472	3,943	4,645	4,356	5,228	4,318	4,710	4,338	4,548	4,284	4,545

6. STREET CONNECTIVITY AND TRANSIT ACCESSIBILITY

Implementation of previously described measures would increase transit LOS in terms of both frequency and coverage through proposed transit service improvements and street network modifications. This chapter presents frameworks for measuring street connectivity and transit accessibility, rather than using traditional mobility oriented transportation performance measures. Similar frameworks can be utilized as indicators of quality of service for alternative transportation modes, complementary to previously introduced performance measures for vehicular traffic.

6.1 Measuring Street Connectivity

Increasing street connectivity is one of the approaches used to enable streets to accommodate not only cars, but also transit, walking, and biking. Well-connected streets decrease traffic congestion and have a positive impact on people's health because they provide for walking and biking and encourage physical activity. In order to encourage alternative modes of transport, network needs to be denser, with frequent intersections, short walking distances, route choice options, and good access management. In short, streets need to be better connected.

How do we assess if a street network is well connected or not? Urban planners and street designers have developed a set of street connectivity measures over the years. The list of measures is given in Table 1 in the Appendix, with the definition of each measure and standards that street networks need to meet in order be well connected.

The goal of this analysis is to use GIS to measure street connectivity in part of the West Valley City street network in order to assess the potentials for future increase of network density, as an alternative to the traditional street widening approach used to increase the network capacity. The test network is given in Figure 1.1.

The first step toward achieving the defined project goal was to perform a literature review of authors who previously used GIS for similar purposes. Then we selected three connectivity measures that we used to evaluate test network connectivity for the purpose of this project:

1) Average census block area
2) Road length per unit area
3) Intersection density

The next step was to download the map of the test network and use GIS to create shapefiles for the basic network elements such as links, nodes, and centroids. Then we used the available tools in ArcMap 10 to calculate the selected street connectivity measures. The ultimate outcome of this project is the assessment of street connectivity on the test network.

Previous Experiences with Using GIS to Measure Street Connectivity

By utilizing GIS, Yi et al. (*52*) measured and compared the levels of street connectivity and pedestrian accessibility of cul-de-sac and grid-like street neighborhoods. This paper was motivated by the debate between New Urbanists, the proponents for the grid street pattern, and developers who want to continue designing cul-de-sac streets in practice. The study then took advantage of GIS tools provided in TransCAD GIS to measure street connectivity and pedestrian accessibility. GIS capability was essential for conducting analyses. To measure street connectivity and pedestrian accessibility, the chosen plans were first digitized using GIS software. Then centroids were assigned to all residential lots. The authors then measured aerial and network distances from centroids to each local destination in the neighborhood. For each particular destination, the average values for areal and network distances were obtained to represent pedestrian accessibility. The authors also used buffer areas of ¼ mile around each important destination to calculate other connectivity measures. The analysis indicated that when a cul-de-sac neighborhood was designed in a way to increase pedestrian accessibility and street interconnectedness with separate pedestrian trails, connectivity and accessibility measures were higher than the typical suburban neighborhood.

Tressider et al. (*15*) examined the different methods used in measuring connectivity, and to evaluate the effectiveness and limitations of those methods by drawing on examples from running connectivity measurements on differently sized study areas. A GIS was the methodology used in creating and evaluating the data. The study includes an examination of the various steps taken to clean and process the data, as well as the various tools used that are available in GIS, and the assumptions and tradeoffs through that process. Once the local street network was defined, the data were processed using the Polyline Tools to clean the shapefile. Using this new shapefile, the Polyline Nodes Extractor (without vertices) in Point & Polyline Tools was utilized to create the nodes (intersection) shapefile. For the connectivity measurements, only the real and dangle nodes are necessary, the vertices show points along the link, but do not correspond to an intersection. Two clean shapefiles, local street and nodes, were created this way. Then each link and node was assigned to appropriate parts of the network in order to calculate street connectivity measures.

A manual by Forsyth (*53*) provides protocols for measuring environmental variables associated with walking. The manual has four purposes. The first is to record the methods for environmental measurement used in the Twin Cities Walking Study. The second purpose of the manual is to provide methods for replication in future studies. The third is to provide a preliminary prototype for other manuals produced by different teams. Finally, the manual aims to make GIS research methods and data sources less opaque, particularly to first-time users.

The manual responds to a general problem in the literature on measuring environmental features thought to be associated with physical activity. Among other features, the manual contains protocols for using GIS to measure street connectivity. The protocols describe how to use ARC MAP to measure average census block areas, number of access points, road length per unit area, intersections per unit area, connected-node ratio, and link-node ratio. Basic concepts and formulas with explanations and potential difficulties a user might face are also included in the manual.

Discussion of Measuring Procedure

Our street connectivity analysis began with the choice of the test network given in Figure 2 in the Appendix. This network is the potential Transit Oriented Development (TOD) site, and dense street network is one of the characteristics of the TOD. The measures of street connectivity presented in this report will also evaluate the current possibilities of the test network to accommodate for TOD features.

In order to start the evaluation of each of the three selected connectivity measures, we needed to download the map of our test network and determine the coordinate system. Using “Database Connection” in the ArcMap 10 catalog, we connected to “gdb93.agrc.utah.gov.sde.” We downloaded the “SGID93. TRANSPORTATION. Roads” polyline shapefile. This shapefile includes all roads in the state, and we only needed a part of the West Valley City network. We selected our test network and used the selected features to create the Roads_Map layer. The downloaded shapefile was projected in “NAD 1983 UTM Zone 12N” coordinate system, which will be the reference for all the new shapefiles we created. What follows is the methodology for the calculation of three selected connectivity measures in ArcMap 10.

Average Census Block Area

Our test network has six transportation analysis zones (TAZ), and for each zone we calculated the average block size. We used the data from the West Valley City census block maps to establish census block areas in each TAZ. We then used the JPEG file as the background image for our test network to make sure we were digitizing the census blocks in the right way. In order to use the JPEG file of our test network, we needed to assign the coordinates to this background image. We used a Georeferencing tool for this, and attached the points from the JPEG to the corresponding points on the Roads_Map shapefile (Map 1).

First we created TAZ and census block layer. To create the centroid layer we downloaded XTools extension from ESRI website. XTools does not limit the location of the centroids to the boundaries of a particular shape. We used the XTools option from the dropdown menu, "Convert Features/Shapes to Centroids," converted Census_Block layer, and exported a new layer that we named Centroid (Map 1). We then added TAZ and census blocks to our roads map and selected the centroids that fall inside TAZ we defined. We did this by using Selection/Selection by Location from the dropdown menu. Then we selected (Selection/Selection by Location) only census blocks that contain the centroids. Once only census blocks that contain the centroids were selected, we exported these census blocks as new layers (right click on the census block layer, Data/Export Data). This new layer is Centroid_Blocks layer on Map 1.

To calculate the area of census blocks that contain the centroids, we used "XTools/Table Operations/Calculate Area…" option. We selected our block areas to be measured in acres, and after XTools calculates the area in this way, new fields are added to the attribute table of Centroid_Blocks. To calculate the average census block size, we used spatial join to join census blocks from each TAZ to the corresponding Centroid_Block. After joining the data, in the attribute table we used option Summarize/Acres/Average to calculate the average census block size for each TAZ.

The average block size could have been calculated by simply using the field calculator from the attribute table. However, we wanted to test XTools extension and see how it creates the layers and what calculation options it offers. Map 1 presents the final results of our calculations for the census block area, and the results are also presented in Figure 1, using Graph options from the attribute table. Metadata for Map 1 are in Appendix D.

Road Length per Unit Area

Road length per unit area presents the length of road with both interstates and ramps removed, and divided roads averaged, per measurement area, with water removed from the land area calculation. Our test network does not include interstates, ramps, divided roads, or major water lands, which made the calculations simpler.

We added two layers: roads polyline and site polygon layer. To calculate the length of roads per unit area, we needed to calculate the area of the observed site and the total length of roads on that site. Since we only needed to include the roads on the observed site, we intersected the two layers using ArcToolbox Window/ Analysis Tool/ Overlay/ Intersect. This is how we exported the new layer Roads_Intersect from Map 2.

To calculate the length of intersected roads from the new layer, we used XTools/Table Operations/ Calculate Area, Length, Acres, and Hectares option. This operation adds the "Length" field to the Intersect_Roads attribute table. We can then use "Summarize" option from the attribute table to calculate the total length of all roads. In a similar way, only by using "Calculate Area" instead of "Calculate Length" from the XTools/Table Operations, we can calculate total land area. Finally, we can calculate the connectivity measure by dividing the total length of roads by the site area. The results are presented on Map 2, while metadata are in Appendix D.

Intersection Density

We used the number of intersections per acre as the measure of intersection density for our test network. We measured intersection density in each TAZ. We first added the roads polyline layer, TAZ polygon layer, and intersections point layer. Then we clipped the intersections to corresponding TAZs by using ArcToolbox Window/Analysis Tools/ Extract/ Clip. This way we created the new clipped layer. We then used this new layer to merge the intersections that are less than 100 meters apart and might work as a single intersection. We used ArcToolbox Window/Analysis Tools/ Proximity/ Buffer option. XTools extension has the option of converting "Shapes to Centroids," which can be used to merge the intersections from the new buffered layer.

To count the number of intersections in each TAZ, we used spatial join to assign the IDs from the TAZ to each intersection. Then we used "Summarize" option from the attribute table of the new joined layer to summarize the intersection count in each zone. The output was a .dbf table that contains the intersection counts for each TAZ.

We calculated the land area for each TAZ in the same way as we did for the previous connectivity measures. Finally, we divided the intersection counts for each TAZ by the corresponding TAZ area, and got the number of intersections per acre as a measure of intersection density. The results are presented on Map 3, while metadata are in the Appendix.

Results of Connectivity Measurements

The results presented in this section are related to three connectivity measures we calculated using the GIS tools. Figure 6.1 presents the average census block area for each TAZ of the test network. The other results are included in Table 6.1 and Maps 1, 2, and 3 (Appendix D). The results are presented in the same order as the methodology of obtaining the connectivity measures as discussed in the previous section.

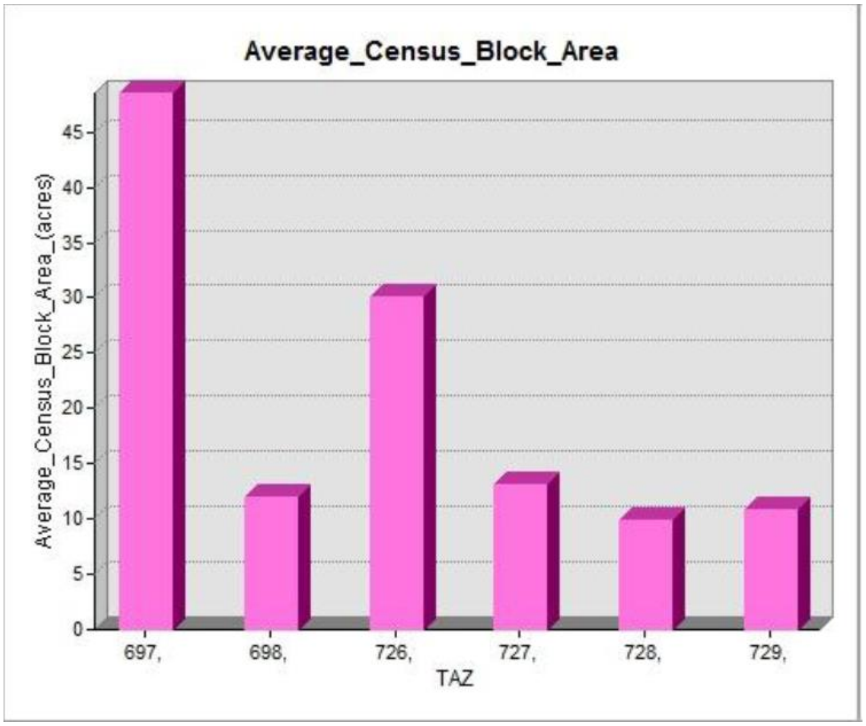


Figure 6.1 Census Block Area (GIS Output)

Table 6.1 GIS Output for Street Connectivity Measurements

TAZ ID	Average TAZ Area (Acres)	Intersections per Acre	Road Length = *40.70 miles* Site Area = *2.05 miles squared* Road Length per Unit Area = *20.30 miles of road per miles squared*
697	48.51	4	
698	11.91	3	
726	30.01	3	
727	13.14	4	
728	9.93	3	
729	10.86	4	

Summary on Street Connectivity Measurements

After using GIS to calculate three selected connectivity measures, we can make some conclusions about the test network connectivity using the standards from the literature given in Table 1 in the Appendix. In terms of average block size, each TAZ exceeds the block size recommended in the literature, so the area cannot be characterized as walkable.

The maximum recommended length of roads per unit area is 26 miles per mile squared, while the preferred road density is 18 miles of road per mile squared of land area. We measured 20 miles of roads per mile squared, which indicates that the road density criterion is met on our test network. However, this does not mean that the network is well connected, only that the significant portion of the network is "paved."

The intersection density criteria from the literature are also met. But the street network average block size indicates that some portions of the test network are dense, while others are disconnected and with many cul-de-sacs. Other connectivity measures should be calculated to make the final decision about the potential improvements of the network design.

6.2 Measuring Transit Accessibility

Transit accessibility shows how easy it is for an individual to travel to a desired destination using public transit. For the existing transit riders, it is the indicator of the service quality; for the potential riders, it might be a factor in their mode choice. And while current policy makers still use transport system metrics that are mobility oriented, partially because they are the most available out there, these performance metrics are excluding some crucial components of urban transportation systems. This part of the study uses spatial and temporal constraints, and a set of transit features that impact access to transit, to develop a conceptual framework for transit accessibility measurements for the case study network.

The proposed methodology builds upon the traffic and transit data from the case study network, and uses an open source tool to perform transit accessibility measurements by calculating the number of accessible transit stops from each transportation analysis zone (TAZ) centroid as a defined origin. The methodology considers acceptable walking time, available time budget, transit user information, transit schedule variability, and spatial constraints as impact factors in accessibility measurements. The goal is to establish a feasible set of transit accessibility indicators that would be used for both the case study street network and transit service modifications into a transit friendly and eventually a TOD environment.

Previous Research

Accessibility is determined by activity patterns and transportation systems in the area. Important factors affecting accessibility are mobility, transport options, land use, and affordability. While there is an agreement among researchers on how to define accessibility, finding an appropriate way to measure it remains a challenge (*54, 55*). Several types of accessibility measures are developed in the existing research.

Cumulative or opportunity measures evaluate accessibility in terms of the number or proportion of opportunities that can be reached within specified travel distances or times from a reference location (*56*). Gravity-based measures weight the activity locations by time, cost, or distance needed to reach them. The differences between various studies of accessibility that utilize this method are mainly in functional forms that measure the cost to move between origin and destination and how opportunities are calculated (*57, 58, 59, 60*). Utility-based measures reflect the utility of all choices and calculate final choice utility relative to the utility of all other choices. Accessibility is defined as the expected value of the individual's maximum utility among the activity schedules available, given a residential location (*61*). The composite accessibility measure introduces a higher level of complexity where time constraints are superimposed and require more data than utility-based measures; it is even more complex in terms of calculations and, accordingly, generalizing it for usage is not an easy task. (*62, 63, 64*).

Accessibility is best measured if those measures capture individuals' perceptions and true access to activity opportunities. This is because accessibility is an individual construct, and each individual sees how accessible transportation mode is different, depending on their value of time and level of destination attractiveness. No one best approach to measuring accessibility exists, and different situations and purposes demand different approaches (*59*).

Space-Time Accessibility Measures

The space-time prism (STP), given in Figure 6.2, and STP-based accessibility measures are powerful techniques for assessing the ability of individuals to travel and participate in activities at different locations and times in a given environment. With the space-time prism, accessibility can be assessed relative to spatial and temporal constraints on individual behavior. The space-time prism determines the feasible set of locations for travel and activity participation in a bounded expanse of space and a limited interval of time. A weakness of STP-based accessibility measures and accessibility measures in general, is their treatment of travel times as static. Empirical research has shown that temporal constraints can significantly impact the ability of individuals to participate in activities (*62*, *63*, *64*). Previous space-time accessibility measures accounted for the distance between two activities, origin and destination uncertainty, spatial distribution of urban opportunities, varying mobility due to transportation configuration and speeds over space, activity participation time, temporal availability of opportunities, various types of delay times (both static and dynamic), and the maximum travel time threshold (*65, 66*).

Transit Accessibility and Travel Choices

Trip makers would consider the public transit system as an option for trip making when the system is properly accessible to and from their trip origins/destinations (spatial coverage), and when service is available at times that one wants to travel (temporal coverage *67, 68*). The relative attractiveness of public transportation depends critically on its performance in terms of the accessibility it provides to link population to employment and activity opportunities. The primary factor affecting pedestrian access is distance. Pedestrian access to a transit stop depends on route directedness and speed, safety and security, pedestrian-friendly design, and way-finding information. Based on an assumed average walking speed of about 4 ft/s, 5 minutes of walking is considered reasonable in urban areas, which is about ¼ of a mile in terms of walking distance (*69*, *70, 71*). In general, access to transit stops affects passenger accessibility and represents the opportunity to use the public transport service. Considering spatial attributes, both the location and the spacing of bus stops significantly affect transit service performance and passenger satisfaction, as they influence travel time in addition to their role in ensuring reasonable accessibility (*72, 73*, *74*). Measuring the ease of access to transit services is important in evaluating existing services, predicting travel demands, allocating transportation investments, and making decisions on land use development (*68, 70*).

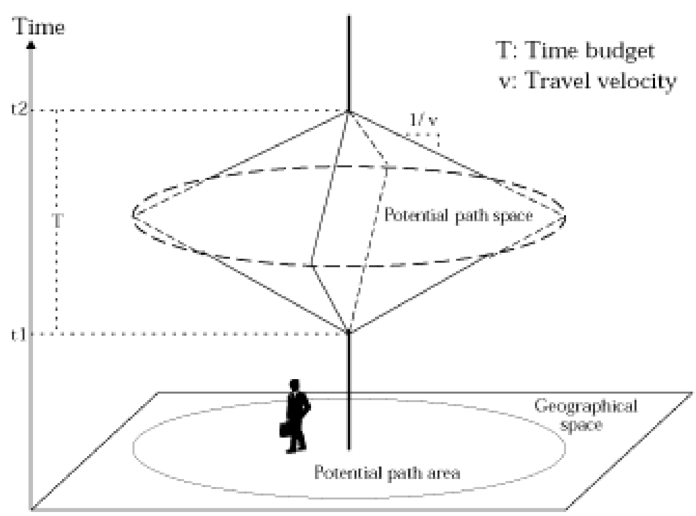


Figure 6.2 Space -Time Prism (*62*)

Proposed Methodology

The TOD by definition involves more accessibility for public transit passengers, due to denser street networks and mixed land use that provides more opportunities. This study develops a conceptual framework for quantifying transit accessibility based on spatio-temporal constraints. The network scenario is developed to reflect a transportation network and transit system on a future TOD location in West Valley City, Utah. Location is chosen based on Wasatch Choice for 2040 map of the potential TOD spots in the Salt Lake Region, and it represents a future town center with the intersection of two Bus Rapid Transit (BRT) lines. A case study network is given in Figure 6.3.

Transit data were provided by the Utah Transit Authority, and loaded into the network through Google Transit Feed (GTFS) (*75*). All GTFS files are in text format and loaded together with base network shapefiles. Particularly important for our accessibility measurements are stop time records, which include a sequence of stops along each trip. Each stop time record contains required data such as trip identification, arrival and departure time, stop identification, and stop sequence. Data prepared in this way were used for the accessibility measurements.

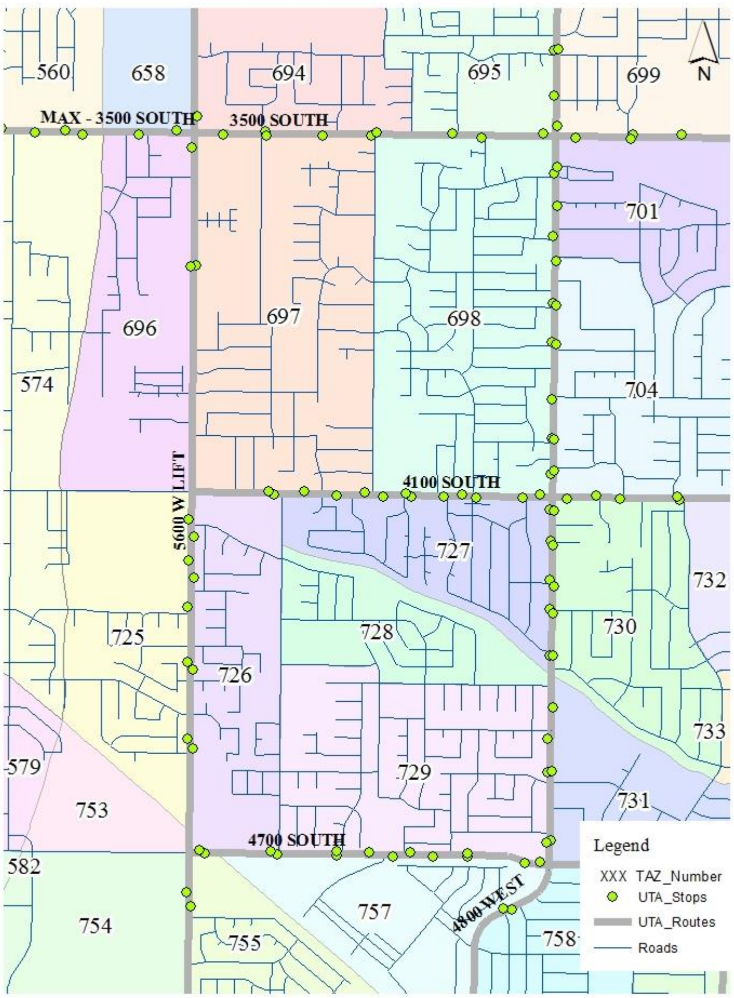


Figure 6.3 Network with Transit Lines and Stops

Accessibility measurements were based on network data shapefiles and transit data feed from Google. Both data sets prepared and adjusted in the way previously described, were loaded into NEXTA (Network Explorer for Traffic Analysis) software. NEXTA is an open-source GUI that aims to facilitate the preparation, post-processing, and analysis of transportation assignment, simulation, and scheduling datasets. One of the advantages of NEXTA is that it facilitates importing transportation network data from both micro and microsimulation environments. This means that it has the ability to integrate with our previously built traffic and transit models. Loading transit data from Google and additional features for accessibility calculations are the most recent specifications of the software.

Together with the case study network, a regional transportation and transit network is loaded to enable calculations to all available transit stops. Network TAZ centroids were defined as origins, while transit stops represent destinations. Accessibility can be calculated from each defined origin or from all origins, and accounts for time variability of transit schedules, which will be discussed later. Accessibility is expressed through a number of reachable destinations from each origin for variable space and time constraints.

For each defined set of constraints, a shortest path was calculated using the algorithm integrated into NEXTA. This algorithm first identifies accessible bus trips using the stop time records within the 15-minute waiting time from the departure time at the origin and within the acceptable walking distance from the origin activity location. Then it identifies stop time records reachable from the origin of each trip within the defined time budget constraints. The number of accessible stop times is counted along each trip as the indicator of accessibility. Average measures across all origin activity locations are also considered. The data input and loading process with the shortest path algorithm procedure are given in Figure 6.4.

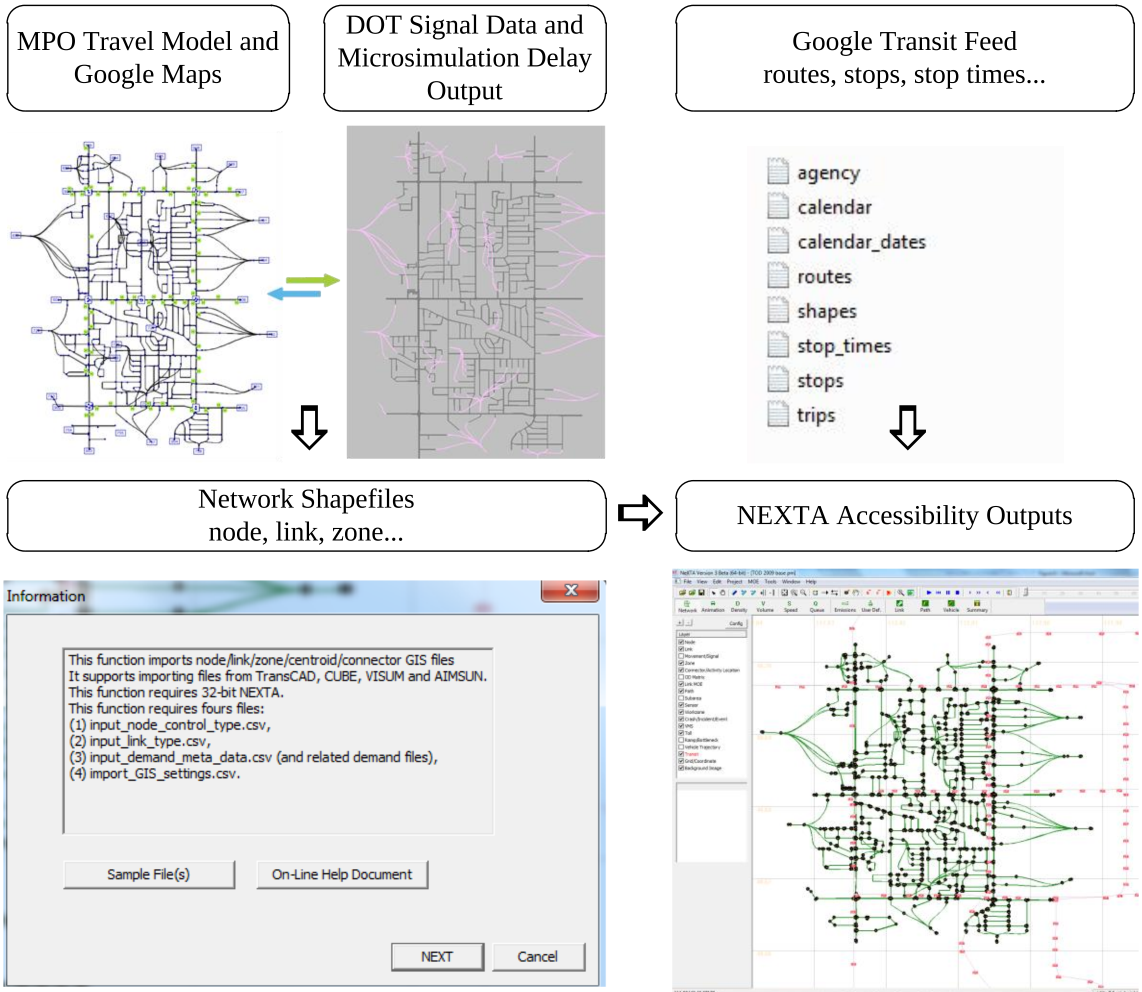


Figure 6.4 Traffic and Transit Data Input and Shortest Path Procedure

Impact Factors

For the network used as a case study, factors that impact space-time constraints are given in the conceptual framework in Figure 6.5. Service variability refers to the frequency of transit service and service span in general. Walking distance is the acceptable walking distance to transit stops. Available time budget defines the time that individuals have to access activity locations from the given trip origin. Transit speeds will differ between BRT lines and regular transit lines. User information refers to transit users' familiarity with the schedule. It is assumed that if users are familiar with the schedule, their waiting time is less than 5 minutes, and in cases where they are not familiar with the schedule, their arrivals are random. Spatial constraints refer to the destination or activity location type. Activity location can be the fixed or final, when the entire time budget is used to reach the destination, or flexible or intermediate.

Transit accessibility is expressed through the number of destinations reachable from the defined origin within the given space-time constraints, and it is calculated through the number of accessible stop times loaded from the transit feed data. In order to represent the time variability aspect of transit accessibility, we also introduce incremental change of accessibility measured with each change in control variables.

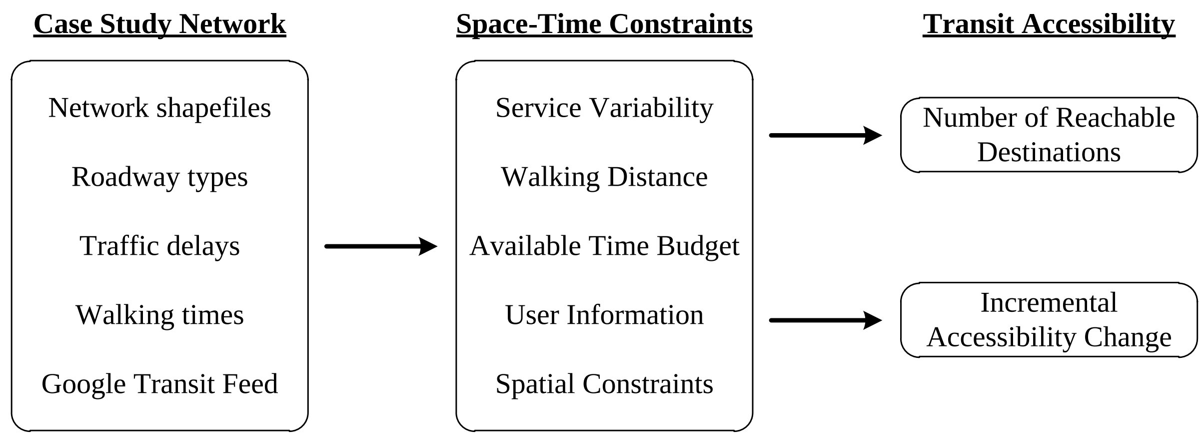


Figure 6.5 Transit Accessibility Measurements - Conceptual Framework

Concept for Accessibility Measurements/Performance Measures

This study uses a constraints-oriented approach based on Miller's interpretation of space-time prism application for transit accessibility calculations. Calculations and assumptions adapted from (*62*) for different space-time constraints applied to compute the number of accessible transit stops are as follows:

Accessibility Equation:

$$M = \{k \in N | T_k = t_{km} + t_t + \sum t_{walk} + t_{wait} + t_d \leq T\}$$

Definitions and Assumptions:

$M -$ *total number of accessible destinations k*

$N -$ *total number of destinations*

$T_k -$ *time needed to each destination k*

$T -$ *available time budget*

$t_{km} -$ *time needed for destination activities*

$t_t -$ *total time spent in transit, different for BRT and regular lines*

$t_{walk} -$ *total distance spent walking to or from the transit stop*

$t_{wait} -$ *total time spent waiting for transit, depending on familiarity with schedule*

$t_d -$ *other delays due to signals, crossing time, and transfers*

Service Variability:

$t_t = 15 \min$ *frequency vs regular lines*

Walking Distance:

$t_{walk} = 0.05; 0.10; 0.15; 0.20; 0.25$ *miles*

Available Time Budget:

$T = 30, 35, 40, 45, 50, 55, 60$ *min*

User Information:

$t_{wait} = 5 \min$ *or random (for unfamiliar users)*

Spatial Constraints:

Zonal Access Distribution

Results and Discussion

The impact of transit service variability on the accessibility of transit stops is given in Figure 6.6. Only results for one origin are presented to provide better visualization. Service schedule is presented dependent on time, while other variables are kept constant. Time variability is presented for the PM peak period and evening period. The assumed constant acceptable walking distance in this case is 0.25 miles, or equivalent to 5 minutes walking time. The results show emphasized peaks and drops in the number of accessible transit stops prior to 4 PM and after 6 PM. Transit service seems more constant during the peak period, which is expected considering that most of the transit lines in the case study network have higher frequency during the peak hour periods. This is a very good indicator of changes that transit schedules will need to undergo to support a transit friendlier environment. Again, a reminder from the literature, recommendations for TOD transit service frequencies are 15 minutes or less in areas similar to the one analyzed here (*21*). What the simplest analysis also indicates here is how specific transit is in terms of accessibility when compared with other modes, because it is more time dependent due to schedule variability impact.

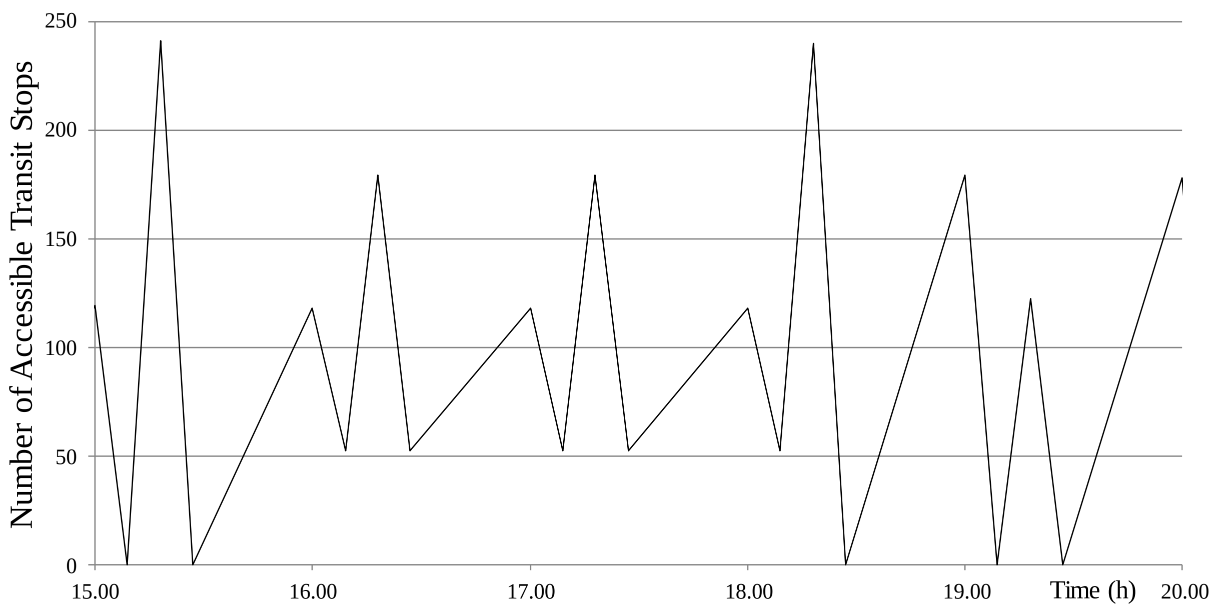


Figure 6.6 Transit Accessibility for Time Variable Service Schedule

Another impact factor analyzed here is the acceptable walking distance. Guidelines on the acceptable walking distance (*20*) recommend up to a quarter-mile distance acceptable from a pedestrian standpoint. While ranges from 0.05 miles to 0.25 miles of walking distance are analyzed, three representative values are given in the Figure 5, again for better visualization. All other variables are kept constant. As expected, the access to transit stops becomes better as the acceptable walking distance increases. With lower acceptable walking distances, there are more points when transit stops are not accessible at all. This is also not surprising, since the analyzed network has many disconnected links or cul-de-sacs, which decrease the number of potential paths to transit. As the network continues to be modified toward a more transit supportive pattern, it is likely that there will be more routing options for pedestrians. The TOD can reduce walking time at signalized intersections, too, and thus increase the potential time for walking within the available time budget, which is the following variable discussed.

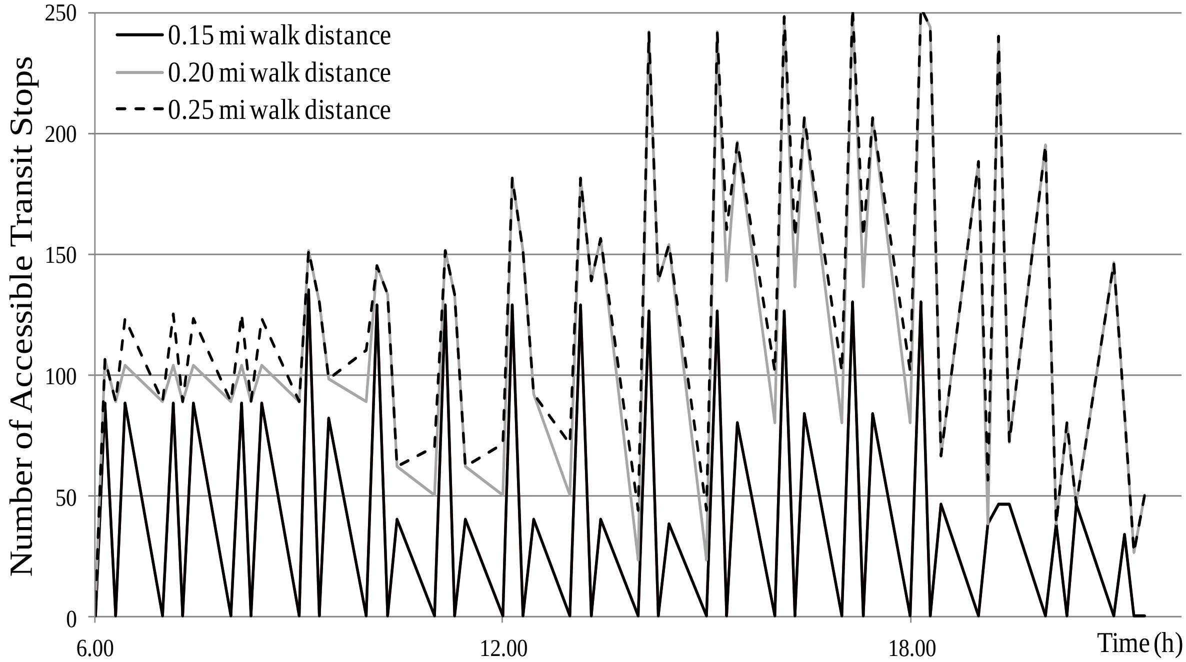


Figure 6.7 Transit Accessibility as a Function of the Acceptable Walking Distance

The impact of the available time budget on transit stops' accessibility within the analyzed network is presented in Figure 6. Three representative values for the available time budget are given to consider 30, 45, and 60 minutes available for an end-to-end transit trip. The results show that the highest number of accessible transit stops for the given time budgets occur between 9 AM and 6 PM. This includes some drops in the number of accessible stops during the midday period. The accessibility values range between 200 and 400 stops on the regional network available during this time period. Figure 6 also shows the service time span, and again the effects of time variable transit schedules. It is noticeable that early morning and late evening time periods have less frequent transit service, and that the service is limited between 6 AM and 22 PM. Figure 6 also indicates how transit accessibility would change depending on the available user information. With the quality information available for transit users, they would spend less time waiting and would have more time to spend in transit within their available time budgets. Considering the future development plans of the case study and the regional network, this is something that should be considered as a factor for improving access to transit.

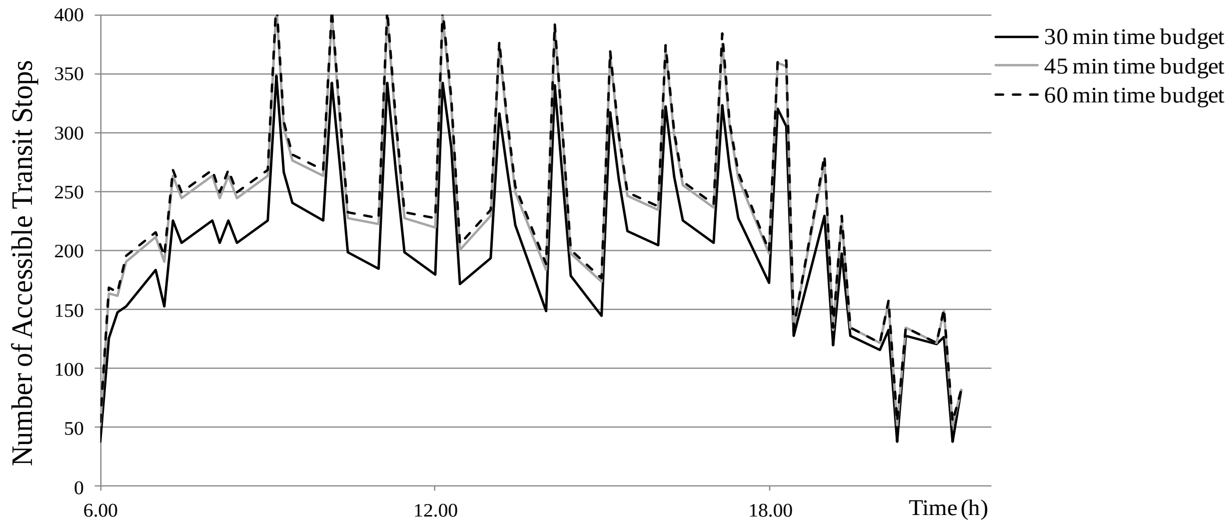


Figure 6.8 Transit Accessibility as a Function of the Available Time Budget

Summary on Transit Accessibility

Measuring accessibility to transit is more challenging when compared with other modes of transportation. The reason is the number of impact factors that affect the ability of users to access transit, starting from transit schedules and available user information, to acceptable walking distances and available time budget for transit trips.

This study presents an alternative approach for measuring transit performance through the accessibility of transit stops, considering both spatial and temporal constraints. Transit accessibility measures and impact factors presented here can easily be related to the available transit performance measures such as LOS. However, they indicate in a more apparent manner how reachable activity locations are from different origins in different times, which is what users can relate to.

The results show how access to transit varies both temporally and spatially. Specific to transit mode, service schedule variability significantly affects the changes in accessibility to transit over the course of a day. Adopted pedestrian criteria for the acceptable walking distances show their impact and the need to improve the existing network connectivity for future development. Considering quality transit service information for the users is recommended as one of the methods for accessibility improvements. The end-to-end transit trips should be shorter in the analyzed area, up to 45 minutes, because as the available time budget increases the number of accessible transit stops remains the same.

7. CONCLUSIONS AND RECOMMENDATIONS

This project examines the effects of different strategies related to street network patterns, intersection designs, and transit service improvements on traffic operations of a future TOD network in West Valley City, Utah. Evaluation methodology addresses mobility performance measures, street connectivity, and transit accessibility. Traditional mobility oriented performance measures were used with regards to the project goal, to provide the evaluation of the effects that TOD supportive solutions have on the vehicular traffic. This is due to the fact that TOD related projects are often faced with assumptions that transit supportive network designs and solutions will decrease the efficiency of vehicular traffic. In addition, connectivity and accessibility measures are applied to the case study network as potential indicators that could be used to evaluate how accessible and walkable transit environment is while it evolves into a TOD.

To evaluate the effects of network designs that have the potential to support TOD, developed scenarios included enhanced street connectivity, innovative intersection designs, and traffic calming measures. These scenarios were modeled for traffic conditions for 2009 and 2040 PM peak periods. After the implementation of the design principles, selected based on the reviewed literature and discussions with stakeholders involved in TOD projects in the region, it was assumed that mode shift did not occur. This assumption was made in order to account for the period of "transition," where street network is changing to encourage transit ridership and alternative modes of transportation, but the mode shift did not occur yet. This could be considered "the worst case scenario" from the travel demand perspective, and represents what scenario engineers would be the most concerned with as they resolve potential conflicts that arise with the attempts to accommodate multimodal transportation in TOD environments.

The analysis of our base case scenarios shows that PM peak period will be more critical in 2040, especially for 5600 W & 3500 S and 4800 W & 4700 S intersections. Both average per vehicle and total delay on the network-wide level increase by more than 50% in AM and 100% in PM peak period, when we compare 2009 and 2040, which means that, as expected, a "no build" solution is not an option. Comparison of travel times and speeds on different segments for 2009 and 2040 shows significant increase in travel time for only one of 12 segments we compared on our test network, meaning that new network designs for 2040 need to focus on intersection operations. Increased street connectivity without improving intersection operations will not accommodate traffic demand for 2040 PM peak period, under the assumption that mode shift does not occur. Comparing street connectivity scenarios for different network segments between main intersections, street widening, and enhanced connectivity show similar results, implying that enhanced connectivity could be a good alternative approach for the corridors.

Network designs with higher levels of street connectivity show better performance on the corridor level than designs with street widening. Increased connectivity, as an alternative to street widening, increases total distance traveled, but the delay values on the network-wide level show that designing the network with multiple connections, rather than simply widening the arterials, would be a good alternative. Adding traffic calming measures to the network design with increased connectivity increases total network delay.

The innovative intersections scenarios analysis shows that Quadrant and Michigan U-Turn intersections perform better than conventional intersections in all four observed time periods. Quadrant intersections not only decrease average and total delay, but also decrease total distance traveled, when compared with other observed intersection designs for 5600 W & 3500 S. So a Quadrant intersection has the potential to decrease VMT and, with the design that supports street connectivity, can improve the TOD potential of our test network. Quadrant intersection and Michigan U-Turn show better performance than the intersection with one added lane on every approach for 2040 PM peak period. In terms of travel time, intersection design with one extra lane on 5600 W performs better than other street widening scenarios and innovative designs.

All these conclusions should be observed with the assumption that enhanced network designs do not cause mode shift and thus decrease the number of private automobile users for 2040. This report also includes conceptual frameworks for measuring street connectivity and transit accessibility, which could serve as indicators of transit quality of service and both spatial and temporal coverage once proposed transit service changes are implemented as a part of the future TOD site.

Future Research Steps

The principal goal of this project was to examine the effects of planned TOD-supportive transportation solutions on vehicular traffic under the highest forecasted travel demand conditions. These solutions included a variety of design principles that were evaluated in terms of generally acknowledged mobility measures. The future research should include evaluation of the effects of combined network design strategies modeled in this study: enhanced street connectivity, innovative intersection designs, traffic calming measures, and TFDs. Future research could also account for a variety of travel demand scenarios, as more reliable data needed to build these scenarios become available.

The major limitation of this study is the applicability of proposed methods and recommendations to other potential TOD sites. While transferability of methods appears feasible, different types of TOD environments operate in different manners, from those in central business districts to developments in suburbia. Recommendations provided in this report could be applicable to potential TOD town center development types, but the analysis of multiple suburban networks from different locations is desired to advance the research presented here. The major contribution of this study are the indications that TOD-supportive network designs are not necessarily associated with negative effects for vehicular traffic, even in conditions where mode shift does not occur and travel demand in terms of auto-mode remains the same. This is a significant finding that could be useful for metropolitan regions looking to retrofit the suburban neighborhoods into multimodal developments.

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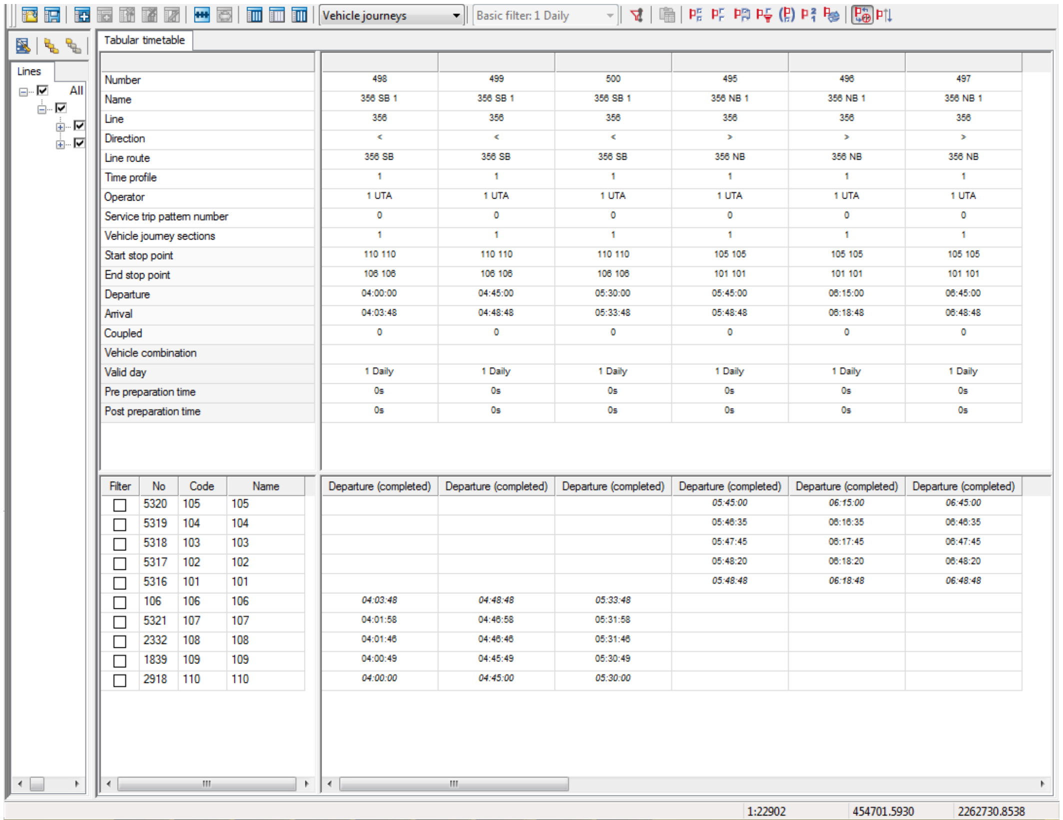
APPENDIX A: TRANSIT SCHEDULES AND TIMETABLES



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Post preparation time	0s	0s	0s	0s	0s	0s

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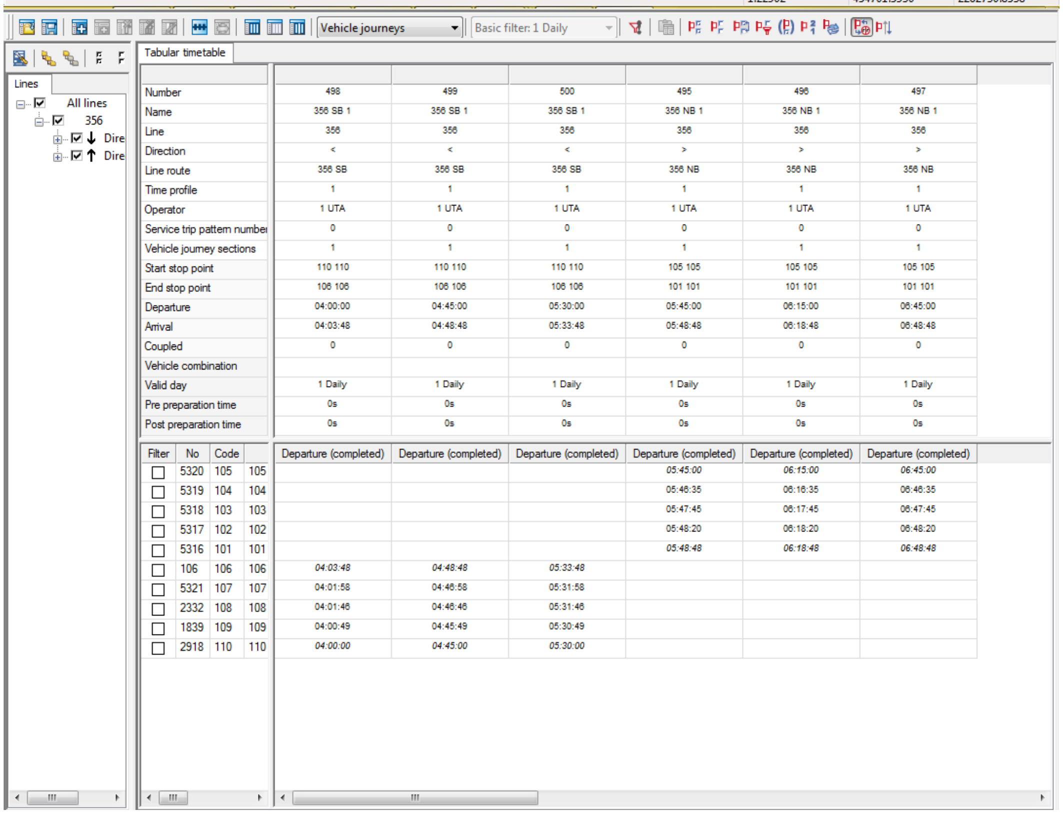

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Time profile	1	1	1	1	1	1
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA
Service trip pattern number	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1
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End stop point	106 106	106 106	106 106	101 101	101 101	101 101
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Arrival	04:03:48	04:48:48	05:33:48	05:48:48	06:18:48	06:48:48
Coupled	0	0	0	0	0	0
Vehicle combination						
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s
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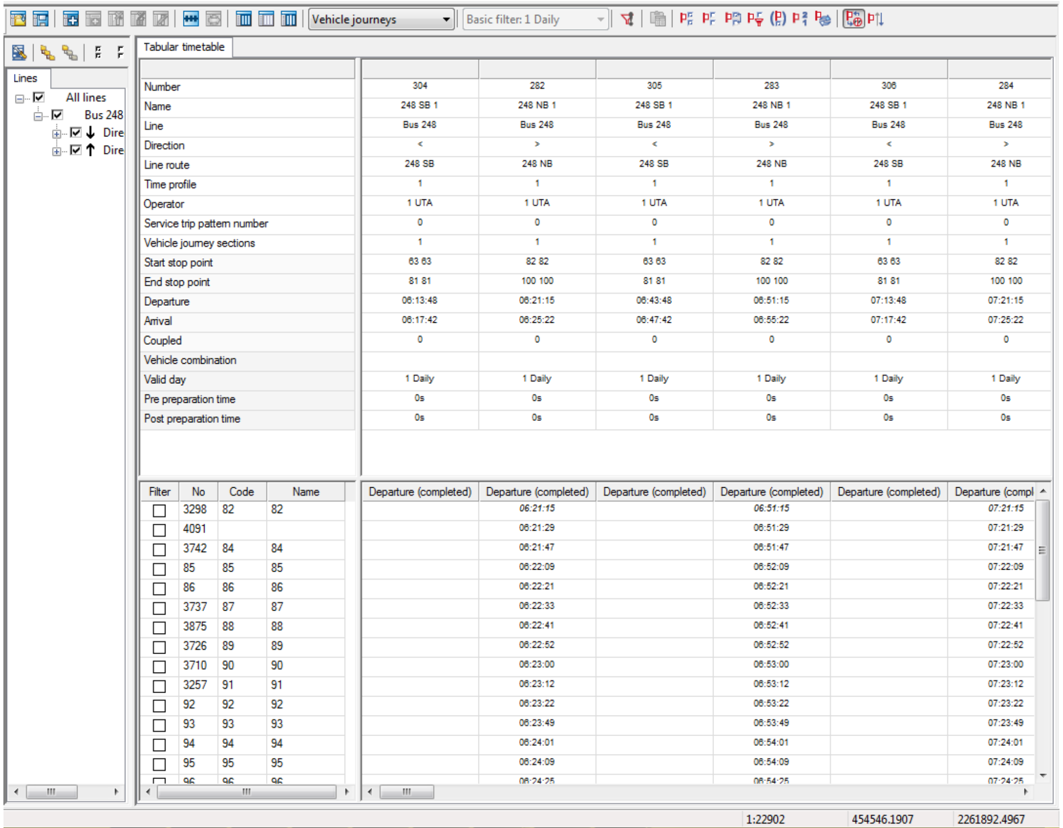

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End stop point	81 81	100 100	81 81	100 100	81 81	100 100
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Vehicle combination						
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Pre preparation time	0s	0s	0s	0s	0s	0s
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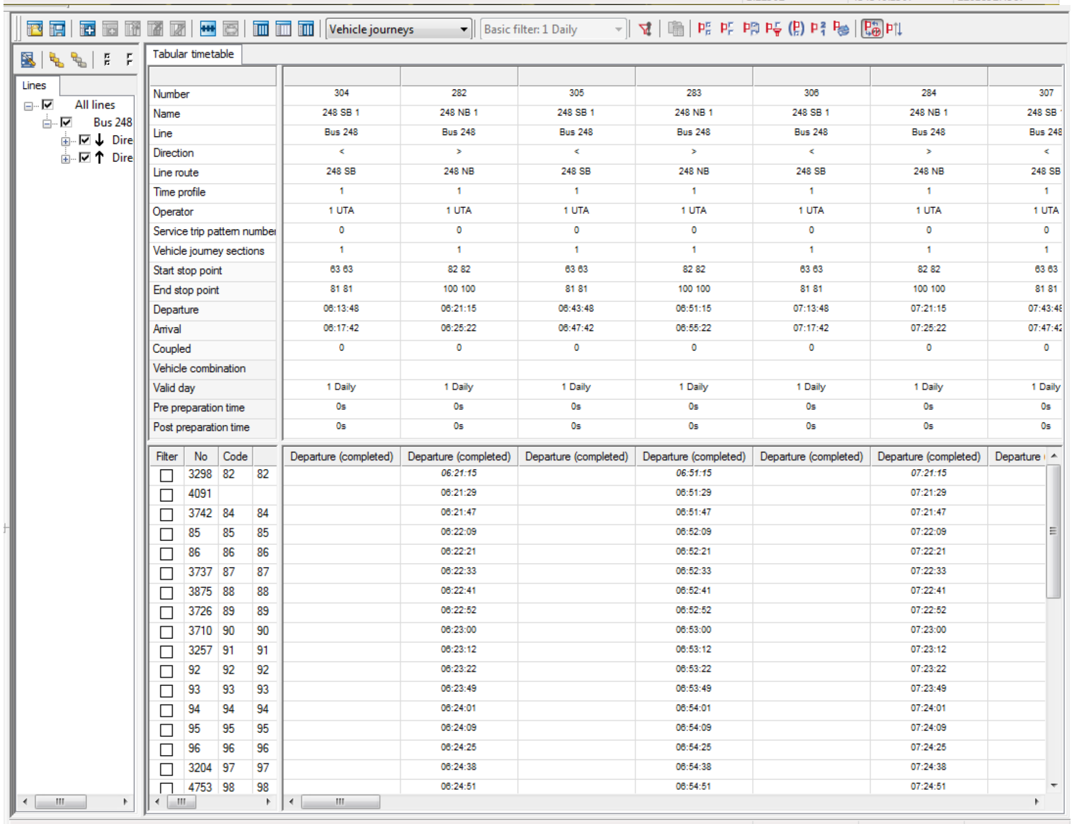

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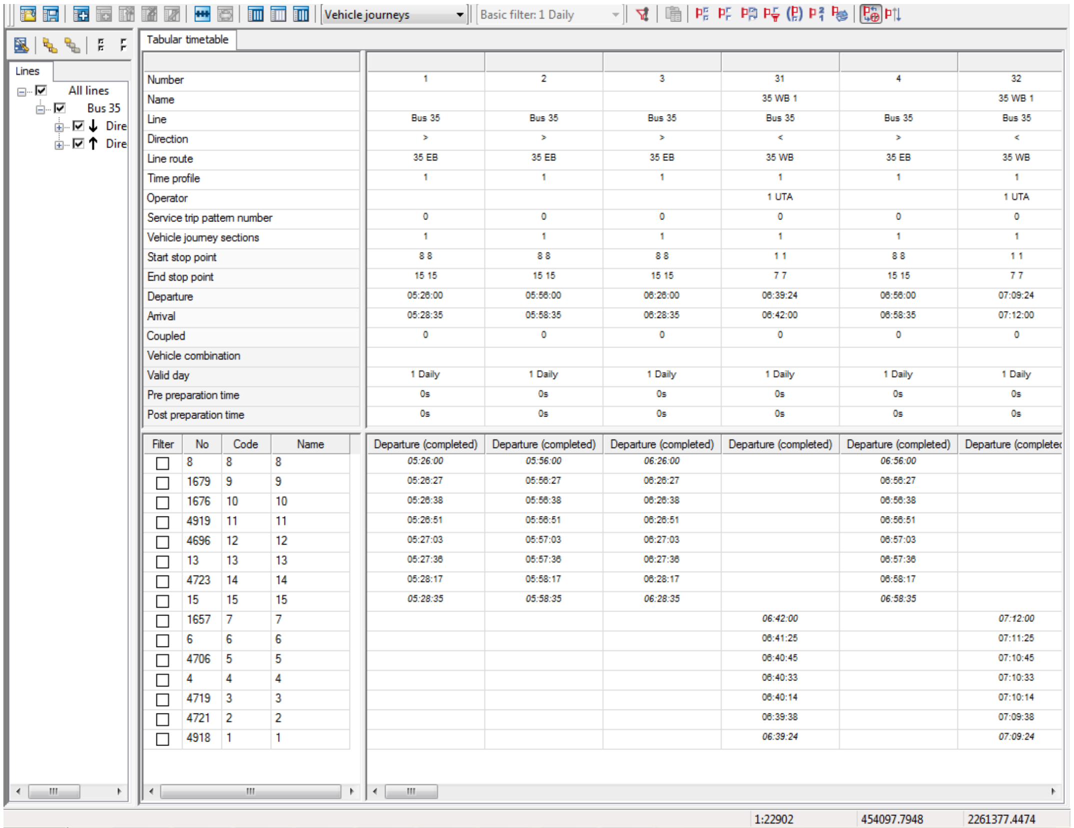
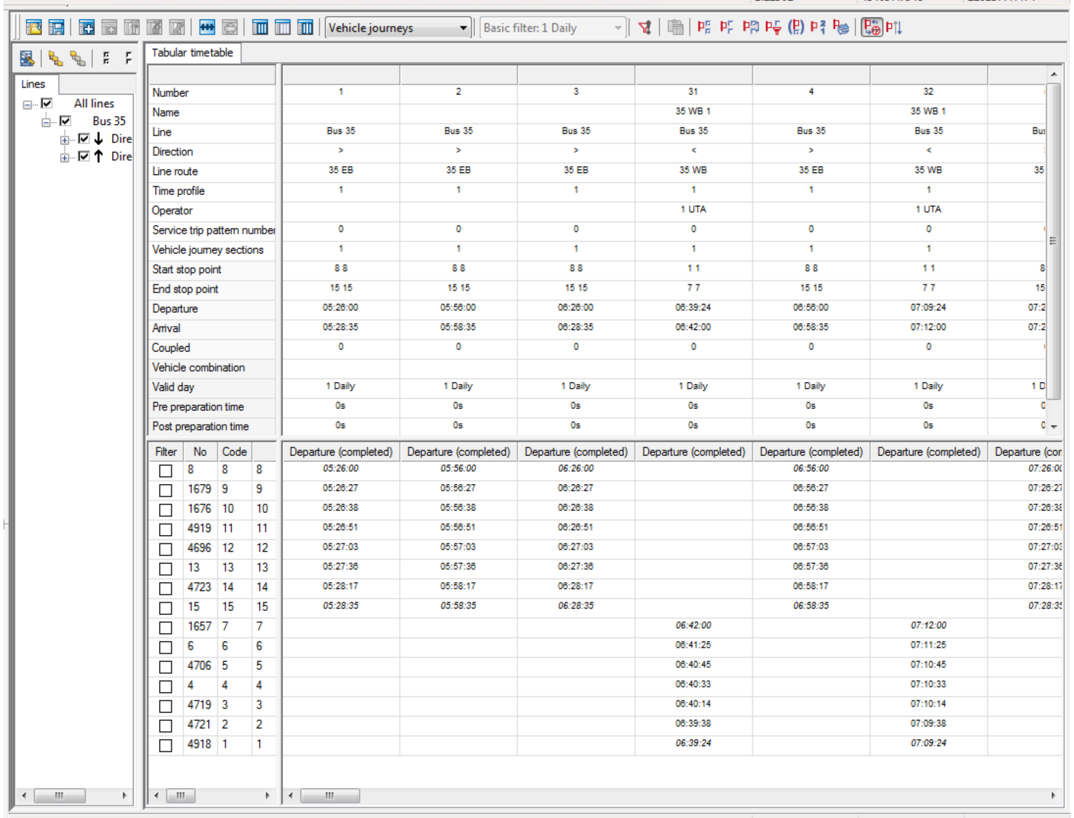
Time profile	1	1	1	1	1	1	1
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA
Service trip pattern number	0	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1	1
Start stop point	63 63	82 82	63 63	82 82	63 63	82 82	63 63
End stop point	81 81	100 100	81 81	100 100	81 81	100 100	81 81
Departure	06:13:48	06:21:15	06:43:48	06:51:15	07:13:48	07:21:15	07:43:48
Arrival	06:17:42	06:25:22	06:47:42	06:55:22	07:17:42	07:25:22	07:47:42
Coupled	0	0	0	0	0	0	0
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s	0s
Post preparation time	0s	0s	0s	0s	0s	0s	0s

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure
☐	3298	82	82		06:21:15		06:51:15		07:21:15	
☐	4091				06:21:29		06:51:29		07:21:29	
☐	3742	84	84		06:21:47		06:51:47		07:21:47	
☐	85	85	85		06:22:09		06:52:09		07:22:09	
☐	86	86	86		06:22:21		06:52:21		07:22:21	
☐	3737	87	87		06:22:33		06:52:33		07:22:33	
☐	3875	88	88		06:22:41		06:52:41		07:22:41	
☐	3726	89	89		06:22:52		06:52:52		07:22:52	
☐	3710	90	90		06:23:00		06:53:00		07:23:00	
☐	3257	91	91		06:23:12		06:53:12		07:23:12	
☐	92	92	92		06:23:22		06:53:22		07:23:22	
☐	93	93	93		06:23:49		06:53:49		07:23:49	
☐	94	94	94		06:24:01		06:54:01		07:24:01	
☐	95	95	95		06:24:09		06:54:09		07:24:09	
☐	96	96	96		06:24:25		06:54:25		07:24:25	
☐	3204	97	97		06:24:38		06:54:38		07:24:38	
☐	4753	98	98		06:24:51		06:54:51		07:24:51	



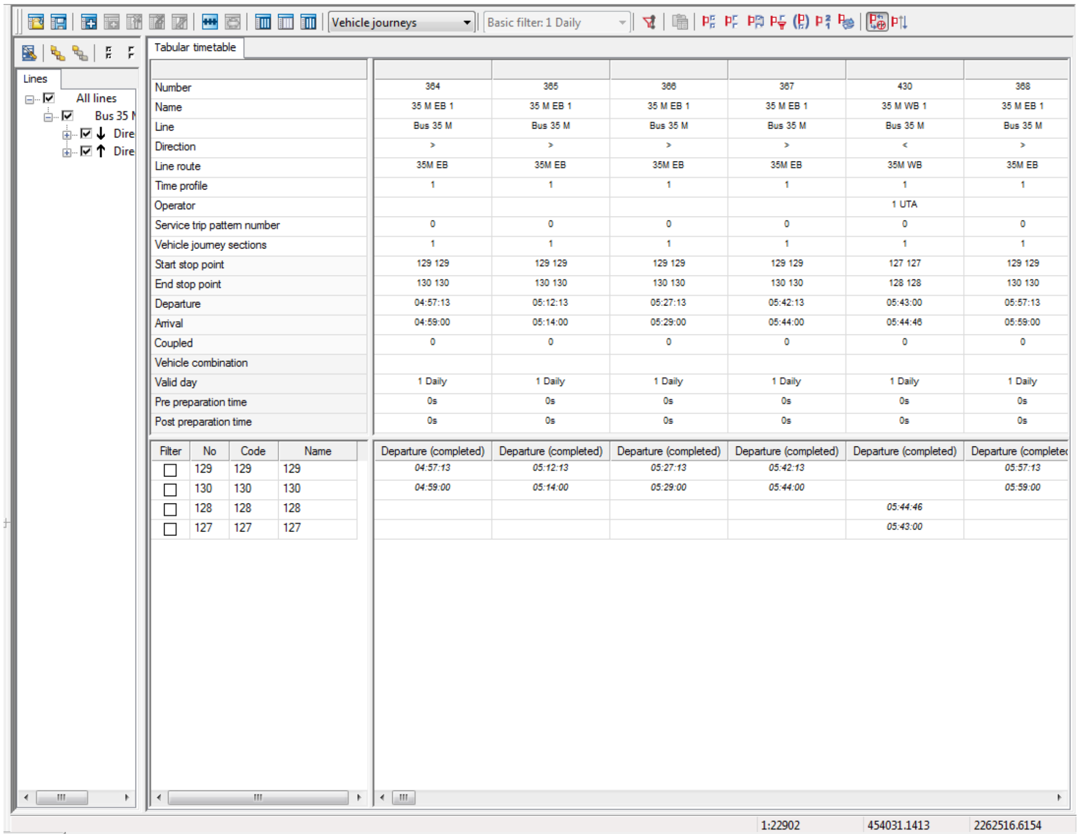
Number	1	2	3	31	4	32
Name				35 WB 1		35 WB 1
Line	Bus 35	Bus 35	Bus 35	Bus 35	Bus 35	Bus 35
Direction	>	>	>	<	>	<
Line route	35 EB	35 EB	35 EB	35 WB	35 EB	35 WB
Time profile	1	1	1	1	1	1
Operator				1 UTA		1 UTA
Service trip pattern number	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1
Start stop point	8 8	8 8	8 8	1 1	8 8	1 1
End stop point	15 15	15 15	15 15	7 7	15 15	7 7
Departure	05:26:00	05:56:00	06:26:00	06:39:24	06:56:00	07:09:24
Arrival	05:28:35	05:58:35	06:28:35	06:42:00	06:58:35	07:12:00
Coupled	0	0	0	0	0	0
Vehicle combination						
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s
Post preparation time	0s	0s	0s	0s	0s	0s

Filter	No	Code	Name	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (complete
☐	8	8	8	05:26:00	05:56:00	06:26:00		06:56:00	
☐	1679	9	9	05:26:27	05:56:27	06:26:27		06:56:27	
☐	1676	10	10	05:26:38	05:56:38	06:26:38		06:56:38	
☐	4919	11	11	05:26:51	05:56:51	06:26:51		06:56:51	
☐	4696	12	12	05:27:03	05:57:03	06:27:03		06:57:03	
☐	13	13	13	05:27:36	05:57:36	06:27:36		06:57:36	
☐	4723	14	14	05:28:17	05:58:17	06:28:17		06:58:17	
☐	15	15	15	05:28:35	05:58:35	06:28:35		06:58:35	
☐	1657	7	7				06:42:00		07:12:00
☐	6	6	6				06:41:25		07:11:25
☐	4706	5	5				06:40:45		07:10:45
☐	4	4	4				06:40:33		07:10:33
☐	4719	3	3				06:40:14		07:10:14
☐	4721	2	2				06:39:38		07:09:38
☐	4918	1	1				06:39:24		07:09:24



Number	1	2	3	31	4	32	
Name				35 WB 1		35 WB 1	
Line	Bus 35	Bus 35	Bus 35	Bus 35	Bus 35	Bus 35	Bu
Direction	>	>	>	<	>	<	
Line route	35 EB	35 EB	35 EB	35 WB	35 EB	35 WB	35
Time profile	1	1	1	1	1	1	
Operator				1 UTA		1 UTA	
Service trip pattern numbe	0	0	0	0	0	0	
Vehicle journey sections	1	1	1	1	1	1	
Start stop point	8 8	8 8	8 8	1 1	8 8	1 1	8
End stop point	15 15	15 15	15 15	7 7	15 15	7 7	15
Departure	05:26:00	05:56:00	06:26:00	06:39:24	06:56:00	07:09:24	07:2
Arrival	05:28:35	05:58:35	06:28:35	06:42:00	06:58:35	07:12:00	07:2
Coupled	0	0	0	0	0	0	
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 D
Pre preparation time	0s	0s	0s	0s	0s	0s	0
Post preparation time	0s	0s	0s	0s	0s	0s	0

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (cor
☐	8	8	8	05:26:00	05:56:00	06:26:00		06:56:00		07:26:0
☐	1679	9	9	05:26:27	05:56:27	06:26:27		06:56:27		07:26:2
☐	1676	10	10	05:26:38	05:56:38	06:26:38		06:56:38		07:26:3
☐	4919	11	11	05:26:51	05:56:51	06:26:51		06:56:51		07:26:5
☐	4696	12	12	05:27:03	05:57:03	06:27:03		06:57:03		07:27:0
☐	13	13	13	05:27:36	05:57:36	06:27:36		06:57:36		07:27:3
☐	4723	14	14	05:28:17	05:58:17	06:28:17		06:58:17		07:28:1
☐	15	15	15	05:28:35	05:58:35	06:28:35		06:58:35		07:28:3
☐	1657	7	7				06:42:00		07:12:00	
☐	6	6	6				06:41:25		07:11:25	
☐	4706	5	5				06:40:45		07:10:45	
☐	4	4	4				06:40:33		07:10:33	
☐	4719	3	3				06:40:14		07:10:14	
☐	4721	2	2				06:39:38		07:09:38	
☐	4918	1	1				06:39:24		07:09:24	



Vehicle journeys | Basic filter: 1 Daily

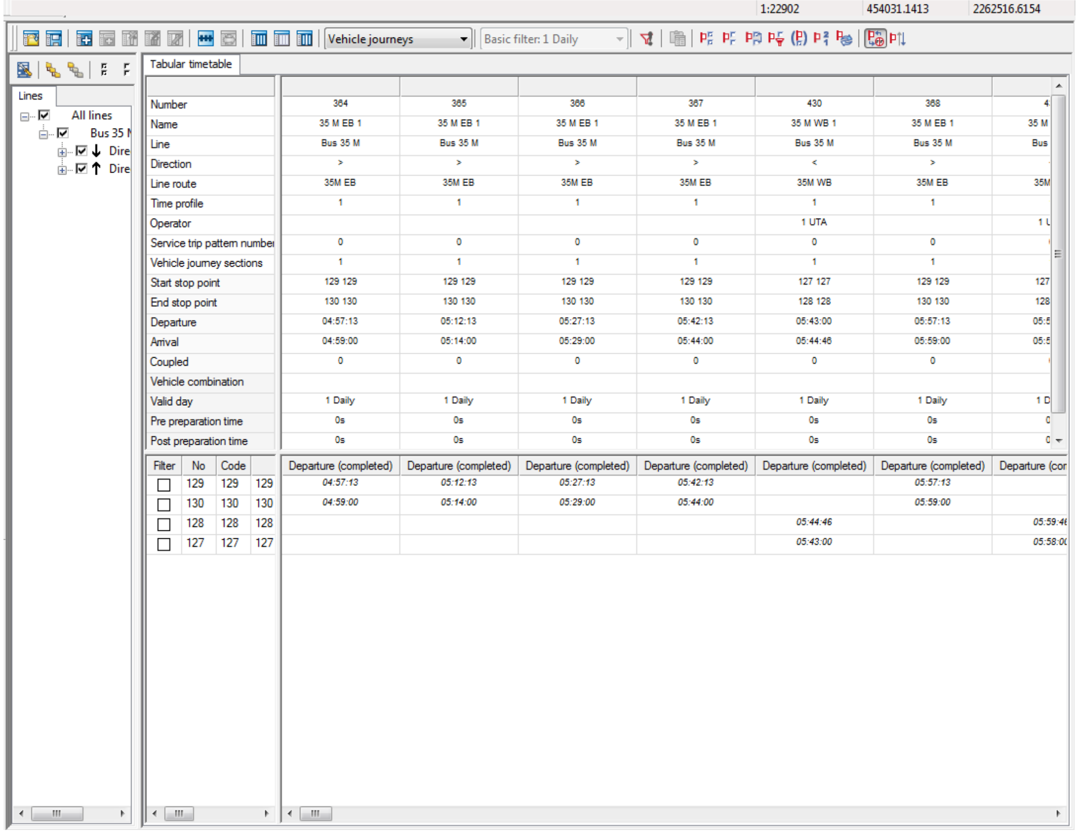
Tabular timetable

Number	364	365	366	367	430	368
Name	35 M EB 1	35 M EB 1	35 M EB 1	35 M EB 1	35 M WB 1	35 M EB 1
Line	Bus 35 M	Bus 35 M	Bus 35 M	Bus 35 M	Bus 35 M	Bus 35 M
Direction	>	>	>	>	<	>
Line route	35M EB	35M EB	35M EB	35M EB	35M WB	35M EB
Time profile	1	1	1	1	1	1
Operator					1 UTA	
Service trip pattern number	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1
Start stop point	129 129	129 129	129 129	129 129	127 127	129 129
End stop point	130 130	130 130	130 130	130 130	128 128	130 130
Departure	04:57:13	05:12:13	05:27:13	05:42:13	05:43:00	05:57:13
Arrival	04:59:00	05:14:00	05:29:00	05:44:00	05:44:46	05:59:00
Coupled	0	0	0	0	0	0
Vehicle combination						
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s
Post preparation time	0s	0s	0s	0s	0s	0s

Filter	No	Code	Name	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (complete
☐	129	129	129	04:57:13	05:12:13	05:27:13	05:42:13		05:57:13
☐	130	130	130	04:59:00	05:14:00	05:29:00	05:44:00		05:59:00
☐	128	128	128					05:44:46	
☐	127	127	127					05:43:00	

Lines: All lines; Bus 35 M; Dire; Dire

1:22902 | 454031.1413 | 2262516.6154



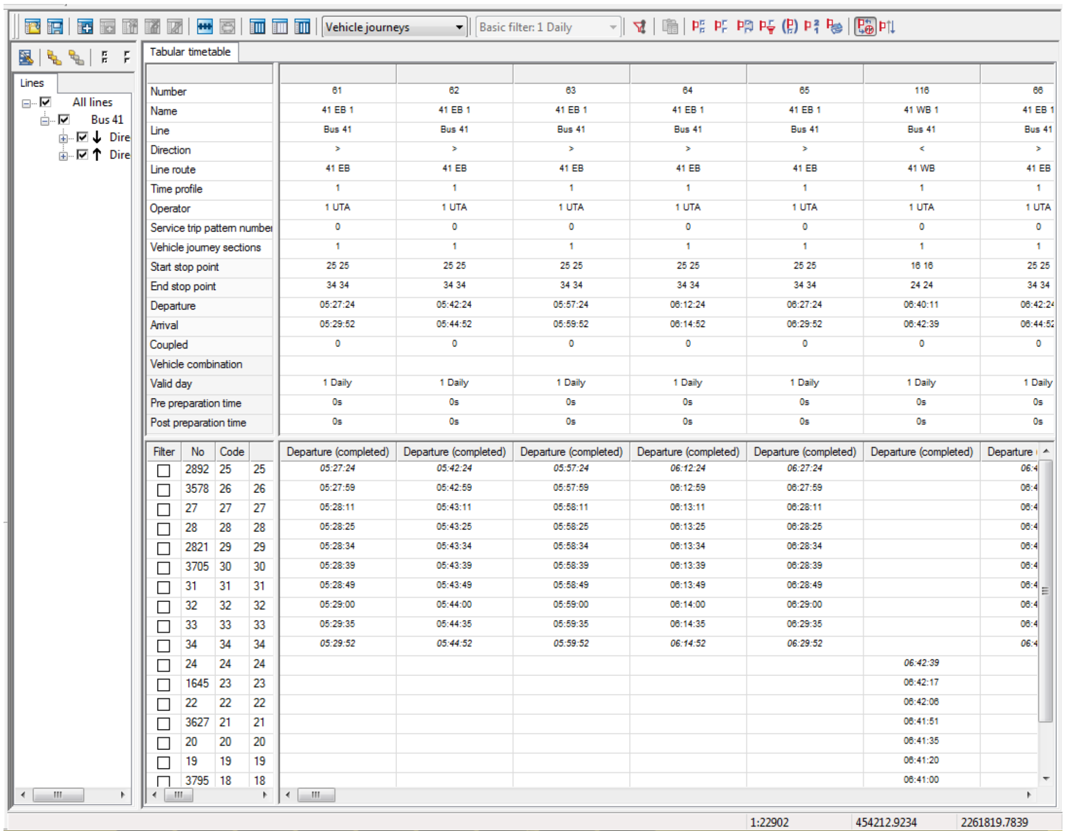
Vehicle journeys | Basic filter: 1 Daily

Tabular timetable

Number	364	365	366	367	430	368	4
Name	35 M EB 1	35 M EB 1	35 M EB 1	35 M EB 1	35 M WB 1	35 M EB 1	35 M
Line	Bus 35 M	Bus 35 M	Bus 35 M	Bus 35 M	Bus 35 M	Bus 35 M	Bus
Direction	>	>	>	>	<	>	
Line route	35M EB	35M EB	35M EB	35M EB	35M WB	35M EB	35M
Time profile	1	1	1	1	1	1	
Operator					1 UTA		1 U
Service trip pattern number	0	0	0	0	0	0	
Vehicle journey sections	1	1	1	1	1	1	
Start stop point	129 129	129 129	129 129	129 129	127 127	129 129	127
End stop point	130 130	130 130	130 130	130 130	128 128	130 130	128
Departure	04:57:13	05:12:13	05:27:13	05:42:13	05:43:00	05:57:13	05:5
Arrival	04:59:00	05:14:00	05:29:00	05:44:00	05:44:46	05:59:00	05:5
Coupled	0	0	0	0	0	0	
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 D
Pre preparation time	0s	0s	0s	0s	0s	0s	0
Post preparation time	0s	0s	0s	0s	0s	0s	0

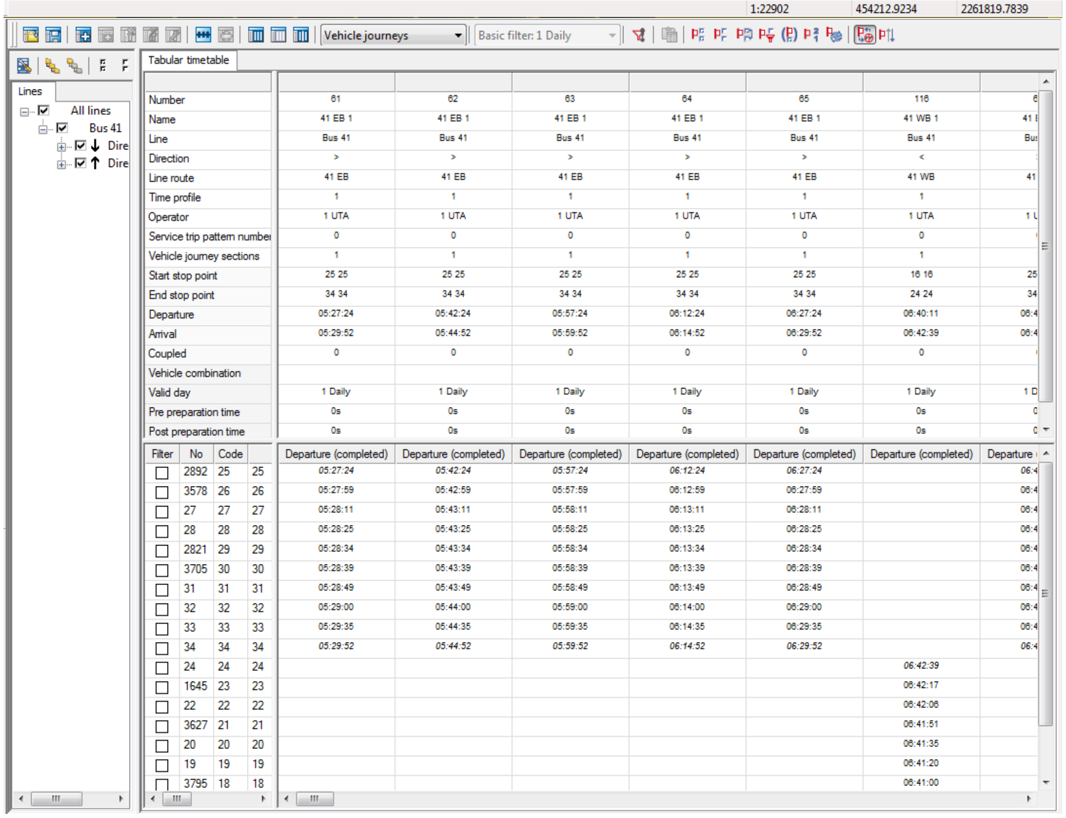
Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (cor
☐	129	129	129	04:57:13	05:12:13	05:27:13	05:42:13		05:57:13	
☐	130	130	130	04:59:00	05:14:00	05:29:00	05:44:00		05:59:00	
☐	128	128	128					05:44:46		05:59:4
☐	127	127	127					05:43:00		05:58:0

Lines: All lines; Bus 35 I; Dire; Dire



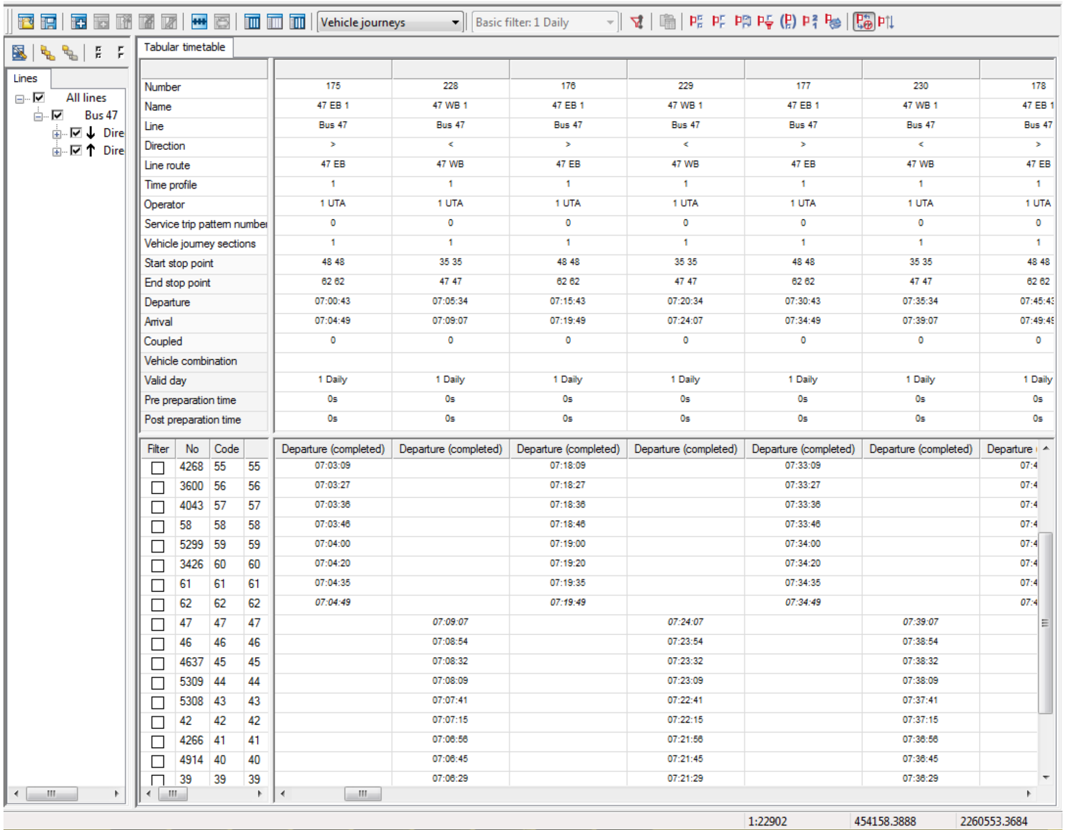
Number	61	62	63	64	65	116	66
Name	41 EB 1	41 EB 1	41 EB 1	41 EB 1	41 EB 1	41 WB 1	41 EB 1
Line	Bus 41	Bus 41	Bus 41	Bus 41	Bus 41	Bus 41	Bus 41
Direction	>	>	>	>	>	<	>
Line route	41 EB	41 EB	41 EB	41 EB	41 EB	41 WB	41 EB
Time profile	1	1	1	1	1	1	1
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA
Service trip pattern number	0	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1	1
Start stop point	25 25	25 25	25 25	25 25	25 25	16 16	25 25
End stop point	34 34	34 34	34 34	34 34	34 34	24 24	34 34
Departure	05:27:24	05:42:24	05:57:24	06:12:24	06:27:24	06:40:11	06:42:24
Arrival	05:29:52	05:44:52	05:59:52	06:14:52	06:29:52	06:42:39	06:44:52
Coupled	0	0	0	0	0	0	0
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s	0s
Post preparation time	0s	0s	0s	0s	0s	0s	0s

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (
☐	2892	25	25	05:27:24	05:42:24	05:57:24	06:12:24	06:27:24		06:4
☐	3578	26	26	05:27:59	05:42:59	05:57:59	06:12:59	06:27:59		06:4
☐	27	27	27	05:28:11	05:43:11	05:58:11	06:13:11	06:28:11		06:4
☐	28	28	28	05:28:25	05:43:25	05:58:25	06:13:25	06:28:25		06:4
☐	2821	29	29	05:28:34	05:43:34	05:58:34	06:13:34	06:28:34		06:4
☐	3705	30	30	05:28:39	05:43:39	05:58:39	06:13:39	06:28:39		06:4
☐	31	31	31	05:28:49	05:43:49	05:58:49	06:13:49	06:28:49		06:4
☐	32	32	32	05:29:00	05:44:00	05:59:00	06:14:00	06:29:00		06:4
☐	33	33	33	05:29:35	05:44:35	05:59:35	06:14:35	06:29:35		06:4
☐	34	34	34	05:29:52	05:44:52	05:59:52	06:14:52	06:29:52		06:4
☐	24	24	24						06:42:39	
☐	1645	23	23						06:42:17	
☐	22	22	22						06:42:06	
☐	3627	21	21						06:41:51	
☐	20	20	20						06:41:35	
☐	19	19	19						06:41:20	
☐	3795	18	18						06:41:00	



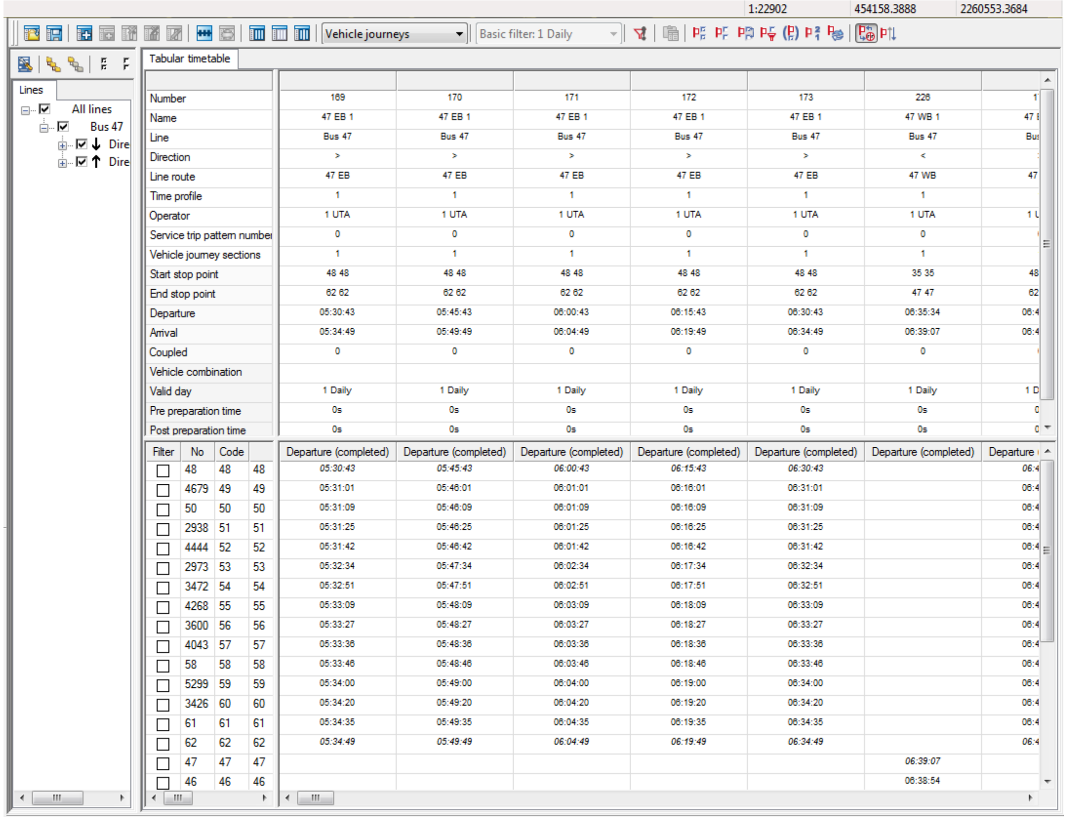
Number	61	62	63	64	65	116	6
Name	41 EB 1	41 EB 1	41 EB 1	41 EB 1	41 EB 1	41 WB 1	41 E
Line	Bus 41	Bus 41	Bus 41	Bus 41	Bus 41	Bus 41	Bu
Direction	>	>	>	>	>	<	
Line route	41 EB	41 EB	41 EB	41 EB	41 EB	41 WB	41
Time profile	1	1	1	1	1	1	
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 U
Service trip pattern number	0	0	0	0	0	0	
Vehicle journey sections	1	1	1	1	1	1	
Start stop point	25 25	25 25	25 25	25 25	25 25	16 16	25
End stop point	34 34	34 34	34 34	34 34	34 34	24 24	34
Departure	05:27:24	05:42:24	05:57:24	06:12:24	06:27:24	06:40:11	06:4
Arrival	05:29:52	05:44:52	05:59:52	06:14:52	06:29:52	06:42:39	06:4
Coupled	0	0	0	0	0	0	
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 D
Pre preparation time	0s	0s	0s	0s	0s	0s	0
Post preparation time	0s	0s	0s	0s	0s	0s	0

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (
☐	2892	25	25	05:27:24	05:42:24	05:57:24	06:12:24	06:27:24		06:4
☐	3578	26	26	05:27:59	05:42:59	05:57:59	06:12:59	06:27:59		06:4
☐	27	27	27	05:28:11	05:43:11	05:58:11	06:13:11	06:28:11		06:4
☐	28	28	28	05:28:25	05:43:25	05:58:25	06:13:25	06:28:25		06:4
☐	2821	29	29	05:28:34	05:43:34	05:58:34	06:13:34	06:28:34		06:4
☐	3705	30	30	05:28:39	05:43:39	05:58:39	06:13:39	06:28:39		06:4
☐	31	31	31	05:28:49	05:43:49	05:58:49	06:13:49	06:28:49		06:4
☐	32	32	32	05:29:00	05:44:00	05:59:00	06:14:00	06:29:00		06:4
☐	33	33	33	05:29:35	05:44:35	05:59:35	06:14:35	06:29:35		06:4
☐	34	34	34	05:29:52	05:44:52	05:59:52	06:14:52	06:29:52		06:4
☐	24	24	24						06:42:39	
☐	1645	23	23						06:42:17	
☐	22	22	22						06:42:06	
☐	3627	21	21						06:41:51	
☐	20	20	20						06:41:35	
☐	19	19	19						06:41:20	
☐	3795	18	18						06:41:00	



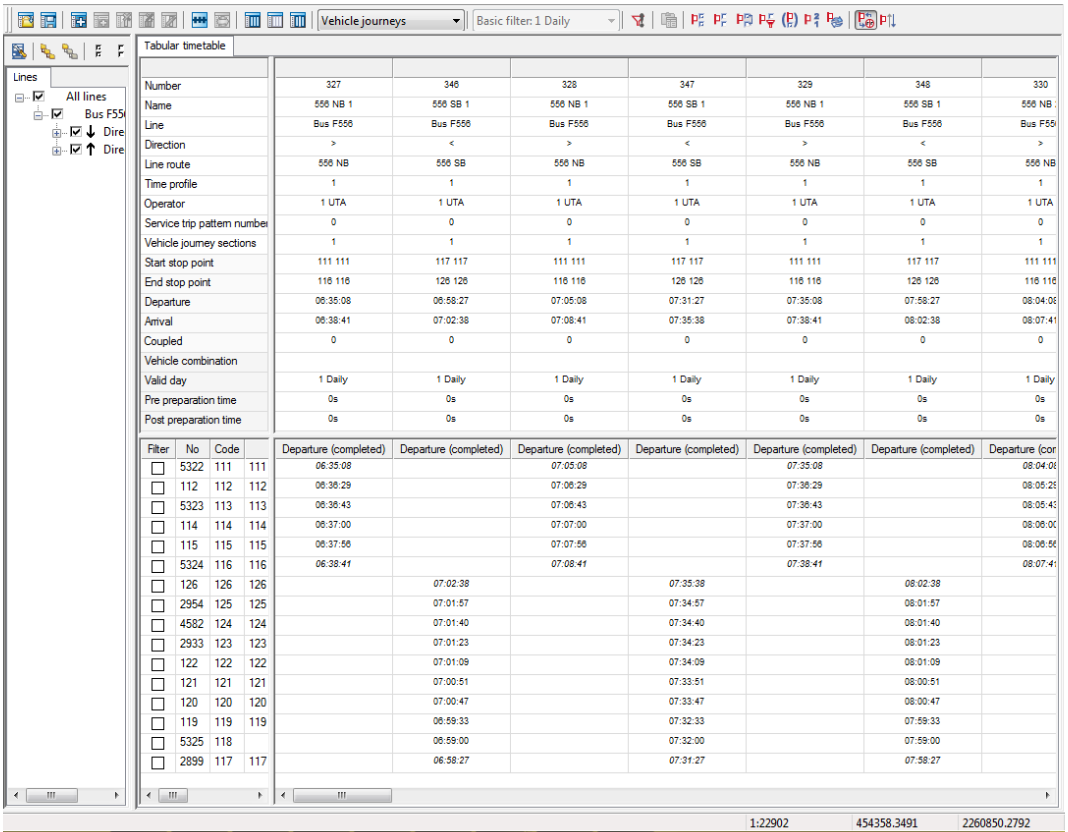
Number	175	228	176	229	177	230	178
Name	47 EB 1	47 WB 1	47 EB 1	47 WB 1	47 EB 1	47 WB 1	47 EB 1
Line	Bus 47	Bus 47	Bus 47	Bus 47	Bus 47	Bus 47	Bus 47
Direction	>	<	>	<	>	<	>
Line route	47 EB	47 WB	47 EB	47 WB	47 EB	47 WB	47 EB
Time profile	1	1	1	1	1	1	1
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA
Service trip pattern numbe	0	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1	1
Start stop point	48 48	35 35	48 48	35 35	48 48	35 35	48 48
End stop point	62 62	47 47	62 62	47 47	62 62	47 47	62 62
Departure	07:00:43	07:05:34	07:15:43	07:20:34	07:30:43	07:35:34	07:45:4
Arrival	07:04:49	07:09:07	07:19:49	07:24:07	07:34:49	07:39:07	07:49:4
Coupled	0	0	0	0	0	0	0
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s	0s
Post preparation time	0s	0s	0s	0s	0s	0s	0s

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure
☐	4268	55	55	07:03:09		07:18:09		07:33:09		07:4
☐	3600	56	56	07:03:27		07:18:27		07:33:27		07:4
☐	4043	57	57	07:03:36		07:18:36		07:33:36		07:4
☐	58	58	58	07:03:46		07:18:46		07:33:46		07:4
☐	5299	59	59	07:04:00		07:19:00		07:34:00		07:4
☐	3426	60	60	07:04:20		07:19:20		07:34:20		07:4
☐	61	61	61	07:04:35		07:19:35		07:34:35		07:4
☐	62	62	62	07:04:49		07:19:49		07:34:49		07:4
☐	47	47	47		07:09:07		07:24:07		07:39:07	
☐	46	46	46		07:08:54		07:23:54		07:38:54	
☐	4637	45	45		07:08:32		07:23:32		07:38:32	
☐	5309	44	44		07:08:09		07:23:09		07:38:09	
☐	5308	43	43		07:07:41		07:22:41		07:37:41	
☐	42	42	42		07:07:15		07:22:15		07:37:15	
☐	4266	41	41		07:06:56		07:21:56		07:36:56	
☐	4914	40	40		07:06:45		07:21:45		07:36:45	
☐	39	39	39		07:06:29		07:21:29		07:36:29	



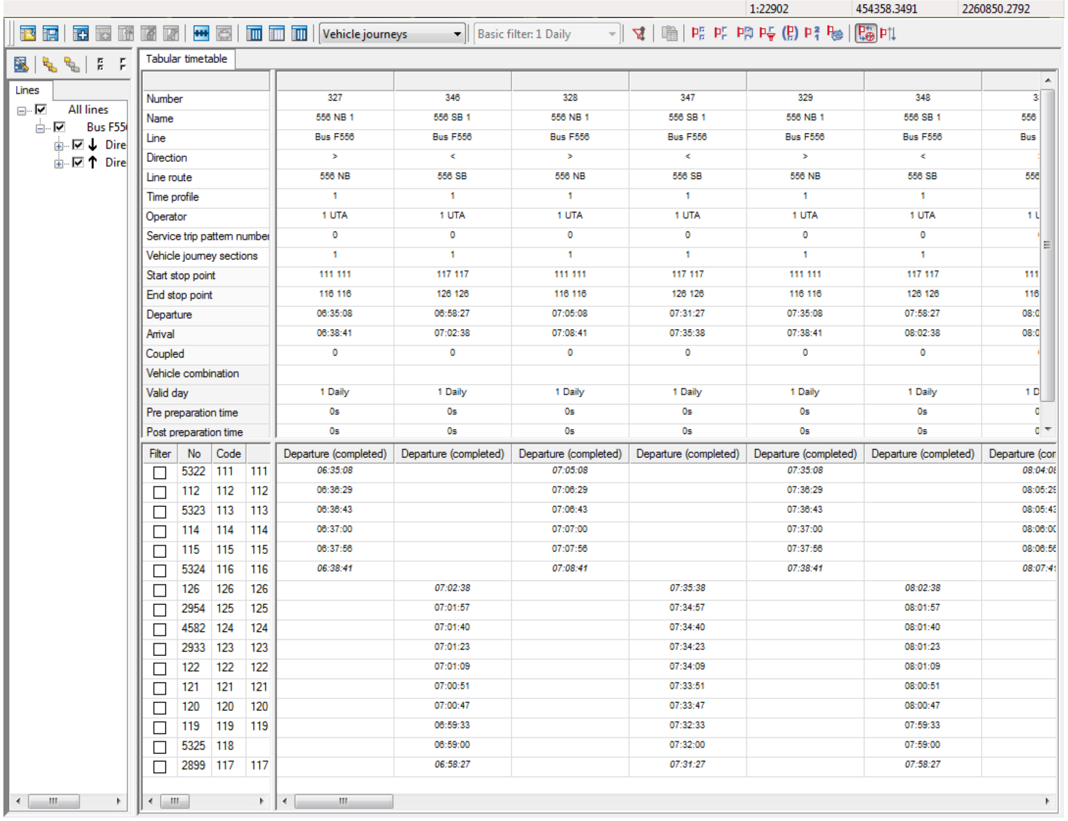
Number	169	170	171	172	173	226	1
Name	47 EB 1	47 EB 1	47 EB 1	47 EB 1	47 EB 1	47 WB 1	47 E
Line	Bus 47	Bus 47	Bus 47	Bus 47	Bus 47	Bus 47	Bu
Direction	>	>	>	>	>	<	
Line route	47 EB	47 EB	47 EB	47 EB	47 EB	47 WB	47
Time profile	1	1	1	1	1	1	
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 U
Service trip pattern numbe	0	0	0	0	0	0	
Vehicle journey sections	1	1	1	1	1	1	
Start stop point	48 48	48 48	48 48	48 48	48 48	35 35	48
End stop point	62 62	62 62	62 62	62 62	62 62	47 47	62
Departure	05:30:43	05:45:43	06:00:43	06:15:43	06:30:43	06:35:34	06:4
Arrival	05:34:49	05:49:49	06:04:49	06:19:49	06:34:49	06:39:07	06:4
Coupled	0	0	0	0	0	0	
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 D
Pre preparation time	0s	0s	0s	0s	0s	0s	0
Post preparation time	0s	0s	0s	0s	0s	0s	0

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure
☐	48	48	48	05:30:43	05:45:43	06:00:43	06:15:43	06:30:43		06:4
☐	4679	49	49	05:31:01	05:46:01	06:01:01	06:16:01	06:31:01		06:4
☐	50	50	50	05:31:09	05:46:09	06:01:09	06:16:09	06:31:09		06:4
☐	2938	51	51	05:31:25	05:46:25	06:01:25	06:16:25	06:31:25		06:4
☐	4444	52	52	05:31:42	05:46:42	06:01:42	06:16:42	06:31:42		06:4
☐	2973	53	53	05:32:34	05:47:34	06:02:34	06:17:34	06:32:34		06:4
☐	3472	54	54	05:32:51	05:47:51	06:02:51	06:17:51	06:32:51		06:4
☐	4268	55	55	05:33:09	05:48:09	06:03:09	06:18:09	06:33:09		06:4
☐	3600	56	56	05:33:27	05:48:27	06:03:27	06:18:27	06:33:27		06:4
☐	4043	57	57	05:33:36	05:48:36	06:03:36	06:18:36	06:33:36		06:4
☐	58	58	58	05:33:46	05:48:46	06:03:46	06:18:46	06:33:46		06:4
☐	5299	59	59	05:34:00	05:49:00	06:04:00	06:19:00	06:34:00		06:4
☐	3426	60	60	05:34:20	05:49:20	06:04:20	06:19:20	06:34:20		06:4
☐	61	61	61	05:34:35	05:49:35	06:04:35	06:19:35	06:34:35		06:4
☐	62	62	62	05:34:49	05:49:49	06:04:49	06:19:49	06:34:49		06:4
☐	47	47	47						06:39:07	
☐	46	46	46						06:38:54	



Number	327	346	328	347	329	348	330
Name	556 NB 1	556 SB 1	556 NB 1	556 SB 1	556 NB 1	556 SB 1	556 NB
Line	Bus F556	Bus F556	Bus F556	Bus F556	Bus F556	Bus F556	Bus F55
Direction	>	<	>	<	>	<	>
Line route	556 NB	556 SB	556 NB	556 SB	556 NB	556 SB	556 NB
Time profile	1	1	1	1	1	1	1
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA
Service trip pattern number	0	0	0	0	0	0	0
Vehicle journey sections	1	1	1	1	1	1	1
Start stop point	111 111	117 117	111 111	117 117	111 111	117 117	111 111
End stop point	116 116	126 126	116 116	126 126	116 116	126 126	116 116
Departure	06:35:08	06:58:27	07:05:08	07:31:27	07:35:08	07:58:27	08:04:08
Arrival	06:38:41	07:02:38	07:08:41	07:35:38	07:38:41	08:02:38	08:07:41
Coupled	0	0	0	0	0	0	0
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily
Pre preparation time	0s	0s	0s	0s	0s	0s	0s
Post preparation time	0s	0s	0s	0s	0s	0s	0s

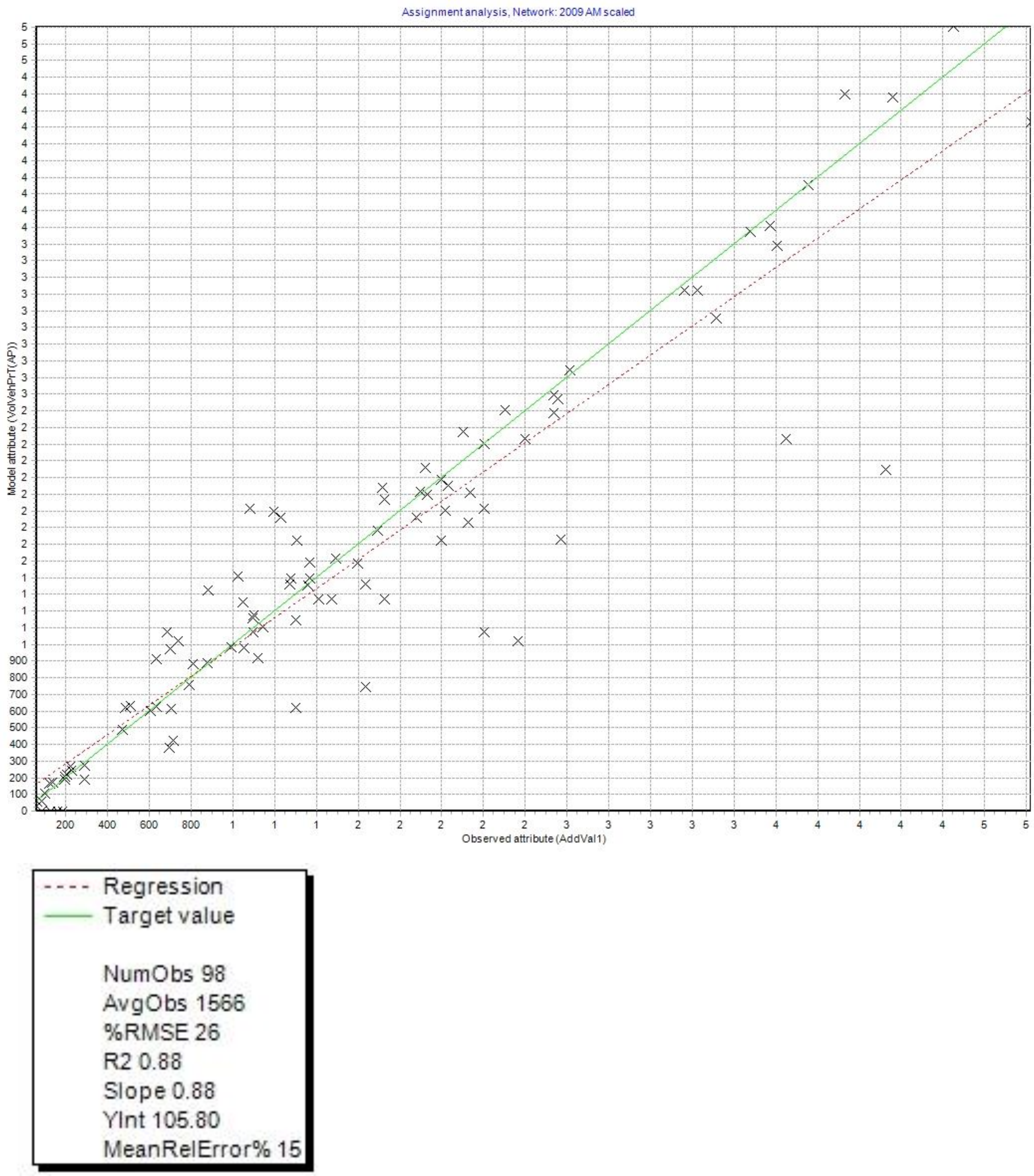
Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (cor
☐	5322	111	111	06:35:08		07:05:08		07:35:08		08:04:08
☐	112	112	112	06:36:29		07:06:29		07:36:29		08:05:29
☐	5323	113	113	06:36:43		07:06:43		07:36:43		08:05:43
☐	114	114	114	06:37:00		07:07:00		07:37:00		08:06:00
☐	115	115	115	06:37:56		07:07:56		07:37:56		08:06:56
☐	5324	116	116	06:38:41		07:08:41		07:38:41		08:07:41
☐	126	126	126		07:02:38		07:35:38		08:02:38	
☐	2954	125	125		07:01:57		07:34:57		08:01:57	
☐	4582	124	124		07:01:40		07:34:40		08:01:40	
☐	2933	123	123		07:01:23		07:34:23		08:01:23	
☐	122	122	122		07:01:09		07:34:09		08:01:09	
☐	121	121	121		07:00:51		07:33:51		08:00:51	
☐	120	120	120		07:00:47		07:33:47		08:00:47	
☐	119	119	119		06:59:33		07:32:33		07:59:33	
☐	5325	118			06:59:00		07:32:00		07:59:00	
☐	2899	117	117		06:58:27		07:31:27		07:58:27	

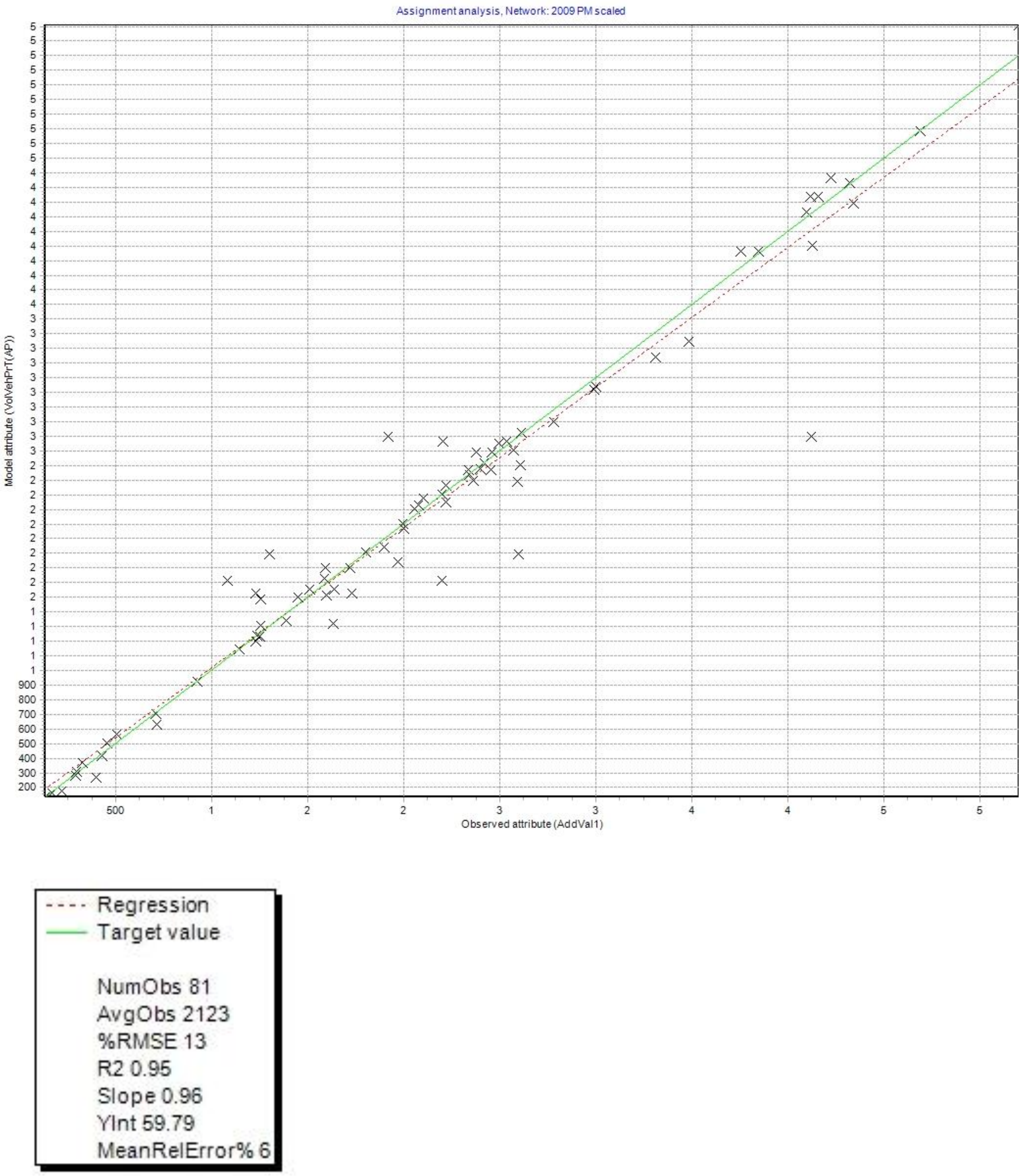


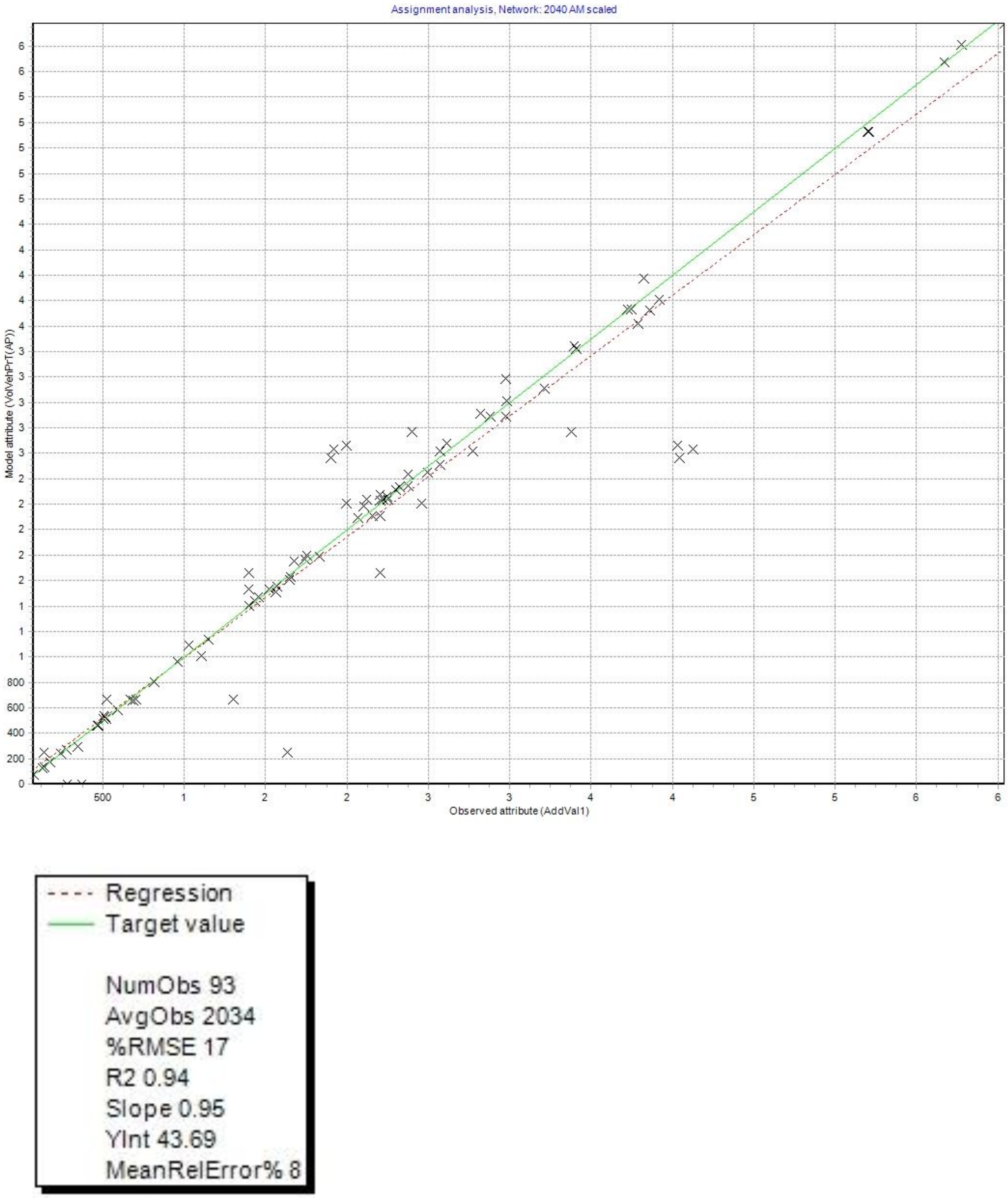
Number	327	346	328	347	329	348	3
Name	556 NB 1	556 SB 1	556 NB 1	556 SB 1	556 NB 1	556 SB 1	556
Line	Bus F556	Bus F556	Bus F556	Bus F556	Bus F556	Bus F556	Bus
Direction	>	<	>	<	>	<	
Line route	556 NB	556 SB	556 NB	556 SB	556 NB	556 SB	556
Time profile	1	1	1	1	1	1	
Operator	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 UTA	1 U
Service trip pattern number	0	0	0	0	0	0	
Vehicle journey sections	1	1	1	1	1	1	
Start stop point	111 111	117 117	111 111	117 117	111 111	117 117	111
End stop point	116 116	126 126	116 116	126 126	116 116	126 126	116
Departure	06:35:08	06:58:27	07:05:08	07:31:27	07:35:08	07:58:27	08:0
Arrival	06:38:41	07:02:38	07:08:41	07:35:38	07:38:41	08:02:38	08:0
Coupled	0	0	0	0	0	0	
Vehicle combination							
Valid day	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 Daily	1 D
Pre preparation time	0s	0s	0s	0s	0s	0s	0
Post preparation time	0s	0s	0s	0s	0s	0s	0

Filter	No	Code		Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (completed)	Departure (cor
☐	5322	111	111	06:35:08		07:05:08		07:35:08		08:04:08
☐	112	112	112	06:36:29		07:06:29		07:36:29		08:05:29
☐	5323	113	113	06:36:43		07:06:43		07:36:43		08:05:43
☐	114	114	114	06:37:00		07:07:00		07:37:00		08:06:00
☐	115	115	115	06:37:56		07:07:56		07:37:56		08:06:56
☐	5324	116	116	06:38:41		07:08:41		07:38:41		08:07:41
☐	126	126	126		07:02:38		07:35:38		08:02:38	
☐	2954	125	125		07:01:57		07:34:57		08:01:57	
☐	4582	124	124		07:01:40		07:34:40		08:01:40	
☐	2933	123	123		07:01:23		07:34:23		08:01:23	
☐	122	122	122		07:01:09		07:34:09		08:01:09	
☐	121	121	121		07:00:51		07:33:51		08:00:51	
☐	120	120	120		07:00:47		07:33:47		08:00:47	
☐	119	119	119		06:59:33		07:32:33		07:59:33	
☐	5325	118			06:59:00		07:32:00		07:59:00	
☐	2899	117	117		06:58:27		07:31:27		07:58:27	

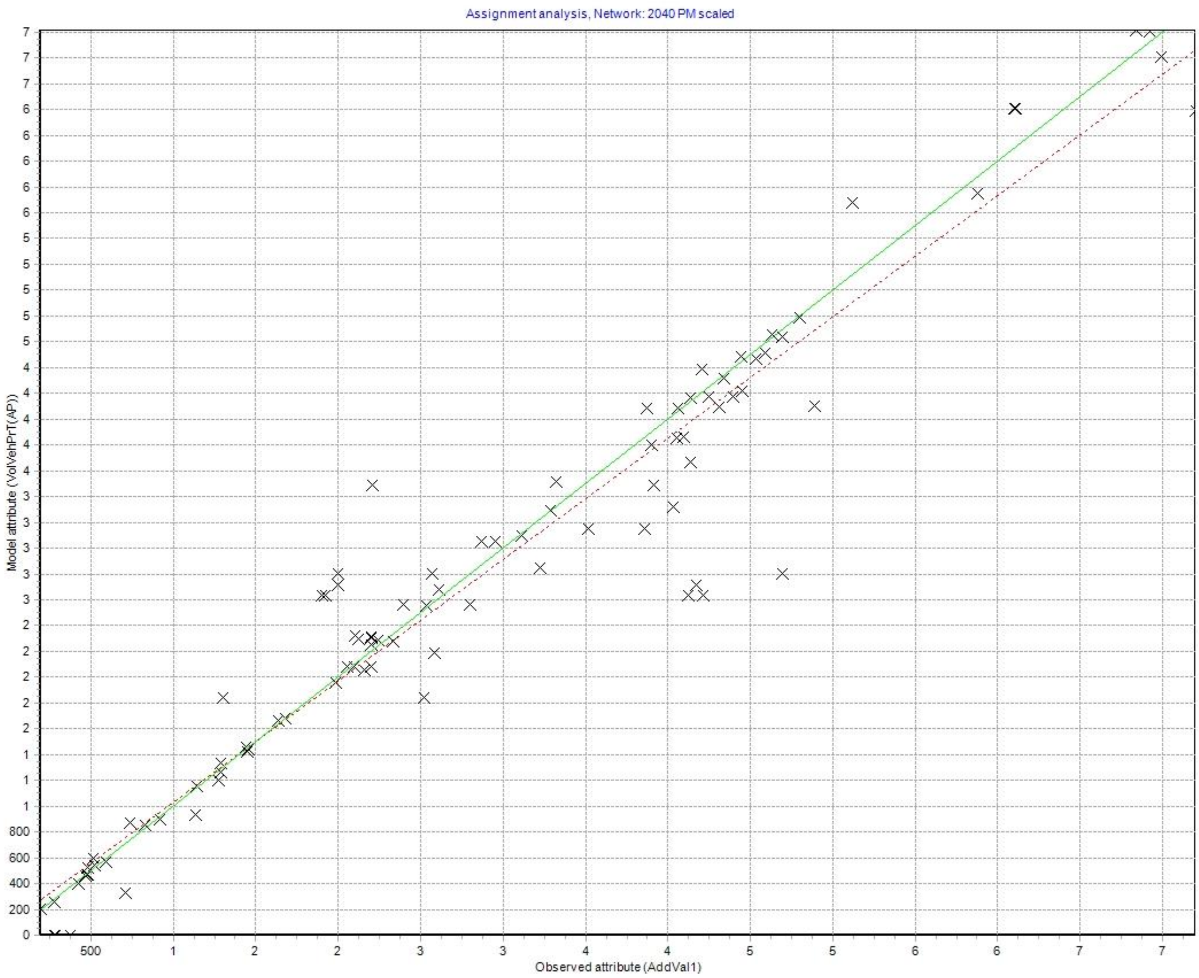
APPENDIX B: BASE CASE SCENARIOS CALIBRATION RESULTS




Assignment analysis, Network: 2009 PM scaled
Model attribute (VolVehPrT(AP))
Observed attribute (AddVal1)
Regression
Target value
NumObs 81
AvgObs 2123
%RMSE 13
R2 0.95
Slope 0.96
YInt 59.79
MeanRelError% 6



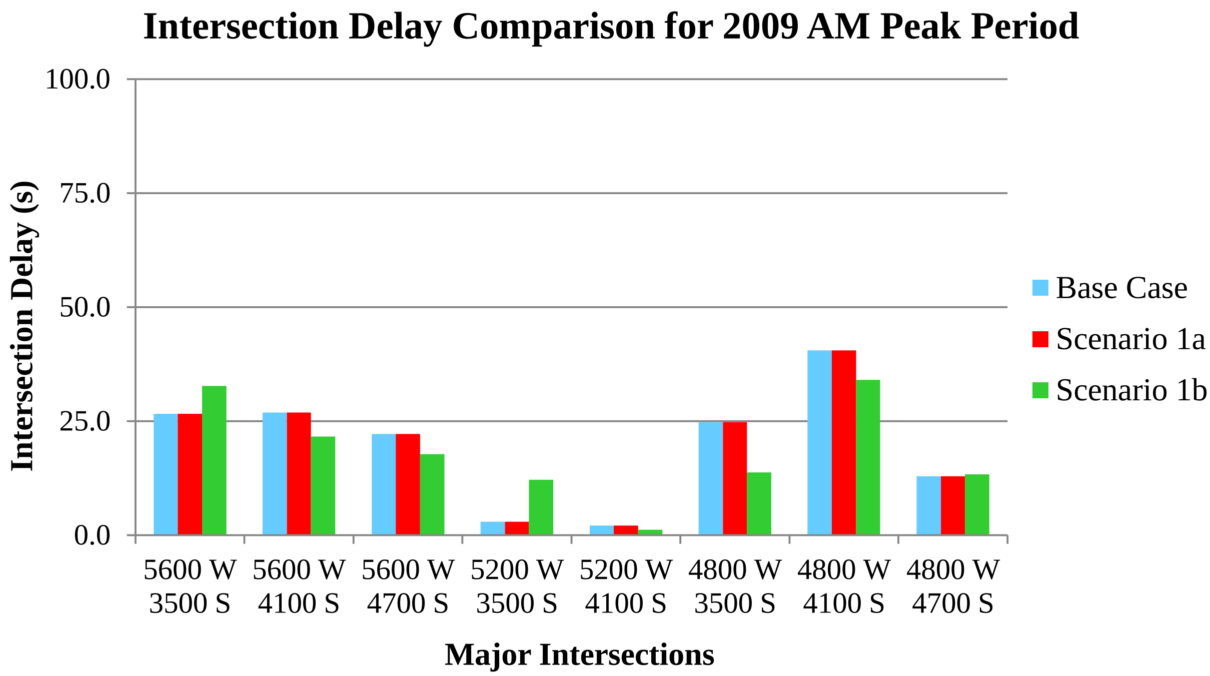
Assignment analysis, Network: 2040 AM scaled
Model attribute (VolVehPrT(AP))
Observed attribute (AddVal1)
Regression
Target value
NumObs 93
AvgObs 2034
%RMSE 17
R2 0.94
Slope 0.95
YInt 43.69
MeanRelError% 8

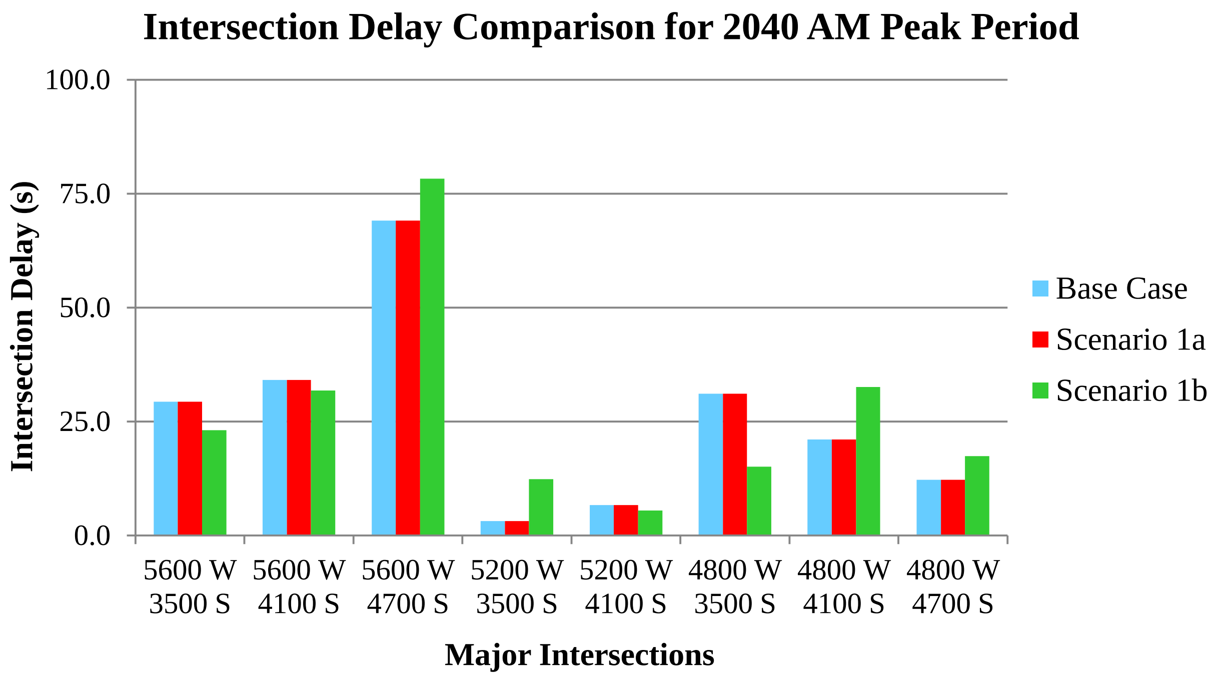


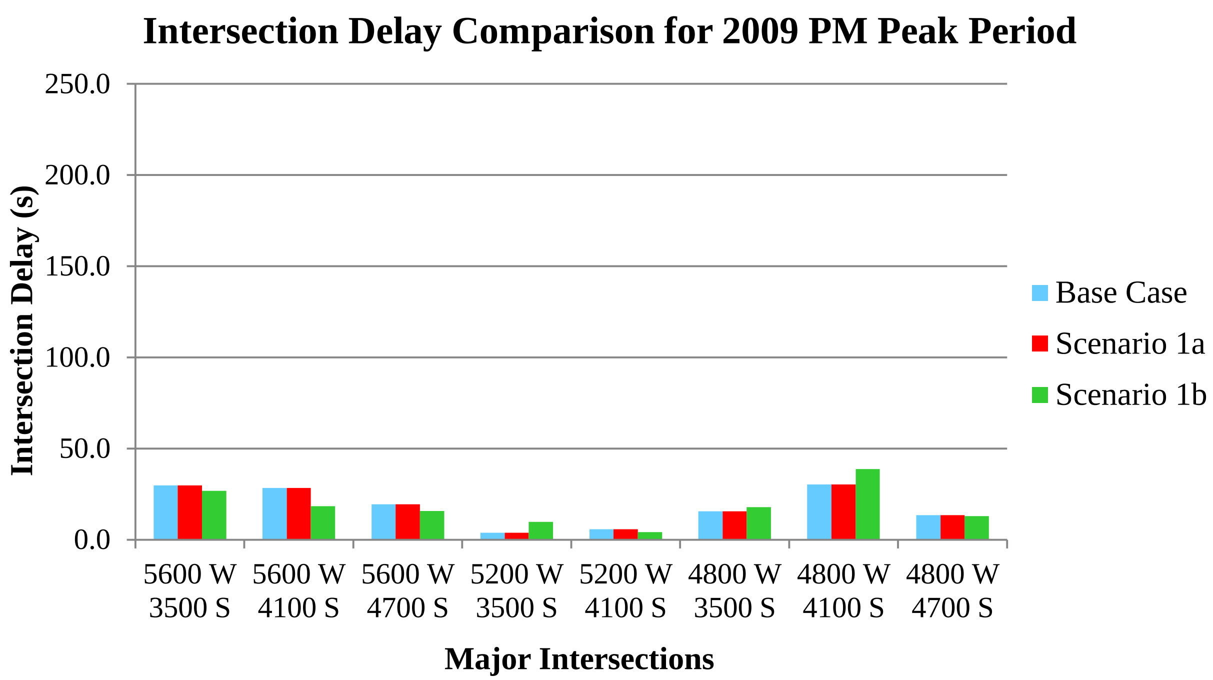
---- Regression
—— Target value

NumObs 94
AvgObs 2839
%RMSE 16
R2 0.93
Slope 0.94
YInt 91.38
MeanRelError% 9

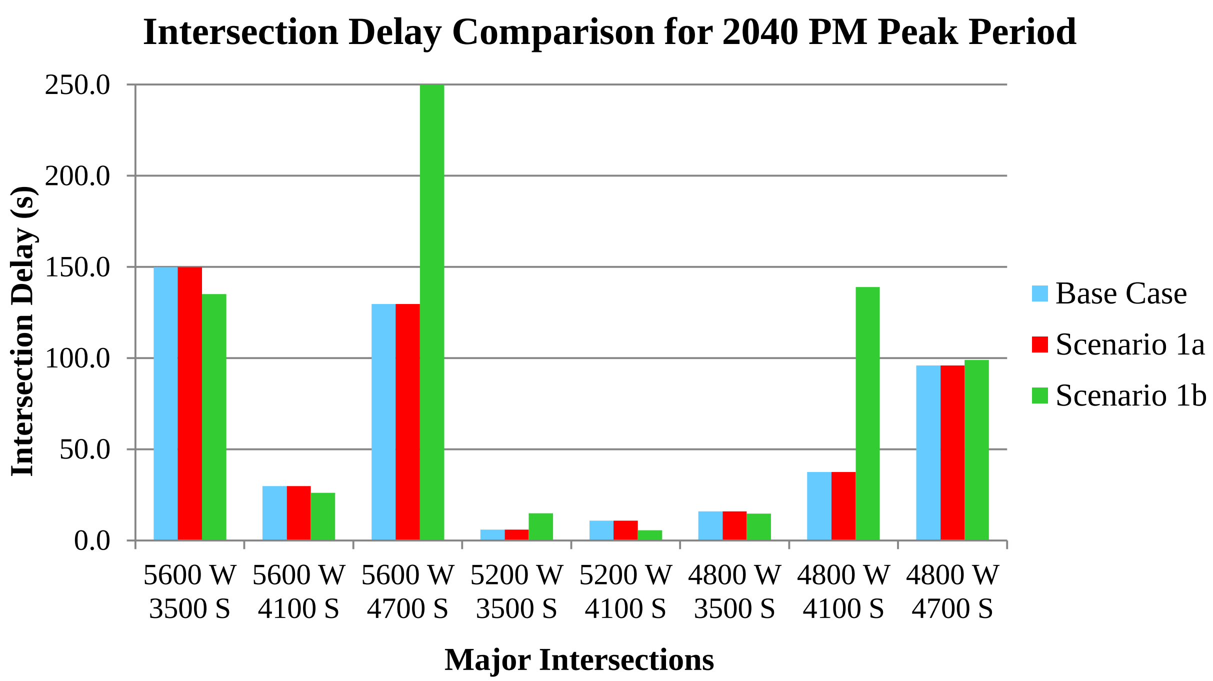
APPENDIX C: VISSIM BASED TRAFFIC ANALYSIS





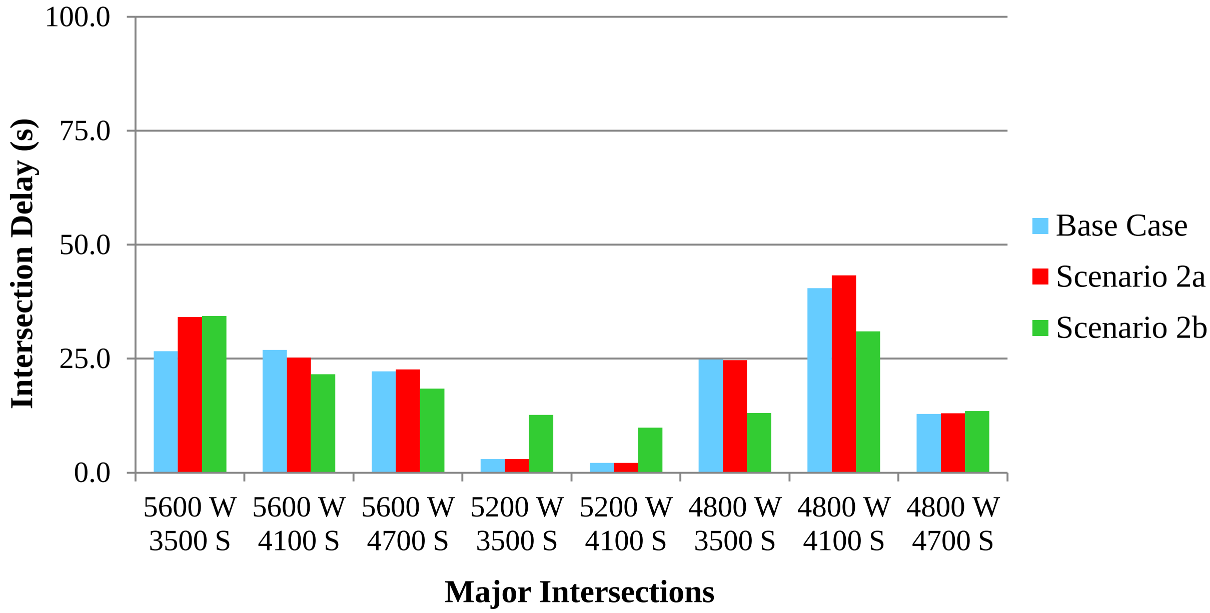


Intersection Delay Comparison for 2009 PM Peak Period
Intersection Delay (s)
250.0
200.0
150.0
100.0
50.0
0.0
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections
Base Case
Scenario 1a
Scenario 1b

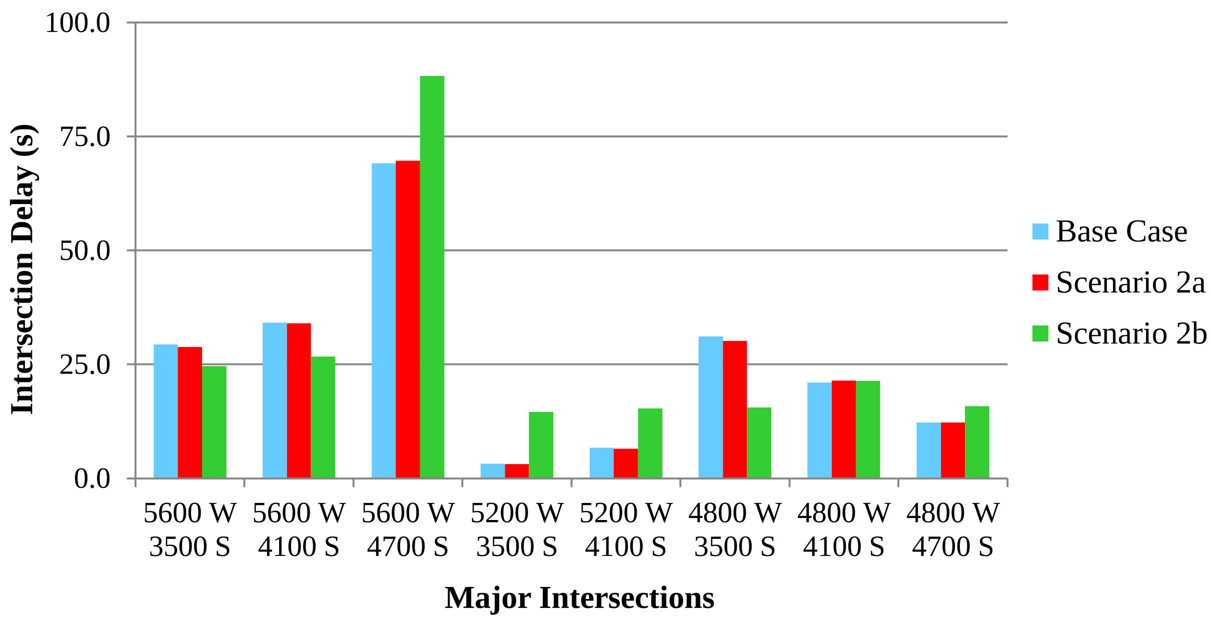


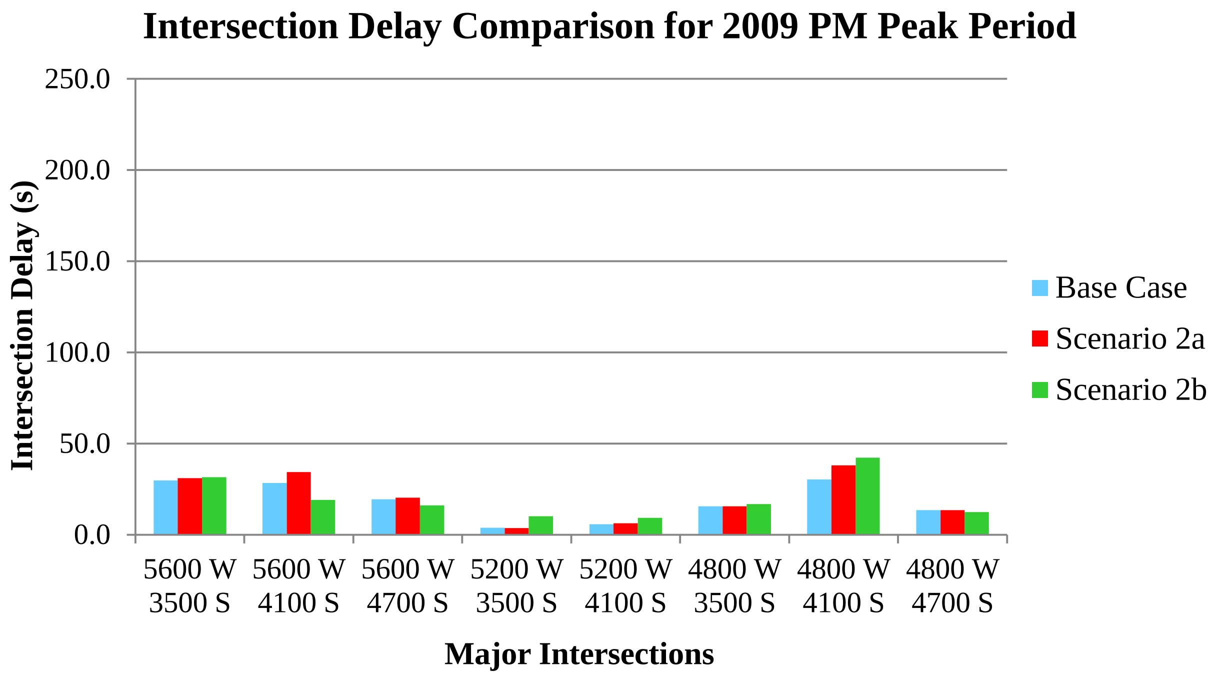
Intersection Delay Comparison for 2040 PM Peak Period
Intersection Delay (s)
250.0
200.0
150.0
100.0
50.0
0.0
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections
Base Case
Scenario 1a
Scenario 1b

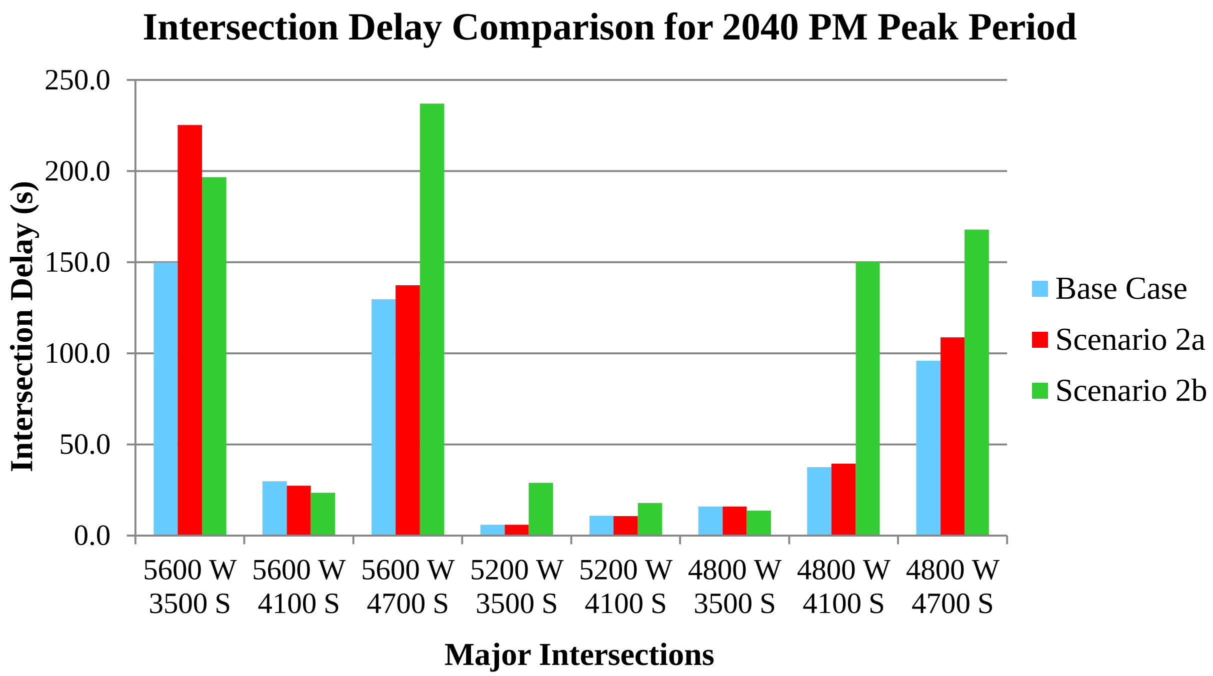
Intersection Delay Comparison for 2009 AM Peak Period

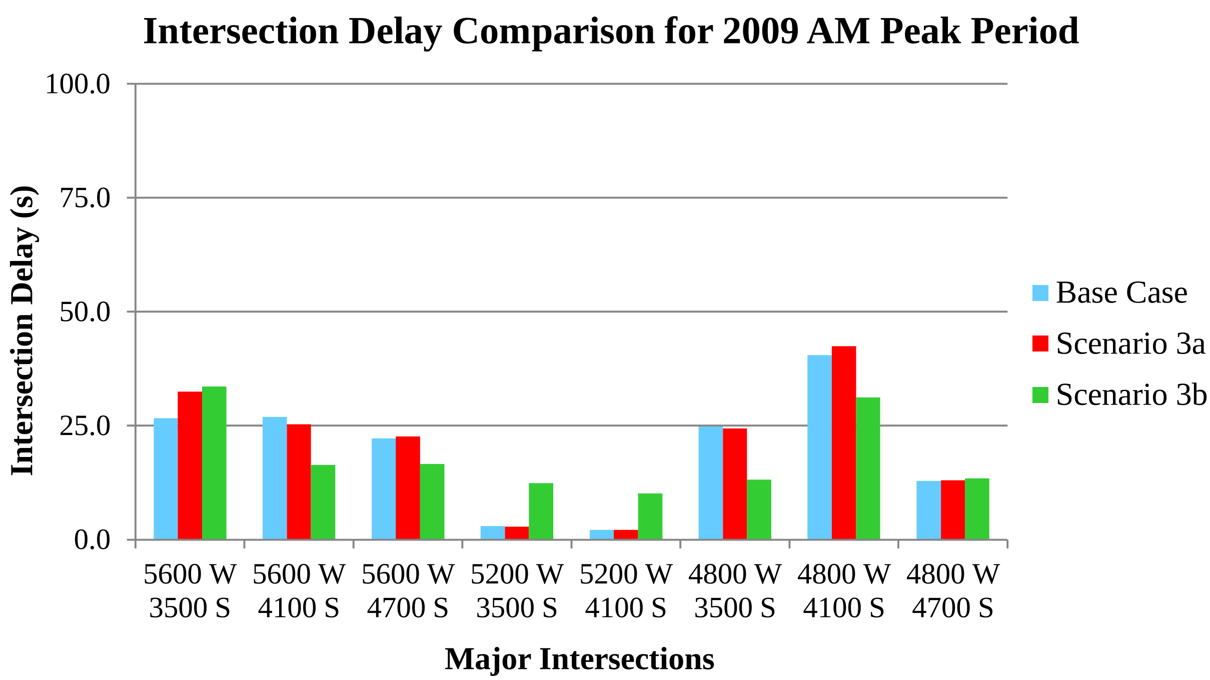


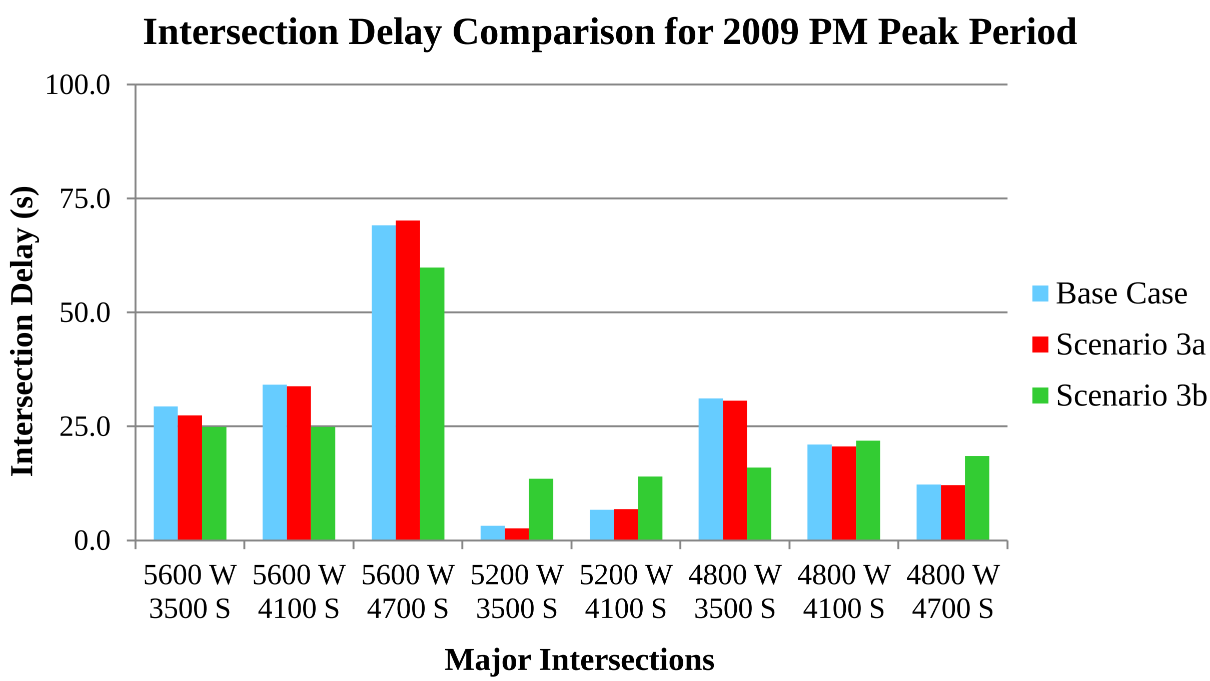
Intersection Delay Comparison for 2040 AM Peak Period

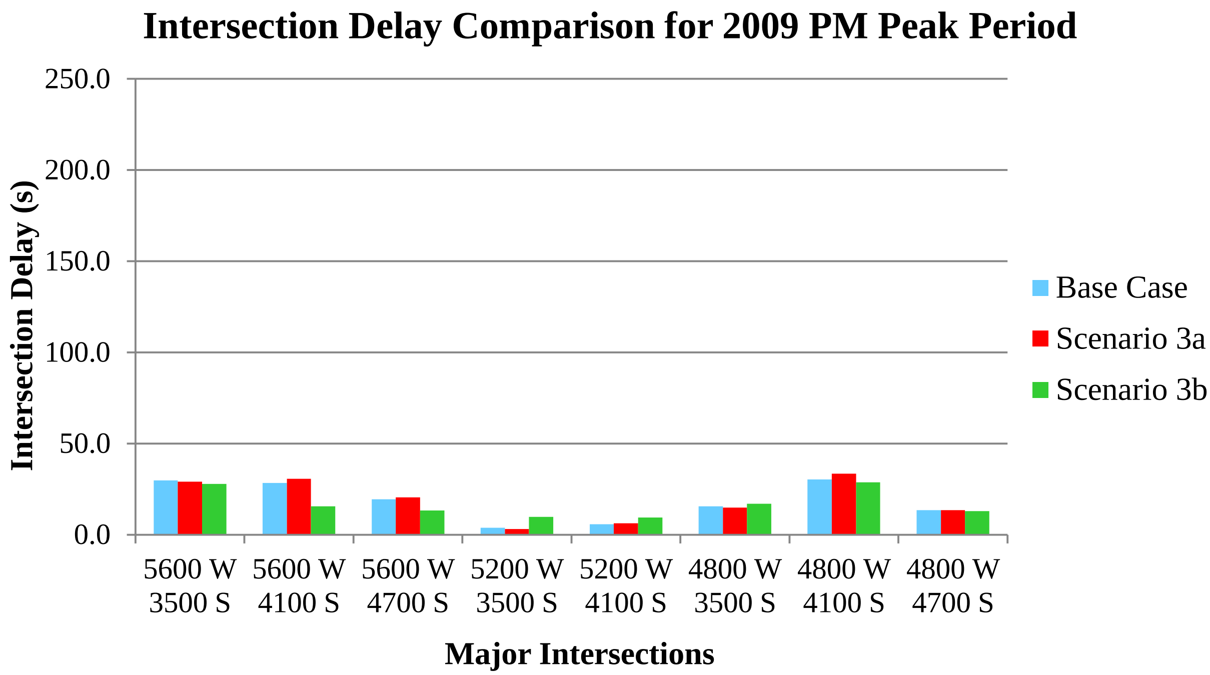


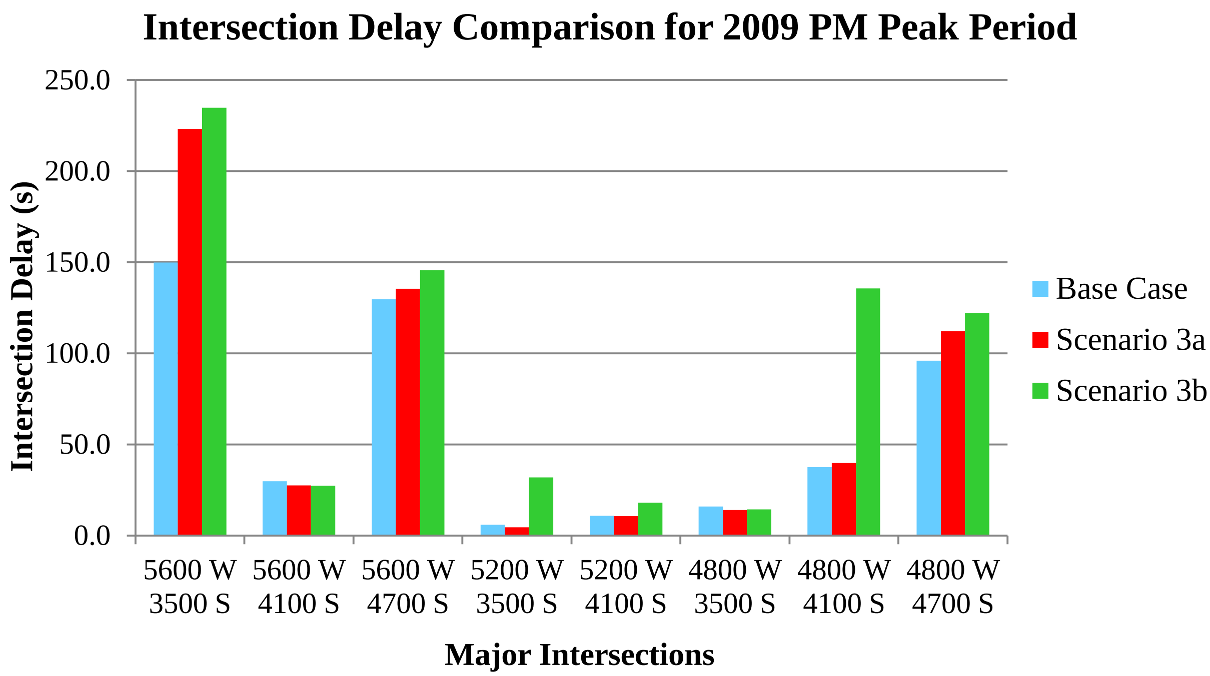

Intersection Delay Comparison for 2009 PM Peak Period
250.0
200.0
150.0
100.0
50.0
0.0
Intersection Delay (s)
Base Case
Scenario 2a
Scenario 2b
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections

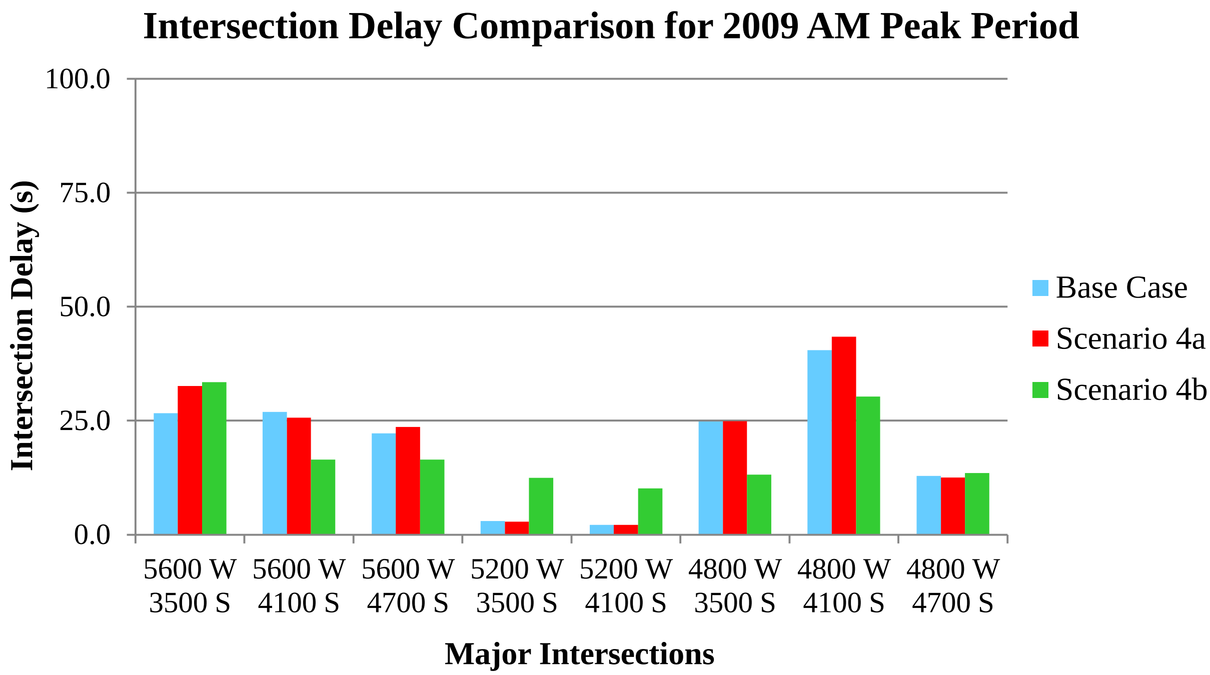

Intersection Delay Comparison for 2040 PM Peak Period
250.0
200.0
150.0
100.0
50.0
0.0
Intersection Delay (s)
Base Case
Scenario 2a
Scenario 2b
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections

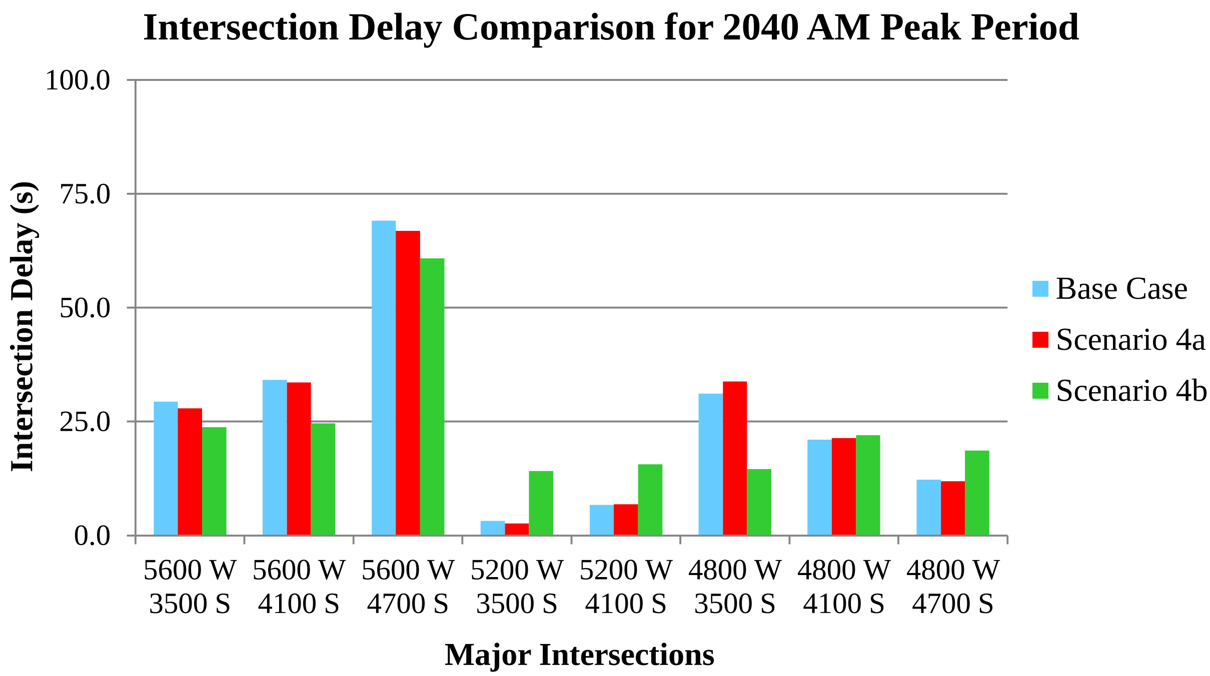

Intersection Delay Comparison for 2009 AM Peak Period
Intersection Delay (s)
100.0
75.0
50.0
25.0
0.0
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections
Base Case
Scenario 3a
Scenario 3b

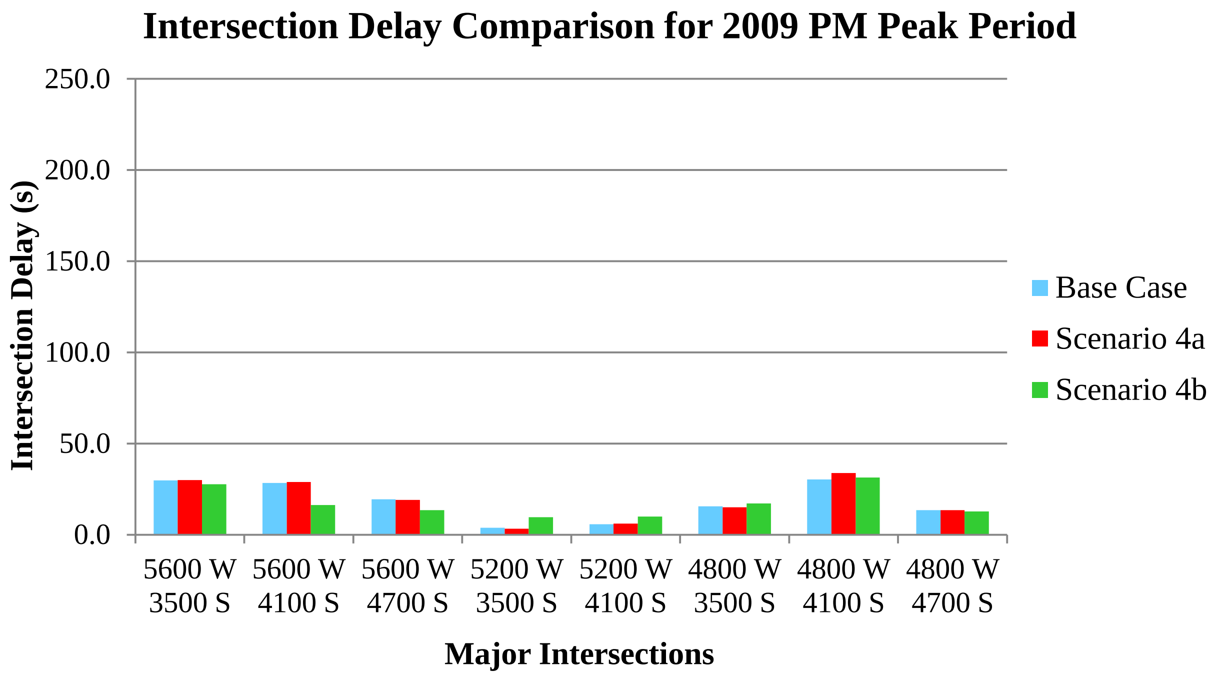

Intersection Delay Comparison for 2009 PM Peak Period
Intersection Delay (s)
100.0
75.0
50.0
25.0
0.0
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections
Base Case
Scenario 3a
Scenario 3b


Intersection Delay Comparison for 2009 PM Peak Period
250.0
200.0
150.0
100.0
50.0
0.0
Intersection Delay (s)
Base Case
Scenario 3a
Scenario 3b
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections

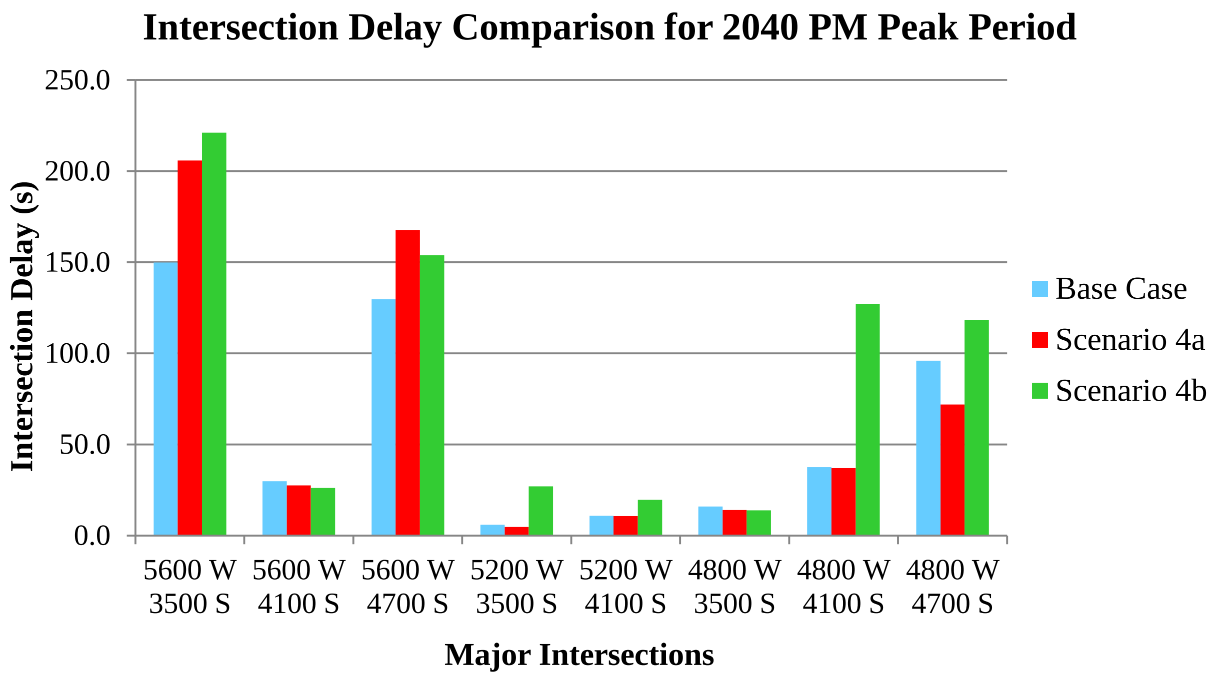

Intersection Delay Comparison for 2009 PM Peak Period
250.0
200.0
150.0
100.0
50.0
0.0
Intersection Delay (s)
Base Case
Scenario 3a
Scenario 3b
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections


Intersection Delay Comparison for 2009 AM Peak Period
100.0
75.0
50.0
25.0
0.0
Intersection Delay (s)
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections
Base Case
Scenario 4a
Scenario 4b

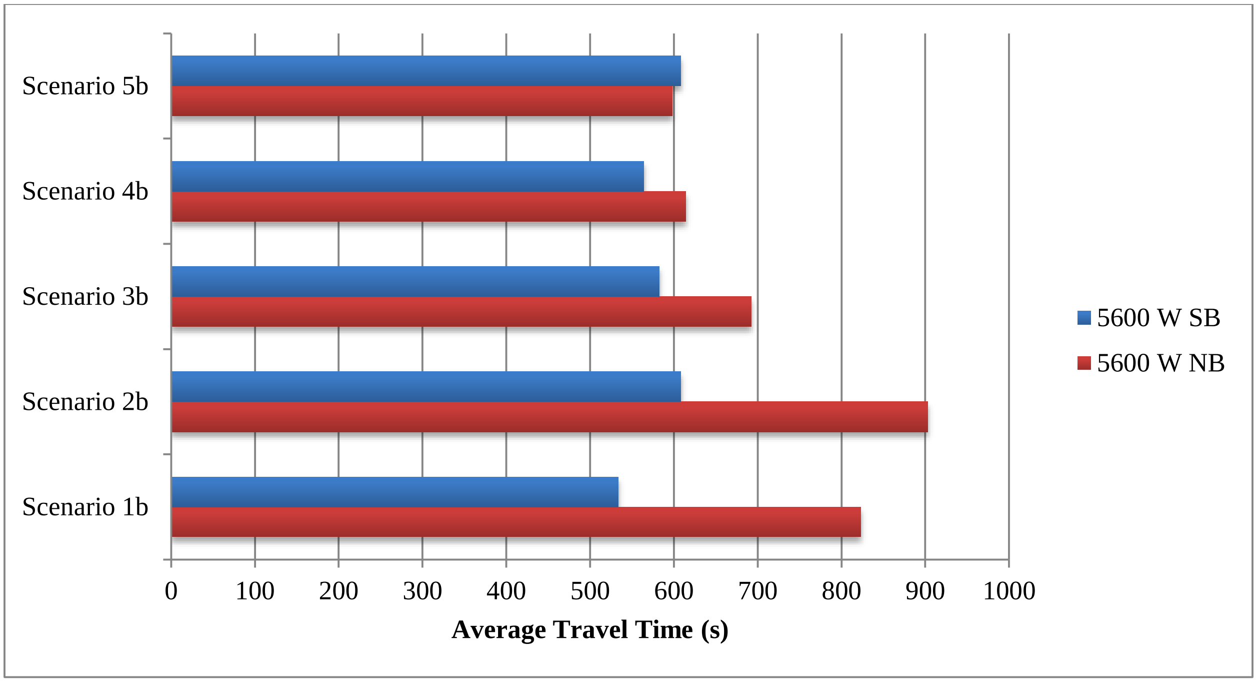

Intersection Delay Comparison for 2040 AM Peak Period
100.0
75.0
50.0
25.0
0.0
Intersection Delay (s)
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections
Base Case
Scenario 4a
Scenario 4b



Intersection Delay Comparison for 2009 PM Peak Period
250.0
200.0
150.0
100.0
50.0
0.0
Intersection Delay (s)
Base Case
Scenario 4a
Scenario 4b
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections



Intersection Delay Comparison for 2040 PM Peak Period
250.0
200.0
150.0
100.0
50.0
0.0
Intersection Delay (s)
Base Case
Scenario 4a
Scenario 4b
5600 W 3500 S
5600 W 4100 S
5600 W 4700 S
5200 W 3500 S
5200 W 4100 S
4800 W 3500 S
4800 W 4100 S
4800 W 4700 S
Major Intersections


Scenario 5b
Scenario 4b
Scenario 3b
Scenario 2b
Scenario 1b
0
100
200
300
400
500
600
700
800
900
1000
Average Travel Time (s)
5600 W SB
5600 W NB

56 W 35 S															
Vehicles	SBL	SBT	SBR	WBL	WBT	WBR	NBL	NBT	NBR	EBL	EBT	EBR	Total	Left Turns	% Left
Base Case	1847	1575	815	441	2592	1312	668	401	84	200	1090	847	11872	3156	26.58
Widening 1	2107	1857	1009	439	2584	1329	671	399	84	210	1056	885	12630	3427	27.13
Connectivity 1	1768	1489	701	454	2588	1416	607	327	68	200	1090	846	11554	3029	26.22
Widening 2	1697	1399	677	441	2589	1312	655	389	85	200	1089	846	11379	2993	26.30
Connectivity 2	1621	1538	624	446	2617	1687	1128	318	66	198	1094	989	12326	3393	27.53
Widening 3	1701	1405	677	436	2583	1327	652	392	85	207	1056	885	11406	2996	26.27
Connectivity 3	1569	1770	660	388	2601	1649	1145	403	80	198	1010	1074	12547	3300	26.30
Widening 4	1719	1423	697	437	2583	1330	677	416	87	208	1056	884	11517	3041	26.40
Connectivity 4	1581	1772	655	385	2586	1643	1136	382	86	198	1006	1073	12503	3300	26.39
Widening 5	1681	1385	662	459	2581	1322	682	414	87	209	1055	886	11423	3031	26.53
Connectivity 5	1521	1712	641	389	2628	1655	1137	388	88	199	1009	1081	12448	3246	26.08
Traffic Calming	1534	1732	642	345	2299	1513	1083	371	85	198	1007	1081	11890	3160	26.58
MUT	0	2566	1544	0	2597	1399	0	1133	440	0	1166	1054	11899	0	0.00
Bowtie	0	1669	2315	0	3062	1451	0	362	593	0	2895	948	13295	0	0.00
Quadrant	0	2108	1027	0	2583	1304	0	585	75	0	1165	851	9698	0	0.00

56 W 41 S															
Vehicles	SBL	SBT	SBR	WBL	WBT	WBR	NBL	NBT	NBR	EBL	EBT	EBR	Total	Left Turns	% Left
Base Case	292	2939	103	428	2742	0	746	1144	157	15	2459	3	11028	1481	13.43
Widening 1	298	3272	105	427	2742	0	745	1141	157	15	2459	3	11364	1485	13.07
Connectivity 1	265	2858	107	336	1412	0	522	941	0	15	2455	3	8914	1138	12.77
Widening 2	552	0	297	0	3102	483	0	0	0	351	2804	0	7589	903	11.90
Connectivity 2	634	2727	93	326	1911	0	500	887	0	15	2457	2	9552	1475	15.44
Widening 3	288	2828	99	427	2745	0	724	1117	151	15	2459	3	10856	1454	13.39
Connectivity 3	252	3369	93	11	1749	0	1032	1298	0	15	2449	5	10273	1310	12.75
Widening 4	288	2843	100	428	2735	0	743	1166	154	15	2457	3	10932	1474	13.48
Connectivity 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Widening 5	285	2825	105	427	2728	0	742	1167	154	15	2457	3	10908	1469	13.47
Connectivity 5	249	3328	93	10	1731	0	972	1194	0	15	2453	5	10050	1246	12.40
Traffic Calming	250	3318	82	10	1254	0	1441	1205	0	21	2433	5	10019	1722	17.19
MUT	508	2926	103	744	2710	0	678	996	145	15	2457	3	11285	1945	17.24
Bowtie	466	2532	98	751	2728	0	630	935	142	15	2457	3	10757	1862	17.31
Quadrant	506	3247	100	432	2724	0	665	970	150	15	2459	3	11271	1618	14.36

56 W 47 S															
Vehicles	SBL	SBT	SBR	WBL	WBT	WBR	NBL	NBT	NBR	EBL	EBT	EBR	Total	Left Turns	% Left
Base Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Widening 1	797	2583	763	2084	587	603	82	1223	2267	445	832	116	12382	3408	27.52
Connectivity 1	867	2281	606	2175	610	513	55	752	1473	439	800	111	10682	3536	33.10
Widening 2	795	2272	597	2049	568	596	72	1151	2189	445	832	117	11683	3361	28.77
Connectivity 2	838	2191	593	2190	626	510	51	644	1444	429	814	111	10441	3508	33.60
Widening 3	794	2286	615	2035	566	594	73	1164	2196	445	832	116	11716	3347	28.57
Connectivity 3	70	2359	644	2232	648	11	94	1156	2522	481	760	110	11087	2877	25.95
Widening 4	796	2317	625	2087	603	594	85	1238	2344	439	823	116	12067	3407	28.23
Connectivity 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Widening 5	795	2286	607	2084	605	597	84	1238	2343	439	823	116	12017	3402	28.31
Connectivity 5	68	2328	640	2235	669	7	93	1141	2514	480	759	110	11044	2876	26.04
Traffic Calming	70	2308	638	2228	653	11	94	1147	2498	480	759	110	10996	2872	26.12
MUT	801	2608	735	2090	592	597	59	966	1731	439	829	117	11564	3389	29.31
Bowtie	784	2341	665	2079	596	568	54	885	1658	439	823	116	11008	3356	30.49
Quadrant	798	2611	723	2088	602	563	62	955	1741	445	832	117	11537	3393	29.41

48 W 47 S														
Vehicles	SBL	SBT	SBR	WBL	WBT	WBR	NBL	NBT	NBR	EBL	EBT	EBR	Total	Left Turns	% Left
Base Case	832	744	161	0	1996	592	1172	321	0	441	1626	1630	9515	2445	25.70
Widening 1	838	746	159	0	1998	590	1161	321	0	441	1624	1632	9510	2440	25.66
Connectivity 1	758	706	147	0	1882	729	1324	359	0	342	1276	1347	8870	2424	27.33
Widening 2	819	750	160	0	1996	591	1110	307	0	439	1593	1601	9366	2368	25.28
Connectivity 2	702	633	143	0	1812	681	1170	319	0	234	1273	1373	8340	2106	25.25
Widening 3	812	743	159	0	1980	586	1101	300	0	440	1594	1604	9319	2353	25.25
Connectivity 3	1072	913	76	0	1593	955	1127	683	0	187	1183	1465	9254	2386	25.78
Widening 4	812	743	159	0	2007	577	1311	357	0	448	1661	1648	9723	2571	26.44
Connectivity 4	1084	910	76	0	1592	953	1124	682	0	190	1167	1451	9229	2398	25.98
Widening 5	804	744	161	0	2019	577	1286	348	0	452	1660	1648	9699	2542	26.21
Connectivity 5	1112	936	0	0	1585	942	1127	679	0	212	1259	1498	9350	2451	26.21
Traffic Calming	1111	918	0	0	1596	958	1118	677	0	255	1259	1497	9389	2484	26.46
MUT	832	785	161	0	2002	596	1173	327	0	366	1388	1428	9058	2371	26.18
Bowtie	543	0	656	0	3098	483	0	0	0	351	2980	0	8111	894	11.02
Quadrant	829	777	160	0	1960	588	1019	294	0	387	1368	1435	8817	2235	25.35

48 W 41 S															
Vehicles	SBL	SBT	SBR	WBL	WBT	WBR	NBL	NBT	NBR	EBL	EBT	EBR	Total	Left Turns	% Left
Base Case	427	1425	475	736	3214	476	204	718	465	857	1699	560	11256	2224	19.76
Widening 1	418	1435	469	737	3214	476	204	715	465	861	1705	558	11257	2220	19.72
Connectivity 1	521	1633	412	593	1409	1563	173	1049	474	722	1484	415	10448	2009	19.23
Widening 2	424	1422	471	737	3214	476	204	718	456	858	1689	557	11226	2223	19.80
Connectivity 2	522	1251	414	512	1413	1487	173	672	307	818	1703	380	9652	2025	20.98
Widening 3	420	1407	477	736	3214	476	204	715	452	857	1692	555	11205	2217	19.79
Connectivity 3	518	990	369	568	1623	1718	0	697	336	715	1784	304	9622	1801	18.72
Widening 4	420	1408	471	736	3214	476	204	744	469	857	1689	560	11248	2217	19.71
Connectivity 4	517	1007	374	580	1657	1756	0	692	341	721	1789	310	9744	1818	18.66
Widening 5	411	1397	462	736	3214	476	204	736	466	860	1694	556	11212	2211	19.72
Connectivity 5	517	1003	373	574	1592	1690	0	710	338	723	1793	312	9625	1814	18.85
Traffic Calming	509	1088	371	565	1586	1687	0	765	386	724	1754	310	9745	1798	18.45
MUT	426	1233	412	736	3224	472	204	685	464	864	1696	769	11185	2230	19.94
Bowtie	0	0	0	580	4194	0	201	0	197	0	2786	204	8162	781	9.57
Quadrant	425	1234	412	737	3220	472	203	672	449	854	1693	764	11135	2219	19.93

48 W 35 S															
Vehicles	SBL	SBT	SBR	WBL	WBT	WBR	NBL	NBT	NBR	EBL	EBT	EBR	Total	Left Turns	% Left
Base Case	185	670	1125	794	3971	215	48	410	653	83	2860	497	11511	1110	9.64
Widening 1	185	670	1125	794	3978	216	49	411	653	90	3062	506	11739	1118	9.52
Connectivity 1	177	711	1178	766	3911	175	0	415	665	71	2828	465	11362	1014	8.92
Widening 2	185	670	1125	792	3971	215	48	410	651	72	2756	481	11376	1097	9.64
Connectivity 2	176	703	1179	651	4072	181	0	391	574	64	2833	448	11272	891	7.90
Widening 3	185	670	1125	796	3978	216	50	409	651	67	2765	453	11365	1098	9.66
Connectivity 3	176	714	1169	651	4073	181	0	415	617	67	2929	231	11223	894	7.97
Widening 4	185	670	1126	797	3978	216	50	419	668	67	2782	454	11412	1099	9.63
Connectivity 4	177	716	1168	649	4063	181	0	422	620	66	2928	236	11226	892	7.95
Widening 5	189	661	1127	796	3978	216	49	416	663	65	2748	448	11356	1099	9.68
Connectivity 5	177	716	1168	650	4064	181	0	422	487	66	3026	228	11185	893	7.98
Traffic Calming	169	709	1123	613	3752	171	0	425	485	65	2982	229	10723	847	7.90
MUT	185	670	1126	796	3970	210	56	405	654	59	1787	247	10165	1096	10.78
Bowtie	185	670	1123	794	3956	213	56	404	649	77	2742	301	11170	1112	9.96
Quadrant	185	670	1125	794	3970	215	55	396	644	38	1487	238	9817	1072	10.92

Base Case

2009 AM

Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
Vehicles	8349	7431	5609	2980	2934	5761	6835	4744	237	508	433	262	713
Delay (s)	26.6	26.9	22.2	3.0	2.1	24.8	40.5	12.9	0.4	2.3	0.7	1.8	1.1
Stop delay (s)	16.4	19.4	14.6	1.1	0.5	13.7	28.6	6.5	0.0	0.0	0.0	0.1	0.0
Stops	0.7	0.6	0.6	0.2	0.1	0.7	1.1	0.6	0.0	0.0	0.0	0.0	0.0
Avg Queue (ft)	46.7	48.2	28.7	1.5	0.4	48.8	111.9	12.8	0.0	0.0	0.0	0.0	0.0
Max Queue (ft)	269.5	291.3	220.5	117.3	54.1	371.2	512.8	167.5	0.0	0.0	0.0	0.0	0.0
LOS	C	C	C	A	A	C	D	B	A	A	A	A	A

2009 PM

Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
Vehicles	9560	8592	7099	4853	4414	7891	9971	5439	484	425	897	423	1029
Delay (s)	29.8	28.3	19.4	3.7	5.8	15.5	30.3	13.4	1.2	2.1	0.7	2.4	1.6
Stop delay (s)	20.8	19.8	12.0	1.2	2.9	8.9	19.3	6.5	0.0	0.0	0.0	0.1	0.0
Stops	0.7	0.7	0.6	0.2	0.2	0.5	0.9	0.6	0.0	0.0	0.0	0.0	0.0
Avg Queue (ft)	60.1	61.6	28.8	2.9	3.4	23.9	94.5	14.0	0.0	0.0	0.0	0.0	0.0
Max Queue (ft)	336.7	343.2	299.9	108.8	123.9	228.5	568.6	168.6	0.0	0.0	0.0	0.0	0.0
LOS	C	C	B	A	A	B	C	B	A	A	A	A	A

2040 AM

Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
Vehicles	6148	7849	9425	4526	5203	6826	8138	7031	676	362	1013	408	886
Delay (s)	29.4	34.1	69.1	3.2	6.7	31.1	21.1	12.3	1.0	1.8	0.4	3.1	1.4
Stop delay (s)	21.2	26.0	21.8	0.9	2.3	18.7	11.4	4.9	0.0	0.0	0.0	0.4	0.0
Stops	0.6	0.7	1.0	0.1	0.3	0.8	0.8	0.5	0.0	0.0	0.0	0.0	0.0
Avg Queue (ft)	43.3	67.2	97.7	1.3	6.9	93.7	41.3	17.6	0.0	0.0	0.0	0.0	0.0
Max Queue (ft)	249.8	343.3	555.0	125.6	345.5	598.9	339.5	191.9	0.0	0.0	0.0	0.0	0.0
LOS	C	C	E	A	A	C	C	B	A	A	A	A	A

2040 PM

Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
Vehicles	11872	11028	12067	8634	7600	11511	11256	9515	1333	215	1685	549	963
Delay (s)	149.8	29.7	129.6	5.9	10.8	15.9	37.5	95.9	1.6	1.9	0.5	3.4	1.5
Stop delay (s)	80.4	19.7	49.3	1.6	3.7	7.9	25.9	47.0	0.0	0.2	0.0	0.6	0.0
Stops	2.7	0.8	2.4	0.2	0.4	0.6	0.9	2.7	0.0	0.0	0.0	0.1	0.0
Avg Queue (ft)	653.9	73.4	685.6	8.1	18.5	31.0	119.4	381.6	0.0	0.0	0.0	0.0	0.0
Max Queue (ft)	1106.7	426.2	1210.5	220.3	390.6	287.8	635.4	1077.2	0.0	0.0	0.0	0.0	0.0
LOS	F	C	F	A	B	B	D	F	A	A	A	A	A

Connectivity 1a

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	8359	7406	5602	3000	2934	5788	6835	4743	237	508	433	262	713
	Delay (s)	18.1	26.9	22.2	2.9	2.1	24.9	43.7	13.0	0.4	2.4	0.8	2.0	1.1
	Stop delay (s)	11.5	19.3	14.6	1.0	0.5	13.9	30.9	6.5	0.0	0.0	0.0	0.2	0.0
	Stops	0.4	0.6	0.6	0.2	0.1	0.7	1.1	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	23.8	47.8	28.6	1.3	0.4	46.9	124.1	12.9	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	228.2	292.1	224.0	98.0	53.2	338.9	539.2	163.6	0.0	0.0	0.0	0.0	0.0
	LOS	B	C	C	A	A	C	D	B	A	A	A	A	A

2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	9550	8624	7057	4869	4428	7899	9964	5385	494	425	907	423	1015
	Delay (s)	26.5	29.7	20.0	3.2	6.3	15.0	33.2	13.6	1.2	2.2	0.8	2.3	1.6
	Stop delay (s)	18.6	20.6	12.0	1.2	3.2	8.8	21.1	6.5	0.0	0.0	0.0	0.1	0.0
	Stops	0.6	0.7	0.6	0.2	0.2	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	51.6	62.0	28.4	2.4	3.9	21.9	108.6	14.2	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	322.7	373.0	251.2	100.1	115.5	234.0	497.4	187.8	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	B	A	A	B	C	B	A	A	A	A	A

2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	6164	7840	9412	4552	5216	6843	8134	7033	681	362	1019	408	887
	Delay (s)	26.7	33.3	69.4	2.8	6.9	31.8	20.6	12.3	1.1	1.9	0.4	2.9	1.4
	Stop delay (s)	19.6	25.2	21.9	0.9	2.3	19.2	11.0	4.9	0.0	0.0	0.0	0.2	0.0
	Stops	0.6	0.7	1.0	0.1	0.3	0.8	0.7	0.5	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	32.0	65.8	99.1	1.2	6.7	90.9	39.2	17.9	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	204.8	351.2	510.4	122.0	338.6	564.8	363.5	270.5	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	E	A	A	C	C	B	A	A	A	A	A

2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	12630	11364	12382	8846	7590	11739	11257	9510	1329	215	1677	549	967
	Delay (s)	76.4	30.0	129.0	4.7	10.5	14.6	41.4	96.0	1.7	1.8	0.5	3.7	1.5
	Stop delay (s)	43.2	19.7	51.3	1.4	3.5	7.5	28.8	47.5	0.0	0.1	0.0	0.7	0.0
	Stops	1.5	0.8	2.4	0.2	0.4	0.6	1.0	2.7	0.0	0.0	0.0	0.1	0.0
	Avg Queue (ft)	468.2	77.2	661.2	5.7	17.8	24.7	142.4	372.2	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	967.2	479.0	1243.8	154.7	414.0	227.1	746.2	1122.8	0.0	0.0	0.0	0.0	0.0
	LOS	E	C	F	A	B	B	D	F	A	A	A	A	A

Connectivity 2a

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	8353	7427	5597	2969	2937	5763	6843	4735	237	508	433	262	713
	Delay (s)	34.1	25.3	22.7	3.0	2.1	24.7	43.3	13.1	0.4	2.3	0.8	1.9	1.1
	Stop delay (s)	21.6	18.5	14.9	1.1	0.5	13.6	30.6	6.5	0.0	0.0	0.0	0.1	0.0
	Stops	0.8	0.6	0.6	0.2	0.1	0.7	1.1	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	76.8	37.2	27.9	1.5	0.4	48.3	124.0	12.7	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	280.5	208.0	212.2	106.1	36.8	368.6	543.6	151.0	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	C	A	A	C	D	B	A	A	A	A	A

2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	9565	8580	7052	4876	4416	7900	9962	5425	484	425	897	423	1028
	Delay (s)	31.1	34.4	20.2	3.6	6.2	15.5	38.1	13.4	1.2	2.1	0.8	2.3	1.5
	Stop delay (s)	21.9	24.7	12.2	1.1	3.1	8.8	24.3	6.5	0.0	0.0	0.0	0.1	0.0
	Stops	0.7	0.8	0.6	0.2	0.2	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	61.2	72.6	28.2	2.9	3.5	23.5	141.2	14.1	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	289.1	410.4	269.2	105.0	99.5	227.7	643.0	176.9	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	C	A	A	B	D	B	A	A	A	A	A

2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	6153	7836	9362	4525	5208	6824	8146	6993	676	362	1012	408	886
	Delay (s)	28.8	34.0	69.7	3.2	6.5	30.1	21.4	12.3	1.0	1.8	0.4	2.9	1.4
	Stop delay (s)	20.6	25.6	22.4	0.9	2.2	17.9	11.6	4.9	0.0	0.0	0.0	0.3	0.0
	Stops	0.6	0.7	1.0	0.1	0.3	0.8	0.8	0.5	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	41.5	63.3	89.4	1.1	6.0	87.6	42.0	17.1	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	242.6	337.1	515.8	110.0	287.4	600.2	338.6	240.8	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	E	A	A	C	C	B	A	A	A	A	A

2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	11379	10783	11683	8472	7589	11376	11226	9366	1333	215	1684	549	963
	Delay (s)	225.3	27.4	137.3	5.9	10.7	15.8	39.4	108.7	1.7	1.8	0.5	3.8	1.4
	Stop delay (s)	131.4	18.1	53.2	1.6	3.8	7.9	27.4	54.4	0.0	0.1	0.0	0.8	0.0
	Stops	4.3	0.7	2.7	0.2	0.4	0.6	0.9	3.0	0.0	0.0	0.0	0.1	0.0
	Avg Queue (ft)	633.7	59.4	523.1	7.2	18.6	30.6	131.0	400.6	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	1050.3	375.4	946.3	209.3	431.7	291.2	729.7	1239.9	0.0	0.0	0.0	0.0	0.0
	LOS	F	C	F	A	B	B	D	F	A	A	A	A	A

Connectivity 3a

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	8362	7404	5588	2990	2938	5793	6835	4734	237	508	433	262	713
	Delay (s)	32.5	25.3	22.7	2.9	2.1	24.4	42.5	13.0	0.4	2.3	0.8	1.9	1.1
	Stop delay (s)	21.1	18.6	14.8	1.0	0.5	13.8	29.8	6.4	0.0	0.0	0.0	0.1	0.0
	Stops	0.8	0.6	0.6	0.2	0.1	0.7	1.1	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	68.1	37.1	27.7	1.3	0.3	46.0	119.9	12.6	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	240.9	211.8	217.3	87.9	37.3	364.5	532.9	151.7	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	C	A	A	C	D	B	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	9560	8624	7108	4889	4431	7897	9964	5426	494	425	907	423	1015
	Delay (s)	29.0	30.7	20.4	3.1	6.3	14.8	33.5	13.4	1.2	2.1	0.8	2.3	1.6
	Stop delay (s)	20.5	21.9	12.2	1.1	3.1	8.7	21.4	6.4	0.0	0.1	0.0	0.1	0.0
	Stops	0.7	0.7	0.6	0.1	0.2	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	55.4	61.7	28.8	2.4	3.8	21.2	111.3	14.1	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	351.0	316.8	229.6	85.7	171.0	241.8	565.9	175.1	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	C	A	A	B	C	B	A	A	A	A	A
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	6166	7825	9350	4550	5215	6851	8138	6988	681	362	1018	408	887
	Delay (s)	27.4	33.8	70.2	2.6	6.9	30.7	20.6	12.1	1.1	1.8	0.4	2.9	1.4
	Stop delay (s)	20.1	25.5	22.7	0.8	2.3	18.9	10.9	4.8	0.0	0.0	0.0	0.2	0.0
	Stops	0.6	0.7	0.9	0.1	0.3	0.7	0.7	0.5	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	32.2	63.4	91.6	1.1	6.6	85.2	39.6	16.5	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	213.6	325.4	501.0	91.7	328.2	560.6	346.6	216.9	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	E	A	A	C	C	B	A	A	A	A	A
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	11406	10856	11716	8440	7584	11365	11205	9319	1330	215	1675	548	968
	Delay (s)	223.3	27.5	135.4	4.4	10.5	14.0	39.8	112.1	1.6	1.8	0.6	3.6	1.4
	Stop delay (s)	131.9	18.2	50.4	1.3	3.6	7.4	27.5	56.2	0.0	0.1	0.0	0.6	0.0
	Stops	4.2	0.7	2.7	0.2	0.4	0.5	1.0	3.1	0.0	0.0	0.0	0.1	0.0
	Avg Queue (ft)	594.2	60.3	534.9	4.9	18.4	23.5	129.6	405.9	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	863.0	373.2	933.8	126.3	397.9	214.0	686.0	1287.2	0.0	0.0	0.0	0.0	0.0
	LOS	F	C	F	A	B	B	D	F	A	A	A	A	A

Connectivity 4a

1	2	3	4	5	6	7	8	9	10	11	12	13
5600 W	5600 W	5600 W	5200 W	5200 W	4800 W	4800 W	4800 W	5200 W	4980 W	5200 W	5400 W	5215 W
3500 S	4100 S	4700 S	3500 S	4100 S	3500 S	4100 S	4700 S	3745 S	3725 S	4025 S	4210 S	4415 S
8352	7400	5570	2985	2936	5797	6853	4737	237	508	433	262	711
32.6	25.7	23.6	2.8	2.1	24.9	43.4	12.5	0.5	2.3	0.8	1.8	1.1
21.0	18.8	15.7	1.0	0.5	14.0	30.4	6.2	0.0	0.0	0.0	0.1	0.0
0.8	0.6	0.6	0.2	0.1	0.7	1.1	0.6	0.0	0.0	0.0	0.0	0.0
71.2	37.9	29.3	1.4	0.4	48.3	125.9	11.0	0.0	0.0	0.0	0.0	0.0
236.8	206.8	246.9	95.2	37.4	364.8	497.3	146.0	0.0	0.0	0.0	0.0	0.0
C	C	C	A	A	C	D	B	A	A	A	A	A

1	2	3	4	5	6	7	8	9	10	11	12	13
5600 W	5600 W	5600 W	5200 W	5200 W	4800 W	4800 W	4800 W	5200 W	4980 W	5200 W	5400 W	5215 W
3500 S	4100 S	4700 S	3500 S	4100 S	3500 S	4100 S	4700 S	3745 S	3725 S	4025 S	4210 S	4415 S
9553	8622	7097	4890	4419	7907	9990	5429	487	425	900	423	1014
29.9	28.8	19.1	3.2	6.1	15.0	33.8	13.5	1.3	2.1	0.8	2.3	1.6
21.2	20.4	11.2	1.2	3.0	8.8	21.4	6.5	0.0	0.0	0.0	0.1	0.0
0.7	0.7	0.5	0.2	0.2	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.0
58.2	57.2	25.5	2.5	3.6	21.9	116.1	13.5	0.0	0.0	0.0	0.0	0.0
343.6	271.9	231.5	87.8	117.6	252.6	629.0	173.9	0.0	0.0	0.0	0.0	0.0
C	C	B	A	A	B	C	B	A	A	A	A	A

1	2	3	4	5	6	7	8	9	10	11	12	13
5600 W	5600 W	5600 W	5200 W	5200 W	4800 W	4800 W	4800 W	5200 W	4980 W	5200 W	5400 W	5215 W
3500 S	4100 S	4700 S	3500 S	4100 S	3500 S	4100 S	4700 S	3745 S	3725 S	4025 S	4210 S	4415 S
6165	7817	9341	4554	5212	6850	8176	6986	676	362	1014	408	889
27.9	33.6	66.9	2.7	6.8	33.8	21.4	11.9	1.0	1.8	0.4	3.0	1.5
20.4	25.3	20.5	0.8	2.3	21.0	11.5	4.7	0.0	0.0	0.0	0.3	0.0
0.6	0.7	0.8	0.1	0.3	0.8	0.8	0.5	0.0	0.0	0.0	0.0	0.0
33.2	62.6	77.8	0.9	6.6	102.6	44.1	13.2	0.0	0.0	0.0	0.0	0.0
199.0	312.1	471.6	103.6	354.1	540.7	461.6	202.9	0.0	0.0	0.0	0.0	0.0
C	C	E	A	A	C	C	B	A	A	A	A	A

1	2	3	4	5	6	7	8	9	10	11	12	13
5600 W	5600 W	5600 W	5200 W	5200 W	4800 W	4800 W	4800 W	5200 W	4980 W	5200 W	5400 W	5215 W
3500 S	4100 S	4700 S	3500 S	4100 S	3500 S	4100 S	4700 S	3745 S	3725 S	4025 S	4210 S	4415 S
11517	10932	12067	8469	7595	11412	11248	9723	1335	215	1682	549	966
205.9	27.5	167.7	4.6	10.7	14.0	36.9	71.9	1.6	1.8	0.5	3.6	1.5
121.8	18.0	78.3	1.4	3.6	7.4	25.3	33.0	0.0	0.1	0.0	0.7	0.0
4.0	0.7	2.8	0.2	0.4	0.5	0.9	2.1	0.0	0.0	0.0	0.1	0.0
590.0	60.1	501.0	5.1	18.1	23.5	119.5	326.8	0.0	0.0	0.0	0.0	0.0
928.5	378.2	858.9	155.4	435.4	201.3	628.7	654.1	0.0	0.0	0.0	0.0	0.0
F	C	F	A	B	B	D	E	A	A	A	A	A

Connectivity 5a

2009 AM														
	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	8370	7401	5573	2999	2941	5813	6844	4735	239	507	435	262	713
	Delay (s)	32.0	25.6	23.1	2.9	2.1	21.9	29.1	12.3	0.4	2.4	0.7	1.9	1.1
	Stop delay (s)	20.6	18.8	15.3	1.1	0.5	12.8	21.1	5.8	0.0	0.0	0.0	0.1	0.0
	Stops	0.8	0.6	0.6	0.2	0.1	0.7	0.8	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	67.2	38.0	28.6	1.4	0.3	25.3	44.5	9.8	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	246.6	213.5	210.1	81.4	37.4	190.6	263.9	115.3	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	C	A	A	C	C	B	A	A	A	A	A

2009 PM														
	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	9561	8608	7091	4865	4422	7903	9991	5442	488	423	900	423	1017
	Delay (s)	29.4	31.3	19.2	3.3	6.1	14.2	25.9	13.5	1.2	2.3	0.8	2.3	1.5
	Stop delay (s)	20.9	22.4	11.3	1.2	3.0	8.6	16.8	6.2	0.0	0.0	0.0	0.1	0.0
	Stops	0.7	0.8	0.5	0.2	0.2	0.5	0.8	0.6	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	56.1	62.0	25.9	2.6	3.6	14.9	53.6	13.8	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	428.0	268.0	238.4	94.7	117.0	171.7	313.5	185.6	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	B	A	A	B	C	B	A	A	A	A	A

2040 AM														
	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	6162	7809	9316	4551	5210	6871	8132	6978	676	364	1014	408	889
	Delay (s)	28.2	33.9	66.9	2.8	6.8	18.7	18.7	12.7	1.0	1.9	0.4	2.9	1.5
	Stop delay (s)	20.8	25.6	20.5	0.8	2.2	11.7	10.3	5.0	0.0	0.0	0.0	0.3	0.0
	Stops	0.6	0.7	0.9	0.1	0.3	0.5	0.7	0.5	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	33.0	63.8	73.3	1.2	6.5	27.3	29.3	14.2	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	208.9	331.0	410.6	104.0	333.1	216.6	270.8	179.1	0.0	0.0	0.0	0.0	0.0
	LOS	C	C	E	A	A	B	B	B	A	A	A	A	A

2040 PM														
	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S
	Vehicles	11423	10908	12017	8416	7581	11356	11212	9699	1334	213	1683	549	961
	Delay (s)	227.1	26.9	165.8	4.5	10.5	13.4	29.2	70.0	1.6	2.1	0.5	3.7	1.4
	Stop delay (s)	133.9	17.7	79.7	1.3	3.6	7.1	20.0	30.4	0.0	0.1	0.0	0.7	0.0
	Stops	4.3	0.7	2.7	0.2	0.4	0.5	0.8	2.1	0.0	0.0	0.0	0.1	0.0
	Avg Queue (ft)	588.7	58.5	493.3	5.2	19.6	18.7	73.3	309.9	0.0	0.0	0.0	0.0	0.0
	Max Queue (ft)	862.3	414.3	790.0	133.6	441.3	172.5	465.5	480.4	0.0	0.0	0.0	0.0	0.0
	LOS	F	C	F	A	B	B	C	E	A	A	A	A	A

Connectivity 1b

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	8473	7171	5466	3163	2481	5767	6792	4689	535	0	225	179	743	4707	3220	806	2651	3533	2888
	Delay (s)	32.8	21.6	17.7	12.1	1.2	13.8	34.0	13.3	0.6	0.0	0.1	2.0	1.2	4.3	2.2	1.0	0.6	8.3	6.7
	Stop delay (s)	22.7	12.0	11.1	6.8	0.1	6.2	22.4	6.0	0.0	0.0	0.0	0.0	0.0	1.4	0.1	0.0	0.0	2.5	2.3
	Stops	0.7	0.7	0.6	0.4	0.0	0.6	1.0	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.4	0.3
	Avg Queue (ft)	59.4	182.2	20.9	11.7	0.1	19.5	73.8	13.8	0.0	0.0	0.0	0.0	0.0	3.6	0.8	0.0	0.0	6.1	4.5
	Max Queue (ft)	306.4	376.8	190.3	148.8	39.3	209.5	440.8	166.4	0.0	0.0	0.0	0.0	0.0	209.0	60.5	0.0	0.0	150.1	128.7
	LOS	C	C	B	B	A	B	C	B	A	N/A	A	A	A	A	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	9533	8137	7080	4927	3499	7659	10075	5425	743	0	534	117	1069	4982	4133	1360	2971	4583	4306
	Delay (s)	26.8	18.3	15.7	9.8	4.2	17.7	38.7	12.8	0.8	0.0	0.1	1.8	0.7	4.2	4.9	0.8	0.8	10.1	6.7
	Stop delay (s)	15.9	10.2	8.2	4.8	1.1	11.6	21.5	5.2	0.0	0.0	0.0	0.1	0.0	1.0	0.5	0.0	0.0	2.5	1.4
	Stops	0.8	0.7	0.6	0.4	0.2	0.5	1.1	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.5	0.3
	Avg Queue (ft)	60.1	31.9	24.2	11.5	2.1	30.3	148.6	13.2	0.0	0.0	0.0	0.0	0.0	2.9	1.4	0.0	0.0	6.7	4.1
	Max Queue (ft)	411.3	262.8	251.7	144.2	89.2	266.4	881.6	148.2	0.0	0.0	0.0	0.0	0.0	151.8	139.7	0.0	0.0	174.4	149.0
	LOS	C	B	B	A	A	B	D	B	A	N/A	A	A	A	A	A	A	A	A	A
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	6509	7812	9686	5163	4516	6903	8351	7148	899	0	581	167	912	3005	3384	1205	5246	3590	3110
	Delay (s)	23.1	31.8	78.3	12.4	5.5	15.1	32.6	17.4	0.8	0.0	0.1	2.0	1.3	3.7	2.3	0.8	1.5	8.3	7.6
	Stop delay (s)	14.3	20.4	20.7	5.5	1.4	7.1	20.0	6.9	0.0	0.0	0.0	0.0	0.0	0.6	0.1	0.0	0.0	1.5	2.1
	Stops	0.7	0.8	1.4	0.5	0.2	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.4
	Avg Queue (ft)	32.9	332.8	403.4	14.6	4.9	31.8	99.3	38.8	0.0	0.0	0.0	0.0	0.0	1.5	0.5	0.0	0.0	4.7	5.8
	Max Queue (ft)	226.6	716.2	1107.7	208.0	244.4	317.9	469.6	524.1	0.0	0.0	0.0	0.0	0.0	148.9	140.7	0.0	19.1	187.6	121.4
	LOS	C	C	E	B	A	B	C	B	A	N/A	A	A	A	A	A	A	A	A	A
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	11554	8914	10682	9180	5189	11362	10448	8870	1832	0	935	325	1057	4889	4723	3070	6248	5122	3987
	Delay (s)	135.0	26.0	249.9	14.8	5.6	14.7	139.0	99.0	1.5	0.0	0.1	2.0	1.0	8.1	4.2	0.9	118.6	18.5	6.7
	Stop delay (s)	90.1	17.1	129.1	8.0	1.6	7.3	54.6	44.9	0.0	0.0	0.0	0.0	0.0	2.7	0.2	0.0	27.3	6.5	1.5
	Stops	2.1	0.7	5.7	0.4	0.2	0.5	2.7	2.9	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	2.7	0.7	0.2
	Avg Queue (ft)	652.2	142.9	762.8	24.6	4.4	30.4	556.9	388.7	0.0	0.0	0.0	0.0	0.0	9.1	0.8	0.0	713.2	33.7	4.3
	Max Queue (ft)	1053.5	562.9	1186.9	377.1	201.8	306.7	991.8	916.9	0.0	0.0	0.0	0.0	0.0	209.4	93.6	0.0	917.0	679.7	208.9
	LOS	F	C	F	B	A	B	F	F	A	N/A	A	A	A	A	A	A	F	B	A

Connectivity 2b

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	8971	7283	5495	3840	3926	5918	6590	4692	1207	0	1213	26	1677	4892	3172	1783	3287	3279	2322
	Delay (s)	34.4	21.6	18.4	12.7	9.8	13.1	31.0	13.5	0.4	0.0	0.2	1.2	2.4	4.1	2.2	1.6	0.9	8.4	1.8
	Stop delay (s)	23.5	12.0	11.6	7.0	4.7	6.1	20.7	6.2	0.0	0.0	0.0	0.0	0.0	1.3	0.1	0.1	0.0	2.7	0.3
	Stops	0.8	0.7	0.7	0.4	0.4	0.5	0.9	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.4	0.1
	Avg Queue (ft)	68.3	129.8	22.4	12.1	12.0	18.3	56.4	13.9	0.0	0.0	0.0	0.0	0.0	2.9	0.7	0.0	0.0	6.2	0.4
	Max Queue (ft)	425.4	337.9	185.8	147.3	157.4	261.6	380.4	156.8	0.0	0.0	0.0	0.0	0.0	174.1	59.6	0.0	0.0	153.9	92.3
	LOS	C	C	B	B	A	B	C	B	A	N/A	A	A	A	A	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	10442	8551	7103	5633	5785	7842	9584	5363	1405	0	1846	7	2462	5494	4080	2633	3437	4046	3177
	Delay (s)	31.5	19.0	16.1	10.0	9.2	16.8	42.2	12.4	0.7	0.0	0.2	1.9	2.3	3.9	4.6	1.5	1.0	9.3	3.2
	Stop delay (s)	18.8	10.8	8.3	5.1	3.5	10.9	24.0	4.7	0.0	0.0	0.0	0.0	0.0	0.9	0.4	0.0	0.0	2.3	0.5
	Stops	0.9	0.7	0.6	0.4	0.4	0.5	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.4	0.1
	Avg Queue (ft)	92.9	34.5	26.0	11.0	8.6	29.2	142.2	12.1	0.0	0.0	0.0	0.0	0.0	2.9	1.3	0.0	0.0	5.4	1.1
	Max Queue (ft)	641.9	324.9	230.7	137.8	155.8	248.4	914.0	168.2	0.0	0.0	0.0	0.0	0.0	211.9	90.2	7.7	0.0	153.3	121.3
	LOS	C	B	B	A	A	B	D	B	A	N/A	A	A	A	A	A	A	A	A	A
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	7216	8296	9499	5793	6834	7001	8006	6956	1542	0	1873	8	2509	3352	3212	2466	5651	3194	2294
	Delay (s)	24.6	26.7	88.3	14.6	15.3	15.6	21.4	15.8	0.7	0.0	0.2	1.2	4.2	3.6	2.4	1.6	1.7	7.8	2.5
	Stop delay (s)	15.2	17.7	22.1	7.2	7.4	7.7	12.4	6.5	0.0	0.0	0.0	0.0	0.0	0.6	0.1	0.0	0.1	1.5	0.3
	Stops	0.7	0.7	1.7	0.5	0.6	0.5	0.7	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.1
	Avg Queue (ft)	38.7	79.4	511.7	19.0	29.1	35.2	40.1	29.6	0.0	0.0	0.0	0.0	0.0	1.1	0.5	0.0	0.1	3.8	0.6
	Max Queue (ft)	231.7	359.4	1017.1	244.0	340.9	427.6	382.6	440.4	0.0	0.0	0.0	0.0	0.0	75.1	100.0	9.8	82.3	105.4	72.4
	LOS	C	C	F	B	B	B	C	B	A	N/A	A	A	A	A	A	A	A	A	A
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	12326	9552	10441	9666	8162	11272	9652	8340	2507	0	2645	10	3361	5592	4484	4660	6584	4440	0
	Delay (s)	196.8	23.5	237.1	28.8	17.9	13.6	150.3	168.0	1.5	0.0	0.3	1.8	3.4	8.0	3.9	2.0	133.3	13.6	0.0
	Stop delay (s)	116.3	15.0	118.1	16.5	9.3	6.7	58.7	84.1	0.0	0.0	0.0	0.0	0.0	2.2	0.3	0.1	33.8	4.7	0.0
	Stops	3.0	0.7	5.6	0.7	0.6	0.5	3.0	4.5	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	3.1	0.6	0.0
	Avg Queue (ft)	777.7	50.9	724.6	71.2	35.3	27.8	559.2	566.0	0.0	0.0	0.0	0.0	0.0	7.7	0.9	0.0	671.2	15.2	0.0
	Max Queue (ft)	1366.7	342.0	1198.2	479.8	394.3	321.0	851.3	1166.1	0.0	0.0	0.0	0.0	0.0	225.2	165.4	24.7	811.4	242.5	0.0
	LOS	F	C	F	C	B	B	F	F	A	N/A	A	A	A	A	A	A	F	B	N/A

Connectivity 3b

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	8964	6991	4686	3735	3458	5869	6506	4666	1154	0	1174	0	3817	4980	3603	1699	2667	3195	3339
	Delay (s)	33.6	16.4	16.6	12.4	10.1	13.2	31.2	13.5	0.4	0.0	0.2	0.0	3.1	4.2	6.9	1.5	1.0	8.3	5.1
	Stop delay (s)	22.9	9.7	10.9	6.8	5.1	6.1	21.0	6.2	0.0	0.0	0.0	0.0	0.1	1.3	2.7	0.0	0.0	2.6	0.8
	Stops	0.8	0.6	0.6	0.4	0.4	0.5	0.9	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.4	0.3
	Avg Queue (ft)	65.6	27.1	19.0	11.7	11.9	18.7	57.3	13.4	0.0	0.0	0.0	0.0	0.0	3.5	4.1	0.0	0.0	5.6	1.5
	Max Queue (ft)	373.8	246.2	179.5	148.7	162.6	186.3	387.8	150.1	0.0	0.0	0.0	0.0	25.6	185.2	101.1	0.0	0.0	138.2	89.3
	LOS	C	B	B	B	B	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A

2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	10257	7784	5489	5254	4797	7363	8837	5010	1247	0	1689	71	5194	5464	4754	2319	1734	3501	4809
	Delay (s)	27.8	15.5	13.2	9.7	9.4	16.9	28.7	12.9	0.8	0.0	0.3	4.6	3.3	3.9	8.2	1.4	0.8	8.8	7.4
	Stop delay (s)	16.5	8.2	6.8	4.9	3.7	11.2	16.5	4.6	0.0	0.0	0.0	0.0	0.1	0.8	2.4	0.0	0.0	2.1	1.3
	Stops	0.8	0.6	0.5	0.4	0.4	0.5	0.9	0.6	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.0	0.4	0.4
	Avg Queue (ft)	69.6	26.1	16.0	9.8	6.6	27.3	78.5	14.8	0.0	0.0	0.0	0.0	0.0	2.9	4.3	0.0	0.0	4.5	3.6
	Max Queue (ft)	445.7	248.8	169.7	154.4	123.8	254.2	714.6	199.1	0.0	0.0	0.0	0.0	39.2	183.7	125.0	0.0	0.0	139.4	123.5
	LOS	C	B	B	A	A	B	C	B	A	N/A	A	A	A	A	A	A	A	A	A

2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	7376	8285	9910	5642	6132	6895	7664	7323	1532	0	1922	0	4301	3610	4344	2427	5522	3010	3103
	Delay (s)	24.9	24.9	59.9	13.5	14.0	16.0	21.9	18.5	0.7	0.0	0.2	0.0	6.2	3.7	6.4	1.5	2.0	8.1	5.6
	Stop delay (s)	15.3	16.4	16.5	6.3	6.4	8.0	12.8	7.8	0.0	0.0	0.0	0.0	0.4	0.5	1.4	0.1	0.1	1.5	1.0
	Stops	0.7	0.6	0.9	0.5	0.5	0.5	0.7	0.7	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.0	0.0	0.3	0.3
	Avg Queue (ft)	39.8	47.7	164.1	15.7	24.5	37.1	38.9	44.4	0.0	0.0	0.0	0.0	2.7	1.3	3.2	0.0	0.2	4.1	2.6
	Max Queue (ft)	254.1	320.3	1036.1	255.1	285.1	492.0	360.8	491.1	0.0	0.0	0.0	0.0	182.3	96.6	146.4	0.0	159.6	180.2	108.4
	LOS	C	C	E	B	B	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A

2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	12547	10273	11087	9492	7617	11223	9622	9254	2542	0	2698	0	6195	6116	6402	4641	6317	4253	4587
	Delay (s)	234.7	27.2	145.6	31.9	18.0	14.3	135.7	122.1	1.5	0.0	0.3	0.0	9.4	38.3	8.5	1.9	119.7	13.4	46.6
	Stop delay (s)	145.1	18.1	46.9	19.3	9.2	6.9	45.7	56.7	0.0	0.0	0.0	0.0	1.5	20.5	2.2	0.1	29.4	4.5	25.3
	Stops	3.5	0.7	3.3	0.7	0.6	0.5	2.5	3.2	0.0	0.0	0.0	0.0	0.2	1.1	0.3	0.0	2.8	0.5	1.3
	Avg Queue (ft)	827.3	66.8	859.7	78.4	31.3	29.6	591.4	529.8	0.0	0.0	0.0	0.0	41.4	67.1	5.6	0.0	539.2	15.7	152.7
	Max Queue (ft)	1242.7	409.5	1209.6	467.9	339.7	320.4	983.8	1396.0	0.0	0.0	0.0	0.0	863.1	655.8	176.0	22.1	766.3	224.6	1023.2
	LOS	F	C	F	C	B	B	F	F	A	N/A	A	N/A	A	D	A	A	F	B	D

Connectivity 4b

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	8924	6943	4680	3742	3465	5878	6507	4667	1159	0	1180	0	3650	4931	3544	1704	2655	3196	3336
	Delay (s)	33.4	16.4	16.5	12.5	10.2	13.2	30.3	13.5	0.4	0.0	0.2	0.0	3.0	4.2	6.9	1.5	0.9	8.4	5.1
	Stop delay (s)	22.8	9.7	10.8	6.9	5.2	6.2	20.3	6.2	0.0	0.0	0.0	0.0	0.1	1.3	2.8	0.0	0.0	2.7	0.8
	Stops	0.8	0.6	0.5	0.4	0.4	0.5	0.9	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.4	0.3
	Avg Queue (ft)	64.4	26.9	18.8	11.7	12.1	18.6	54.2	13.6	0.0	0.0	0.0	0.0	0.1	3.1	4.1	0.0	0.0	5.8	1.6
	Max Queue (ft)	379.4	245.2	166.6	156.2	159.1	179.4	407.4	158.7	0.0	0.0	0.0	0.0	26.7	172.0	121.2	0.0	0.0	139.4	104.0
	LOS	C	B	B	B	B	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A

2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	10318	8054	5674	5359	5003	7662	9112	5270	1337	0	1813	0	5180	5591	4858	2491	1759	3758	5051
	Delay (s)	27.6	16.3	13.4	9.6	10.0	17.0	31.3	12.8	0.8	0.0	0.2	0.0	3.3	3.8	8.9	1.4	0.8	8.9	7.6
	Stop delay (s)	16.3	8.5	7.0	4.8	4.0	11.2	18.2	4.3	0.0	0.0	0.0	0.0	0.2	0.9	2.5	0.0	0.0	2.1	1.4
	Stops	0.8	0.6	0.5	0.4	0.5	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.0	0.4	0.4
	Avg Queue (ft)	69.9	30.4	17.5	9.8	7.6	29.1	90.9	14.4	0.0	0.0	0.0	0.0	0.1	3.0	5.1	0.0	0.0	4.7	4.1
	Max Queue (ft)	483.9	315.0	193.0	138.9	139.4	248.2	700.2	199.5	0.0	0.0	0.0	0.0	22.0	231.1	170.1	0.0	0.0	122.5	137.4
	LOS	C	B	B	A	A	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A

2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	7328	8208	9891	5645	6123	6895	7688	7307	1535	0	1924	0	4118	3567	4269	2426	5478	3009	3104
	Delay (s)	23.7	24.6	60.8	14.1	15.6	14.6	22.0	18.7	0.6	0.0	0.2	0.0	6.1	3.3	6.1	1.5	2.1	8.5	5.7
	Stop delay (s)	14.5	16.2	16.8	6.6	7.8	7.3	12.9	7.8	0.0	0.0	0.0	0.0	0.4	0.5	1.3	0.0	0.1	1.7	1.1
	Stops	0.7	0.6	1.0	0.5	0.6	0.5	0.7	0.7	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.0	0.0	0.4	0.3
	Avg Queue (ft)	37.9	46.7	171.2	17.2	28.6	31.0	40.0	42.6	0.0	0.0	0.0	0.0	2.6	1.0	3.2	0.0	0.5	4.9	2.7
	Max Queue (ft)	226.5	297.3	1040.1	237.4	371.0	295.0	313.8	476.3	0.0	0.0	0.0	0.0	139.6	88.9	151.1	23.3	295.1	212.1	92.2
	LOS	C	C	E	B	B	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A

2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	12503	10141	11061	9512	7637	11226	9744	9229	2552	0	2697	0	5705	6102	6224	4669	6225	4285	0
	Delay (s)	221.1	26.0	153.8	27.0	19.5	13.7	127.2	118.4	1.5	0.0	0.3	0.0	9.3	11.6	8.6	1.9	121.5	13.2	0.0
	Stop delay (s)	136.9	17.2	46.8	16.0	10.6	6.7	41.7	53.6	0.0	0.0	0.0	0.0	1.9	4.0	2.4	0.1	30.9	4.4	0.0
	Stops	3.3	0.7	3.4	0.6	0.6	0.5	2.5	3.1	0.0	0.0	0.0	0.0	0.2	0.4	0.3	0.0	3.0	0.5	0.0
	Avg Queue (ft)	810.1	62.7	861.5	61.1	35.1	27.6	570.2	518.7	0.0	0.0	0.0	0.0	45.9	10.5	6.2	0.0	581.7	15.1	0.0
	Max Queue (ft)	1183.8	462.4	1190.5	403.8	355.1	309.9	861.0	1474.0	0.0	0.0	0.0	0.0	844.1	242.0	219.4	23.2	780.2	197.3	0.0
	LOS	F	C	F	C	B	B	F	F	A	N/A	A	N/A	A	B	A	A	F	B	N/A

Connectivity 5b

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	8942	6942	4682	3504	3452	5875	6523	5020	1146	0	1170	0	3641	4932	3544	1693	2689	2913	3365
	Delay (s)	33.9	16.3	16.6	11.4	10.1	13.3	31.2	14.5	0.4	0.0	0.3	0.0	2.9	4.3	7.1	1.5	1.3	6.6	5.2
	Stop delay (s)	23.1	9.7	10.9	6.4	5.1	6.5	21.0	6.8	0.0	0.0	0.0	0.0	0.1	1.3	2.8	0.0	0.0	1.5	0.8
	Stops	0.8	0.6	0.5	0.4	0.4	0.5	0.9	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.3	0.3
	Avg Queue (ft)	65.9	26.7	19.1	10.4	11.7	18.8	57.0	15.6	0.0	0.0	0.0	0.0	0.0	3.2	4.3	0.0	0.0	3.2	1.8
	Max Queue (ft)	311.1	205.5	172.4	140.3	171.0	226.1	388.7	168.3	0.0	0.0	0.0	0.0	26.6	178.0	126.1	0.0	0.0	147.2	98.3
	LOS	C	B	B	B	A	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	10316	8059	5683	5345	5017	7678	9123	5543	1350	0	1824	0	5190	5585	4868	2501	1783	3525	5057
	Delay (s)	27.9	15.9	13.0	9.4	9.8	17.1	30.4	12.7	0.7	0.0	0.2	0.0	3.4	3.8	8.4	1.5	0.9	7.5	7.5
	Stop delay (s)	16.6	8.2	6.7	4.7	3.8	11.3	17.6	4.5	0.0	0.0	0.0	0.0	0.2	0.9	2.3	0.0	0.0	1.4	1.3
	Stops	0.8	0.6	0.5	0.4	0.4	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.0	0.3	0.4
	Avg Queue (ft)	71.4	28.4	16.4	9.6	7.3	29.4	86.2	13.9	0.0	0.0	0.0	0.0	0.2	3.1	4.6	0.0	0.0	2.8	4.0
	Max Queue (ft)	595.2	300.1	188.7	125.9	135.9	245.7	661.9	189.8	0.0	0.0	0.0	0.0	68.1	193.5	112.8	0.0	0.0	119.4	112.2
	LOS	C	B	B	A	A	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	7308	8208	9911	5163	6115	6913	7682	7463	1536	0	1923	0	4104	3553	4276	2427	5486	2810	3118
	Delay (s)	24.9	24.9	59.9	10.3	15.9	15.7	22.0	26.8	0.6	0.0	0.2	0.0	6.3	3.2	6.5	1.5	2.2	7.2	6.0
	Stop delay (s)	15.4	16.4	16.7	4.6	7.6	8.0	13.1	10.4	0.0	0.0	0.0	0.0	0.4	0.5	1.5	0.0	0.1	0.9	1.1
	Stops	0.7	0.6	0.9	0.4	0.6	0.5	0.7	0.9	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.0	0.0	0.3	0.3
	Avg Queue (ft)	40.3	47.1	159.8	11.0	29.7	34.4	40.0	117.9	0.0	0.0	0.0	0.0	2.6	1.0	3.7	0.0	0.4	2.9	3.2
	Max Queue (ft)	220.9	292.6	1025.5	201.8	322.7	378.4	357.7	767.6	0.0	0.0	0.0	0.0	167.2	115.3	199.0	0.0	288.1	217.0	137.7
	LOS	C	C	E	B	B	B	C	C	A	N/A	A	N/A	A	A	A	A	A	A	A
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	12448	10050	11044	8975	7599	11185	9625	9350	2545	0	2709	0	5742	6023	6189	4631	6235	4101	4676
	Delay (s)	229.2	26.1	138.1	10.7	19.2	14.5	136.9	115.0	1.5	0.0	0.3	0.0	11.7	9.3	8.2	1.8	129.3	11.8	49.2
	Stop delay (s)	138.4	17.1	43.9	5.2	10.2	7.2	47.4	52.3	0.0	0.0	0.0	0.0	3.6	3.1	2.2	0.1	34.1	3.3	25.9
	Stops	3.4	0.7	3.1	0.3	0.7	0.5	2.6	3.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.0	3.1	0.5	1.3
	Avg Queue (ft)	812.3	63.1	836.8	15.1	34.1	30.1	586.1	515.9	0.0	0.0	0.0	0.0	38.1	8.0	5.6	0.0	605.4	11.8	141.6
	Max Queue (ft)	1243.0	415.3	1180.5	256.0	325.2	343.3	876.1	1509.2	0.0	0.0	0.0	0.0	864.6	193.5	188.6	12.2	769.1	236.2	1029.4
	LOS	F	C	F	B	B	B	F	F	A	N/A	A	N/A	B	A	A	A	F	B	D

Traffic Calming

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	8934	6943	4689	3392	3234	5773	6532	5100	1030	0	1045	0	3453	4935	3570	1578	2617	2929	3440
	Delay (s)	33.5	16.2	16.8	11.8	9.5	13.1	33.1	14.5	0.4	0.0	0.3	0.0	3.0	4.1	6.8	1.4	1.3	6.6	5.2
	Stop delay (s)	22.8	9.5	11.1	6.7	4.8	6.4	22.3	6.9	0.0	0.0	0.0	0.0	0.1	1.3	2.6	0.0	0.0	1.6	0.8
	Stops	0.8	0.5	0.6	0.4	0.4	0.5	1.0	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.3	0.3
	Avg Queue (ft)	65.3	27.0	19.2	10.9	9.4	18.2	64.8	16.0	0.0	0.0	0.0	0.0	0.1	3.1	4.0	0.0	0.0	3.2	1.8
	Max Queue (ft)	404.9	242.3	183.5	141.9	159.4	211.8	448.9	170.5	0.0	0.0	0.0	0.0	27.9	177.4	121.7	0.0	0.0	117.8	101.9
	LOS	C	B	B	B	A	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	10321	8060	5691	5295	4739	7620	9183	5618	1298	0	1705	0	4989	5594	4941	2444	1714	3585	5129
	Delay (s)	27.4	15.6	14.0	9.7	9.4	17.3	31.0	13.6	0.7	0.0	0.2	0.0	3.4	3.7	8.8	1.4	0.9	7.8	7.7
	Stop delay (s)	16.4	8.1	7.4	4.9	3.6	11.6	17.9	5.0	0.0	0.0	0.0	0.0	0.3	0.8	2.5	0.0	0.0	1.4	1.5
	Stops	0.8	0.6	0.6	0.4	0.4	0.5	1.0	0.6	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.0	0.3	0.4
	Avg Queue (ft)	66.8	27.9	18.5	10.0	6.5	29.6	91.2	16.1	0.0	0.0	0.0	0.0	0.4	3.0	5.0	0.0	0.0	3.0	4.5
	Max Queue (ft)	509.5	304.2	181.4	131.4	145.5	250.0	713.3	190.1	0.0	0.0	0.0	0.0	71.9	210.0	134.4	7.6	0.0	140.3	134.4
	LOS	C	B	B	A	A	B	C	B	A	N/A	A	N/A	A	A	A	A	A	A	A
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	12236	8982	9697	7958	3883	10606	6704	7857	1725	0	1509	0	3766	5533	5291	3131	5427	3390	3471
	Delay (s)	315.7	308.1	228.2	154.0	289.5	89.7	287.3	230.8	92.6	0.0	268.1	0.0	326.6	228.0	229.3	199.1	106.7	154.4	299.1
	Stop delay (s)	175.8	152.9	92.7	72.6	213.3	27.9	187.3	130.9	85.9	0.0	242.5	0.0	226.8	116.2	145.8	160.1	31.5	106.8	212.9
	Stops	5.4	6.7	5.3	2.3	3.4	1.9	4.6	4.9	0.5	0.0	2.1	0.0	6.2	4.6	5.4	2.4	2.4	2.8	4.6
	Avg Queue (ft)	1205.9	868.2	760.9	674.9	631.4	391.2	560.4	783.0	397.6	0.0	371.3	0.0	701.5	326.2	291.5	447.0	382.3	385.6	650.3
	Max Queue (ft)	1438.4	1452.0	1144.8	1570.9	1008.4	1129.9	1182.3	1656.0	691.9	0.0	545.4	0.0	1656.0	681.8	669.9	829.2	1587.4	970.6	1638.2
	LOS	F	F	F	F	F	F	F	F	F	N/A	F	N/A	F	F	F	F	F	F	F
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W 3800 S	5600 W 4400 S	5200 W 3800 S	5200 W 4700 S	4800 W 3800 S	4800 W 4400 S
	Vehicles	11890	10019	10996	8491	6857	10723	9745	9389	2475	0	2507	0	5597	5895	6630	4565	6158	4221	4697
	Delay (s)	339.2	36.3	145.9	126.1	13.8	85.0	136.3	121.8	1.5	0.0	0.2	0.0	5.0	48.1	8.8	3.3	132.5	11.5	40.6
	Stop delay (s)	185.3	23.7	46.7	22.8	6.5	21.7	47.8	55.7	0.0	0.0	0.0	0.0	0.3	29.1	2.3	0.7	33.8	3.3	17.8
	Stops	5.1	0.9	3.3	2.5	0.5	2.1	2.6	3.1	0.0	0.0	0.0	0.0	0.1	1.1	0.4	0.1	3.1	0.4	1.2
	Avg Queue (ft)	1214.6	114.1	848.1	612.0	21.2	419.8	583.7	532.0	0.0	0.0	0.0	0.0	1.2	96.6	6.4	2.5	605.2	11.5	135.8
	Max Queue (ft)	1435.0	553.3	1161.1	996.4	284.9	1163.7	898.2	1388.8	0.0	0.0	0.0	0.0	154.9	671.0	176.8	239.1	811.8	169.3	1023.6
	LOS	F	D	F	F	B	F	F	F	A	N/A	A	N/A	A	D	A	A	F	B	D

Michigan U Turn

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	MUT North	MUT South
	Vehicles	10260	7434	5572	2390	3055	5330	6859	0	294	508	524	262	710	3700	4296
	Delay (s)	14.5	27.6	22.1	12.6	2.2	24.1	42.6	0.0	0.5	2.5	0.7	1.6	1.1	4.2	1.1
	Stop delay (s)	8.4	20.0	15.1	10.8	0.5	14.5	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
	Stops	0.4	0.7	0.6	0.1	0.1	0.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	28.0	48.6	30.3	20.9	0.4	47.8	119.0	0.0	9.5	0.0	0.0	0.0	0.0	0.2	0.1
	Max Queue (ft)	319.1	284.1	232.8	138.3	57.3	307.8	525.0	0.0	205.3	0.0	0.0	0.0	0.0	86.5	36.8
	LOS	B	C	C	B	A	C	D	N/A	A	A	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	MUT North	MUT South
	Vehicles	9217	8714	7068	3424	4668	6803	9888	0	648	425	986	423	1033	3988	4641
	Delay (s)	20.8	49.8	19.1	4.9	5.6	15.5	29.5	0.0	1.3	2.0	0.8	2.1	1.7	1.3	0.6
	Stop delay (s)	14.2	36.0	12.1	2.5	2.8	9.5	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stops	0.5	1.0	0.6	0.2	0.2	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	35.7	168.9	28.5	2.4	3.4	23.5	75.7	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Max Queue (ft)	295.5	569.8	256.9	94.7	83.3	197.2	517.4	0.0	0.0	0.0	0.0	0.0	0.0	64.1	29.9
	LOS	C	D	B	A	A	B	C	N/A	A	A	A	A	A	A	A
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	MUT North	MUT South
	Vehicles	6898	8062	9927	3731	5181	6263	8088	0	650	362	1006	417	888	1995	2515
	Delay (s)	22.1	37.6	86.1	3.0	26.5	26.5	23.0	0.0	1.1	1.8	0.5	2.4	1.4	3.6	0.8
	Stop delay (s)	15.5	27.9	28.5	1.0	15.8	15.5	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Stops	0.5	0.7	1.6	0.0	0.5	0.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	35.4	75.0	380.4	3.2	134.8	74.8	46.8	0.0	156.3	0.0	53.6	0.0	0.0	0.2	0.0
	Max Queue (ft)	324.7	444.1	1040.9	149.7	1252.3	590.3	477.0	0.0	402.4	0.0	256.0	0.0	0.0	104.6	0.0
	LOS	C	D	F	A	C	C	C	N/A	A	A	A	A	A	A	A
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	MUT North	MUT South
	Vehicles	11899	11285	11564	7121	8177	10165	11185	0	1828	215	2046	577	955	4680	4066
	Delay (s)	31.9	85.5	229.5	8.8	10.0	15.1	37.7	0.0	2.0	1.6	0.7	23.9	1.4	2.7	1.4
	Stop delay (s)	20.4	50.7	101.0	3.6	3.3	7.9	25.2	0.0	0.0	0.0	0.0	7.3	0.0	0.0	0.1
	Stops	0.7	1.7	5.4	0.2	0.4	0.5	0.9	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
	Avg Queue (ft)	112.5	384.1	743.6	6.8	16.2	27.6	111.9	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
	Max Queue (ft)	644.2	795.1	1071.8	216.8	357.6	314.0	648.8	0.0	0.0	0.0	0.0	0.0	0.0	126.6	130.0
	LOS	C	F	F	A	A	B	D	N/A	A	A	A	C	A	A	A

Bowtie Intersection

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	BT East	BT West
	Vehicles	11183	7437	5590	2960	3049	5741	6850	4753	331	508	528	262	713	4661	5375
	Delay (s)	21.0	27.8	22.5	4.9	2.1	27.2	37.4	13.1	0.4	2.4	0.6	1.7	1.0	4.3	1.7
	Stop delay (s)	12.0	20.4	15.3	2.6	0.4	15.7	26.2	6.3	0.0	0.0	0.0	0.0	0.0	0.4	0.1
	Stops	0.6	0.6	0.6	0.2	0.1	0.8	0.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	52.8	50.0	30.0	1.8	0.4	57.3	93.2	11.7	0.0	0.0	0.0	0.0	0.0	4.7	0.7
	Max Queue (ft)	407.1	263.6	243.4	161.1	35.7	388.7	593.4	148.9	0.0	0.0	0.0	0.0	0.0	393.4	166.0
	LOS	C	C	C	A	A	C	D	B	A	A	A	A	A	A	A
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	BT East	BT West
	Vehicles	11701	8720	7088	4641	4679	7699	9907	5432	655	425	991	423	1029	4654	5532
	Delay (s)	27.0	65.5	38.1	4.7	6.0	15.4	27.6	13.8	1.2	2.4	0.7	2.4	1.0	1.5	11.8
	Stop delay (s)	17.2	47.4	27.9	2.0	3.0	9.3	17.7	6.5	0.0	0.0	0.0	0.1	0.0	0.1	2.1
	Stops	0.6	1.2	0.7	0.1	0.2	0.5	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	Avg Queue (ft)	28.5	65.0	27.0	0.9	1.2	7.3	22.0	4.0	0.0	0.0	0.0	0.0	0.0	0.1	10.5
	Max Queue (ft)	134.5	189.6	109.7	47.2	23.0	74.3	155.2	50.7	0.0	0.0	0.0	0.0	0.0	31.0	133.1
	LOS	C	E	D	A	A	B	C	B	A	A	A	A	A	A	B
2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	BT East	BT West
	Vehicles	7919	8124	9931	4426	5430	6724	8152	7312	866	362	1153	417	889	4269	4388
	Delay (s)	25.5	35.6	86.8	5.7	6.3	27.9	19.2	13.5	1.0	1.8	0.4	2.4	1.4	1.8	2.1
	Stop delay (s)	17.3	26.7	30.8	2.3	1.8	16.5	10.2	4.9	0.0	0.0	0.0	0.0	0.0	0.1	0.1
	Stops	0.6	0.7	1.6	0.2	0.3	0.7	0.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Avg Queue (ft)	17.3	22.0	125.2	1.3	2.0	25.7	10.9	5.8	0.0	0.0	0.0	0.0	0.0	0.2	0.3
	Max Queue (ft)	133.3	115.7	317.1	68.7	92.7	220.4	93.8	102.5	0.0	0.0	0.0	0.0	0.0	40.5	40.7
	LOS	C	D	F	A	A	C	B	B	A	A	A	A	A	A	A
2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	BT East	BT West
	Vehicles	13511	10782	11061	8311	8139	11200	11090	8686	1829	215	2049	577	956	7438	7683
	Delay (s)	149.6	82.8	253.9	8.7	16.8	14.3	32.5	157.3	1.5	1.7	19.1	13.5	1.3	78.8	29.3
	Stop delay (s)	61.1	50.4	123.8	2.4	6.2	7.4	22.0	76.7	0.0	0.0	11.3	3.1	0.0	24.4	3.9
	Stops	3.0	1.7	5.9	0.2	0.5	0.5	0.8	4.9	0.0	0.0	0.1	0.2	0.0	1.3	0.5
	Avg Queue (ft)	208.9	100.5	232.6	2.7	12.2	9.3	29.0	134.8	0.0	0.0	12.8	0.0	0.0	120.4	61.9
	Max Queue (ft)	272.9	240.5	339.1	77.6	204.5	105.4	210.6	329.7	0.0	0.0	299.2	0.0	0.0	335.4	163.5
	LOS	F	F	F	A	B	B	C	F	A	A	B	B	A	E	C

Quadrant Intersection

2009 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W Quadrant
	Vehicles	6308	7449	5577	2203	2955	5078	6847	4760	238	508	434	262	712	5214
	Delay (s)	16.0	27.2	23.0	2.8	1.9	31.2	36.5	13.6	0.4	2.4	0.7	1.7	1.0	23.0
	Stop delay (s)	11.0	19.3	15.3	1.1	0.4	17.5	26.0	6.6	0.0	0.0	0.0	0.0	0.0	12.8
	Stops	0.4	0.7	0.6	0.2	0.1	0.8	0.9	0.6	0.0	0.0	0.0	0.0	0.0	0.6
	Avg Queue (ft)	19.0	46.7	30.3	0.7	0.4	71.3	86.6	12.1	0.0	0.0	0.0	0.0	0.0	30.4
	Max Queue (ft)	239.0	284.4	222.3	84.8	55.5	487.5	638.0	155.0	0.0	0.0	0.0	0.0	0.0	442.3
	LOS	B	C	C	A	A	C	D	B	A	A	A	A	A	C

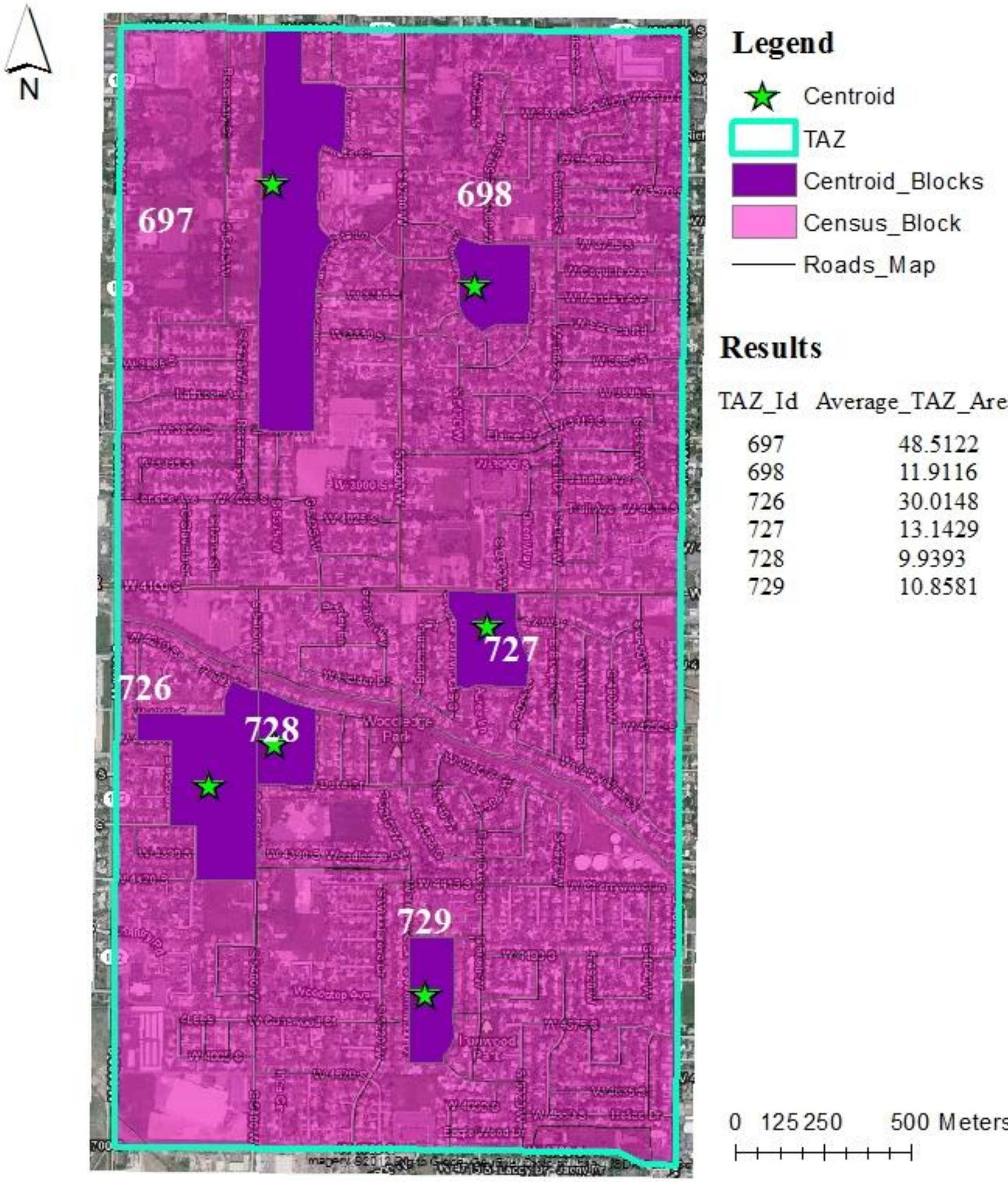
2009 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W Quadrant
	Vehicles	7902	8714	7062	3299	4569	6674	9896	5432	558	425	896	423	1033	5040
	Delay (s)	22.6	28.2	19.2	3.8	5.6	16.1	29.6	13.7	1.2	2.1	0.7	2.2	1.1	11.8
	Stop delay (s)	14.9	19.5	11.9	1.3	2.9	9.7	19.1	6.3	0.0	0.0	0.0	0.0	0.0	6.9
	Stops	0.6	0.7	0.5	0.2	0.2	0.5	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.3
	Avg Queue (ft)	34.9	59.6	28.5	2.3	3.5	23.2	77.1	12.8	0.0	0.0	0.0	0.0	0.0	13.9
	Max Queue (ft)	296.7	334.1	263.6	97.0	82.1	211.7	456.5	140.6	0.0	0.0	0.0	0.0	0.0	266.7
	LOS	C	C	B	A	A	B	C	B	A	A	A	A	A	B

2040 AM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W Quadrant
	Vehicles	4643	8058	9764	3584	5308	5884	8150	7210	739	362	1026	417	886	2749
	Delay (s)	28.2	33.6	79.3	3.1	6.5	69.5	21.0	13.4	1.0	1.8	0.3	2.5	1.4	14.4
	Stop delay (s)	20.3	25.3	22.9	1.0	2.0	39.2	11.6	4.9	0.0	0.0	0.0	0.0	0.0	8.2
	Stops	0.6	0.7	1.2	0.1	0.3	1.3	0.7	0.5	0.0	0.0	0.0	0.0	0.0	0.4
	Avg Queue (ft)	47.5	65.6	306.7	1.3	8.1	371.4	42.2	16.7	0.0	0.0	0.0	0.0	0.0	6.5
	Max Queue (ft)	465.5	395.2	987.5	109.9	333.1	707.0	318.5	256.7	0.0	0.0	0.0	0.0	0.0	211.1
	LOS	C	C	E	A	A	E	C	B	A	A	A	A	A	B

2040 PM	Node number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Intersection	5600 W 3500 S	5600 W 4100 S	5600 W 4700 S	5200 W 3500 S	5200 W 4100 S	4800 W 3500 S	4800 W 4100 S	4800 W 4700 S	5200 W 3745 S	4980 W 3725 S	5200 W 4025 S	5400 W 4210 S	5215 W 4415 S	5600 W Quadrant
	Vehicles	9698	11271	11537	6770	7827	9817	11135	8817	1491	215	1711	577	953	4589
	Delay (s)	30.8	31.4	228.6	6.4	10.6	14.8	35.3	157.9	1.7	1.6	0.5	2.4	1.3	11.2
	Stop delay (s)	19.8	21.1	98.3	1.6	3.7	7.7	23.9	76.9	0.0	0.0	0.0	0.0	0.0	6.6
	Stops	0.6	0.8	5.4	0.2	0.4	0.5	0.8	4.8	0.0	0.0	0.0	0.0	0.0	0.3
	Avg Queue (ft)	90.0	83.2	738.2	7.9	19.5	26.2	102.5	443.5	0.0	0.0	0.0	0.0	0.0	12.0
	Max Queue (ft)	602.7	432.8	1164.8	228.1	353.1	276.6	560.2	965.9	0.0	0.0	0.0	0.0	0.0	245.4
	LOS	C	C	F	A	B	B	D	F	A	A	A	A	A	B

APPENDIX D: GIS METADATA FOR CONNECTIVITY MEASURES

Map 1: Average Census Block Area



Results

TAZ_Id	Average_TAZ_Area (Acres
697	48.5122
698	11.9116
726	30.0148
727	13.1429
728	9.9393
729	10.8581

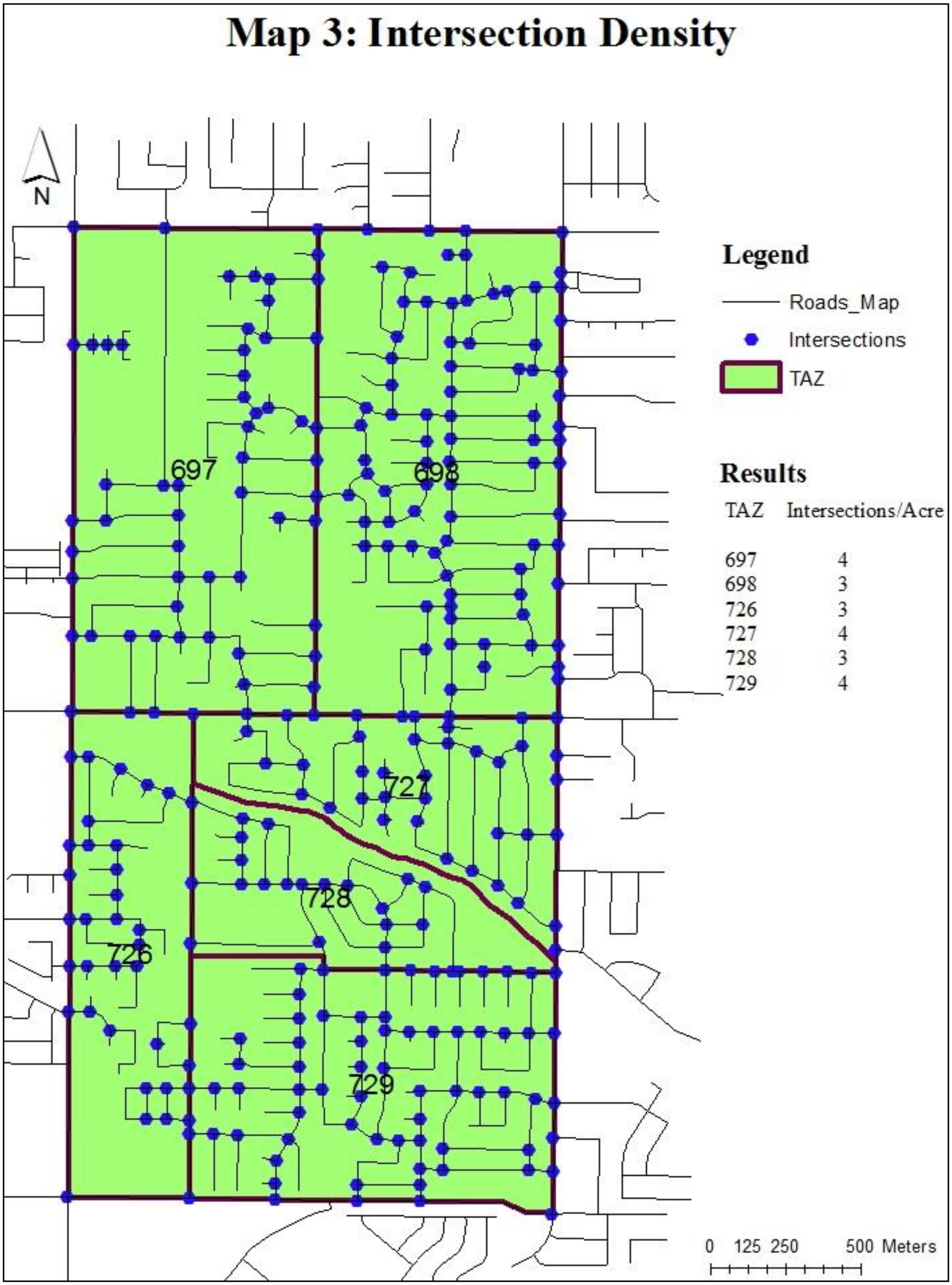
Map 2: Road Length per Unit Area

Results

Road Length = 40.70 miles

Site Area = 2.05 miles squared

Road Length per Unit Area = 20.30 miles of road /mile squared


Map 3: Intersection Density
N
697
698
727
728
726
729
Legend
Roads_Map
Intersections
TAZ
Results
TAZ Intersections/Acre
697 4
698 3
726 3
727 4
728 3
729 4
0 125 250 500 Meters