Final Technical Report
TNW2009-06

IMPACTS OF TRAFFIC RESTRICTIONS AND INFRASTRUCTURE IMPROVEMENTS ON DOWNTOWN PEAK HOUR CONGESTION: A SYNCHRO ANALYSIS FOR BELLEVUE, WASHINGTON

Chris Masek, P.E.   Nancy Nihan, Ph.D.

Department of Civil and Environmental Engineering
University of Washington
Seattle, WA 98195

A report prepared for

Transportation Northwest (TransNow)
University of Washington
135 More Hall, Box 352700
Seattle, Washington 98195-2700

August 2009

DISCLAIMER

ABSTRACT

As urban areas continue to grow and demand on city streets increases, cities like Bellevue, Washington are looking for new and innovative ways to reduce vehicle delays and travel times. Downtown areas pose a particular challenge due to limited rights-of-way for roadway expansion, increased numbers of pedestrians, and the need to balance the interests of business owners and homeowners with trip-makers. This study evaluated the benefits and negative impacts of small-scale control and infrastructure improvements on PM peak hour traffic in downtown Bellevue. The performance measures used for evaluation were intersection stopped delays. Bellevue's downtown street network was modeled, using Synchro software (Husch 2004) for the 2007 base network and for four alternative scenarios in the year 2017. The future alternatives investigated included the 2017 base, which assumed no changes except for the expected traffic growth and the re-optimization of the signal timing plan, plus three alternatives that included peak hour traffic control restrictions and/or spot infrastructure improvements.

The results showed that locations with new turn restrictions experienced significant reductions in intersection delay, while nearby intersections without such restrictions experienced greater delays. For intersections on street corridors that were currently under-used, this type of trade-off, made more effective use of the entire street network. The authors learned that the most aggressive approach to turn restrictions combined with some infrastructure improvements yielded the best results. A reasonable balance of feasible infrastructure improvements appeared to be necessary for turn restrictions to work effectively in congested downtown networks.

I. INTRODUCTION AND BACKGROUND

A. Background

The City of Bellevue, Washington, which is located within the Seattle Metropolitan area, is experiencing increasing traffic congestion with few realistic alternatives for capacity improvements to its signalized street network. During the last 5 years, the downtown Bellevue area has experienced a significant amount of growth in office, retail and residential space ,and its current population of over 120,000 (US Census Bureau, July 2008) is steadily increasing.

As the downtown area continues to grow and more people live downtown, additional demand will be placed on the existing street network. Major expansion of the street network is not an option due to limited rights-of-way and new buildings that have been constructed with little or no setbacks from the rights-of-way. Spot intersection improvements and limited amounts of road widening have been programmed into the City's Capital Investment Program (CIP). Most of the projects will be constructed in the next 10-15 years. Even with the CIP project improvements, forecasting models have shown that many of downtown Bellevue's intersections will not meet concurrency requirements and will have significant increases in intersection delays in the years 2017, 2020 and beyond. Additional non-construction options must be considered in tandem with the CIP improvements to help alleviate the problem

In order to address future demand and delay issues in downtown Bellevue, the City has considered a couple of alternatives in lieu of traditional infrastructure improvements. The City previously looked at converting two streets, 106th Avenue NE and 108th Ave NE to a one-way couplet (Figure 1). The analysis of this alternative showed no significant improvement in intersection delays or corridor travel times for the year 2017 or 2020. However, the one-way couplet solution may prove to be beneficial in the years beyond 2020 or 2030, depending on how downtown Bellevue grows and traffic patterns change in future years.

Another alternative that was considered but not yet analyzed was restricting left turns at select intersections in downtown Bellevue during the PM peak traffic hours of 4 pm to 6 pm. This paper describes an investigation of the potential use of this traffic management option along with the planned capital spot improvements and evaluates their combined expected impacts, both negative and positive.

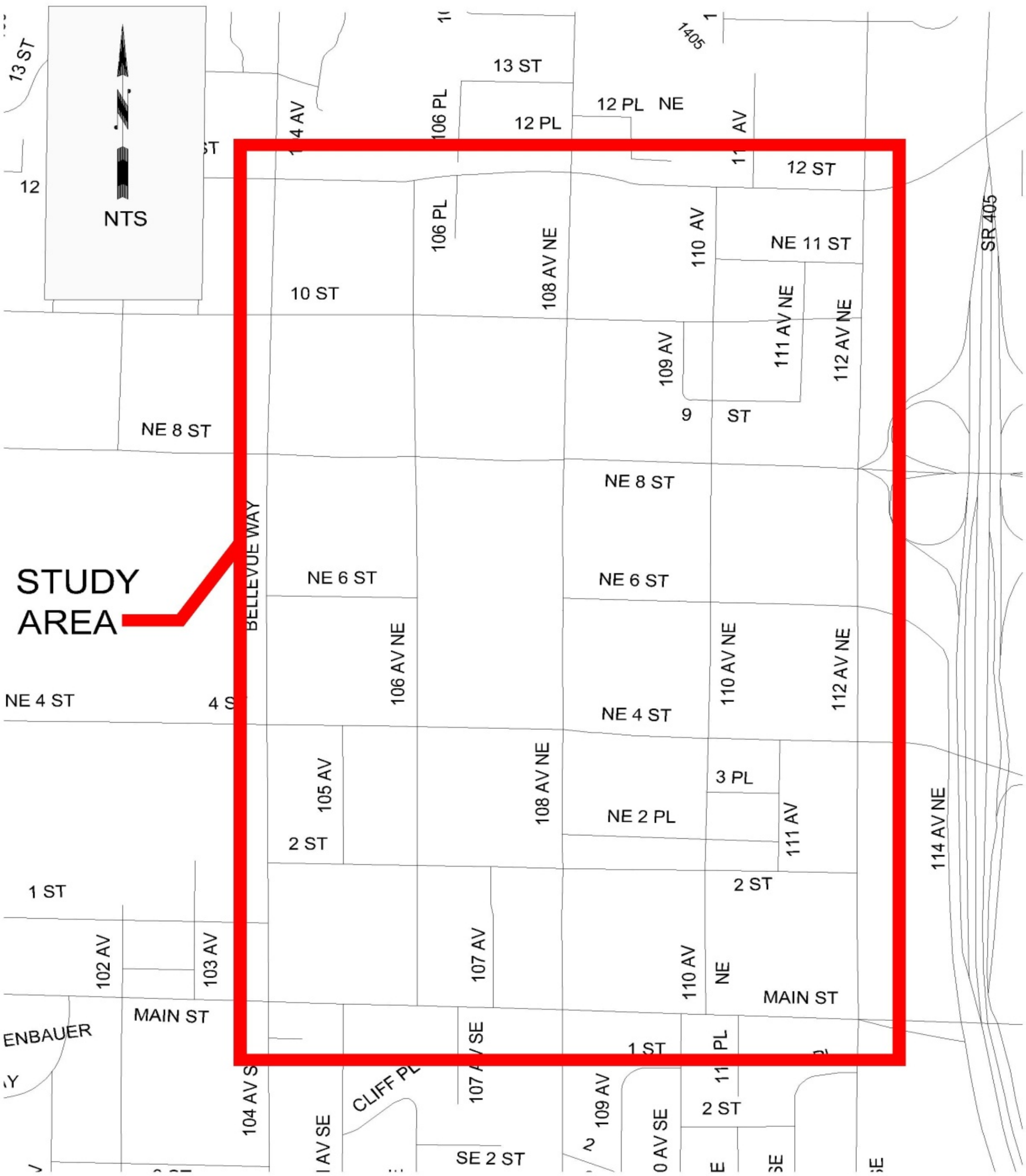

Figure 1: Vicinity Map of Study Area (Downtown Bellevue)

B. Goals and Objectives

This research study explored the possible benefits and negative impacts of restricting left turns at selected signalized intersections in downtown Bellevue during the PM peak traffic period in conjunction with planned minor capital improvements. The Synchro software package version 6 (Husch 2004) was used to evaluate the effectiveness of this combined traffic control/capacity enhanced option.

The study area for this research was bound by four major streets: NE 12th St, Bellevue Way NE, Main St, and 112th Ave NE (Figure 1). The goal of this study was to determine whether restricting turn movements and/or making spot infrastructure improvements would significantly improve delays for individual intersections and improve the overall travel times on heavily traveled streets within the study area. Several alternatives were considered to test the effectiveness of this traffic management/street widening option. Significant improvement in delays was defined as a decrease in delay per intersection of at least one LOS letter for intersections currently experiencing a base condition of LOS E or F during the peak hour. The objective was to reduce delays at the intersections currently experiencing the highest delays without significantly degrading the LOS at surrounding intersections.

II. LITERATURE REVIEW

A review of the literature on signal operations in urban areas was performed to provide the authors with a general understanding of the existing body of research on this topic and a more specific understanding of the techniques and measures of effectiveness (MOEs) used to calibrate Synchro Models. No publications on the topic of restricting left turns in downtown areas were found, and only a few covered simulation model calibration techniques. Most of the publications that discussed calibration techniques described the selected MOEs used to calibrate their model, but neglected to give detailed descriptions and justifications of the model parameters that were changed to obtain outputs consistent with these MOEs.

Park et al. (2006), was one of the few publications that discussed and emphasized the importance of model calibration and provided techniques for modeling signalized systems.

Although the authors' research investigated an actuated signal system and, therefore, their models used actuated signal timing plans, unlike the semi-actuated signals used by the City of Bellevue, their calibration approach was still relevant. To calibrate and validate their models, Park, et al. used travel time data collected from video cameras that tracked license plates. The authors also used queue length data to calibrate their model.

Sadek (2004) discussed the use of macro and micro simulation models at signalized intersections in inclement weather conditions. The parameters that were adjusted for model calibration included driver types, driver startup lost times, queue discharge rates, average car speeds between links, and queue lengths. The author used average delay time as a measure of effectiveness for calibrating the traffic simulation models. Some of the other calibrating parameters Sadek mentions are not applicable to Synchro since his study used both CORSIM and Synchro modeling programs.

Riniker et al. (2008) discusses calibration of Synchro models in a paper on signal timing optimization for the City of Baltimore. In order to calibrate the model, the author collected both travel time and delay data. The validation methods used focused on adjusting the Synchro model to match the travel times for certain corridors which proved to be effective according to the author. The author did not provide any specific information on the parameters that were adjusted to calibrate the Synchro model.

Washburn (2002) compared signalized delay estimation results for Transyt-7F, Synchro, and HCS. Each program calculates signal delay differently. Travel time data was collected and used as the baseline comparison MOE to calibrate each of the models for this study. Of the three models analyzed, the Synchro model estimated the highest delay for 2 of the 3 intersections studied.

Schroeder (2006) investigated the interaction of pedestrians and vehicles at unsignalized intersections using a VISSIM microscopic model. The performance measures used as the target MOEs for model calibration included pedestrian delay, vehicle delay, and the likelihood of vehicle- pedestrian collisions. The interaction between pedestrians and vehicles is not always accounted for in models and could potentially have a significant impact on intersection delays. The author did not have the opportunity to calibrate his model and planned to perform the calibration as part of future research.

III. RESEARCH APPROACH

A. 2007 Base Model Development

Setting up the Synchro model for the downtown Bellevue study was a multi-step process. The City's existing Synchro model was used as the platform for creating the 2007 base model. The City-provided Synchro model included the City of Bellevue's entire street network with signalized intersections, timing plans, lane widths and 2006 traffic volumes.

To develop the current study's base 2007 model, the traffic volume data in the older Synchro model was updated with the most recent PM peak hour traffic counts from the 2007 City of Bellevue Transportation Data Book (2008). Most of the intersection data in that most recent traffic data book were counted in 2007. The model was also updated with the City's most current pedestrian count information. The City of Bellevue conducts pedestrian and bicycle counts when vehicle volume and turning movement counts are taken for signalized intersections every year. The pedestrian count data are typically measured for the entire 2-hour traffic study period and are not broken down into a peak hour. Since the Synchro model developed by the City only modeled the peak hour, all pedestrian volumes from these counts were divided in half for input to the updated model.

Two new signalized intersections, Bellevue Way and NE 7th St and NE 8th St and 105th Ave NE that were added to the traffic signal network within the last three years were also included in the updated base model. Since no traffic volume data had previously been collected for these intersections, traffic volumes for the two newly signalized intersections were approximated based on volume balancing data outputs from the Synchro Model for key adjacent intersections. Consequently, the new intersection volumes were properly balanced with the traffic volumes at the intersections of Bellevue Way and NE 8th St, Bellevue Way and NE 6th St, and NE 8th St and 106th Ave NE. After updating the Synchro model with the 2007 data, the model was calibrated to create the final 2007 base model.

B. Data Collection and 2007 Base Model Calibration/Verification

Model calibration is the process of making model adjustments that result in a reasonable match between model outputs and observed conditions for the existing system. The model must be able to simulate actual field-measured conditions before it can be used to predict future conditions that may result from future changes in traffic patterns and/or system improvements.

Data Collection: Field data collection was required to compare the Synchro model outputs for the existing 2007 system with real world conditions. Intersection delays were selected as the MOEs for the calibration because these data are key measures for evaluating system performance and because delay studies are quick and easy to conduct. Other traffic studies that would have been helpful for developing additional performance measures for calibrating the model included saturation flow studies, corridor travel time studies, and queue studies. Unfortunately, there was not enough time or resources to conduct these additional studies.

Delay studies were conducted at intersection approaches where the delays calculated by the Synchro model appeared to be unusually or unrealistically high. Additional locations were selected to get an overall idea of how well the Synchro model was predicting existing system intersection delays. Delay studies were conducted at the 11 intersections shown in Figure 2. The delay field data were collected using the standard procedure for conducting a delay study described in the ITE Traffic Engineering Studies Handbook (Robertson, 1994). Each data collection was conducted using a stop watch and deviated from the Handbook somewhat, since no traffic volumes were measured at the time of the delay study. Due to limited resources, the traffic volumes from the traffic data book - City of Bellevue (2008) were used instead.

Model Calibration: The first step in calibrating the 2007 base model involved making network-wide parameter adjustments suggested by the Synchro User Guide for intersections that were already experiencing over-capacity volumes. Consequently, for all intersection approaches where the volume to capacity ratio was greater than or equal to 1, the peak hour factor was set to 1. All volume to capacity ratios were checked by approach at all 36 intersections within the study area.

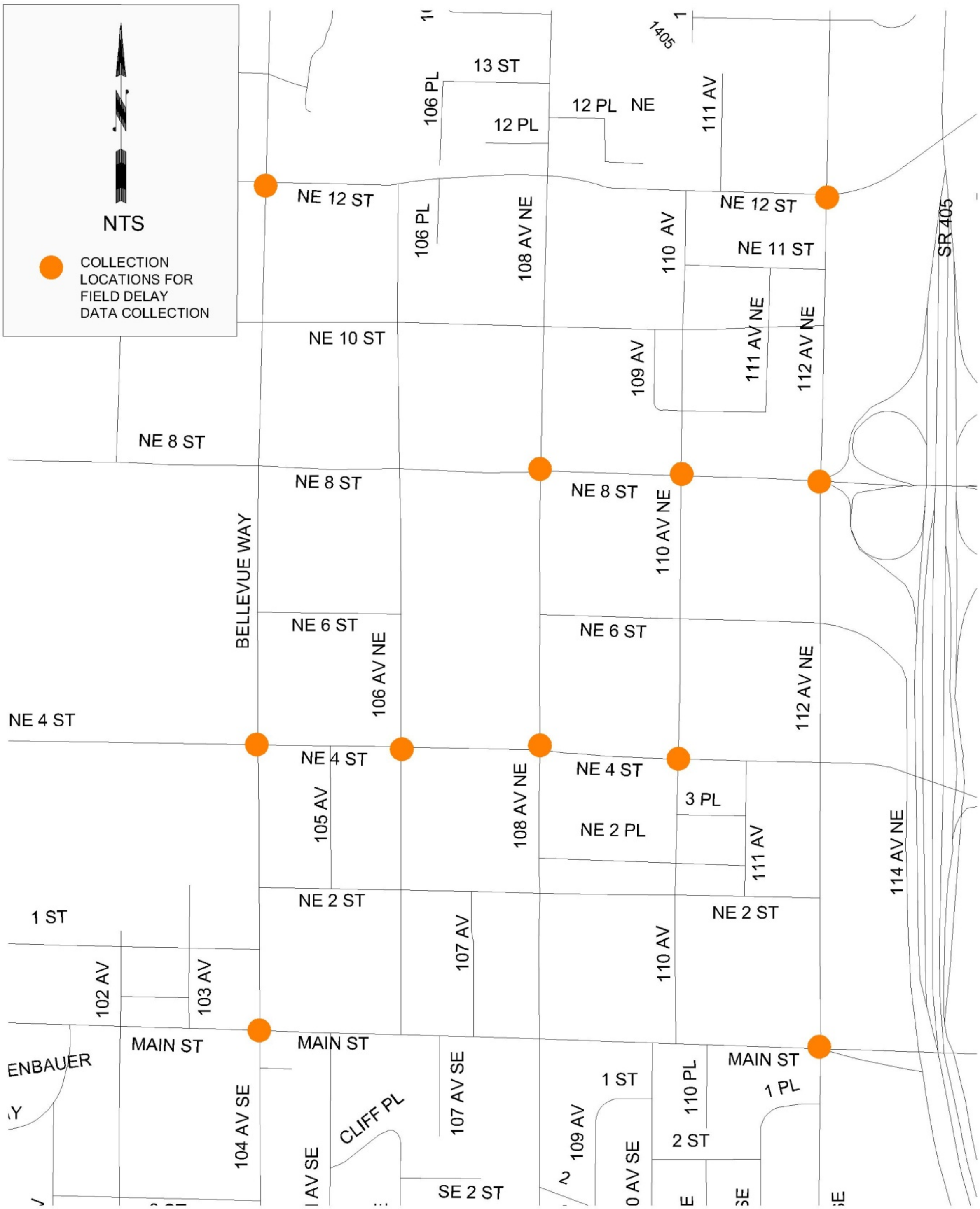

Figure 2: Delay Study Locations

Another network-wide adjustment that was used for calibration was volume balancing. Volume balances between all of the intersections within the study area were evaluated based on the authors' familiarity with the current mid-block flows between specific intersection pairs. The targeted goal for the majority of links was to have 200 or fewer vehicles entering or leaving traffic flows between intersections. This was typical for the number of driveways and the type of traffic coming in and out of those driveways during the peak period. Some locations, where there was a high volume of traffic entering a link between intersections during the pm peak period, such as traffic leaving the parking lots of large office buildings, were left with imbalances higher than 200 vehicles. The other exception to the 200-vehicle threshold for mid-block source or sink volumes was for links where there were no driveways and no places to turn. The corresponding approach volumes for the intersection pairs connected by these links were balanced so that all mid-block flows were set to zero.

After overall network parameters were adjusted, further model adjustments were made for individual intersections based on model delay outputs when such adjustments could be reasonably justified. The stopped delays estimated by the Synchro model were compared to the stopped delays measured in the field to identify intersections where significant discrepancies occurred. Table 1 shows the percent difference in stopped delays between the field measurements and the uncalibrated 2007 model outputs. There was a significant amount of variation between the two. Table 1 also shows the percent differences in the same field measurements and the final 2007calibrated base model. The calibration decisions and the reasoning behind them are discussed below.

The following parameter adjustments were considered for specific locations during the calibration process: lane utilization factors, ideal saturation flow rates, permit Right Turns on Red, and number of vehicles making right turns on red. The lane utilization factor was the most common parameter that was changed at most of the locations. This factor was adjusted for several reasons including heavy pedestrian movements that were known to prevent vehicles from turning right and situations where traffic in the left turn lane of an approach would spill over into the through lane. Adjustments to the lane utilization factor had a significant impact on stopped delay indicating that the model was sensitive to this type of parameter change. In a few cases, the observed amount of overflow traffic from a left turn lane on a particular approach resulted in a lower operational saturation flow rate for that approach than would be normally be assumed for the given number of approach lanes. The model's ideal saturation flow rate for such approaches was adjusted to compensate for the difference. Another factor that was adjusted was the Right Turn on Red factor. In some cases such as most intersections with NE 8th St, Right Turn on Red was turned off because the east-west traffic volumes were so heavy that it was nearly impossible for vehicles to turn right on red. In other cases, right turns on red were common, but the number of vehicles allowed to make right turns on red was adjusted in the model to account for that observation in the field.

Table 1: Calibration Results

Intersection	**Approach Measured**	**Field Measured Stopped Delay (secs)**	**Synchro Stopped Delay before Calibration (secs)**	**% Difference between Field and Uncalibrated Model**	**Synchro Stopped Delay after Calibration (secs)**	**% Difference between Field and Calibrated Model**
112 Ave NE / NE 8 St	SB Left	67.12	154.5	-56.55%	67.52	0.60%
110 Ave NE / NE 8 St	SB Thru	65.25	32.8	99.12%	63.30	-2.99%
108th Ave NE / NE 8th St	SB Thru-Right	42.26	28.8	46.89%	42.90	1.51%
108 Ave NE / NE 8 St	NB Thru-Right	87.86	39.5	122.21%	84.90	-3.37%
110 Ave NE / NE 4 St	SB Thru	52.9	46.8	12.92%	60.20	13.80%
108 Ave NE / NE 4 St	SB Thru	27.84	52.8	-47.32%	33.20	19.25%
106 Ave NE / NE 4 St	NB Thru-Right	31.67	53.5	-40.76%	34.80	9.88%
Bellevue Way / NE 4 St	EB Thru-Right	54.16	28.6	89.27%	48.40	-10.64%
112 Ave / Main St	SB Thru-Right	20.09	23.8	-15.76%	20.00	-0.44%
112 Ave / Main St	NB Thru-Right	20.93	38.1	-45.02%	23.30	11.31%
Bellevue Way / Main St	WB Thru	40.35	37.8	6.62%	38.85	-3.73%
Bellevue Way / Main St	EB Thru-Right	51.76	40.0	29.41%	54.90	6.06%
Bellevue Way / NE 12 St	EB Thru-Right	33.20	31.8	4.24%	33.90	2.12%
112 Ave NE / NE 12tSt	WB Thru-Right	14.91	51.5	-71.03%	16.00	7.34%

Model Verification and Additional Adjustments - After completing the parameter adjustments described above, many of the intersections had acceptable agreement between their model delay outputs and observed field delays.

To help verify the model, the intersections that still had significant delay discrepancies were brought closer to observed delay measurements by adjusting traffic volumes where such adjustments seemed reasonable, based on the probable error in the original volume data. One could argue that there was sufficient variation associated with the City's volume data used as model inputs that the remaining model output discrepancies could be explained by input errors. First, there are known day-to-day variations in actual volumes (even during peak hours) for any given year and, second, the 2007 volume data for different intersections were collected by the City on different days over the year. Therefore, input volume adjustments within a reasonably expected error range could be justified to produce model delay outputs that were consistent with field delay data collected on a particular day. Table 2 shows that, although traffic volume counts from year to year vary, on average, by only 3% some can vary as much as 15%. Consequently, volume adjustments were considered only after model parameter adjustments that could be supported were made, and these were made only to test potential model validity.

In making selected volume adjustments, the factors used to multiply collected counts ranged from 0.75 – 1.25., based on field observations made while conducting the delay studies. In nearly all cases, volume adjustments were made with factors between .90 and 1.10. In many cases, the volume adjustments allowed the Synchro-calculated stopped delays to match the stopped delays measured in the field. However, there were several cases where volume adjustments alone (within the justified error range) were not enough to produce model delays that were sufficiently close to field-measured delays. And, unfortunately, although two intersections on 8th Street improved their stopped-delay discrepancies using a reasonable correction factor, the volume adjustments for those intersections had to be reversed. Their resulting volumes turned out to be inconsistent with volumes at the other intersections along NE 8th St. Therefore, the volume-correction factors for those two intersections, in the east and west directions only, were removed to fix this problem.

The targeted calibration and verification goal for the 2007 base model was, for each approach to have, a difference between field-measured and Synchro-measured stopped delays of 10% or less and an average percent difference of 5% or less. The former was accomplished for most of the locations (Table 1) and their average absolute error was 6.6%. Without additional data collection, the model could not reasonably be adjusted any further to reconcile delays. However, it was still considered adequate for preliminary evaluations of the relative impacts of the future 2017 alternatives' to be modeled.

After the calibration and verification process was completed, two outliers were investigated further and finally accepted after all of the applicable calibration and verification techniques were used and the delays still did not match the field measured delay. The model could not reasonably be adjusted any further to reconcile the two delays.

Table 2: Changes in Traffic Volume Counts from Year to Year

Intersection	Most Recent Traffic Count Volume	Second Most Recent Traffic Count Volume	Most Recent Count vs. Second Most Recent Count (%)
NE 8th St and 112th Ave NE	5321	5249	-1.37
NE 8th St and 108th Ave NE	3247	3401	4.53
NE 4th St and 108th Ave NE	2848	2677	-6.39
NE 4th St and Bellevue Way	2819	3314	14.94
Main St and 112th Ave	3437	3480	1.24
Main St and Bellevue Way	3369	3596	6.31
NE 12th St and Bellevue Way	3170	3169	-0.03
NE 12th St and 112th Ave NE	3427	3537	3.11
		Average	**2.79**

After the calibration of the 2007 base model was completed, the calibrated model was used as a base to develop the 2017 base model and the three 2017 traffic control alternatives.

C. 2017 Base Model

Traffic flows for the year 2017 were input to the original base model to create the 2017 base model, a model of the existing network with no improvements serving the expected increased traffic demands of 2017. A growth factor of 3% per year was applied to the 2007 traffic volumes in the base-year calibrated Synchro model to estimate the expected 2017 traffic volumes. After incorporating the expected 3% traffic volume increases, the signal timing plans were optimized using the procedures in Synchro 6 User Manual (2004), to produce the 2017 base model.

The 2017 base model outputs were used as a basis of comparison to determine the effectiveness of the traffic control and spot infrastructure improvement alternatives that were proposed to achieve necessary reductions in vehicle and pedestrian delays for the expected growth in travel demand in 2017. The base 2017 model allowed for a comparison of the delays observed for the existing system in 2007 and those expected in 2017 if no improvements, except optimization of the timing plans, were made and for modeling and comparing the expected results in 2017 if the proposed system alternatives were incorporated.

The existing system alternative was used to examine the effects of "doing nothing" to the existing system over the next 10-year period. This alternative was based on the assumption that no traffic control or spot construction improvements were made to the existing system by the year 2017 and that the only change that occurred was the expected 3% growth in traffic volumes for all intersections and the Synchro optimization of the timing plan for these additional volumes. The differences in outputs of the base 2017 and base 2007 Synchro Models gave the predicted results for this Do-Nothing Alternative.

D. 2017 Alternatives

Three alternative improvement options were proposed, and models of their respective 2017 scenarios were prepared for analysis and impact evaluation.

Alternative 1 – Left Turn Restrictions Only, Selected Intersections Inside Perimeter. The first alternative was developed to examine the effects of restricting left turns at intersections internal to the study area. A total of 10 out of 36 intersections were selected for left turn restrictions (Figure 3). These intersections were judged to be the best candidates for significantly decreasing intersection delays and corridor travel times, while continuing to allow full left turn access to the desired set of key intersections. Based on current planning policy, the authors decided that streets along the perimeter of the study area should continue to have full access to protected left turns including Bellevue Way NE, Main Street, 112th Avenue NE and NE 12th Street.

Alternatively, restricting left turns at 10 signalized intersections inside the study area perimeter would allow those intersections to operate on a 2-phased signal timing plan instead of their current timings of 3 or more phases. This could potentially reduce overall vehicle and pedestrian delays and potentially increase vehicle thru-put without the need to build additional capacity.

At the authors' request, the City of Bellevue Transportation Modeling Group used the EMME/2 model to determine the trip routing for downtown Bellevue in the year 2007 for the scenario that assumed left turns were restricted at the 10 intersections shown in Figure 3. The authors used these outputs of the macroscopic EMME/2 model to determine the turning movement splits for the 2017 Synchro model for this traffic control alternative. Using the total approach volumes obtained by applying the 3% growth factor to the base-year approach volumes, the volume splits from the 2007 EMME/2 model were applied to these approach volumes to determine the new turning movements for Alternative 1. After the Alternative 1 model was developed, the signal timing plans were again optimized using the procedures in Synchro 6 User Manual (2004).

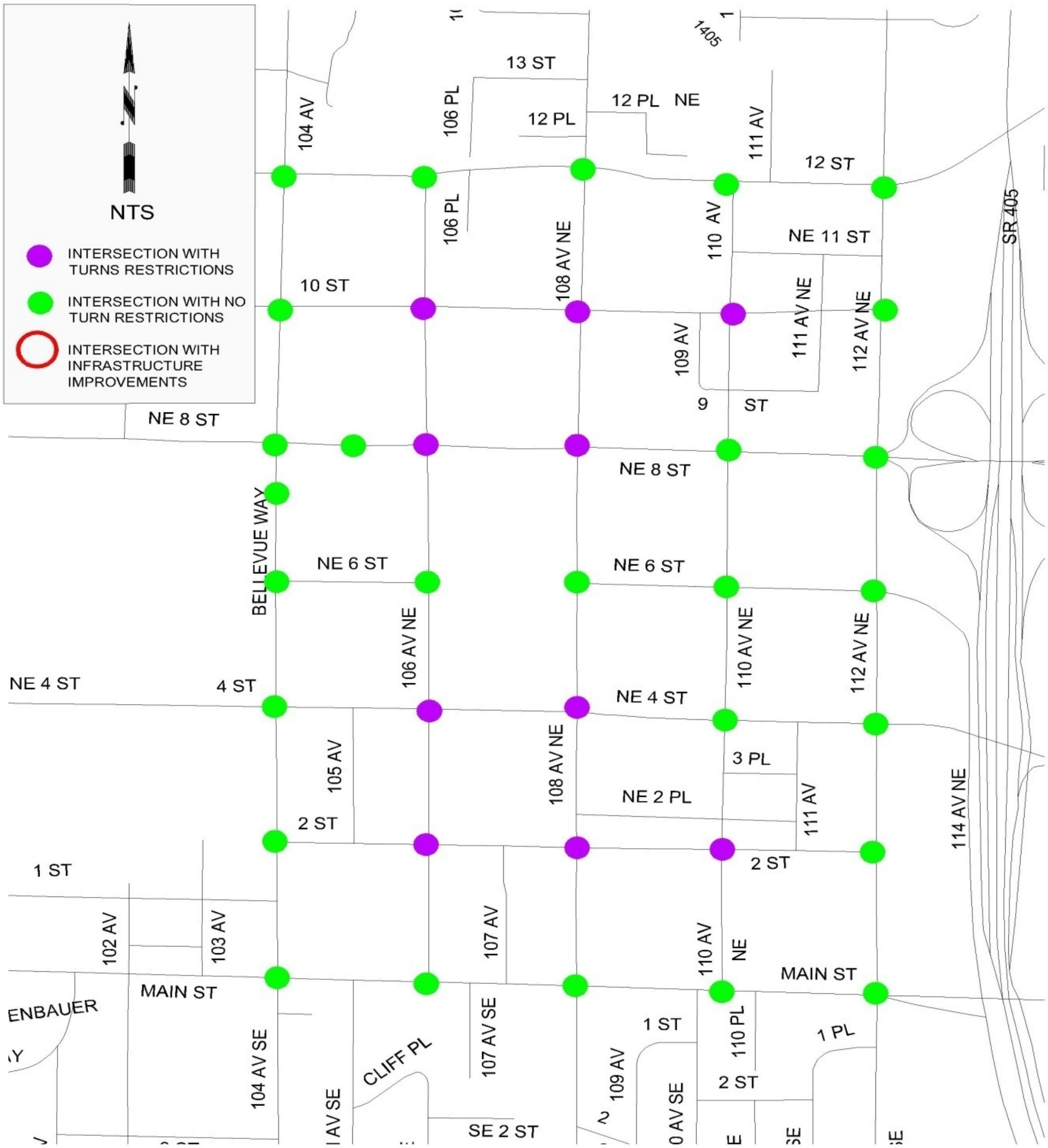

Figure 3: Alternative 1 – Left Turn Restrictions Only, Selected Intersections Inside Perimeter

Alternative 2 – Alternative 1 with Infrastructure Improvements plus Left Restrictions at One Perimeter Intersection. The second alternative included the same left turn restrictions in Alternative 1 plus additional restrictions coupled with some infrastructure improvements. The infrastructure improvements considered for Alternative 2 were from the City of Bellevue's Capital Improvement Program and will likely be constructed sometime in the next 8 to 10 years. In addition to the left turn restrictions in Alternative 1, this alternative also restricted left turn movements at one more intersection, which was located on the perimeter. Alternative 2 (Figure 4) included the following modifications to Alternative 1:

- Eastbound Left Turn from Main St to Bellevue Way Restricted (moved to 106th Ave)
- Eastbound Right Turn lane added at 112th Ave and Main St (EB to SB 112th Ave)
- Southbound Right Turn lane added at NE 4th St and Bellevue Way NE (SB to WB NE 4thSt)
- Westbound Right Turn lane added at NE 4th St and Bellevue Way NE (WB to NB Bellevue Way)
- Second Northbound Left Turn lane added at 110th Ave NE and NE 8th St (NB to WB NE 8th St)
- Second Southbound Left Turn lane added at 110th Ave NE and NE 8th St (SB to EB NE 8th St) Southbound Right Turn lane added at NE 8th St and Bellevue Way NE (SB to WB NE 8th St)

The infrastructure improvements listed above were limited by the amount of right of way available. The lack of right of way makes major capacity improvements cost-prohibitive. The improvements listed are intended to improve delay at intersections and address specific issues.

After the Alternative 2 model was developed, the signal timing plans were optimized using the procedures in the Synchro 6 User Manual (2004).

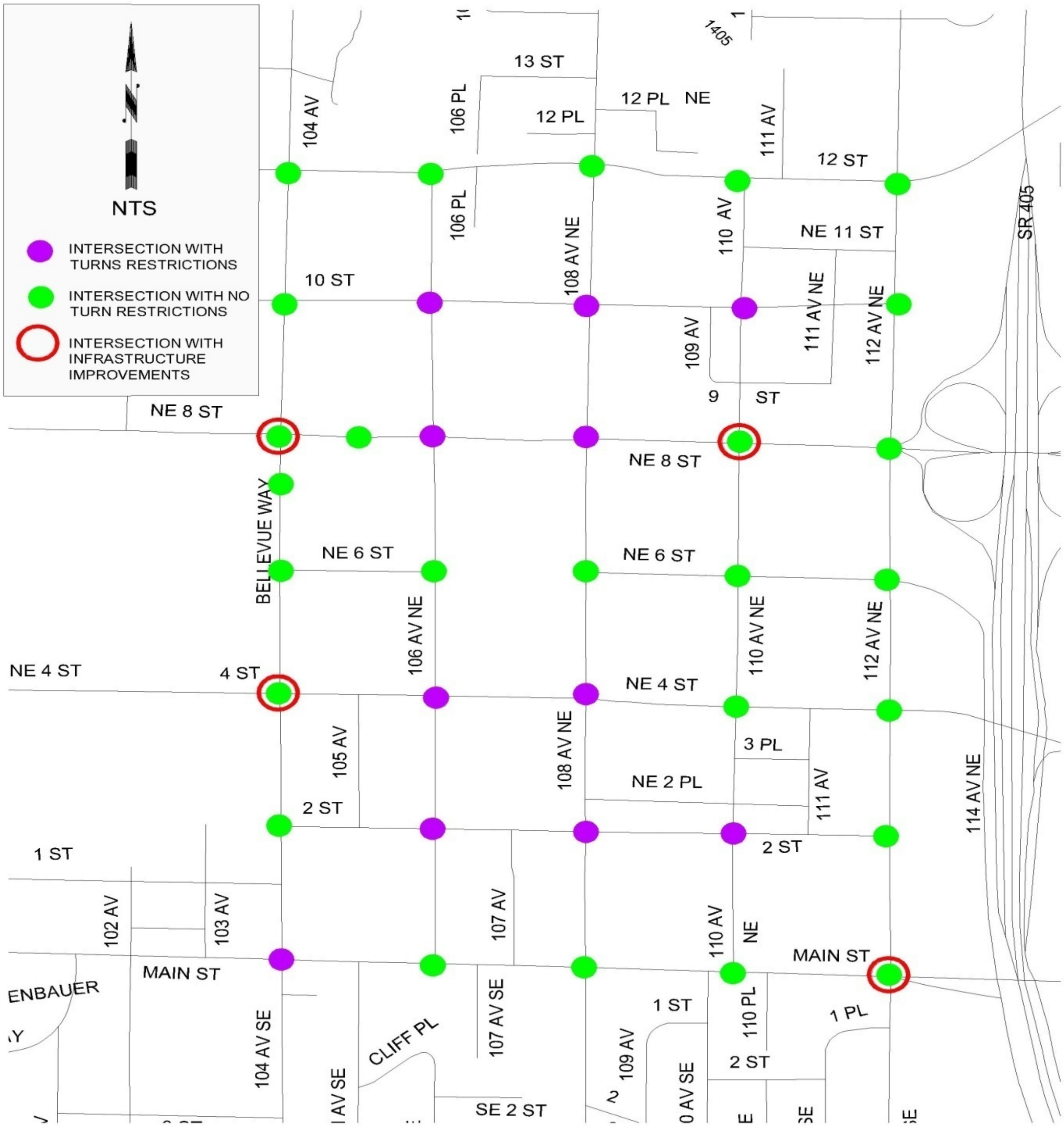

Figure 4: Alternative 2 – Alternative 1 with Infrastructure Improvements plus Left Turn Restriction on One Perimeter Intersection.

Alternative 3 – Alternative 2 with Additional Left Turn Restrictions on Perimeter Intersections. The third alternative includes everything included in Alternative 2 and takes a more aggressive approach to turn restrictions by making some restrictions on perimeter streets in the study area that are currently may be considered infeasible by policy-makers and planners. Selected movements at intersections on the perimeter of the study area were restricted in order to reduce intersection delays that produced unacceptable LOS results. Alternative 3 (Figure 5) includes the following modifications to Alternative 2:

- No Left Turns from Westbound NE 10 St and to Southbound Bellevue Way (Assume these lefts are made at NE 10 St and 102 Ave NE)
- No Left Turn from Northbound NE 8 St and Westbound Bellevue Way (Assume Left turns are split evenly between NE 10 St and NE 4 St)
- No Left at NE 8 St and 110th Ave NE – EB to NB. (Assume vehicles go right at 112th and come back up 110th to get across NE 8th St)
- No Left turns at NE 4 St and 110th Ave NE – EB to NB. Assume vehicles go left on 112th
- No Right turns from NE 8 St to SB Bellevue Way NE. Split Evenly between NE 4 St and NE 10 St

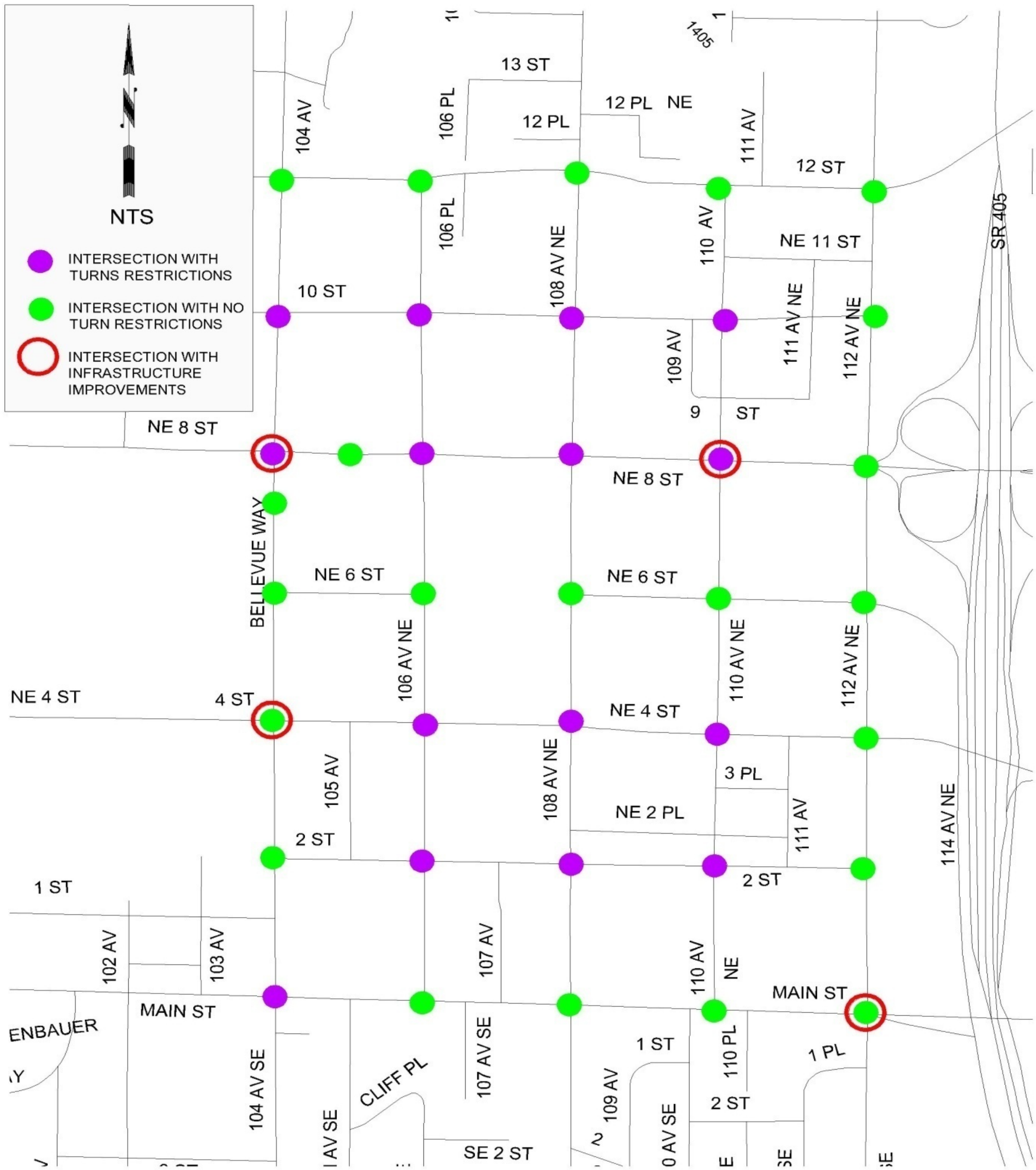

Figure 5: Alternative 3 – Alternative 2 with Additional Left Turn Restrictions on Perimeter Intersections.

IV. RESULTS

The models were run and the performance of the intersections and the street corridors were compared. The metric used to measure intersection performance was stopped delay (seconds/vehicle) and the metric used to measure corridor performance was travel time (seconds). Figures 6-11 show intersection delays on selected intersections for the 2007 Base Model, 2017 Base Model, and 2017 Alternatives 1-3. Delay data for each intersection and percent changes between models can be found in the tables in Appendix A.

In all of the individual intersection results, there is clearly a significant increase in delay between the 2007 base model and the 2017 base model. This result is not surprising and confirms the results of other models and studies performed by the City of Bellevue and also highlights the need for making improvements to reduce expected delays resulting from the expected increases in future traffic demands..

In Figure 6, the delays at the intersections of Main St/Bellevue Way and Main St/112 Ave doubled from 2007 to 2017. The intersection delay got slightly worse with Alternative 1 at Main St and Bellevue Way, but improved significantly once the left turn restrictions were added in Alternatives 2 and 3. At Main St and 112 Ave, Alternative 1 made the delay even worse than the 2017 base model. Alternatives 2 and 3 improved the delay because both alternatives included a new right turn lane at that intersection. The delay changes to the other intersections on Main St and 106$^{th\ Ave}$, 108th Ave, and 110th Ave were minor compared to those at the intersections with Bellevue Way and 112th Ave. There were notable delay changes at the intersection of Main St and 106th Ave for Alternatives 2 and 3 when compared with Alternative 1. This was due to the additional left turn movements coming from the traffic that was turn-restricted at the intersection of Bellevue Way and Main St.

Figure 7 shows the delays for intersections located along NE 2nd St between Bellevue Way NE and 112th Ave NE. Overall, there were no significant changes in intersection delays between the 2007 base model and the 2017 base model. There were some additional delays at certain intersections that were the result of additional left-turn movements arriving from intersections with left turn restrictions in Alternatives 1-3; however the increases were small and not a concern.

Figure 8 shows the intersection delays along NE 4th St. There were small increases in delays between the 2007 base model and the 2017 base model. Alternatives 1-3 significantly reduced those delays at the intersections of NE 4th St/106th Ave NE and NE 4th St/108th Ave NE. The delay reductions were significant at those intersections because all of the left turn movements were restricted and, therefore, the number of timing phases for each intersection was reduced. Alternatives 1-3 had noticeable positive delay effects at the intersection of NE 4th St and 112th Ave NE. However, Alternatives 1-3 had negative impacts for the intersection of NE 4th St and Bellevue Way NE, even with the additional right turn lanes added under Alternatives 2 and 3. For this intersection, Alternative 3 was worse than Alternatives 1-2 because half of the left turns from the restricted intersection NE 8th St and Bellevue Way NE were moved to improve delay at that location. This was one of the trade-offs that was made to improve the worst intersections in the study area. Overall, the delays at the intersections with turn restrictions on NE 4th St were reduced while the intersections of NE 4th St/Bellevue Way and NE 4th St/112th Ave NE got noticeably worse.

Figure 9 shows the delays for intersections on NE 8th Street between Bellevue Way NE and 112th Ave NE. There is a notable increase in delays for these intersections between 2007 and 2017 with the exception of NE 8th St and Bellevue Way, which appeared to stay about the same.

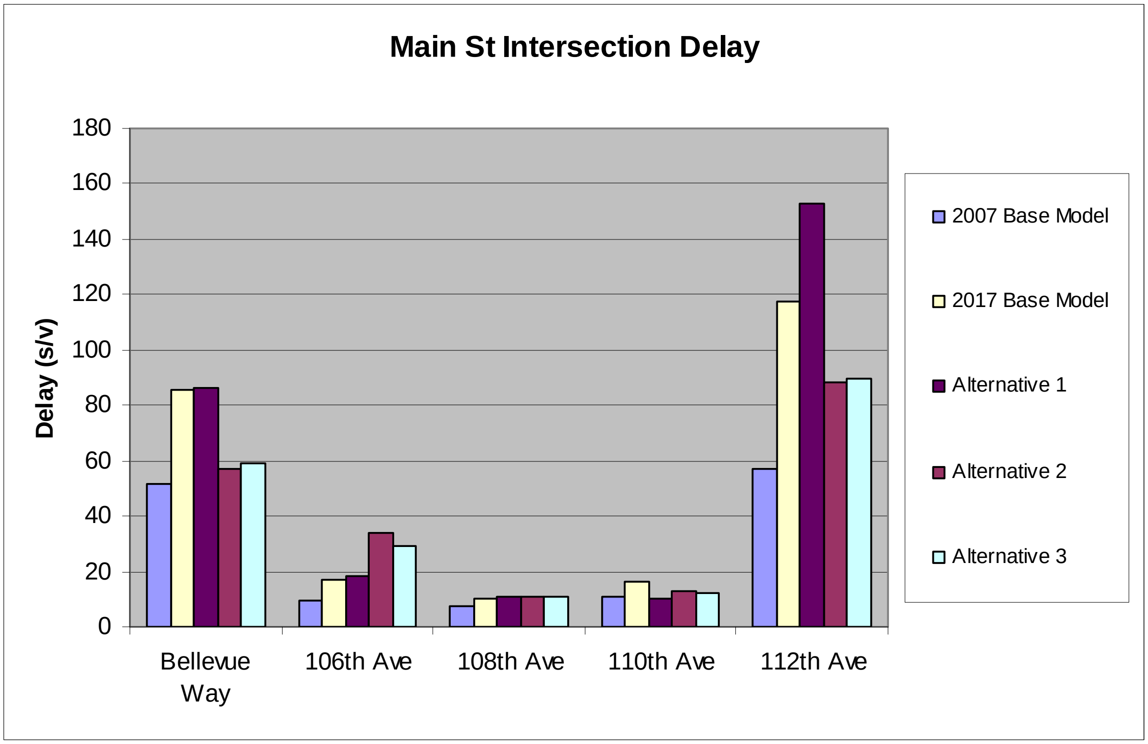

Figure 6: Intersection Delays on Main St – Bellevue Way to 112th Ave

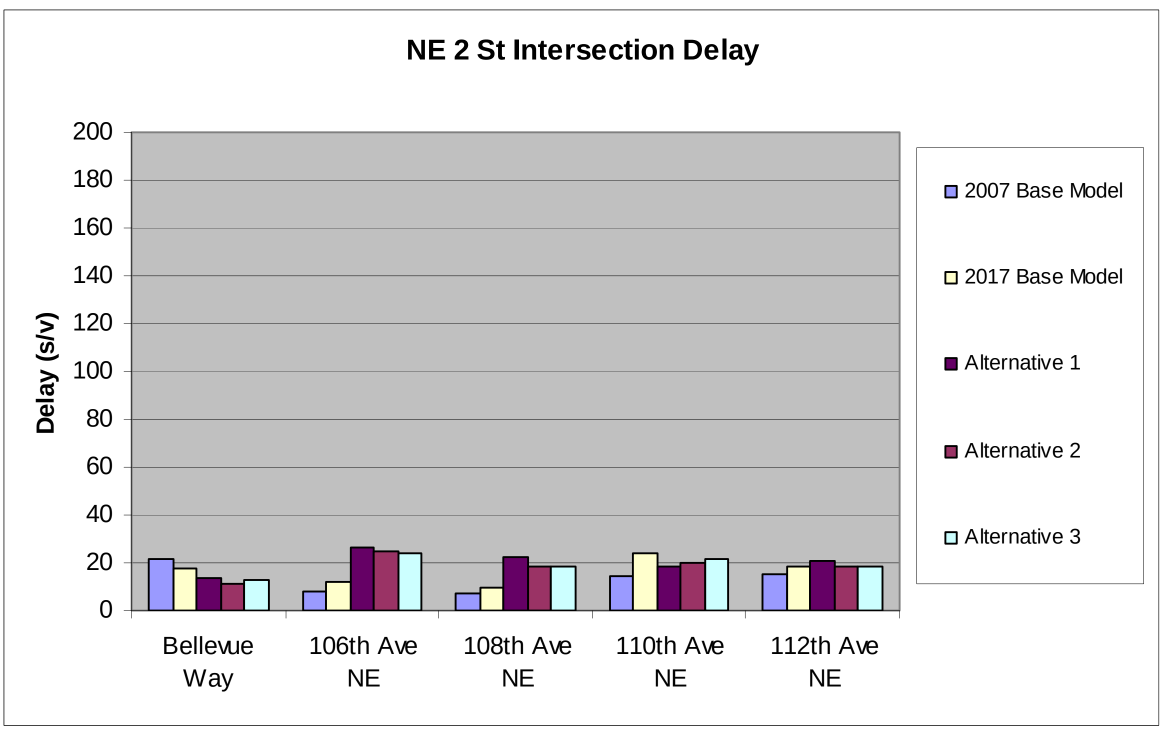

Figure 7: Intersection Delays on NE 2nd St – Bellevue Way to 112th Ave NE

Delays at the intersection of Bellevue Way increased significantly with Alternatives 1 and 2 because more traffic was forced to make left turns at that intersection due to the left turn restrictions elsewhere along the corridor. The infrastructure improvements in Alternative 2 gave it a slight advantage over Alternative 1. Alternative 3 reduced delay significantly at NE 8th St and Bellevue Way to a level below the 2007 delay, which was due to restricting a left turn movement and a right turn movement. At the intersections of NE 8th St / 106th Ave NE and NE 8th St / 108th Ave NE, there were significant delay decreases resulting from all three alternatives. These significant decreases in delay were due to restricting left turns on all approaches at these intersections which simplified the signal timing. Alternatives 1 and 2 increased the delays at the intersections of NE 8th St/110th Ave NE and NE 8th St/112th Ave NE. This was due to no-turn restrictions at these intersections for these alternatives. Alternative 3 improved the delay at the intersection of NE 8th St and 110th Ave NE to the 2017 base delay level. The configuration at the 5 leg intersection of NE 8th St and 112th Ave NE and its location at a freeway on ramp made it impossible to restriction movements for that intersection. The delay at this intersection increased with Alternatives 1-3 since more vehicles reached this already over-capacity intersection faster than they did without the turn restrictions at the other intersections on NE 8th St.

Figure 10 shows the delays for intersections located along NE 10th St between Bellevue Way NE and 112th Ave NE. Overall, there were no significant delay changes between the 2007 base model and the 2017 base model at the intersections of NE 10th St/106th Ave NE, NE 10th St/108th. Ave NE and NE 10th St/110th Ave NE. There were some additional delays resulting from additional traffic at these intersections due to turn restrictions at other locations in Alternatives 1-3. However, these increases were not substantial and therefore not a concern. Alternative 3 increased the delay at the intersection of Bellevue Way and NE 10th St since some the left turning traffic from the intersection of Bellevue Way NE and NE 8th St was moved to this intersection. This was a trade-off to improve the delay at the intersection of NE 8th St and Bellevue Way NE. Alternatives 1-3 slightly improved the delay at the intersection of NE 10th St and 112th Ave NE over the 2017 Base Model, which is unusual since intersections on the perimeter street typically had worse delays as a result of turn restrictions on internal nodes.

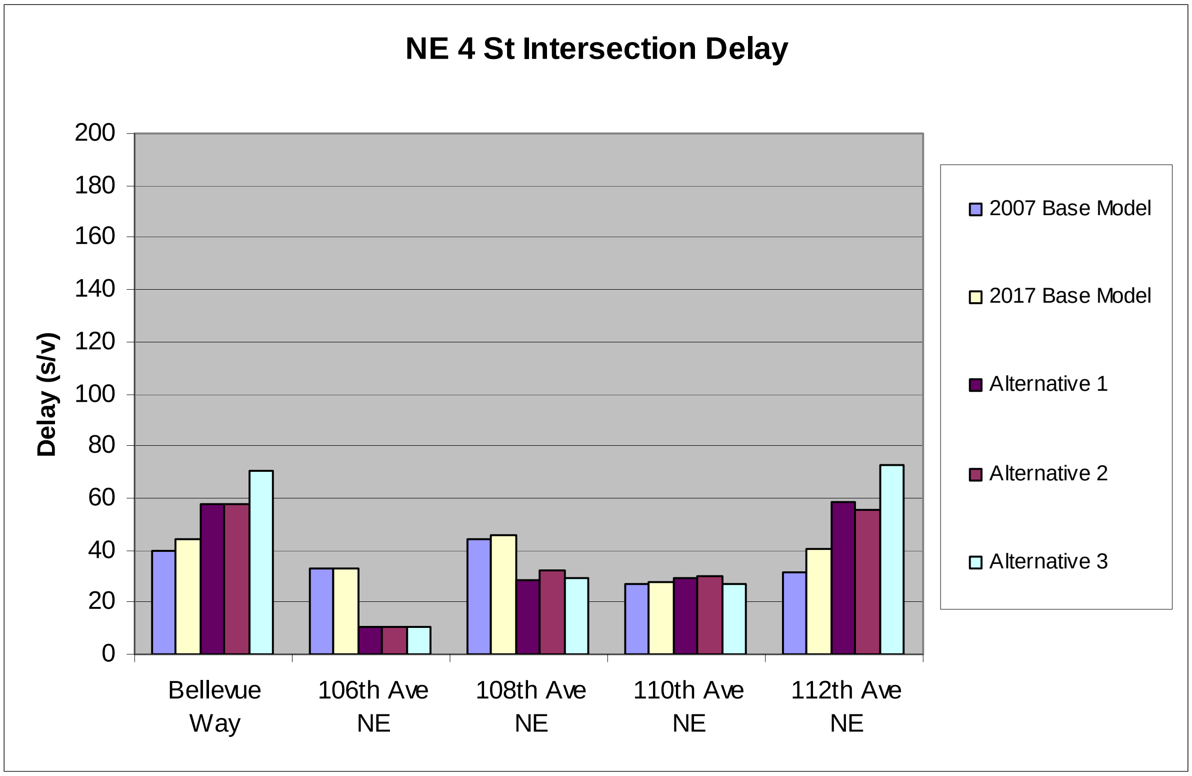

Figure 8: Intersections Delay on NE 4th St – Bellevue Way to 112th Ave NE

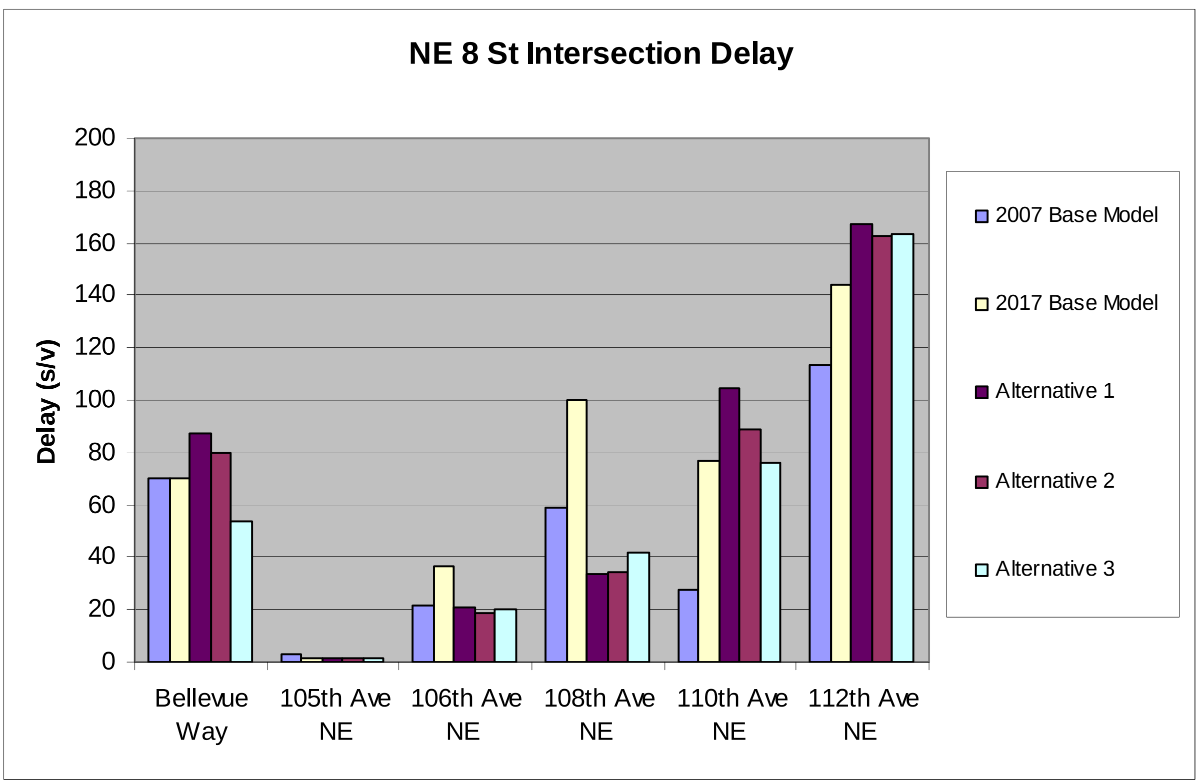

Figure 9: Intersections Delay on NE 8th St – Bellevue Way to 112th Ave NE

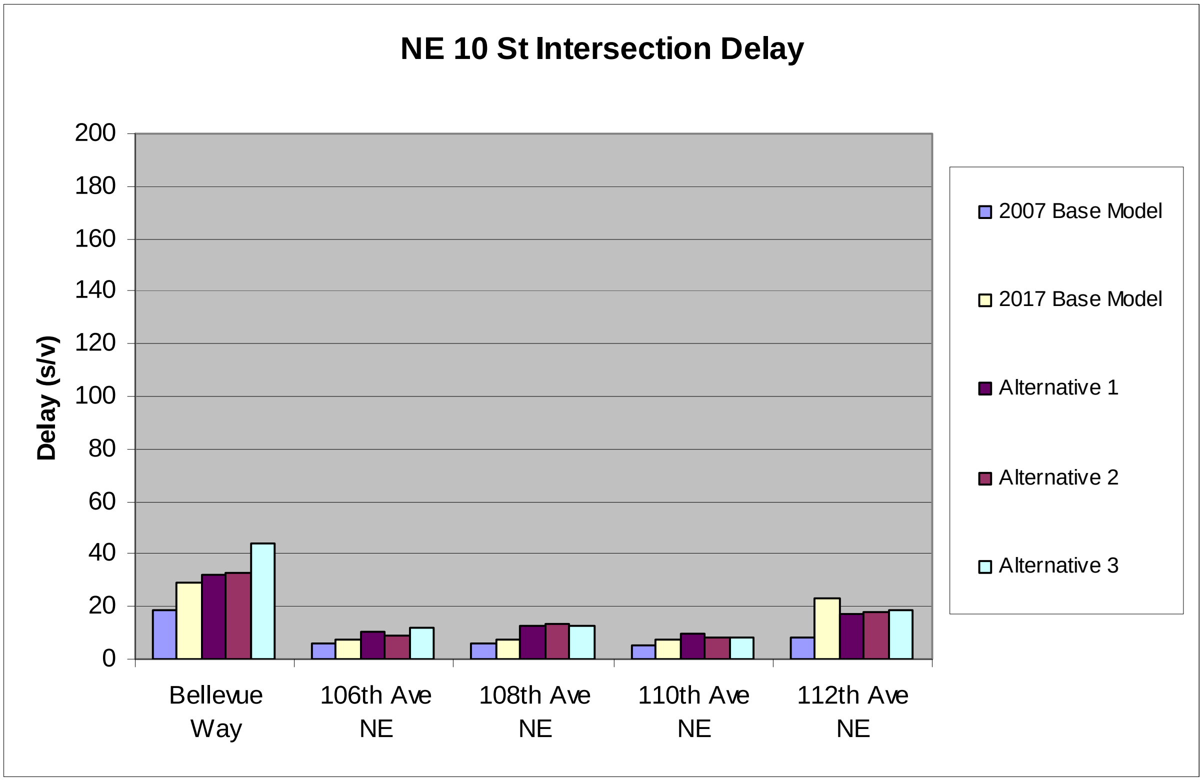

Figure 10: Intersection Delays on NE 10th St – Bellevue Way to 112th Ave NE

Figure 11 shows the delays for intersections along the NE 12th Street corridor from Bellevue Way NE to 112th Ave NE. All the intersections along NE 12th St had increased delays from the 2007 base model to the 2017 base model except for the intersection of NE 12th St and 110th Ave NE, which stayed close to the same. Delays at all of the intersections increased with all of the alternatives over the 2017 base model. The delay increases for Alternatives 1-3 were most notable at the intersections of NE 12th St/Bellevue Way and NE 12th St / 112th Ave NE. There were delay increases at the other intersections as well, but the increases were not as significant.

Figures 12-15 show the corridor travel time outputs for all of the major streets in the study area for the respective model runs. Travel time data for each intersection and percent changes between models can be found in the tables in Appendix A.

The changes in travel times in the northbound directions (Figure 12) were insignificant for all the alternatives, and there minor increases and decreases in corridor travel times between the 2017 base model and the three alternatives, which were also insignificant.

In the southbound directions (Figure 13), some corridors had increased travel times and others corridors improved when compared with the base 2007 network. Bellevue Way NE experienced increased corridor travel times in 2017 for all cases when compared to the 2007 base. Also, for this corridor, the 2017 base model had a lower travel time than all three improvement alternatives. The same overall result occurred for the southbound 110th Ave NE and 112th Ave NE corridors, but to a lesser extent. For Southbound 110th, the base 2007 corridor time was only slightly better than the base 2017 travel time, which was, in turn, better than the corridor times for Alternatives 1-3. The increase in corridor times from 2007 to 2017 for Southbound 112thAve NE, however, was significantly higher with the base 2017 system, which, in turn, did as well or better than the three improvement alternatives. The corridor travel times in the southbound direction for 108th Ave NE improved slightly for Alternatives 2 and 3 and showed insignificant decreases for Alternative 1 and the base 2017 system. There were also decreases in corridor travel times on Southbound 106th Ave NE for Alternative 2. The improvements in the 106th Ave and 108th Ave southbound corridors are not surprising, since all of the traffic signals on these corridors had turn restrictions for the three alternatives.

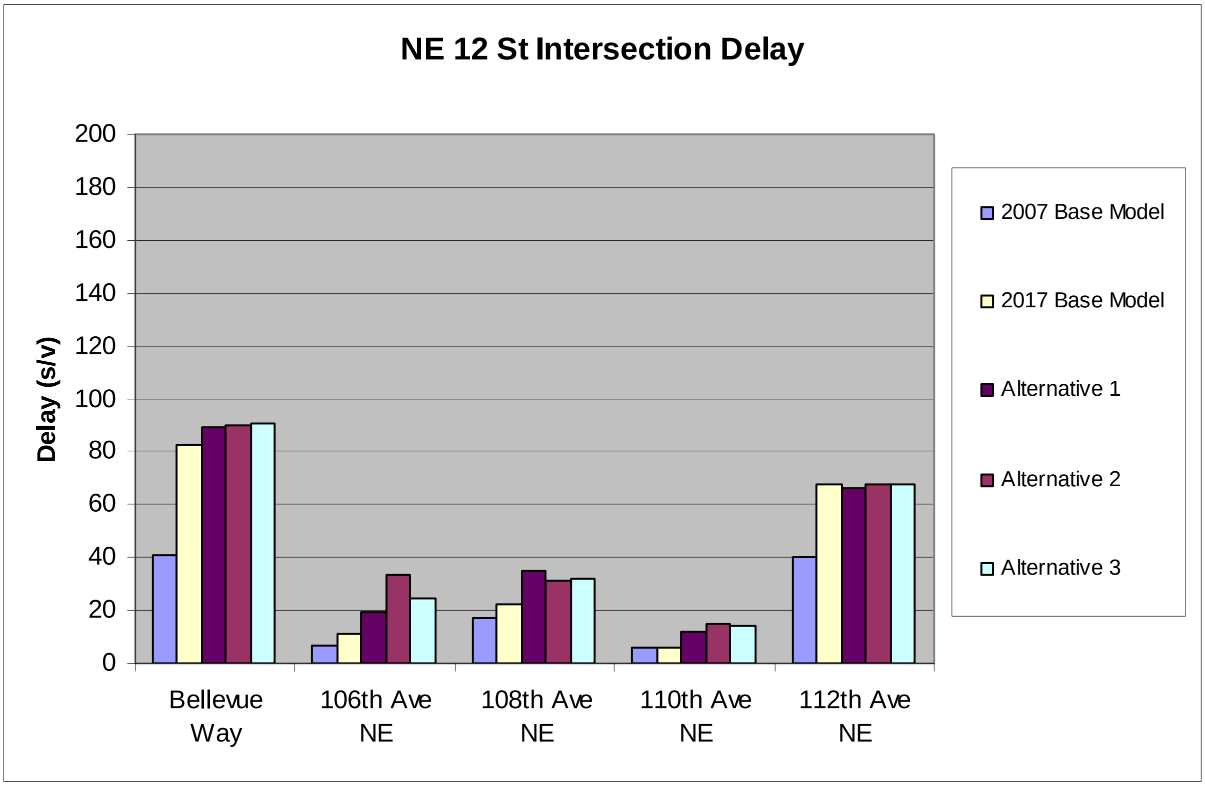

Figure 11: Intersection Delays on NE 12th St – Bellevue Way to 112th Ave NE

In the westbound direction (Figure 14), the changes in corridor travel time outputs between both 2007 and 2017 base models and the three alternatives were either insignificant or relatively minor for the NE 10th St, NE 4th St. and NE 2nd St corridors. For the other corridors, the base 2017 model predicted significant changes in corridor times than those obtained for the 2007 base. For NE 12th St and Main St., the 2017 base times were significantly higher, with Alternatives 1-3 having similar results on NE 12thSt, but significantly improved results on Main. On the NE 8th St corridor, the base 2017 corridor times were significantly better than those for the 2007 base with Alternative 1 showing a similar travel time decrease, Alternatives 2 & 3 demonstrated further significant travel time improvements for this important corridor.

In the eastbound directions (Figure 15), changes in corridor travel times between both of the 2007 and 2017 base models and the three alternatives were small and/or insignificant on the NE 12th St and NE 10th St corridors. For the other corridors, the base 2017 model had significantly higher corridor times than those for the 2007 base. On NE 4th St and on NE 2nd St., the alternatives all exhibited minor travel time improvements over the 2017 base. On the other hand, the alternative systems produced increases in corridor travel times in the eastbound directions on NE 8th St and Main St when compared to the 2017 base outputs for those two corridors. On Main St, the increase was very significant for Alternative 1, but minor for Alternatives 2 and 3. The increase in corridor travel times on NE 8th St in the eastbound direction comes as no surprise because of the turn restrictions included in the alternatives and because this is a very heavy PM peak travel direction.

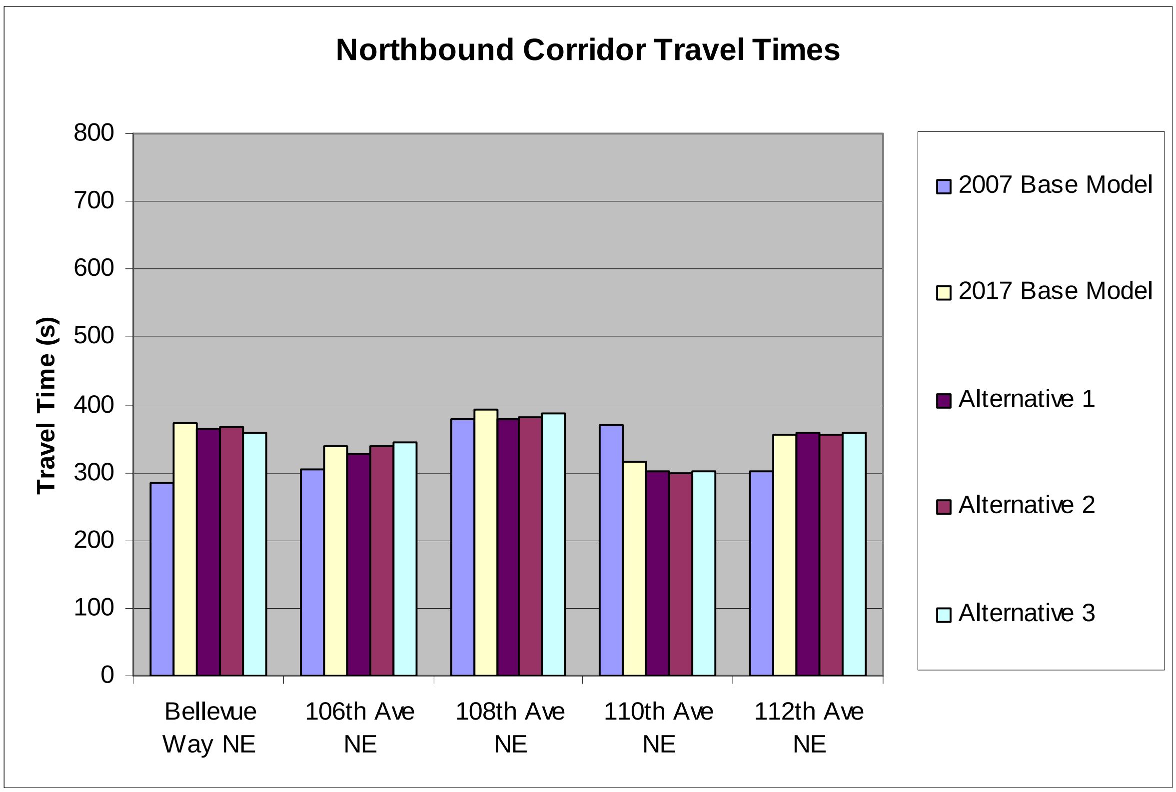

Figure 12: Corridor Travel Times – Northbound Direction

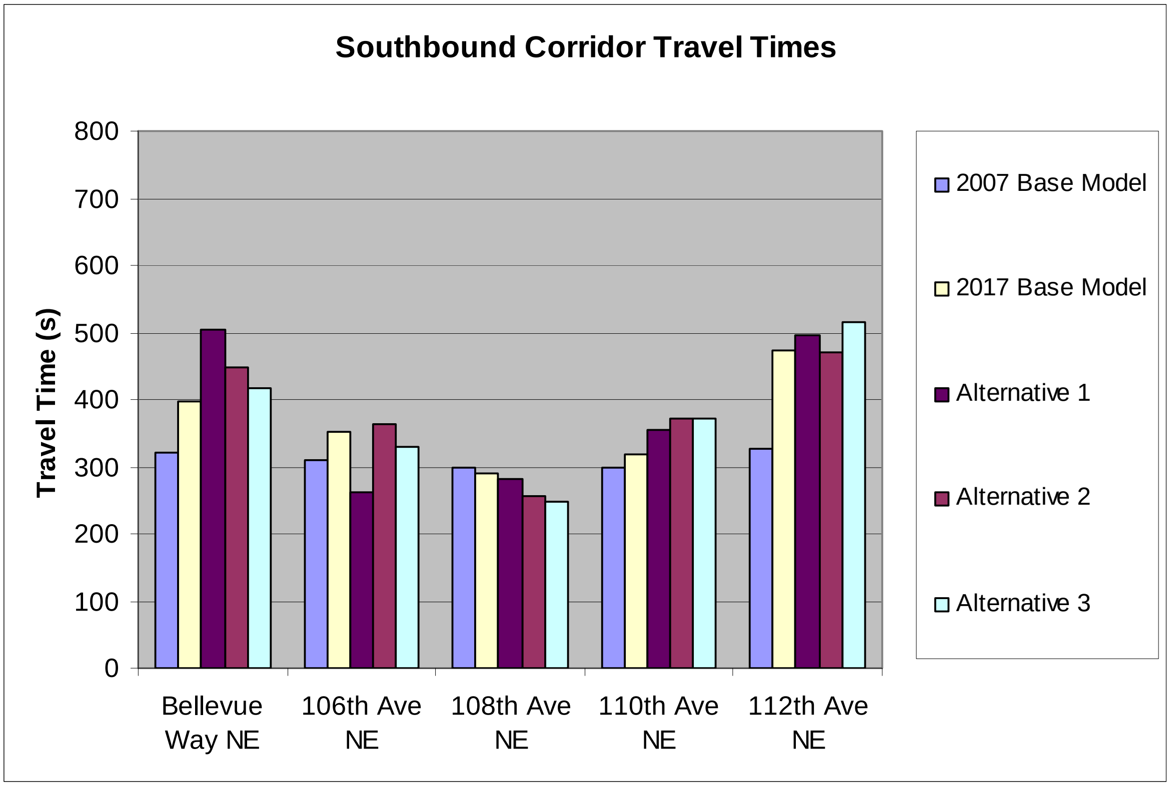

Figure 13: Corridor Travel Times – Southbound Direction

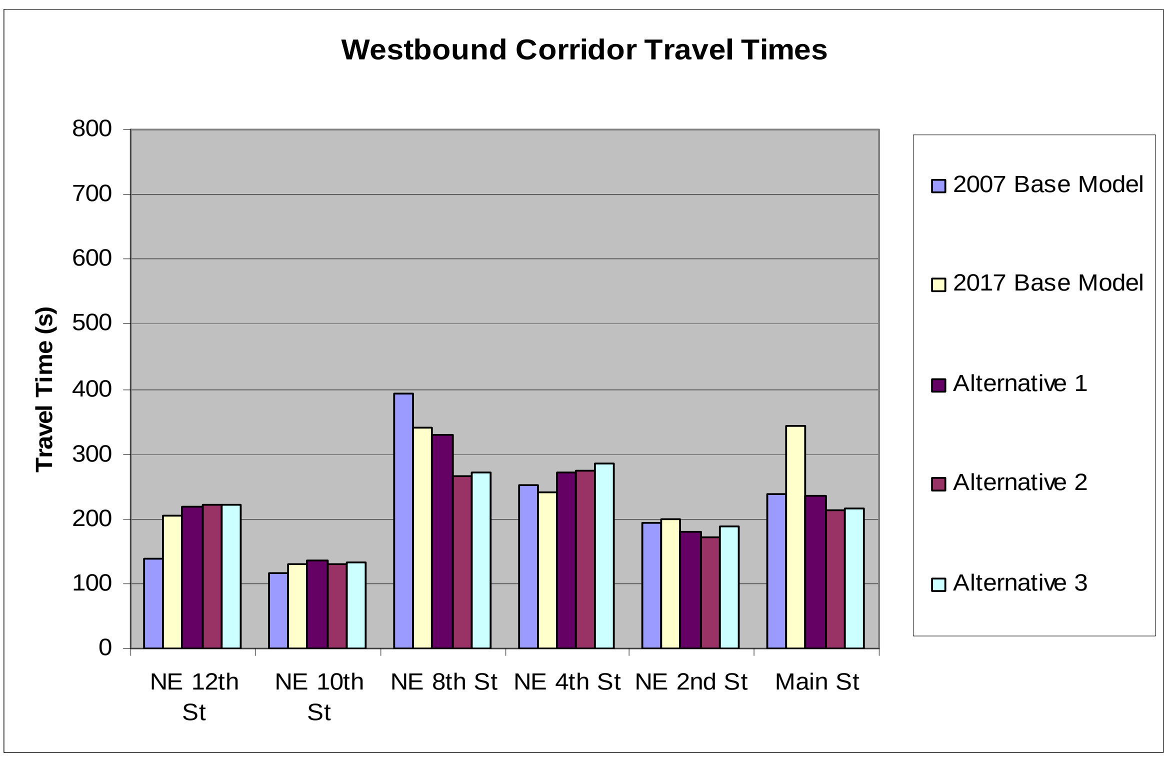

Figure 14: Corridor Travel Times – Westbound Direction

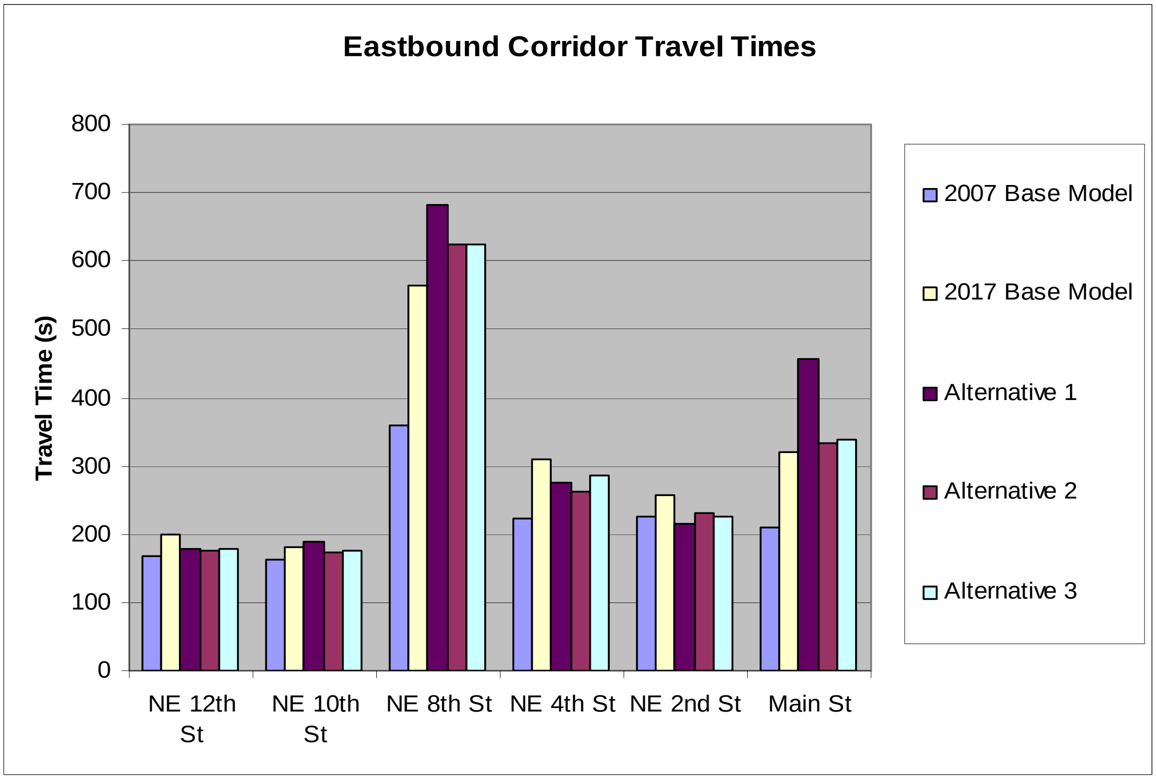

Figure 15: Corridor Travel Times – Eastbound Direction

V. CONCLUSIONS

A. Effectiveness of Alternatives

A comparison of the outputs of the 2007 and 2017 base models showed significant increases in intersection delays and the majority of directional corridor travel times over the 10 year period. This result was expected because of the assumed growth rate for traffic volumes of 3% per year. Comparisons of the 2017 base model with Alternatives 1, 2 and 3 are shown in figures 16-18. The letters shown on the nodes in the figures are LOS measurements.

Alternative 1 produced changes to traffic patterns and trip routing due to the restriction of left turns shown in Figure 1. The change in traffic volumes and routing resulted in traffic increases and corresponding delay increases, on streets such as Main St, Bellevue Way, NE 12th St, and 112th Ave NE where there were no left turn restrictions. Other locations with increased delays were intersections where left turns were allowed such as NE 8th St / 110th Ave NE, and NE 4th St / 110th Ave NE. Since the NE 2nd St and NE 10th St corridors have unused capacity, an increase in delay and usage of these streets is a desirable trade-off. Restricting left turns at selected intersections resulted in more traffic making use of underused streets. This was a benefit because it relieved traffic on the heavily used streets such as NE 8th St and NE 4th St.

Several intersections had significant decreases in delay under Alternative 1 including NE 8th St/106th Ave NE, NE 4th St/108th Ave NE, NE 4th St/106th Ave NE, and NE 8th St/108th Ave NE. The delays at these intersections decreased by 30% or more, which is very significant since NE 8th St and NE 4th St are the two busiest streets in downtown Bellevue. Of the 36 intersections within the study area, 11 had delay decreases as a result of Alternative 1 (Figure 16).

Alternative 2 added some infrastructure improvements to intersections that really needed to improve intersection performance. Such improvements included additional left turn lanes and right turn lanes. These infrastructure improvements decreased delays at 15 of the 36 intersections in the study area below the 2017 base model delay (see figure 17). A comparison of Alternatives 1 and 2 showed decreases in overall intersection delays. There was a direct relationship between infrastructure improvements and turn restrictions at intersections like Main St and Bellevue Way. However, infrastructure improvements in Alternative 2 at Bellevue Way/ NE 4th St, Bellevue Way/NE 8 St, and NE 8th St/110th Ave NE did not decrease the intersection delays to levels below the 2017 model. In other words, the improvements in Alternative 2 did not offset all of the negative impacts of Alternative 1 when compared to the base 2017 condition.

Alternative 3 incorporated everything that was included in Alternatives 1 and 2 and took an even more aggressive approach to turn restrictions. These additional turn restrictions decreased delays at 18 of the 36 intersections in the study area below the 2017 base model delay (see figure 18). This more aggressive approach to turn restrictions improved delays at the intersections of NE 8th St/110th Ave NE, NE 4th St/110th Ave NE and NE 8th St/ Bellevue Way. The decrease in delay at Bellevue Way and NE 8th St was very significant and resulted in a delay measurement that was actually below the 2007 Base model. The intersections of Bellevue Way/NE 4th St and Bellevue Way/NE 10th St had delay increases when compared to Alternatives 1 and 2 because additional left turns from the intersection of NE 8th St and Bellevue Way were added to these intersections.

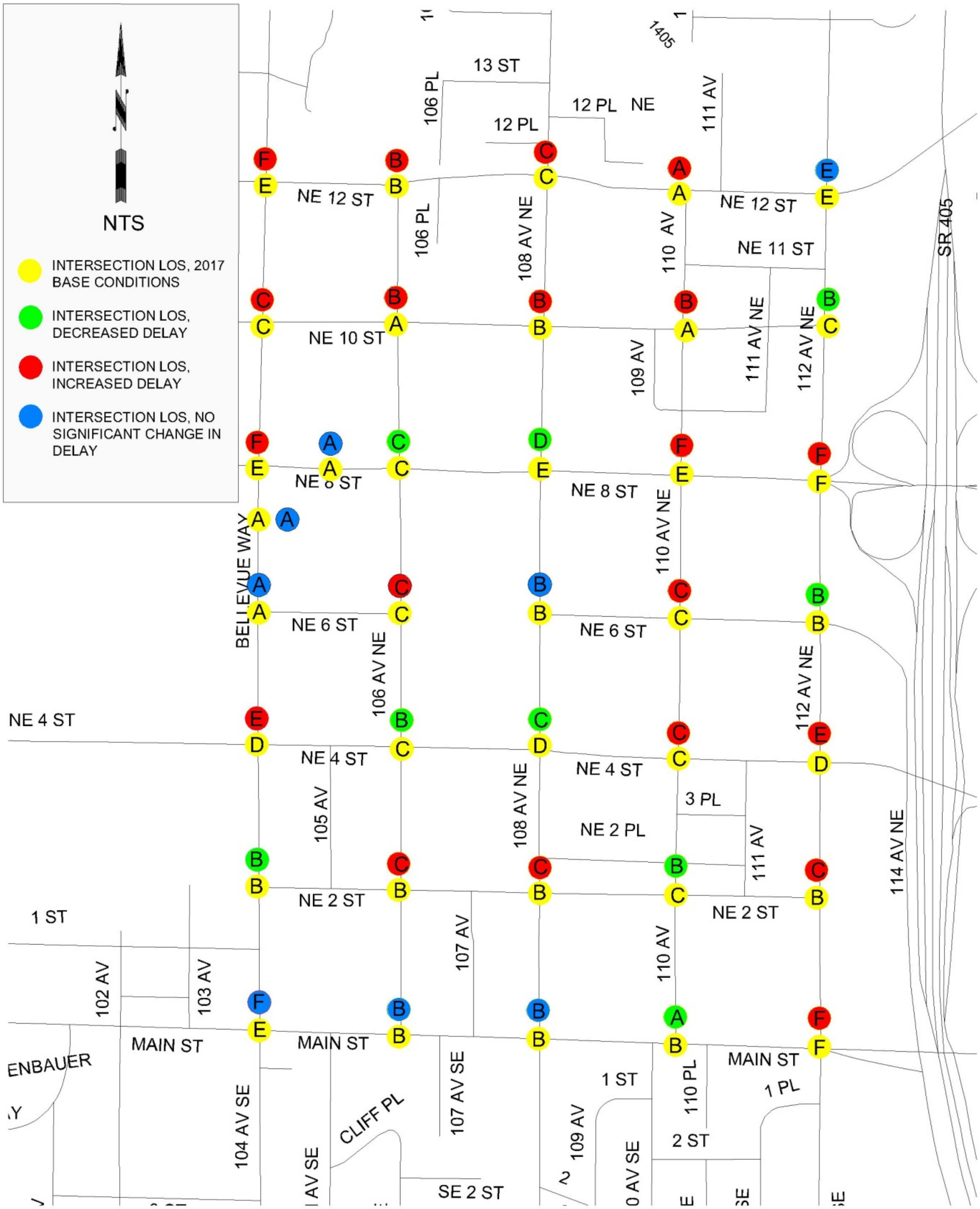

Figure 16: Intersection LOS – 2017 Base Model vs. Alternative 1

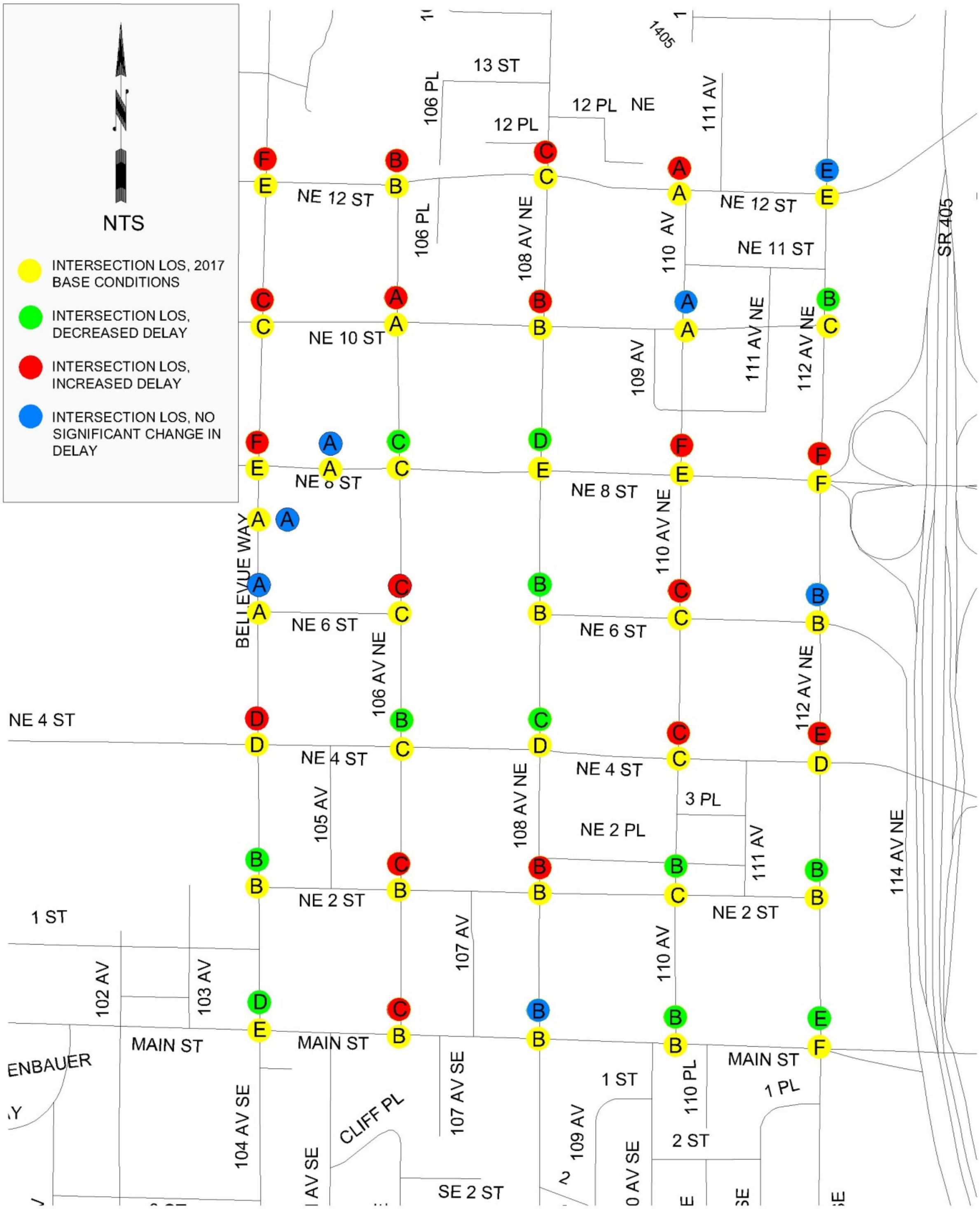

Figure 17: Intersection LOS – 2017 Base Model vs. Alternative 2

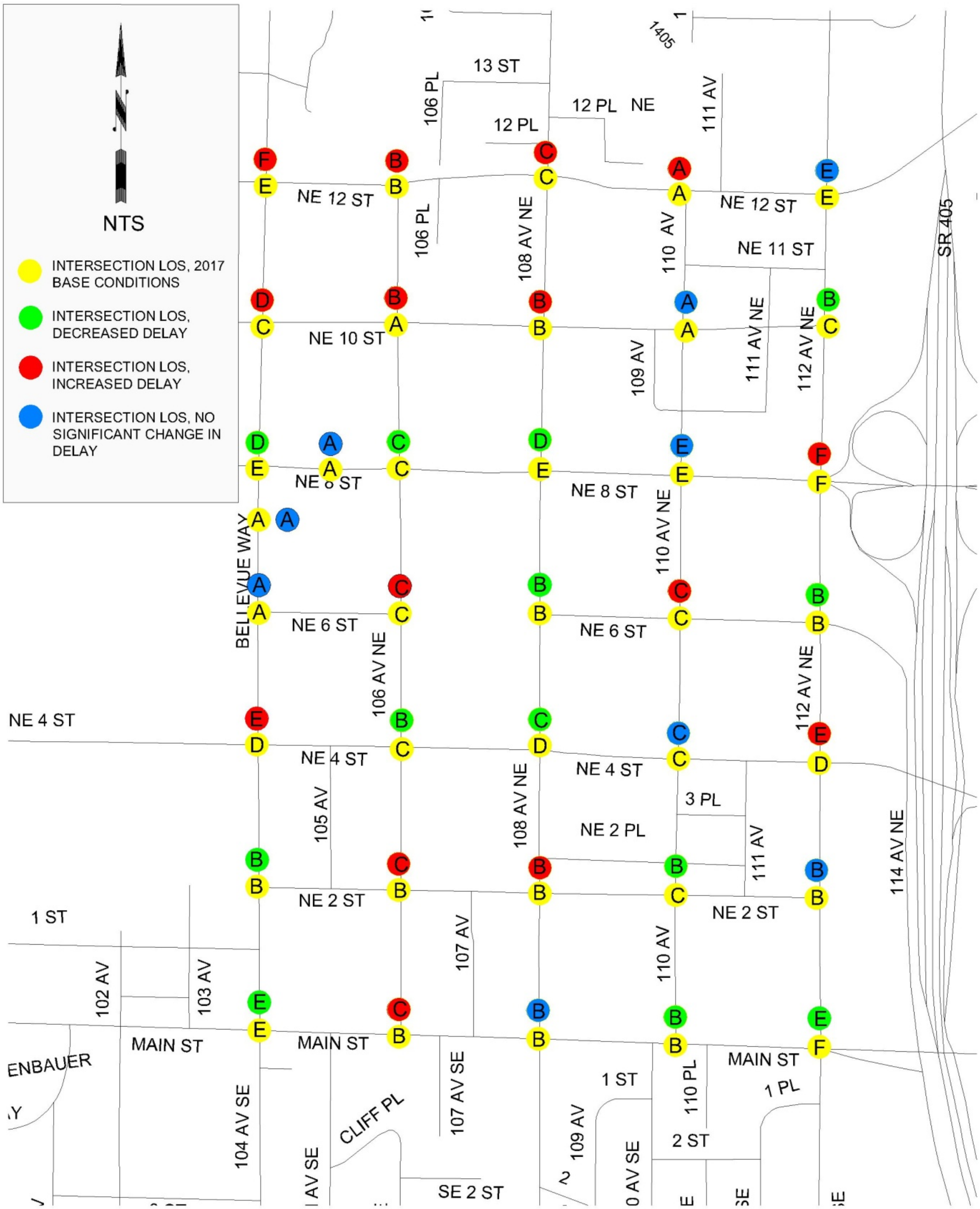

Figure 18: Intersection LOS – 2017 Base Model vs. Alternative 3

B. Lessons Learned

For turning movement restrictions to work effectively on a congested signalized network, the authors concluded that analysis must be done on an intersection by intersection basis. There will be trade-offs needed in order to reduce delay at heavily congested intersections. Decisions must be made as to which intersections can best handle delay increases while balancing those increases with reductions in delay at intersections with very high delays (LOS E or F). They learned that the Synchro model can be very sensitive to some changes and adjustments, while other adjustments have little or no effect on the model. The authors concluded that turn restrictions when coupled with targeted infrastructure improvements can prove to be very effective at reducing delay and improving LOS.

This type of simulation work can demonstrate to planners and engineers the value in testing small improvement proposals like these before implementing them. Modeling such concepts first gives one a good idea of how effective or not they may be for congested, sensitive networks. Through modeling, the authors learned that the most aggressive approach to turn restrictions combined with some infrastructure improvements yielded the best results as demonstrated by Alternative 3. A reasonable balance of feasible infrastructure improvements appears necessary for turn restrictions to work effectively. Selected left turn restrictions such as those in Alternative 1 are not effective by themselves, particularly if they are limited to internal, and possibly, less critical intersections. Alternative 1 does improve the delays at intersections internal to the study area, but it can make the delays worse at intersections on the perimeter streets. In the case of downtown Bellevue, the intersections on the perimeter streets already have some of the worst delays and need relief.

One of questions that came up during the analysis of the Bellevue network was how well the Synchro model accounts for the interaction between vehicles and pedestrians. Table 3 was developed to show the effect that pedestrians would have on the model outputs. The NE 8th Street corridor was selected because it has some of the highest vehicle and pedestrian volume numbers within the study area. Table 3 shows that the effect of pedestrians on the Synchro model delay results was minimal. Synchro uses the Highway Capacity Manual formula to calculate intersection delays. The impact of removing pedestrian volumes from the Synchro 2017 base model only decreased intersection delays within a range of -0.31% to -7.43%. It is very possible that these results understate the real effect of pedestrians on delay, especially at high-volume intersections.

Table 3: 2017 Delay with Pedestrians vs. Delay without Pedestrians

Intersection	2017 Delay (s/v)	2017 Delay w/o Peds(s/v)	% Change in Delay 2017 with ped vs. 2017 without peds
NE 8th St and Bellevue Way	81.2	78.8	-3.05
NE 8th St and 106th Ave NE	47.7	47.1	-1.27
NE 8th St and 108th Ave NE	133	123.8	-7.43
NE 8th St and 110th Ave NE	62.5	62.1	-0.64
NE 8th St and 112th Ave NE	161.4	160.9	-0.31

Another issue that was considered while setting up the Synchro model was the fact that the City's intersection and corridor data were collected over the year on different days with each set of data collected during the PM peak for particular intersections or corridors on a given day providing a snapshot in time of the actual condition that day. Although traffic conditions during the peak hour on "typical" days are not expected to vary widely, field measurements of traffic conditions conducted on portions of the network on different days of the year may or may not be sufficiently consistent for acceptable model accuracy.

C. Recommendations

Small CIP Investments Coupled With Traffic Control Alternatives Can Significantly Improve Peak Hour Downtown Traffic Flows. The practice of restricting turns at signalized intersections when combined with some infrastructure improvements appears to be beneficial for cities like Bellevue with central business districts that have significant intersection delays but do not have high enough traffic volumes to realize the benefits of a one-way street network. In this study, the authors demonstrated that, for cities like Bellevue, Washington with a semi-actuated signalized network and protected left-turn phases in their downtown grid, the more locations that had turn restrictions, the greater the reduction in intersection delay at those intersections. Concurrently, intersection delays increased slightly at nearby intersections that were currently under-used. This type of trade-off, when applied judiciously, makes more effective use of the entire street network. There were significant decreases in delays at several intersections with originally high delays on heavily traveled streets like NE 8th St and NE 4th St. Overall; Alternative 3 performed the best of three alternatives. The resulting LOS measures are shown in figure 18. The results indicate some intersections benefited from a combination of turn restrictions during the PM peak and small infrastructure improvements, while some others had increased delays as a result. Many of the intersections that had increased delays still had a LOS of C or better, so these were examples of satisfactory trade-off results. Overall, corridor travel times decreased as a result of restricting left turns in at least one direction on all streets except 112th Ave NE and NE 10th St.

The combination of turn restrictions during the PM Peak and infrastructure improvements in Alternative 3 will improve traffic flow and intersection delays on key streets like NE 8th St and NE 4th St during the PM Peak and will transfer traffic to other streets that are underused. This allows for better use of the street grid and a more uniform distribution of the traffic. The turn restriction alternatives would only be active during the PM peak, which allows for the flexibility making left turns at all intersections during the rest of the day. The benefits realized at many intersections on NE 8th St and NE 4th St will outweigh the increases in delays at other intersections within the study area. Many of the intersections that had delay increases as a result of restricting left turns were locations with initially small delays. The practice of restricting turns at intersections coupled with some infrastructure improvements helps redistribute traffic from heavily traveled streets like NE 8th St and NE 4th St to less frequently used streets like NE 10th St or NE 2nd St.

Implementation of turn restrictions solely during the PM peak limits potentially negative impacts of this traffic control option on surrounding businesses and homeowners and potentially benefits commuters at the same time. Some business owners will likely be opposed to the idea of restricting turns at intersections because it may make it more difficult and inconvenient for their customers to reach their business. However, restricting turns at intersections does have less negative impact on businesses than converting the streets to a one-way grid.

Reducing overall intersection delays and corridor travel times is also beneficial to the environment. The faster vehicles can be moved through an intersection, the less time they will idle. Intersection delays and corridor travel times were improved on some of the streets in downtown Bellevue including NE 8th St, which has the worst intersection delays and travel times. Not every street or intersection benefited from restricting turns and some intersections had increases in delay. The goal of reducing delays and improving as many intersections with LOS E or F as possible can be achieved by taking an aggressive approach to turn restricting combined with making some infrastructure improvements. However, there are some locations where actions like these, aimed at improving LOS, are not feasible such as intersections near freeway on ramps.

New Technologies for Real-Time Data Collection Will Significantly Improve Model Calibrations and, Therefore, Prediction Accuracy. At the beginning of this research study, traffic volume data were collected using counts from induction loops approaching intersections on NE 8th St and NE 4th St within the study area. The volumes were counted using the 3M Canoga 800 Loop Amplifier Card. Data were collected during the Christmas holiday season in 2007 and in January 2008 in an effort to measure traffic at its worst levels. The analysis and processing of the loop data proved to be more time consuming than expected and could not be completed within the scope of this research project. The original intent was to use that volume data and run scenarios under the worst traffic volumes.

The City of Bellevue currently has the technology to collect and transmit real-time data from the induction loops at signalized intersections to the City’s traffic control center. Future research using these data will lead to improved traffic forecasts. To better understand how accurately Synchro estimates delays and travel times, future research could include real-time data from the signalized intersections that could be fed directly into the models. This would allow for concurrent field delay data to be collected and compared directly to the Synchro model outputs.

The City of Bellevue is already working on several innovative tools to help ease congestion in the downtown area including a traffic flow map that helps drivers identify the problem locations. The City of Bellevue will also be upgrading its traffic signal computer in the next few years, which will allow for more opportunities for data collection and more efficient operation and coordination of downtown traffic signals.

Other Potential Model Improvements. Another issue of ongoing discussion in traffic engineering practice relates to analysts' assumptions about pedestrian walking speeds. Since meeting the walking speed needs of the elderly will continue to be an important issue in the future, research on the network impacts of lower walking speeds would be useful to determine whether significant increases in intersection delays would result from right-turning vehicles waiting for pedestrians to cross the street.

Some other items to consider for future research would be to refine the Synchro model to include the new bridge across I-405 at NE 10th St to see how it impacts the 2017 models results and Alternatives 1-3. Another way to test the effectiveness of turn restrictions would be to model the entire downtown street network in VISSIM and then compare that to the overall network performance in Synchro.

REFERENCES

Bellevue, City of, 2007 Transportation Department Traffic Data Book, January 2008

EMME/2 User's Manual Software Release 8.0. INRO Consultants Inc., Montreal, Canada, 1996.

Husch, David, Albeck, John, Synchro 6 User Guide, Trafficware, Albany California, 2004.

Park, Byungkyu; Won, Jongsun; Yun, Ilsoo, Application of microscopic simulation model Calibration and validation procedure: Case study of coordinated actuated signal system, National Research Council, Washington, DC 2007,United States, 2006, p 113-122

Riniker, Keith, Silberman, Paul, Sabra, Ziad A., Signal Timing Optimization Methodologies and Challenges for the City of Baltimore, MD, USA, Central Business District and Gateways, ITE Journal, Washington DC, June 2008

Robertson, H. Douglas, Manual of Transportation Engineering Studies, Institute of Transportation Engineers (ITE), 1994.

Sadek, Dr. Adel W., Aminson-Agbolosu, Seli J., Validating Traffic Simulation Models to Inclement Weather Travel Conditions with Applications to Arterial Coordinated Signal Systems, University of Vermont, Burlington Vt, November 2004.

Schroeder-EI-Bastian-J; Rouphail-Nagui-M, A Framework for Evaluating Pedestrian-Vehicle Interactions at Unsignalized Crossing Facilities in a Microscopic Modeling Environment, Transportation Research Board. Held: 20070121- 20070125. 2007. 22p (3 Fig., 3 Tab., Refs.) RN: Report Number: 07-2263

TRB 2000, Transportation Research Board, Highway Capacity Manual. Washington, DC, 2000

US Census Bureau, http://www.census.gov/popest/cities/SUB-EST2007.html, Site last updated July 9, 2009, Site last accessed on July 27, 2008.

Washburn, Scott, Larson, Nate, Signalized Intersection Delay Estimation: Case Study Comparison of TRANSYT-7F, Synchro and HCS, ITE Journal, Washington DC, March 2002.

APPENDIX A – MODEL DELAY OUTPUTS

Table 4: Synchro Model Intersection Delays

Int.#	Intersection	2007 Base Model	2017 Base Model	Alternative 1	Alternative 2	Alternative 3
28	NE 6th St and Bellevue Way	0.9	1	0.7	0.9	0.9
323	NE 7th St and Bellevue Way	3	0.6	0.7	0.7	0.7
179	NE 6th St and 106th Ave NE	15	18.2	24.2	32.9	26.6
126	NE 6th St and 108th Ave NE	19.4	22.6	22.6	14.3	12.9
124	NE 6th St and 110th Ave NE	16.2	16.5	19.9	19.2	20.5
107	NE 6th St and 112th Ave NE	9.5	20.3	15.3	14.3	14.8
	Main St					
9	Bellevue Way	51.8	85.3	86.5	56.8	58.8
19	106th Ave	9.2	16.7	18.4	34	29.1
24	108th Ave	7.2	10.1	10.9	11.1	11
157	110th Ave	10.7	16.6	10.4	12.7	11.9
36	112th Ave	57.1	117.2	152.7	88.1	89.5
	NE 2 St					
31	Bellevue Way	21.9	18	13.5	11.3	13.1
18	106th Ave NE	7.9	11.7	26.6	24.6	24.4
23	108th Ave NE	7	9.6	22.8	18.6	18.5
158	110th Ave NE	14.4	23.8	18.7	20	21.6
128	112th Ave NE	15.5	18.7	20.9	18.5	18.4
	NE 4 St					
8	Bellevue Way	39.4	44.3	58	57.6	70.2
17	106th Ave NE	33.3	33	10.3	10.5	10.2
22	108th Ave NE	44	45.4	28.8	32.2	28.9
159	110th Ave NE	26.7	27.8	29.4	29.6	26.9
72	112th Ave NE	31.5	40.6	58.2	55.2	72.8

	NE 8 St					
7	Bellevue Way	70.1	70	87.5	79.6	53.5
322	105th Ave NE	3	1.7	1.7	1.7	1.7
16	106th Ave NE	21.5	36.7	21.1	18.4	20.3
21	108th Ave NE	58.6	99.7	33.3	34.7	42
27	110th Ave NE	27.5	76.8	104.5	88.9	76.2
26	112th Ave NE	113.4	144.4	167.1	162.5	163.3
	NE 10 St					
6	Bellevue Way	18.5	28.8	31.9	32.6	43.7
154	106th Ave NE	5.8	7.5	10.6	9.1	11.7
190	108th Ave NE	6	7.1	12.4	13.1	12.5
235	110th Ave NE	5.4	7.3	9.4	8.2	8
234	112th Ave NE	8.5	23.5	17.4	17.9	18.5
	NE 12 St					
5	Bellevue Way	41.1	82.5	88.9	90.3	90.8
15	106th Ave NE	6.6	11.2	19.5	33.8	24.5
20	108th Ave NE	16.8	22	34.6	31.3	31.6
162	110th Ave NE	6.2	6.2	11.8	14.7	13.8
25	112th Ave NE	40.4	67.8	66.2	67.5	67.7

Table 5: Synchro Model Corridor Travel Times

	2007 Base Model	2017 Base Model	Alternative 1	Alternative 2	Alternative 3
Corridor	**NB**	**NB**	**NB**	**NB**	**NB**
Bellevue Way NE	285.4	374	363.7	367.3	359.6
106th Ave NE	304.8	339	326.1	340.1	343.1
108th Ave NE	378.4	394.1	377.6	380.8	388.2
110th Ave NE	369.8	316.6	301.4	299.1	302.7
112th Ave NE	302.5	357.2	358.3	355	358.4
Corridor	**EB**	**EB**	**EB**	**EB**	**EB**
NE 12th St	167.2	199.1	178.8	176.6	177.5
NE 10th St	163.5	179.9	189.5	173.1	177
NE 8th St	358.4	564.2	681.5	623.5	625.5
NE 4th St	222.5	309.9	275.5	262.4	285.6
NE 2nd St	225	258.3	216.3	230.3	224.4
Main St	211	318.7	457.4	332.7	338
Corridor	**SB**	**SB**	**SB**	**SB**	**SB**
Bellevue Way NE	322.2	398.2	503.2	448.7	416.4
106th Ave NE	311.2	350.8	262.9	362.9	330.9
108th Ave NE	299.6	290.8	282	255.7	247
110th Ave NE	297.7	318.6	356.2	371	371.1
112th Ave NE	325.8	472	495.6	469.9	514.1
Corridor	**WB**	**WB**	**WB**	**WB**	**WB**
NE 12th St	139.4	204.2	219.1	220.8	220.2
NE 10th St	115.1	129.1	135.1	131	133.8
NE 8th St	392.6	339.7	329.7	265.6	271.1
NE 4th St	252.3	240.3	271.9	274.4	285.9
NE 2nd St	194.4	198.2	179.2	171.1	189.5
Main St	238.3	342.1	234.7	213.7	215.5