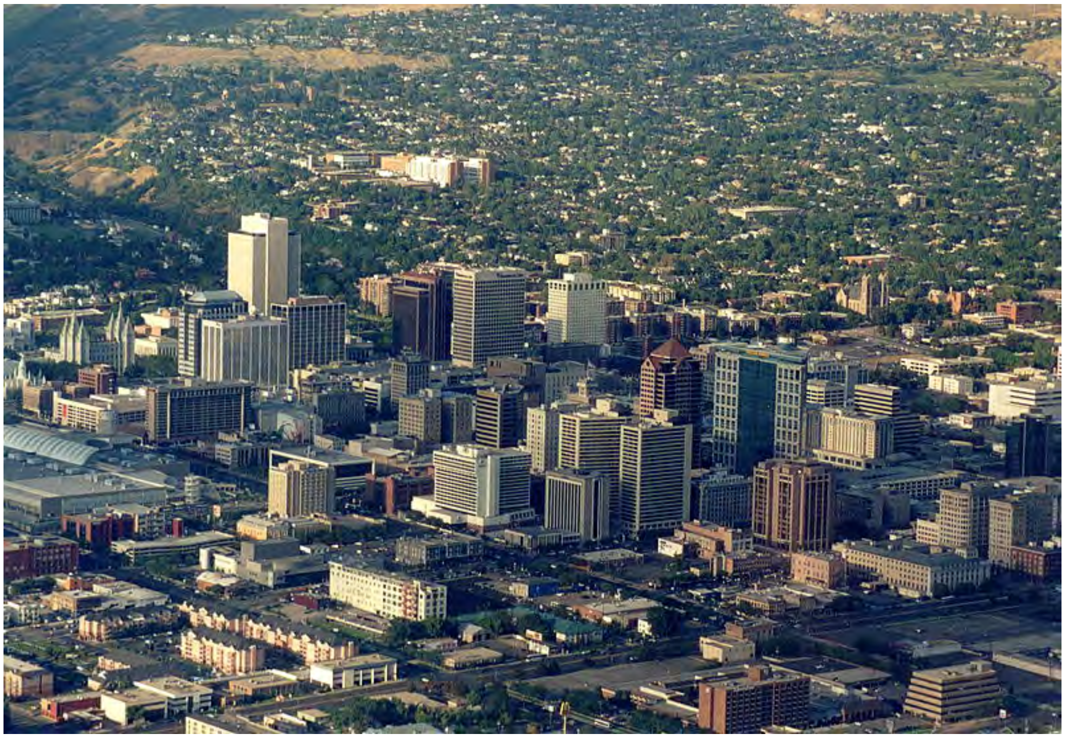
Traffic Signal Management and Synchronization Project
City of Salt Lake City



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Executive Summary

KOA Corporation (KOA) was retained by Salt Lake City as the consultant to conduct a traffic signal coordination study for 164 intersections[1] within the greater Central Business District (CBD) area of Salt Lake City, Utah. The signals within the study area are under the control of Salt Lake City and the Utah Department of Transportation (UDOT). The goal of the study was to develop traffic signal management and synchronization recommendations to reduce traffic delays, pollutant emissions, and petroleum fuel consumption. Other goals included determining the optimal frequency of retiming the signals and resources needed to do so and comparing the performance of the traffic signal operation in Salt Lake City to other cities with similar characteristics.

KOA completed the following tasks during this study:

- Conducted detailed field reviews of the project site
- Updated the City's original Synchro[2] network with new count volumes and timing parameters
- Used Synchro's volume balancing tool to fill in the gaps at locations with no volume counts available
- Conducted field calibrations using the SimTraffic tool from Synchro
- Optimized traffic signal coordination timing plans using Synchro
- Fine-tuned and field-reviewed the City-installed timing plans
- Conducted the "After Study" travel time runs and compared with the "Before Study" runs
- Conducted signal performance comparisons with three other cities
- Researched and conducted interviews with other cities to identify the signal timing staffing needs

Traffic Signal Management Improvements

<u>Cycle Length</u>

For the AM and PM peak periods, KOA proposed to retain one uniform 120-second cycle length with the exception of those light rail intersections along Main Street that are currently running free. UDOT intersections are already operating on a 120-second cycle length. For the midday period, the cycle length was reduced at some of the city-maintained intersections to an 81-second cycle. The unusual cycle was selected to harmonize with the existing 108-second cycle length currently set for the State and some major City intersections. Intersections with the two different cycle lengths will reach a common base point every four cycles.

Minimal changes are recommended to arterial corridors with light rail operation. The signalized intersections with light rail tracks in the median were previously calibrated and were optimized for the light rail operation by UDOT. Those signals also provide priority to the light rail operation.

[1] – Salt Lake City has a total of 173 intersections in its system network

[2] – A software application tool used in optimizing traffic signal timing

Signal Synchronization Measures of Effectiveness Improvements

A travel time and delay "after" study was conducted along 16 corridors during the weekday AM, midday, and PM peak periods, which were compared to the results of "before" studies conducted by the City for each corridor. The corridor-based measures of effectiveness (MOE's) performance consisted of average travel time, average speed, number of stops, and total delay. During the AM peak period, the optimized timing plans improved traffic operation by decreasing average travel time of 16 corridors by 8%, increasing average speed by 8%, decreasing number of stops by 17%, and decreasing total delay of each run by 14%. During the midday period, the comparison shows a 6% reduction in average travel time of 16 runs, with the average number of stops decreasing by 3% and total delay decreasing by 12%. The average speed increased by 3%. During the PM peak period, the comparison reports 8% reduction in the travel time, 14% reduction in number of stops and 11% reduction in total delay, the average speed increased by 5%.

In terms of network-wide improvement, with the optimized timing plans, total delay within the downtown area was reduced by 14% for AM Peak, 10% for Midday Period, and 7% for PM Peak. The number of total stops was reduced by 8% for AM Peak, 7% for Midday Period, and 8% for PM Peak.

Fuel Consumption and Pollutant Emission

Based on KOA's recommendation, the Measure of Effectiveness (MOE) from Synchro shows improvements in all three time periods that result in 337,000 gallons of fuel savings per year. The results significantly exceed the target goal of 32,000 gallons for this project by a factor of ten. The daily and annual reduction in pollutant emissions are presented in the table below.

Peak Hour	Network MOE	Existing	Optimized	Reduction
AM	Fuel Consumed (gal)	4715	4437	278 (5.9%)
	CO Emissions (lbs)	728	683	42 (5.8%)
	NOx Emissions (lbs)	141	132	9 (6.3%)
	VOC Emissions (lbs)	168	159	11 (6.6%)
Midday	Fuel Consumed (gal)	4189	4013	176 (4.2%)
	CO Emissions (lbs)	646	617	26 (4.1%)
	NOx Emissions (lbs)	126	121	4 (3.5%)
	VOC Emissions (lbs)	150	143	7 (4.4%)
PM	Fuel Consumed (gal)	5279	5059	220 (4.2%)
	CO Emissions (lbs)	814	780	33 (4.1%)
	NOx Emissions (lbs)	159	152	7 (4.2%)
	VOC Emissions (lbs)	190	181	9 (4.7%)

	Daily Reduction	Annual Reduction
Fuel Savings (gal)	1348	337,000
CO Emissions Reductions (lbs)	203	50,700
NOx Emissions Reductions (lbs)	40	10,000
VOC Emissions Reductions (lbs)	53	13,200

Staffing Resources for Signal Retiming

The City recently lost one staff position in its Traffic Control Center (TCC) due to budgetary constraints. Based on our survey of four other cities (Tallahassee, Amarillo, Knoxville, and Little Rock), we believe that the staffing level in the TCC, currently consisting of two staff members, is inadequate to effectively operate and maintain the signal system while performing other vital daily tasks. Maintaining communication linkage between the TCC and more than 180 signals in the field and various closed circuit television (CCTV) cameras requires substantial effort on a daily basis. Additionally, the City should budget adequate resources to conduct the retiming of the entire signal system on three-year intervals. The primary factors for needing to retime the signals are:

- Land use changes
- Population growth or shifts
- Change in flow profiles (volume and classification)
- Compliance to changes in Federal or state standards for pedestrian clearance and other intervals

Currently, the City maintains a database of the traffic signals, including controller type and history of updates. However, the City does not have enough resource to maintain a Performance Measure of Effectiveness (MOE) database to track the operational performance within the City's roadway network. We recommend that the City assign adequate staff resource to conduct performance survey of MOE once every other year. Performance MOE surveys will also help in identifying areas where signal retiming efforts should be initiated.

As a result, it is recommended that the City budget resources to hire three additional staff – two engineers and one operator. Duties of additional staff include, but not be limited, to the following:

- Resolving traffic operational issues, in particular signal timing related issues, based on citizens' complaints.
- Analyzing and assessing the City's communication infrastructure needs for improvements necessary for the safe and efficient utilization of the roadway network.
- Ensuring coverage by manning in the communication console at all times during the normal business hours in the TCC.
- Coordinating and staffing major/special events requiring changes in timing plans in the TCC.
- Maintaining a Performance Measure of Effectiveness (MOE) database to track the operational performance within the City's roadway network.
- Determining, evaluating and recommending solutions at intersections with high accident rates.
- Completing the retiming of signals on every three-year intervals.

With the additional staffing, the TCC should consist of one Director, two traffic signal engineers, and two operators. Signal retiming and traffic count stations are eligible to be funded through State and Federal sources. While the Federal Congestion Mitigation and Air Quality (CMAQ) program is one of the primary sources of funds for signal retiming projects, other sources of funds are needed to maintain the traffic count stations.

Comparison of Performance with Three Other Cities

There are several features that are unique to Salt Lake City that cannot be found in other cities in the U.S. The most significant feature, perhaps, is the overall size of an average intersection. The downtown streets are unusually wide, resulting in long crosswalks and corresponding long pedestrian clearance times. Outside of the downtown area, many intersections have no pedestrian push buttons. These features result in the need to use a relatively long traffic signal cycle that, in turn, necessitates longer waits at the intersections. Furthermore, the light rail operation that runs on Main Street and 400 South and cuts through the downtown area features traffic signal controllers that provide priority to minimize delays for the light rail operation, possibly at the expense of motor vehicular and pedestrian traffic.

Downtown networks of three other cities were selected for comparison. They are the City of Honolulu, Hawaii, City of Louisville, Kentucky and City of Santa Monica, California. The table summarizes the network-based measures of effectiveness (MOE's) performance for all four cities.

City	Period	No. of I/S in the Network	Average Speed (mph)	Delay/Int (sec)	Stops/Int
Salt Lake City	AM	173	17	9.3	833
	PM	173	16	11.3	939
Honolulu	AM	74	12	10.7	997
	PM	74	10	15.4	1117
Santa Monica	AM	60	14	6.4	733
	PM	60	12	11.4	1123
Louisville *	AM	220	20	10.5	n/a
	PM	220	19.5	13.6	n/a

Note: *Based on a report prepared by Entran, PLC, submitted to the City on October 2009.

Despite its relative large intersection sizes and having a light rail operation running through the downtown area, Salt Lake City fares well in comparison with other cities. It has the second highest average speeds for both peak periods. Salt Lake City has the lowest average delay and number of stops during the evening rush hours.

Newer Central Traffic Management Software

Siemens i2 Central Traffic Management Software (TMS) has been used to manage 755 traffic signals in the Salt Lake Metropolitan area, encompassing three counties, for the past 12 years. In the near future, this software will no longer be supported by the manufacturer and will need to be replaced. Newer generations of central traffic management software are available that are easier to use; could detect, quickly diagnose and correct system problems; and, provide more robust reporting. In general, they operate in more effective and efficient manners. The newer software also provides a more secured interface and supports features such as emergency and/or incident response, transit signal priority and full set of customizable features to fit individual needs of the City. A comprehensive search is needed to review these software packages in order to determine which of them best suits the needs of the Salt Lake City area's traffic signal system.

In our review of the existing Salt Lake City's traffic signal timing, we found the City is demonstrating "good practice" strategies and philosophies while providing balanced levels of service to all modes of travel in its approach to traffic signal operations. The strategies and philosophies, that the City is using, are in line with traffic signal timing industry standards provided by the Institute of Transportation Engineers (ITE).

1. Introduction

KOA Corporation was retained by the Transportation Division, Salt Lake City to develop traffic signal management and synchronization recommendations to reduce traffic delays, pollutant emissions and petroleum fuel consumption. The project is in keeping with the general guideline, established by the Institute of Transportation Engineers (ITE), an international educational and scientific association of transportation professional organization, to retime signal networks on a 3 to 5 year interval. The most recent timing update for the network had been conducted by UDOT and the City in the Fall of 2009. The goal of the 2009 effort was to optimize the coordination progress and decrease the delay on the State highways while maintaining coordination with the City streets.

Salt Lake City is the central city to 1.8 million inhabitants residing in four counties that make up the Wasatch Front and that are within an hour's drive from downtown. The majority of Utah's 2.4 million people live in the Wasatch Front urban corridor, and 20 percent of the state's total work force commutes to jobs located in the city limits. A significant portion of pollutants from nitrous oxides, volatile organic compounds, carbon monoxide, and small particulate matter in the Salt Lake Valley are produced by on-road vehicles.

As an idle reduction and fuel conservation strategy, this study optimized the city-wide traffic signal operation with a long-term effect of reducing fossil fuel emissions and improving air quality along the Wasatch Front.

It was hoped per the funding application that updating traffic signal timing could save an estimated 32,000 gallons or more of petroleum fuel each year by reducing traffic signal delays and reducing vehicle idling. Community residents will save in gasoline costs due to reduced starting and stopping, and idling. In addition to greenhouse gas emissions reductions, the project is anticipated to reduce volatile organic compounds emissions by more than 300 pounds per year and nitrous oxides emissions by over 400 pounds per year, resulting in air quality improvements.

This report summarizes the existing signal operation analysis at the study intersections, development of updated coordination timing plans for each peak period of the day, travel time and delay before and after studies, and other findings.

2. Assessment of Existing Conditions

2.1 Roadway Network

The study includes a total of 164 signalized intersections in Salt Lake City, east and west between 500 West and 1300 East and north and south between 600 North and 900 South. The signals within the study area are under the jurisdictions of Salt Lake City and the Utah Department of Transportation (UDOT). The major study corridors are listed below.

- N Temple
- S Temple
- 200 South
- 300 South
- 400 South
- 500 South
- 600 South
- 700 South
- 800 South
- 900 South
- 600 North
- 400 West
- 300 West
- West Temple
- Main
- State
- 200 East
- 300 East
- 500 East
- 600 East
- 700 East
- 1300 East

Salt Lake City's street network in downtown CBD is primarily a grid network. The signal spacing varies between 700 feet and 900 feet. Light rail runs on 400 South, the major east-west arterial connecting the downtown CBD to the University of Utah campus.

2.2 Traffic Signal Operation

In 2009 the signals in downtown area were re-timed in a joint effort between the City and UDOT to run 164 traffic signals on the same cycle length and time-of-day schedule. A cycle length of 120 seconds was used for the AM and PM peak periods and a cycle length of 108 seconds was used during the off-peak periods. Some virtual one-way couplets were provided to favor certain directions during the peak hours such as 800 South favors westbound and 900 South favors eastbound. The existing cycle length of study intersections is shown in Appendix A.

Opinions about the effectiveness of the re-timing efforts conducted in 2009 have been mixed. Some people have perceived great improvements, while others have expected better performance from the system. As a result, KOA Corporation was hired to, among other tasks, conduct field reviews of the downtown system to analyze whether significant benefits might accrue from further re-timing.

The most significant feature of Salt Lake City's downtown street system, perhaps, is the overall size of an average intersection. The downtown streets are unusually wide, resulting in long crosswalks and accompanying long pedestrian clearance times. Many intersections in the downtown area have simple two phase operation, but some locations provide left turn phases. Some of these provide more efficient protected/permitted left turn phasing, while others provide fully protected left turn phases.

These features, coupled with frequent pedestrian crossing usage, result in the need to use relatively long traffic signal cycles at the larger intersections. The intersection that appears to require the longest natural cycle length is State Street at 400 South. This intersection provides six lanes on each street, left turn phasing on all approaches and a light rail line in the median. This intersection and similarly large locations probably have dictated the use of the 108-second off peak cycle and the 120-second peak cycle length used throughout the downtown area.

2.3 Queuing Observation

During the off peak period, overall traffic conditions appear orderly and uncongested. A detailed study of traffic volumes and alternative signal operation were conducted to determine whether significant improvements can be derived. Different cycle length combinations were tested along some of the less important streets that do not provide frequent left turn phases. The travel time and delay after study was conducted to evaluate whether the faster local operation will compensate for loss of coordinated movement between smaller and larger intersections.

During peak periods, there is considerably more visible traffic congestion. The existing system-wide 120-second cycle results in relatively long queues of vehicles on heavily used through movements Optimization of signal timing will not likely improve this condition substantially, but minor improvements may be achievable. The network appears to have excessive stops that can be potentially reduced through timing adjustments.

Queues were observed during the PM peak hours along 500 South, a wide one-way street traveling from downtown toward a major freeway interchange. These queues were of the type that can occur when the design coordination speed is higher than the travel speed. Initially slow moving cars were "clipped" by the yellow signal and required to stop until the next cycle. Over the peak period, these vehicles built up queues that were standing at the end of the green phase. During a typical cycle, 10 to 15 vehicles per lane could be stopped at the end of the green phase. These stopped vehicles created longer queues due to approaching vehicles in the next cycle stopping behind them. This further aggravated the travel speed and resulted in more queued vehicles at the end of the cycle. This type of congestion could often be alleviated through minor adjustments in the signal timing, either by slowing down the platoon speed if there is sufficient capacity for the approaching phase, or modifying the timing plan to expect that vehicles will be stopped.

2.4 Traffic Volume

The City counted AM, midday, and PM traffic turning movement volumes at 27 study intersections in June 2010. For other locations, the City provided historical traffic counts and estimated volumes for AM, PM, and off-peak periods. KOA conducted field reviews and identified inconsistencies between peak hour traffic volumes in the field and historical data/estimated volumes. KOA manually balanced the traffic volumes at critical locations using Synchro 7 models. The adjusted volumes were reviewed and approved by the City staff as shown in Appendix B.

2.5 Transit

Existing light rail and bus run through the following corridors in downtown areas:

- South Temple
- 200 South
- 400 South
- 700 South
- 200 West
- 400 West
- 600 West
- Main Street

The Siemens NextPhase traffic signal control program was customized to provide TRAX priority over the local signal operation. As agreed with the City and UDOT, signal timings were held at light rail intersections with minor split or offset adjustments. Six intersections on South Temple, twelve intersections on Main Street, ten intersections on 400 South, and seven light rail intersections fall in this category. During all periods, light rail priority generates negative impacts on signal synchronization along north-south streets, especially for State Street, 700 East, and 1300 East, as well as on the light rail corridors themselves, especially 400 South.

2.6 Bicycles

Salt Lake City is recognized as a silver-level Bicycle Friendly Community by the League of American Bicyclists' Bicycle Friendly Community program. The City continues to take steps to improve bicycle facilities, education, and encouragement. Within the project network, bike lanes are provided on the following streets:

- 200 South
- 800 South
- 200 West
- 300 East
- 1300 East

A green shared lane is provided on parts of Main Street, South Temple, and 200 South.

2.7 Uneven Lane Utilization

Uneven lane distribution (when one lane is used significantly more than an adjacent lane or lanes) is usually observed at intersections where there are multiple turn lanes and a downstream traffic generator that requires traffic to use one lane more often than the other. During the PM peak hours, a great amount of traffic on 500 S tends to use the first three through lanes on the left to access the freeway. The designed through phase seems not long enough to release arrival traffic. During the peak hours, the yellow signal cuts the last portion of the platoon.

2.8 Light Rail Operation

In Salt Lake City, light rail travels through the core part of downtown signal system. At the intersection of Main Street and 400 South, the light rail line splits into two routes – one line heads toward University of Utah and the other trains towards the south of the study area, 13 miles south of downtown Salt Lake City. This intersection is the major bottleneck affecting traffic operations on 400 South between 200 W and State Street, and State Street between 300 S and 500 S.

Passage of a light rail train may force signals to cut a traffic platoon affecting operations of auto transportation. At times during peak hours, the stopped vehicles may not be served before the next platoon arrives. The accumulated stopped vehicles can easily queue back to the upstream intersection. This makes traffic signal operation look inefficient and sluggish.

The light rail intersections run on a customized controller program that provides priority to the mobility of trains. Frequent passage of rail cars may cause light rail intersections to change order of phases from normal phasing sequence or prematurely truncate the phase duration, allowing rail cars to pass through the intersection with minimal delays. When that happens, the signals take several cycles to transition back to normal operation, interrupting progression for cars. Motorists may experience more stops or delays when they try to cross light rail lines.

3. Signal Timing Optimization

The development of new timing plans began with an evaluation of the existing traffic conditions within the project network. The cycle lengths for the intersections along state highways and the light rail were not changed, although minor adjustments to the split or offset were provided as needed. The optimization process was performed by using the Synchro 7.0 software. The Synchro models were further adjusted to improve the Measures of Effectiveness (MOE) performance, based on the knowledge of the traffic characteristics of the network and traffic flow pattern during the different time periods of the day.

The evaluation of the existing operation conditions identified several unique features of Salt Lake City downtown network that create challenges to signal coordination: large size intersections resulting in long crosswalks and accompanying long pedestrian clearance interval; light rail traveling through the core part of downtown system and forcing intersections to change order of normal phasing sequence, and protected left turn phases provided at some downtown intersections. 500 South and 600 South carry very heavy traffic during the AM and PM peak hours with the offsets set to favor these two state highways. With the light rail going through most part of 400 South, offset optimizations are limited along north-south city streets. State Street is another state street heavily used by the peak hour commuters. With the light rail crossing at 400 South, it is difficult to achieve stable coordination progression along Main Street. The following items were reviewed during the signal timing optimization:

- Existing queuing conditions
- Cross arterial coordination
- Queuing conditions of left turn phases
- Movements with uneven lane distribution
- Potential oversaturated movements
- Location of high volume unsignalized intersections
- Potential impacts from pedestrians, bicyclists, and transit
- Bus stops locations and usage

The signal coordination analysis and development of optimized timing plans consist of the following tasks:

- Review and balance the traffic turning movement volumes
- Update and calibrate the existing Synchro models
- Evaluate signal grouping and free operation
- Evaluate and select cycle lengths
- Agency review
- Review the split
- Optimize the offset
- Evaluate the final timing plans

3.1 Cycle Length Selection

Cycle length selection is a critical step in the developing signal coordination plans. A longer cycle length may provide better progression along the corridors, but may most likely increase side street delay and queuing. On the other hand, decreasing the cycle length to reduce the side street delay may increase the overall delay and number of total stops. For the Salt Lake City downtown area, most intersections operate below saturated conditions. Pedestrian phases generally determine the minimum cycle length at most two-phase intersections. However, accommodating light rail operation requires increase of the cycle length along corridors.

For the AM and PM peak periods, KOA concurs in using 120-second cycle length. UDOT intersections are already operating on a 120-second cycle length. Some free-running light rail intersection on Main Street and 400 South are kept as actuated-uncoordinated operation. The uniformity of cycle length would provide for better progression with minimal stops for the entire network. KOA also reviewed the flow profiles of critical intersections to identify the appropriate setting for different time of day operations. The review did not necessitate changes to any time of day operations.

For the midday period, the cycle length was reduced at 48 city-maintained intersections to an 81-second cycle. The unusual cycle was selected to harmonize with the existing 108-second cycle length currently set for the State and some major City intersections. It is also close to the natural cycle length of the 48 city-maintained intersections. Intersections with the two different cycle lengths (81 seconds versus 108 seconds) would reach a common base point every four cycles (324 seconds). Further reduction below 81 seconds cycle is not feasible at most of the City intersections while accommodating pedestrian crossing times. Multiple-phase intersections were verified to operate at the lower cycle length without violating the minimum green time for any of the phases. The cycle length for each peak period is shown in Appendix C.

At the City's request, the following signal timing parameters were maintained:

- Yellow and All Red intervals
- Pedestrian Walk and Flashing Don't Walk (FDW) intervals
- Vehicle Extension
- Time-of-Day Schedule

3.2 Fine-Tuning of Proposed Timing Plans

KOA engineers reviewed the signal system operation in the field to insure that all timing plans were inputted properly during all timing periods, as the volumes of many interior intersections in the network were based on estimation of the upstream flows and might not accurately reflect the actual flows. Furthermore, the timing plans generated by any computer model must be fine-tuned by engineers to best accommodate real-world conditions. During the implementation and fine-tuning, KOA engineers also identified some intersections that were not running according to the timing plans and some were in transition from time to time. Discrepancies could be due to the aging traffic signal system. Observed issues were reported to the City staff.

4. System Wide Improvement

The City conducted a travel time and delay "before" study along 46 corridors in 2008 and 2009. KOA summarized and tabulated the field data. KOA then selected 16 corridors to conduct a GPS-based floating car travel time and delay after study in May 2011. Tru-Traffic software was used to collect and process the survey data. A total of three runs were conducted for each direction of the corridor for each peak time period. The corridor-based measures of effectiveness (MOE's) performance were summarized as:

- **Average Travel Time** (seconds): the total elapsed time spent driving along the study corridor from the first intersection to the last intersection. This study reports the average travel time of three runs.
- **Average Speed** (miles per hour): the average distance a vehicle travels within the measured amount of time.
- **Number of Stops**: the average number of stops during three survey runs.
- **Total Delay** (seconds): the time difference between actual travel time and desired travel time.

The network-wide fuel consumption savings and emission decrease are reported by Synchro models using the following measures:

- Fuel Consumption (Pounds)
- Carbon Monoxide Emission (Pounds)
- Oxides of Nitrogen Emission (Pounds)
- Volatile Organic Compounds Emission (Pounds)

The detailed travel time and delay after study reports are included in Appendix D.

4.1 Corridor-Based Measures of Effectiveness (MOEs)

As show in Table 1, 16 corridors were surveyed during the weekday AM, midday, and PM peak periods. Tables 2 through 4 compared the results of before and after studies for each corridor. Optimized timing plans improved average MOE's by approximately 8% to 17% during the peak periods.

- During the AM peak period, the optimized timing plans improved traffic operation by decreasing average travel time of 16 corridors by 8%, increasing average speed by 8%, decreasing number of stops by 17%, and decreasing total delay of each run by 14%.

- During the midday period, the comparison shows 6% reduction in average travel time of 16 runs, with the average number of stops decreasing by 3% and total delay decreasing by 12%. The average speed increased by 3%.

- During the PM peak period, the comparison reports 8% reduction in the travel time, 14% reduction in number of stops, and 11% reduction in total delay, with average speed increasing by 5%.

Table 1 – List of After Study Corridors

No.	Corridor	From	To
1	South Temple	200 West	1200 East
2	100 South	Main St	1300 East
3	200 South	450 West	700 East
4	300 South	300 West	700 East
5	800 South	300 West	1300 East
6	900 South	300 West	1300 East
7	400 West	600 South	900 North
8	300 West	800 South	600 North
9	200 West	900 South	North Temple
10	West Temple	800 South	North Temple
11	State Street	900 South	North Temple
12	200 East	900 South	South Temple
13	300 East	900 South	South Temple
14	400 East	900 South	South Temple
15	700 East	900 South	South Temple
16	900 East	800 South	100 South

- It should be noted that three corridors were under construction during the travel time and delay "after" runs: State Street between 300 South and 500 South, 400 West north of North Temple, and 200 East between 400 South and 500 South. As these on-going constructions slowed down traffic flow and caused extra stops, traffic platoons could not follow the designed progression through multiple sets of intersections. The worst case was observed on State Street northbound between 300 South and 500 South during the AM and Midday peak periods. Northbound drivers had to make hasty lane changes before 400 South to avoid the closed curb lane. The northbound through phases could not serve all arriving traffic after the lane drop The last part of platoon was cut off and queued up between 400 South and 500 South. Vehicles often needed to wait more than one cycle to go through this segment. This explained why the after runs reported worse performance on those corridors.

- During the fine-tuning and implementation process, KOA also identified offsets that were drifting at some intersections on State Street and 700 East during the peak hours. This worsened the after run results on these two corridors.

Table 2 – Travel Time and Delay Study, AM Peak

Corridor		Travel Time (sec)			Average Speed (mph)			Number of Stops			Total Delay (sec)		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
South Temple	EB	508	395	-22%	15.5	19.4	25%	5.2	4.3	-17%	205	139	-32%
	WB	419	420	0%	18.5	19.1	3%	6	5.3	-12%	133	147	11%
100 South	EB	388	414	7%	18.9	17.4	-8%	3.6	4.3	19%	132	157	19%
	WB	457	488	7%	15.5	14.6	-6%	5.2	6.3	21%	179	225	26%
200 South	EB	508	470	-7%	12.4	13.5	9%	7.4	4.7	-36%	256	210	-18%
	WB	399	401	1%	16.4	15.7	-4%	3.6	5	39%	158	156	-1%
300 South	EB	405	336	-17%	13.4	16.5	23%	4.8	3.3	-31%	178	110	-38%
	WB	428	389	-9%	12.7	14.8	17%	6.3	4.7	-25%	197	166	-16%
800 South	EB	557	541	-3%	15.7	16.2	3%	6.8	5.7	-16%	240	229	-5%
	WB	578	516	-11%	15	17	13%	7.4	5	-32%	260	230	-12%
900 South	EB	563	537	-5%	15.5	16.3	5%	6.8	7.3	7%	235	209	-11%
	WB	564	459	-19%	15.6	19.3	24%	6.2	4.7	-24%	231	156	-32%
400 West	NB	401	586	46%	20.3	14	-31%	5.2	5.7	10%	119	276	132%
	SB	483	463	-4%	17	17.8	5%	5.6	4.3	-23%	206	165	-20%
300 West	NB	434	452	4%	18.2	21.5	18%	5.4	4	-26%	180	160	-11%
	SB	395	404	2%	19.6	23.7	21%	4.8	3.3	-31%	147	120	-18%

Table 2 – Travel Time and Delay Study, AM Peak (Continued)

Corridor		Travel Time (sec)			Average Speed (mph)			Number of Stops			Total Delay (sec)		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
200 West	NB	427	331	-22%	12.8	17.7	38%	6.4	4	-38%	191	122	-36%
	SB	542	478	-12%	10	11.6	16%	7	6.3	-10%	323	280	-13%
West Temple	NB	482	379	-21%	9.7	12.5	29%	7.2	4.7	-35%	278	182	-35%
	SB	379	351	-7%	12.5	13.3	6%	5.4	4.7	-13%	185	176	-5%
State Street	NB	403	408	1%	14.8	14.9	1%	3.8	6	58%	195	198	2%
	SB	318	226	-29%	17.7	25.5	44%	3.6	2	-44%	94	47	-50%
200 East	NB	259	230	-11%	19.2	17.6	-8%	3	3.3	10%	77	91	18%
	SB	283	252	-11%	17.5	17	-3%	3	3	0%	103	108	5%
300 East	NB	521	419	-20%	9.3	11.2	20%	6.8	5	-26%	313	228	-27%
	SB	272	280	3%	18.4	17	-8%	3.6	3	-17%	86	107	24%
400 East	NB	469	320	-32%	10.7	15.7	47%	6.2	3.7	-40%	282	134	-52%
	SB	438	352	-20%	11.2	14.2	27%	6.2	5	-19%	245	151	-38%
700 East	NB	242	264	9%	20.9	19.1	-9%	3	3	0%	69	73	6%
	SB	225	246	9%	22.7	19.7	-13%	2.6	3	15%	63	72	14%
900 East	NB	281	180	-36%	18.2	23	26%	2.6	0.5	-81%	97	42	-57%
	SB	260	193	-26%	19.3	21.1	9%	3	1.5	-50%	75	63	-16%
Average		**415**	**381**	**-8%**	**16**	**17**	**8%**	**5**	**4**	**-17%**	**179**	**154**	**-14%**

Table 3 – Travel Time and Delay Study, Midday Peak

Corridor		Travel Time (sec)			Average Speed (mph)			Number of Stops			Total Delay (sec)		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
South Temple	EB	480	425	-11%	15.9	18	13%	6	5	-17%	200	145	-28%
	WB	443	447	1%	17.5	17.1	-2%	5.2	7	35%	165	150	-9%
100 South	EB	375	316	-16%	19.7	23.7	20%	3.8	3.3	-13%	107	64	-40%
	WB	422	461	9%	17.7	16	-10%	4.4	6.3	43%	143	187	31%
200 South	EB	602	503	-16%	12.2	14.7	20%	8	6.7	-16%	308	209	-32%
	WB	405	516	27%	18.4	14.4	-22%	3.4	6.7	97%	139	238	71%
300 South	EB	470	424	-10%	14	15.4	10%	7.2	5.7	-21%	199	139	-30%
	WB	564	472	-16%	11.5	13.9	21%	7.2	6	-17%	291	188	-35%
800 South	EB	431	476	10%	18.8	16.8	-11%	4.4	5.8	32%	141	187	33%
	WB	439	373	-15%	18.2	21.7	19%	5	3.5	-30%	156	94	-40%
900 South	EB	431	352	-18%	16.7	20.2	21%	5.4	4	-26%	159	92	-42%
	WB	428	384	-10%	16.9	19.4	15%	5	4	-20%	154	139	-10%
400 West	NB	337	389	15%	17.8	15.4	-13%	3.6	3.7	3%	108	165	53%
	SB	325	350	8%	18.6	17.4	-6%	4.6	3.3	-28%	96	119	24%
300 West	NB	447	439	-2%	17.1	17.3	1%	5.8	5	-14%	188	171	-9%
	SB	300	327	9%	26.3	23.2	-12%	1.6	3	88%	56	71	27%

Table 3 – Travel Time and Delay Study, Midday Peak (Continued)

Corridor		Travel Time (sec)			Average Speed (mph)			Number of Stops			Total Delay (sec)		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
200 West	NB	460	429	-7%	12.2	12.8	5%	7	6	-14%	241	222	-8%
	SB	460	390	-15%	12.2	14	15%	6.6	6.8	3%	239	166	-31%
West Temple	NB	366	390	7%	13.7	11.9	-13%	4.8	5.7	19%	157	200	27%
	SB	480	395	-18%	10.2	12	18%	6.2	5	-19%	272	210	-23%
State Street	NB	343	367	7%	16	15.3	-4%	3.4	5	47%	132	172	30%
	SB	265	246	-7%	22.3	22.5	1%	2.8	3	7%	62	58	-6%
200 East	NB	252	314	25%	17.5	13	-26%	3.4	5	47%	83	147	77%
	SB	301	263	-13%	14.4	15.5	8%	4	4.3	8%	141	99	-30%
300 East	NB	412	352	-15%	12.1	13.8	14%	5.6	5	-11%	200	134	-33%
	SB	349	289	-17%	14.2	18.4	30%	4.4	3.3	-25%	142	103	-27%
400 East	NB	408	355	-13%	12	14.2	18%	6.6	5	-24%	220	162	-26%
	SB	371	272	-27%	13.3	17.9	35%	5.8	3.7	-36%	181	86	-52%
700 East	NB	279	248	-11%	18.4	19.6	7%	3.4	2.7	-21%	112	72	-36%
	SB	232	228	-2%	21.3	21.9	3%	2.8	3	7%	71	63	-11%
900 East	NB	202	199	-1%	18.7	19.1	2%	2.6	1.7	-35%	58	58	0%
	SB	200	206	3%	19.9	18.5	-7%	1.8	3	67%	55	64	16%
Average		**384**	**362**	**-6%**	**16**	**17**	**4%**	**5**	**5**	**-3%**	**156**	**137**	**-12%**

Table 4 – Travel Time and Delay Study, PM Peak

Corridor		Travel Time (sec)			Average Speed (mph)			Number of Stops			Total Delay (sec)		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
South Temple	EB	377	377	0%	20.7	20.8	0%	4.2	4	-5%	95	117	23%
	WB	458	384	-16%	16.6	19.8	19%	5.8	5.3	-9%	154	104	-32%
100 South	EB	272	309	14%	21.1	18.5	-12%	1.2	3.3	175%	68	100	47%
	WB	404	364	-10%	14	15.8	13%	4.4	3.7	-16%	190	155	-18%
200 South	EB	519	438	-16%	13.1	15.6	19%	6	5	-17%	217	185	-15%
	WB	464	464	0%	14.9	15.2	2%	6	5	-17%	200	207	4%
300 South	EB	390	404	4%	15.3	14.9	-3%	3.2	4.7	47%	150	159	6%
	WB	616	576	-6%	9.7	10.5	8%	7.6	7.7	1%	316	301	-5%
800 South	EB	548	570	4%	16.1	15.4	-4%	6.2	5	-19%	219	262	20%
	WB	502	488	-3%	17.3	17.8	3%	5.8	4.3	-26%	179	191	7%
900 South	EB	547	580	6%	16.1	14.9	-7%	6.2	6.7	8%	209	252	21%
	WB	548	564	3%	16.1	16.2	1%	7.4	6	-19%	206	245	19%
400 West	NB	418	295	-29%	14.2	11.3	-20%	4.4	2.3	-48%	191	142	-26%
	SB	316	293	-7%	19.2	20.9	9%	3.6	2.7	-25%	83	79	-5%
300 West	NB	493	454	-8%	19.5	21	8%	4.8	3.5	-27%	198	155	-22%
	SB	466	396	-15%	20.6	24.2	17%	4.4	2.3	-48%	165	110	-33%

Table 4 – Travel Time and Delay Study, PM Peak (Continued)

Corridor		Travel Time (sec)			Average Speed (mph)			Number of Stops			Total Delay (sec)		
		Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
200 West	NB	452	540	19%	12.1	10.1	-17%	5.6	6.7	20%	238	324	36%
	SB	532	362	-32%	10.2	15.3	50%	6.8	5.3	-22%	317	141	-56%
West Temple	NB	445	440	-1%	11.5	11	-4%	6.3	6.7	6%	210	245	17%
	SB	765	398	-48%	7	12.4	77%	8.2	4.7	-43%	556	208	-63%
State Street	NB	367	265	-28%	15.2	21.1	39%	4.4	2.7	-39%	148	67	-55%
	SB	264	404	53%	20.5	13.5	-34%	2.4	4.7	96%	67	193	188%
200 East	NB	284	340	20%	15.2	12.2	-20%	4.2	3.7	-12%	112	185	65%
	SB	337	195	-42%	12.9	21.2	64%	4.5	2	-56%	156	45	-71%
300 East	NB	354	309	-13%	14.3	15.7	10%	5	4	-20%	152	109	-28%
	SB	414	315	-24%	12.1	15.7	30%	5.6	3.7	-34%	208	116	-44%
400 East	NB	467	414	-11%	10.9	11.8	8%	6	5	-17%	275	224	-19%
	SB	357	302	-15%	14	16.8	20%	4.2	3.3	-21%	179	129	-28%
700 East	NB	240	167	-30%	20.7	23	11%	2.8	1	-64%	64	51	-20%
	SB	241	229	-5%	20.5	17.2	-16%	2.2	2.7	23%	80	96	20%
900 East	NB	207	223	8%	18.7	17.7	-5%	2.8	1.7	-39%	63	69	10%
	SB	230	310	35%	16.6	12.3	-26%	3.2	3.7	16%	80	166	108%
Average		**415**	**380**	**-8%**	**16**	**16**	**5%**	**5**	**4**	**-14%**	**180**	**160**	**-11%**

4.2 Network-Wide Measures of Effectiveness Improvements

The tables in the previous subsection show improvements for the average run, without adjusting for the different traffic volumes on each street. Network-wide total delay and total stops improvements are reported by the Synchro Models and compared in Table 5 with each street weighted according to their current traffic volumes. With the optimized timing plans, total delay within downtown area was reduced by 14% for AM Peak, 10% for Midday Period, and 7% for PM Peak. The number of total stops was reduced by 8% for AM Peak, 7% for Midday Period, and 8% for PM Peak.

Table 5 – Network-Wide Measures of Effectiveness Improvements

Time Period	Total Delay (hr)			Total Stops (#)		
	Before	After	Percent Change	Before	After	Percent Change
AM	1876	1616	-14%	155799	144101	-8%
Midday	1467	1319	-10%	151841	140711	-7%
PM	2154	1995	-7%	176230	162467	-8%

4.3 Fuel Consumption and Pollutant Emission

Minimizing fuel consumption and related pollutant emissions are prime goals of this project. Fuel consumption is closely related to traveling distance, delay and stop/idle time at each intersection. For a vehicle trip of a given length, the number of stops, acceleration and deceleration cycles, and speed changes can affect Carbon Monoxide (CO), Oxides of Nitrogen (NOx), and Volatile Organic Compounds (VOC) Emissions. Signal timing plans were optimized to reduce fuel consumption and pollutant emissions by minimizing system-wide delay and number of stops, and providing higher and steadier cruise speeds along study corridors. Table 6 presents the fuel consumption savings and emissions decrease achieved by optimizing traffic signal operation for each peak period.

Table 6 – Peak Hour Fuel Consumption and Pollutant Emission Comparison

Peak Hour	Network MOE	Existing	Optimized	Reduction
AM	Fuel Consumed (gal)	4715	4437	278 (5.9%)
	CO Emissions (lbs)	728	683	42 (5.8%)
	NOx Emissions (lbs)	141	132	9 (6.3%)
	VOC Emissions (lbs)	168	159	11 (6.6%)
Midday	Fuel Consumed (gal)	4189	4013	176 (4.2%)
	CO Emissions (lbs)	646	617	26 (4.1%)
	NOx Emissions (lbs)	126	121	4 (3.5%)
	VOC Emissions (lbs)	150	143	7 (4.4%)
PM	Fuel Consumed (gal)	5279	5059	220 (4.2%)
	CO Emissions (lbs)	814	780	33 (4.1%)
	NOx Emissions (lbs)	159	152	7 (4.2%)
	VOC Emissions (lbs)	190	181	9 (4.7%)

Based on a literature review, which included the document titled *Methodology for the 2009 Urban Mobility Report*, *David Schrank, 2009,* KOA used the following methodology to calculate the difference in the annual fuel consumption due to the traffic signal optimization for the downtown area:

- Difference in the fuel consumption should be based on the change in fuel consumption during AM, Mid-day and PM peak hours only. The other times of the day will remain unaffected by the recommended traffic signal coordination plans.
- The hourly gasoline consumption rate for the corresponding peak hours (AM, Mid-day, and PM) was extracted from Synchro model output.
- The number of hours that should be considered in the fuel consumption calculations are as follows:
  - AM Peak Hour: 2.0 hours
  - Mid-day Peak Hour: 2.0 hours
  - PM Peak Hour: 2.0 hours
- Annual fuel consumption calculations are based on 250 weekdays and 115 weekend days.
- Normally, the weekend traffic volumes are lower than weekday traffic. Therefore, the weekend fuel consumption calculations should be based on the reduced fuel consumption rate, if the coordination plan is desired to be implemented.

Table 7 – Annual Fuel Consumption Reduction

	Daily Reduction	Annual Reduction
Fuel Savings (gal)	1348	337,000
CO Emissions Reductions (lbs)	203	50,700
NOx Emissions Reductions (lbs)	40	10,000
VOC Emissions Reductions (lbs)	53	13,200

Table 7 presents the annual fuel consumption and emissions reduction as reported by Synchro models. The calculation only includes weekdays and assumes two hours for each peak period and 250 weekdays a year. With the traffic signal timing operation, fuel consumption is reduced by 337,000 gallons per year within the downtown area, which exceeded the reduction target of 32,000 gallon per year by a factor of ten. The daily and annual reduction in pollutant emissions also greatly exceeded their respective reduction targets.

4.4 Economic Analysis

The motorist annual cost savings associated with signal timing optimization efforts within the study network were estimated using the following assumptions:

- Vehicle delay cost is $10.00 per vehicle hour.
- Vehicle stop saving is $0.014 per vehicle stop Fuel cost is $3.00 per gallon

Based on the network-wide measure of effectiveness improvements identified in Table 5, the savings associated with decrease of total delay and total stops are presented in Table 8. A total of $3,091,137 will be saved per year by decreasing total delay and total stops within the study network through signal optimization efforts.

Table 8 – Motorist Cost Savings Associated with Decreased Delay and Stops

Peak Hour	Before	After	Decrease	Peak Hour (hr)	Daily Decrease	Annual Savings	Total
	Total Delay						$3,091,137
AM	1876	1616	260	2	1134	$2,835,000	
Midday	1467	1319	148	2			
PM	2154	1995	159	2			
	Total Stops						
AM	155799	144101	11698	2	73182	$256,137	
Midday	151841	140711	11130	2			
PM	176230	162467	13763	2			

By including the results of fuel consumption analysis, the total economic savings were calculated in Table 9. A conservative value of $3 per gallon of fuel was used for this analysis. Motorists will save $1,011,000-worth of fuel per year.

As shown in Table 9, the total annual savings is $4,102,137. The cost of this project is $200,000. This yielded a one-year benefit-to-cost ratio of 21:1. Traffic signal retiming efforts are recommended by ITE to be conducted at least every three years. The three-year benefit is $12,306,411, while the project cost remains $200,000. This yields a three-year benefit-to-cost ratio of 62:1. It is assumed that the signals are properly maintained and monitored at all times, Given the tremendous benefits to cost ratio, it is important that the City allocate sufficient resources to maintain the city's traffic signal system.

Table 9– Benefit-to-Cost Ratio Analysis

Annual Fuel Consumption Reduction (gallon)	337,000
Dollar Value per Gallon	$3.00
One-Year Benefit	$1,011,000
Savings by Decrease of Delay and Stops	$3,091,137
Total Annual Savings	$4,102,137
Project Cost	$200,000
Benefit-to-Cost Ratio	21:1
Three-Year Benefit	$12,306,411
Three-Year Benefit-to-Cost Ratio	62:1

5. Recommendations for a Three to Five Years Re-Timing Effort

A traffic signal timing update every three year provides significant direct benefits for the traveling public. Many factors contribute to the need for updates. The major factors are listed below:

- Land use changes
- Population growth
- Change in flow profiles (volume and classification)
- New MUTCD requirements related to signal timing
- Increases in the rate of crashes along major corridors
- Traffic signal equipment changes, including a new signal system

Optimal timed signals along major corridors minimize the diversion of traffic to local and residential streets, improving safety and traffic conditions. They also lead to reduced fuel consumption, reduced emissions, and improved air quality. Currently, the City maintains a database of the traffic signals, including controller type and history of updates. However, the City does not have enough resource to maintain a Performance Measure of Effectiveness (MOE) database to track the operational performance within the City's roadway network. We recommend that the City budget adequate staff resource to conduct survey of performance MOE once every other year. The survey of performance MOE will also help in identifying areas where signal retiming efforts should be initiated. Based on the *NCHRP 409 Traffic Signal Retiming Practices in the U.S*. on average, 26 person hours are required to conduct signal retiming per intersection. A staffing level of five in the City's TCC is needed to maintain operational and safety performance of the City's roadway network and retiming of signals in three-year intervals.

5.1 Agency Survey

Many cities throughout the country are benefiting from efficient traffic signal operation within their communities and across jurisdictional boundaries. Listed in Table 10 are four other cities which are considered "comparable" to Salt Lake City in terms of population and population density. A summary of the Traffic Signal Operation Survey is presented in Appendix E.

Table 10 – Selected Cities for Traffic Signal Operation Survey

TCC	City	State	Population	Pop Density (Per Sq. Mile)	Signals	Total Staffing	I/S Per Staffing
Yes	Salt Lake City	Utah	186,440	1,678	184(1)	7(2)	27
Yes	Tallahassee	Florida	181,376	1,809	350	13	27
No	Amarillo	Texas	190,695	1,917	293	14	21
Yes	Knoxville	Tenn	178,874	1,816	393	19	21
No	Little Rock	Ark	193,524	1,624	350	10	35

Note: (1) Number of the City intersections including non-system signals
(2) Two in TCC and Five in Traffic Signal Maintenance

Four comparable cities were phone interviewed in June 2011 by KOA staff to answer 10 questions as summarized in Appendix E. The number of traffic signals operated in those four cities range from 293 to 393. Tallahassee, Amarillo and Knoxville have full control of traffic signals within the city boundary. Little Rock does not maintain County's or State's traffic signals, but provides timing plans for traffic signals within the city boundaries.

Out of the four surveyed cities, Little Rock is the only city that has a light rail operation. However, its operation is far smaller in distance covered and patrons served compared to the light rail operation in Salt Lake City.

5.2 Staffing Needs

Staffing needs for traffic signal system operations are discussed in several literature documents. As shown in the Table 11, *FHWA Traffic Signal Timing Manual* provides general guidelines on staffing needs for a traffic signal system as it relates to signal retiming.

Table 11 – Summary of Staffing Needs*

Position	1 to 50 Traffic Signals	51 to 100 Traffic Signals	101 to 200 Traffic Signals	201 to 500 Traffic Signals	501 to 1000 Traffic Signals
Traffic Signal Engineer	0 to 1	1	1 to 2	2 to 5	5 to 10
Traffic Signal Analyst/Technician	0 to 1	0 to 1	1	1 to 3	3 to 5
ITS Engineer	-	-	0 to 1	1	1 to 3
Traffic Signal Maintenance Technician	1 to 2	2 to 4	4 to 7	7 to 17	17 to 33
Electronic Specialists	1	1	1 to 2	2 to 4	4 to 9
TMC Operators	-	-	2	2 to 4	4 to 9
Public Relations Coordinator	0 to 1	0 to 1	1	1	2

Note: * FHWA Traffic Signal Timing Manual

The ITE "Traffic Control System Operations" manual suggests that a traffic signal system should have one traffic engineer per 75 to 100 traffic signals and one signal technician per 40 to 50 traffic signals or other field devices. An NCHRP report (Synthesis 245) also suggests 38 to 43 signals per technician. The manual also provides staffing guidelines for a continuously operated TMC which includes one center manager, two supervisors, and five system operators.

The unique physical and operational characteristics of Salt Lake City's signal system may require more resources than that of a typical city with similar number of signals. The recommended staff resource for the Traffic Control Center of Salt Lake City is summarized in Table 12. To have adequate resources to handle daily operations, special events and retiming of signals on a scheduled interval, two new engineers and one additional operator are recommended to operate the 184-intersection signal system. The additional operator would replace a position lost due to budget constraints. If the recommendation is followed, the TCC would have a total of 5 people, including the Director.

Table 12 – Recommended Staff Resource for Traffic Control Center

Staff Resource	Traffic Signal Engineer	ITS Engineer	TCC Operators	Total
Per FHWA Guidelines	***1 to 2***	***0 to 1***	***2***	***3 to 5***
Existing	0	0	1	1
Recommended Additional Staff	2	0	1	3
Total	**2**	**0**	**2**	**4**

5.3 Traffic Signal System Improvements

KOA recommends the following measures to improve the traffic signal system performance:

5.3.1 Trouble-Shoot Signal Transition Problems

The review of current signal system operations identified that some city intersections running with customized pedestrian logic may cause signal yield point drift when a controller loses the detection on minor streets. The City staff is working with Econolite engineers toward solving this problem. A few of the UDOT intersections were found to behave differently in the field to what is shown on the central i2 system. UDOT staff may need to check the controller status in the field. Routine review and troubleshooting of signal operations are recommended to keep the signal system efficiently working as designed.

5.3.2 Consistent Pedestrian Crossing Operation

Pedestrian push buttons are provided at most signals in the core CBD area, while at most intersections outside the CBD area, pedestrian push buttons are not installed. Although the pedestrian volumes are low at these intersections outside CBD, the signals are timed to accommodate pedestrian crossing. Due to the size of the intersections, a long cycle length has to be maintained, which create seemingly long delays, especially during off-peak hours. It is recommended that the City allocate funds to install pedestrian push buttons at these intersections so that the current cycle lengths can be reduced with the benefits of reducing delays for motorists.

5.3.3 Traffic Data Collection

Traffic volume data is important to network-wide signal operation optimization efforts. However, the data collection can be costly and time intensive. This project estimated traffic turning volumes at a great number of intersections in Synchro models. For the future operation efforts, the survey of performance MOE can help in identifying areas where traffic data needs to be updated to justify and support signal re-timing efforts. Field fine-tuning efforts identified inconsistencies between real-time traffic and estimation at some intersections. For future signal re-timing efforts, traffic count stations need to be installed to collect data to track changes of the flow profiles at major corridors. Three categories of traffic data should be considered during the data collection:

- **24-Hour tube counts** can be used to evaluate the number of timing plans used during the weekdays and weekend, to decide when to transition from one timing plan to the next, and to develop adjustment factors for some timing periods without conducting other turning movement counts. Tube counts should be collected at critical locations on, but not limited to, the following corridors:
  - State
  - 700 East
  - 1300 East
  - North Temple
  - 400 South
  - 500 South
  - 600 South
  - 900 South

- **Turning movement counts** are typically collected at each of the study intersections in consideration of re-timing. Depending on the traffic patterns along the streets, turning movement counts are often conducted during peak periods: the weekday morning, midday, and afternoon peak hours. Tube counts should be used to identify each peak period for collecting the counts, as well as for developing adjustment factors for the weekend volume. Traffic volumes may be higher or more critical during the weekend at some locations, although that has not been observed to be the case in the Salt Lake City downtown area.

- **Travel time and delay runs** can be used to review the signal operation performance before and after the new timing plans are implemented. The travel time and delay runs can be collected by driving along the study corridors and recording the delay, running time, and stops using GPS-based equipment. Travel time and delay can be reported to elected officials and the public when doing signal timing optimization. The runs are also good to monitor traffic to determine the quality of existing signal operations and the need for retiming efforts. Salt Lake City is maintaining a comprehensive travel time delay runs database within the downtown area.

This project conducted after runs for 16 corridors: three runs for each direction each peak period.

5.3.4 Cross-jurisdictional Traffic Signal Re-Timing

The joint efforts from the City and UDOT have been contributing to the improvements of system-wide signal operations in the downtown area. For the future signal re-timing efforts, the City, UDOT and UTA should jointly discuss operational improvements at intersections with light rail operations.

5.3.5 *Newer Central Traffic Management Software*

Siemens i2 Central Traffic Management Software (TMS) has been used to manage 755 traffic signals in the Salt Lake Metropolitan area, encompassing three counties, for the past 12 years. In the near future, this software will no longer be supported by the manufacturer and will need to be replaced. Newer generations of central traffic management software are available that are easier to use; could detect, quickly diagnose and correct system problems; and, provide more robust reporting. In general, they operate in more effective and efficient manners. The newer software also provides a more secured interface and supports features such as emergency and/or incident response, transit signal priority and full set of customizable features to fit individual needs of the City. A comprehensive search is needed to review these software packages in order to determine which of them best suits the needs of the Salt Lake City area's traffic signal system.

6. Performance Comparisons with Three Other Cities

There are several features that are unique to Salt Lake City that could not be found in other cities in the U.S. The most significant feature, perhaps, is the overall size of the average intersection. The downtown streets are unusually wide, resulting in long crosswalks and accompanying long pedestrian clearance times. Many intersections in the core and peripheral downtown area have simple two-phase operation, but some locations provide left turn phases. Some of these provide more efficient protected/permitted left-turn operation, while other left turn phases are fully protected. Outside of the core downtown area, many large intersections have no pedestrian push buttons. These features result in the need to use relatively a long traffic signal cycle which, in turn, necessitates longer waits at the intersections. Furthermore, the light rail operation that runs on Main Street and 400 South and cuts through the downtown area features traffic signal controllers that provide priority to minimize delays for the light rail operation, possibly at the expense of motor vehicular and pedestrian traffic. All these features constrain traffic signal operation and re-timing efforts within Salt Lake City downtown area.

Downtown networks of three other cities were selected for comparison. They are the City of Honolulu, Hawaii, City of Louisville, Kentucky and City of Santa Monica, California. Like Salt Lake City, the three cities have traffic management centers that allow for monitoring and instant timing updates from its respective center. The average size of their intersections is smaller than that of Salt Lake City, better representing what one finds in other U.S cities. Pedestrian traffic in the cities of Santa Monica and Honolulu is significantly higher than Salt Lake City. There are significantly more one-way streets in downtown Louisville than the other three cities. Within Louisville's project study area, there are 26 corridors, of which 18 of them are either one-way or partial one-way streets. One-way streets are more efficient movers of traffic and provide for higher travel speeds than two-way streets. Table 13 below summarizes the Measures of Effectiveness (MOE's) of the four cities.

Table 13 – Measures of Effectiveness (MOE's) of Four Cities

City	State	No. of I/S in the Network	Average Speed (mph)	Delay/Int	Stops/Int
Salt Lake City	AM	173	17	9.3	833
	PM	173	16	11.3	939
Honolulu	AM	74	12	10.7	997
	PM	74	10	15.4	1117
Santa Monica	AM	60	14	6.4	733
	PM	60	12	11.4	1123
Louisville*	AM	220	20	10.5	n/a
	PM	220	19.5	13.6	n/a

Note: *Based on a report prepared by Entran, PLC, submitted to the City on October 2009.

Despite its relative large intersection size and having light rail operation running through the downtown area, Salt Lake City fares well in comparison with other cities. It has the second highest average speeds for both peak periods. Salt Lake City has the lowest average delay and number of stops during the evening rush hours.

7. Conclusions

This report documented the existing traffic signal operation analysis, optimized timing plan development, field fine-tuning and implementation, performance improvement, and fuel consumption savings associated with the signal retiming efforts within the greater CBD area in Salt Lake City. This report also surveyed and compared traffic signal system operation and management of other agencies, and provided the recommendations for the next 3 to 5-year signal retiming efforts. KOA completed the following tasks during this study:

- Attended kick off meeting and collected traffic volume and existing timing plans. KOA manually balanced the traffic volumes at critical locations using Synchro 7 models. The adjusted volumes were reviewed and approved by the City staff.

- Reviewed and updated Synchro networks for AM, midday, and PM peak periods with existing timing plans and balanced turning volumes. Existing downtown signal operation was reviewed in August 2010. Based on the field review, KOA calibrated the existing Synchro networks for three time periods.

- Optimized three signal timing plans for the weekday AM, midday, and PM periods, using calibrated Synchro networks. Different cycle lengths have been tested with the MOE comparison. KOA concurs in using 120-second cycle length for AM and PM peak periods, and proposed partially harmonic cycle lengths of 108 seconds and 81 seconds during the midday period. Minimal changes are recommended to arterial corridors with light rail operation. Splits and offsets are optimized at other intersections accordingly.

- The optimized timing plans were implemented and fine-tuned in May 2011.

- Sixteen corridors were selected to conduct after studies. A total of three runs were conducted for each direction of the corridor for each peak time period.

The conclusions and findings of the study are provided below:

- The physical and operational characteristics of Salt Lake City's signal system require more staff resources to be adequate for signal system operation maintaining operational and safety performance of the City's roadway network and retiming of signals in three-year intervals. As a result, KOA recommends hiring two new engineers and one additional operator ~~are recommended~~ to operate the 184-intersection signal system.

- The current Siemens i2 Central Traffic Management Software (TMS), which has been used to manage traffic signals in the Salt Lake Metropolitan area for the past 12 years, needs to be replaced. In the near future, this software will no longer be supported by the manufacturer.

The City, together with UDOT and other users of the software, should begin a comprehensive search for a new software package that best suits the needs of the Salt Lake Metropolitan area's traffic signal system.

- The corridor-based measures of effectiveness (MOE's) performance collected were average travel time, average speed, number of stops, and total delay. **The optimized timing plans improved average MOE's by approximately 8% to 17% during the peak periods.** The after study showed that the optimized timing plans balanced the Salt Lake City downtown roadway system with other travel modes, such as light rail**.** The signal coordination favors major corridors with heavy traffic volumes such as Sate Street, 500 South, and 600 South. Meanwhile, the optimized timing plans limit the number of stops and delay on the cross streets and provide better progression along the City corridors.

- In terms of network-wide improvement with the optimized timing plans, total delay within the downtown area was reduced by 14% for AM Peak, 10% for Midday Period, and 7% for PM Peak. The number of total stops was reduced by 8% for AM Peak, 7% for Midday Period, and 8% for PM Peak.

- The Synchro models estimated network-wide fuel consumption, carbon monoxide emission, oxides of nitrogen emission, and volatile Organic compounds emission decreases. With the traffic signal retiming efforts, fuel consumption is reduced by 337,000 gallon per year within the study area, exceeding the reduction target of 32,000 gallon per year by a factor of 10.

- Based on the fuel consumption decrease and MOE improvements, an economic evaluation was conducted to identify a three-year benefit-to-cost ratio of 62:1 achieved by this project.

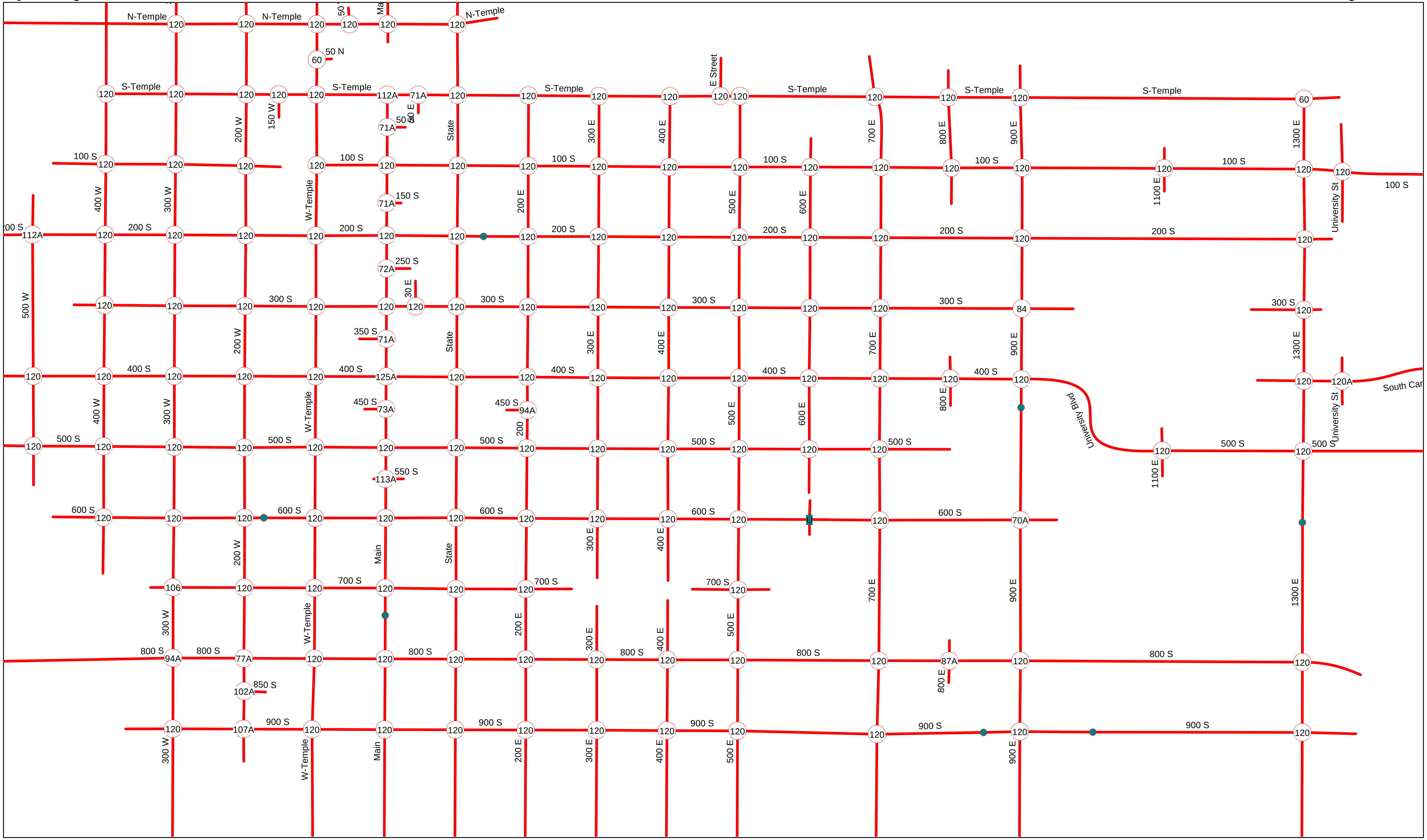
- KOA recommends the following measures to improve traffic signal system performance: routine review and troubleshooting of signal operations, updating the traffic volume database, cross-jurisdictional traffic signal retiming, and updating to a newer generation of central traffic management system.

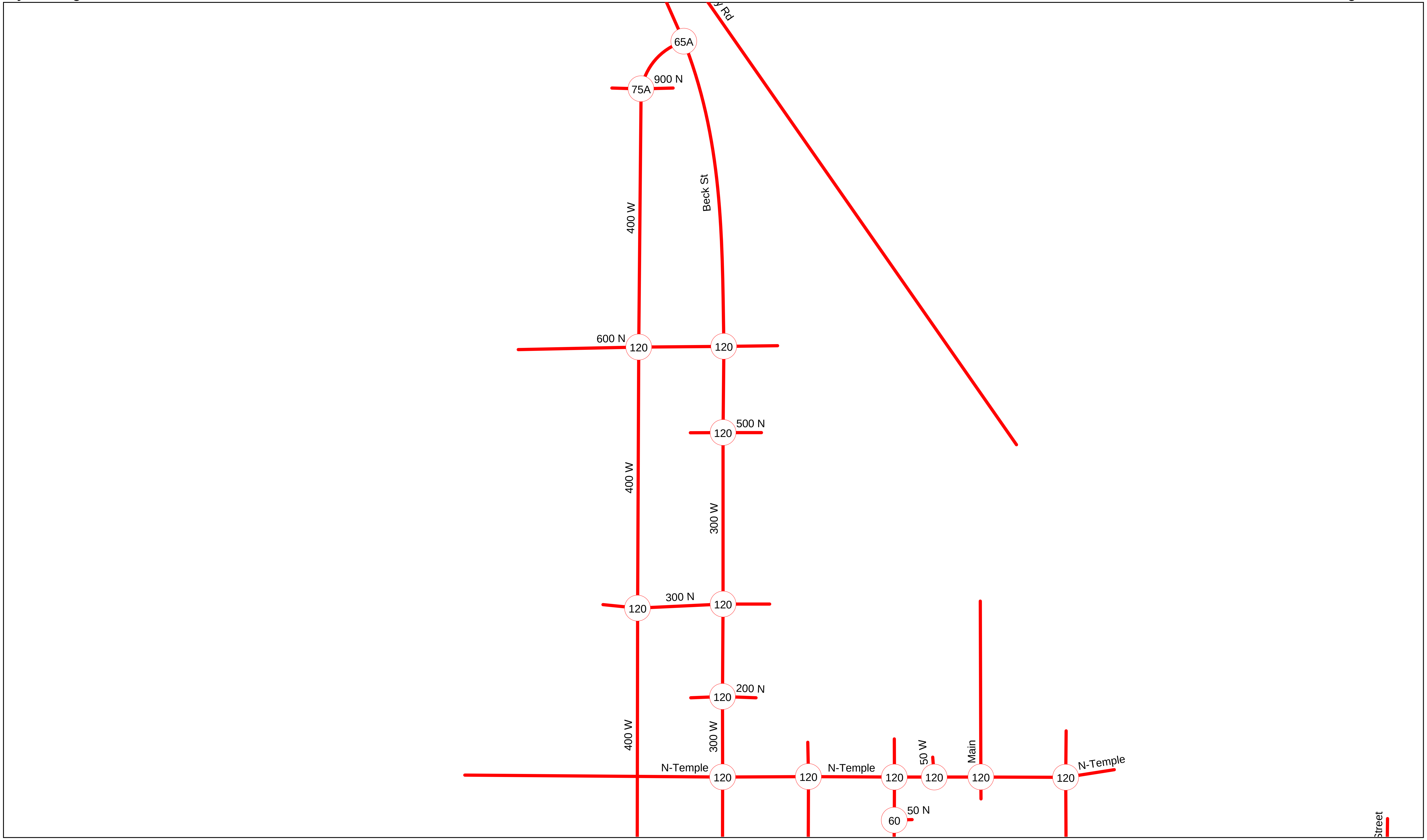
Considering the overall size of the intersections, light rail operation and absence of pedestrian push buttons at many intersections in the surrounding downtown area, **the current traffic system with optimized cycle length, splits and offsets is operating as well as it possibly can using "good practice" strategy and a philosophy of providing transit priority and balanced service to other travel modes.**

APPENDIX A
EXISTING CYCLE LENGTH

Appendix A
Cycle Length

Existing
Timing Plan: AM

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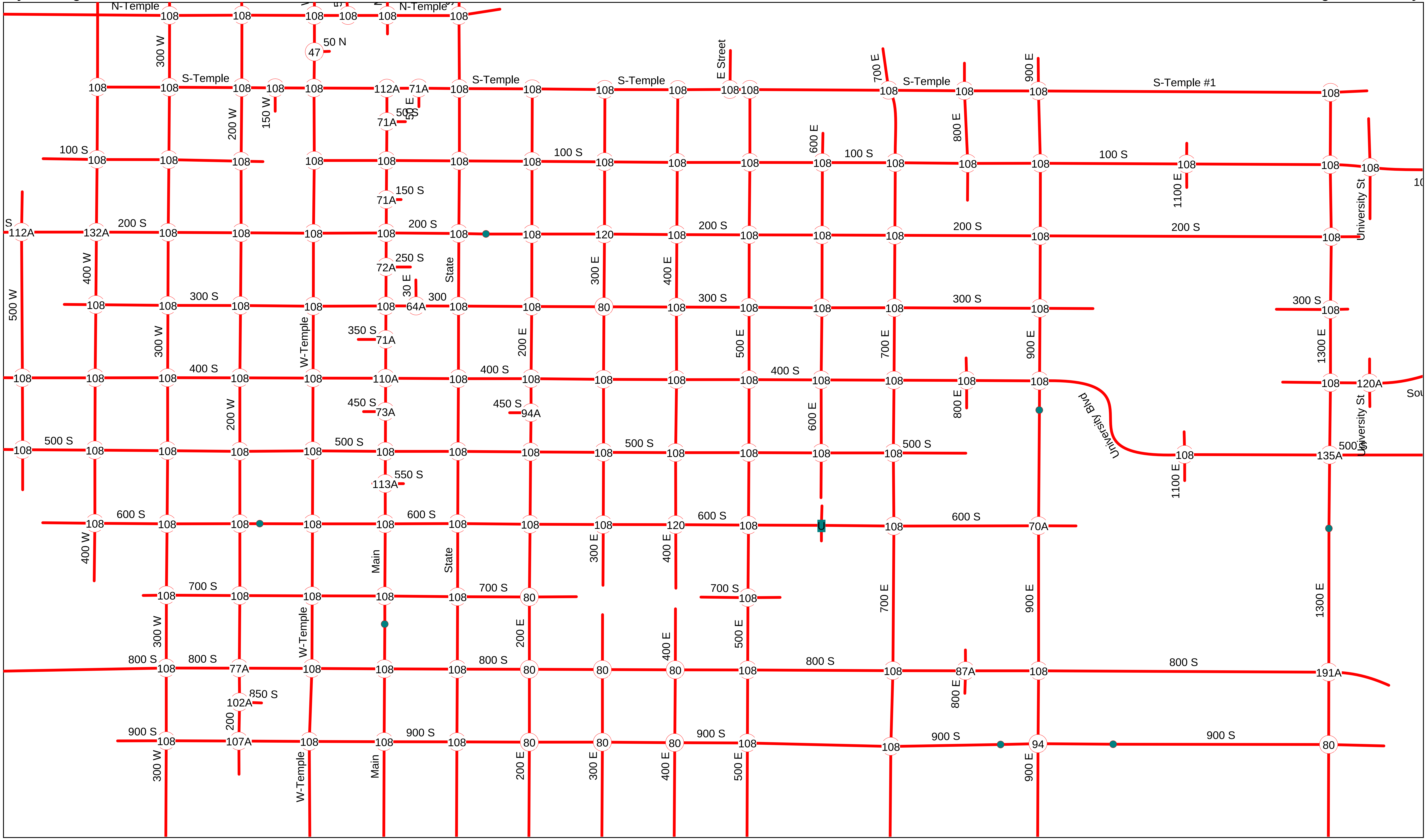
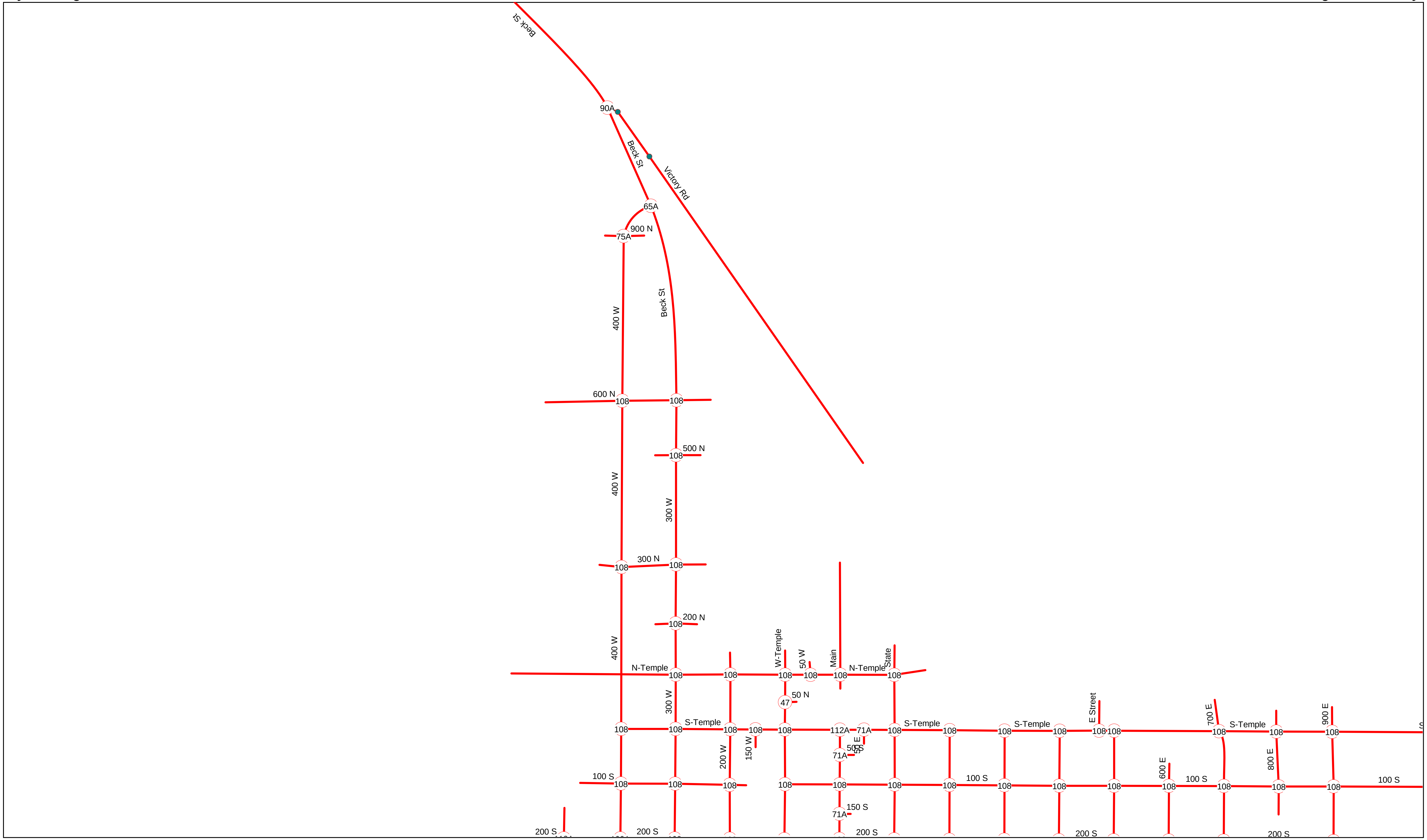
300 W
N-Temple
120
120
N-Temple
120
50 W
120
Main
120
120
N-Temple
50 N
60

Appendix A
Cycle Length

Existing
Timing Plan: Midday

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200 N
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400 W
N-Temple
W-Temple
50 W
Main
N-Temple
State
108
108
108
108
108
108
50 N
47
300 W
S-Temple
S-Temple
S-Temple
E Street
700 E
S-Temple
900 E
108
108
108
108
108
112A
71A
108
108
108
108
108
108
108
108
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50 S
50 E
71A
200 W
150 W
100 S
100 S
600 E
100 S
800 E
100 S
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108
108
108
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108
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71A
200 S
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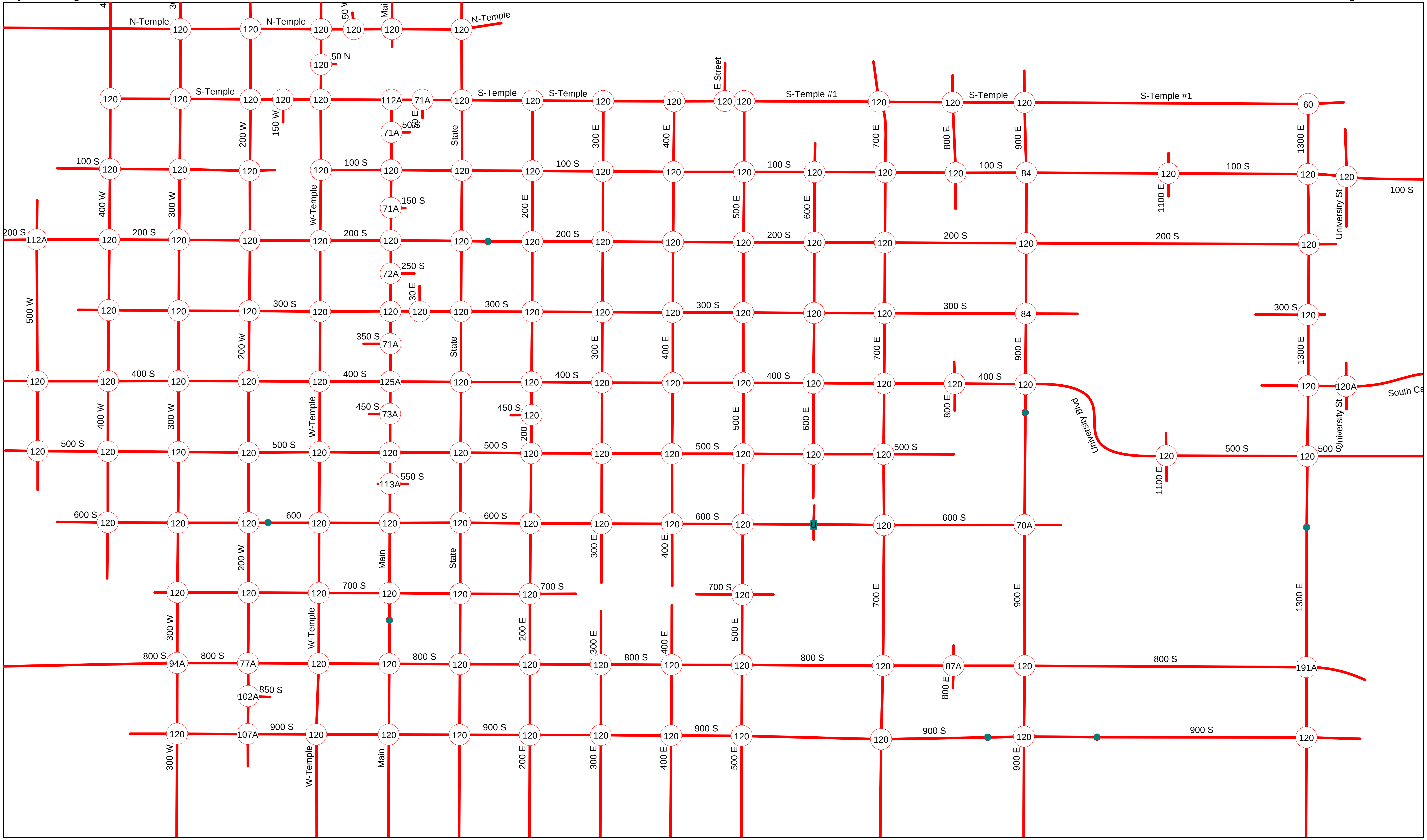
200 S

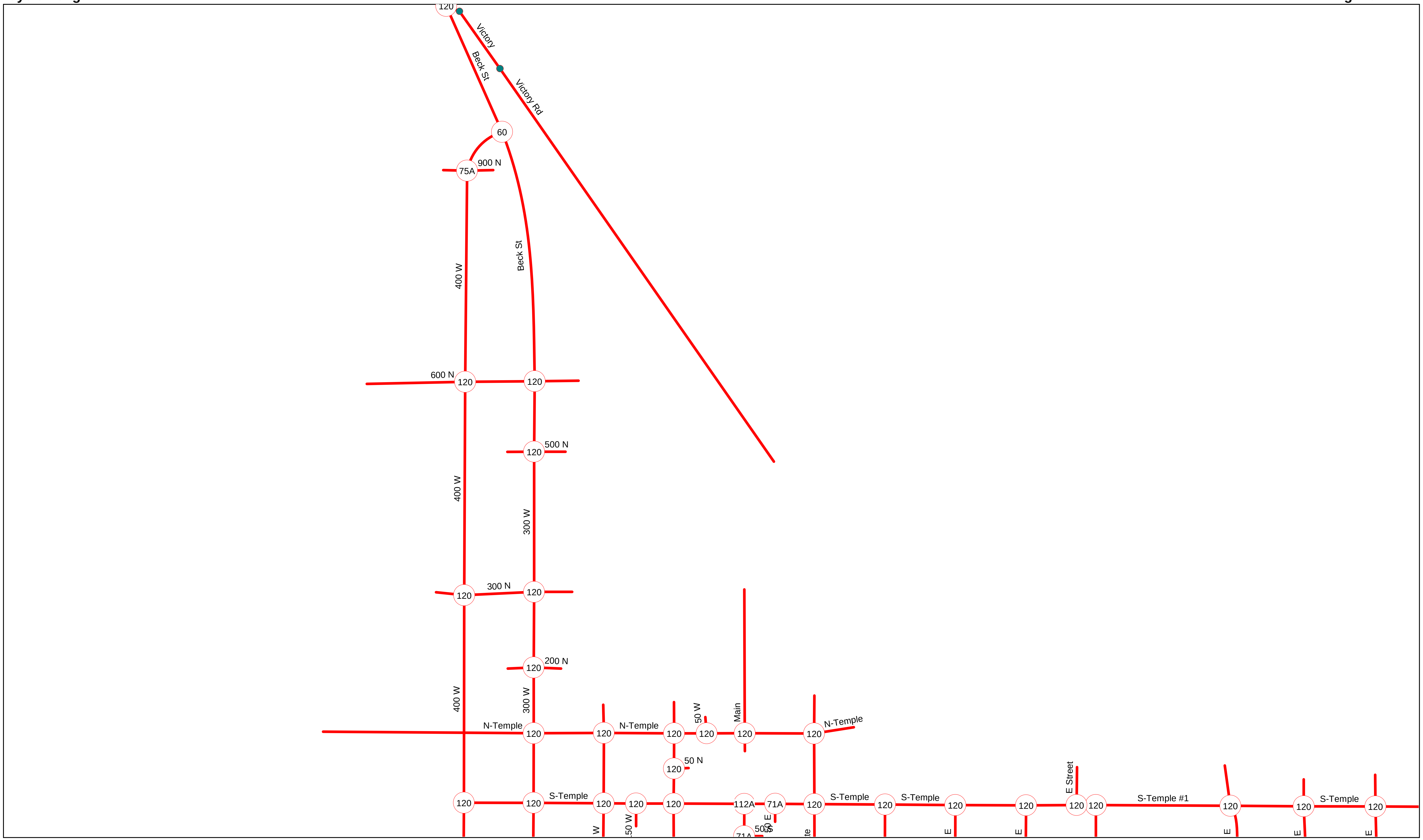
Appendix A
Cycle Length

Existing
Timing Plan: PM



Appendix A
Cycle Length

Existing
Timing Plan: PM

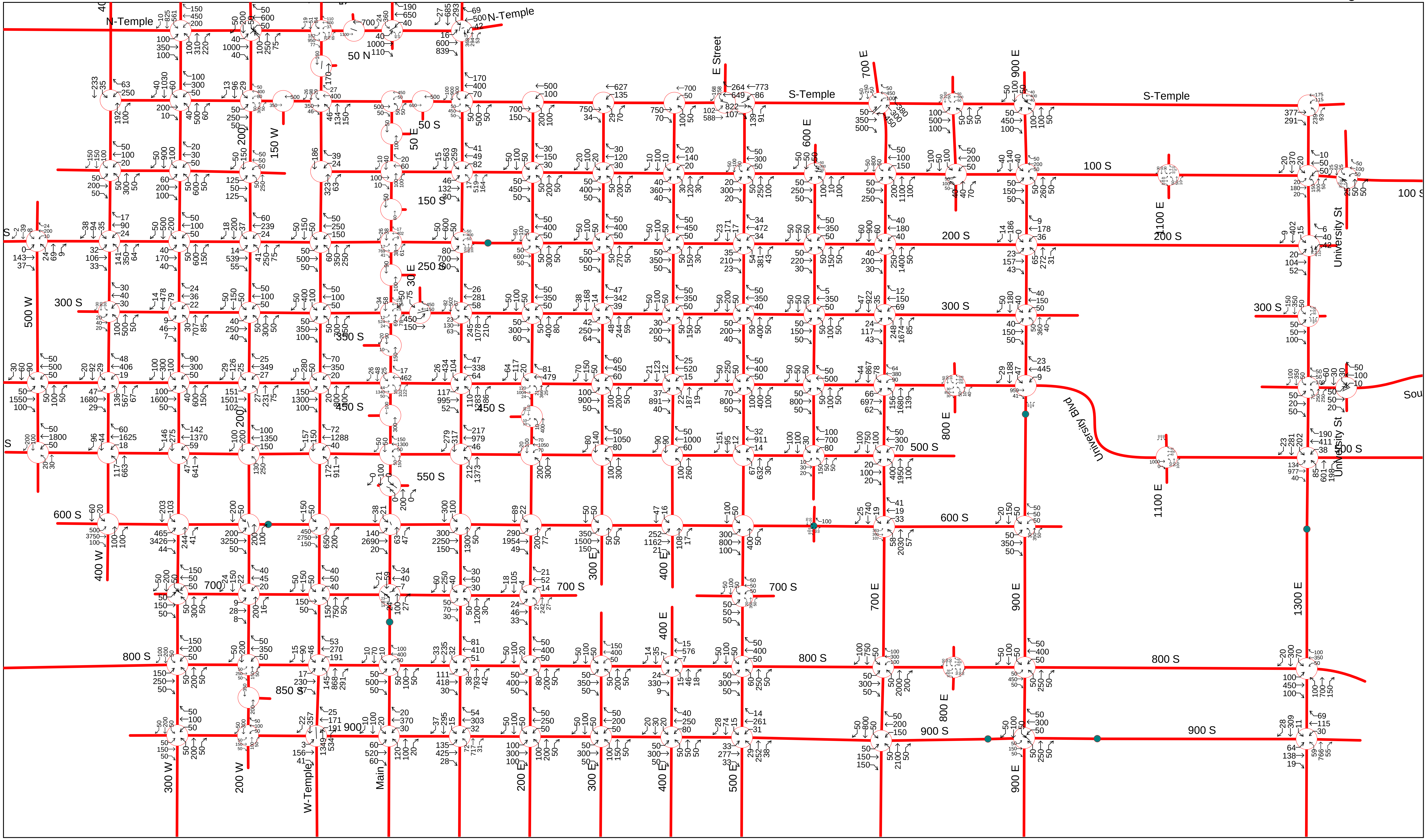


APPENDIX B

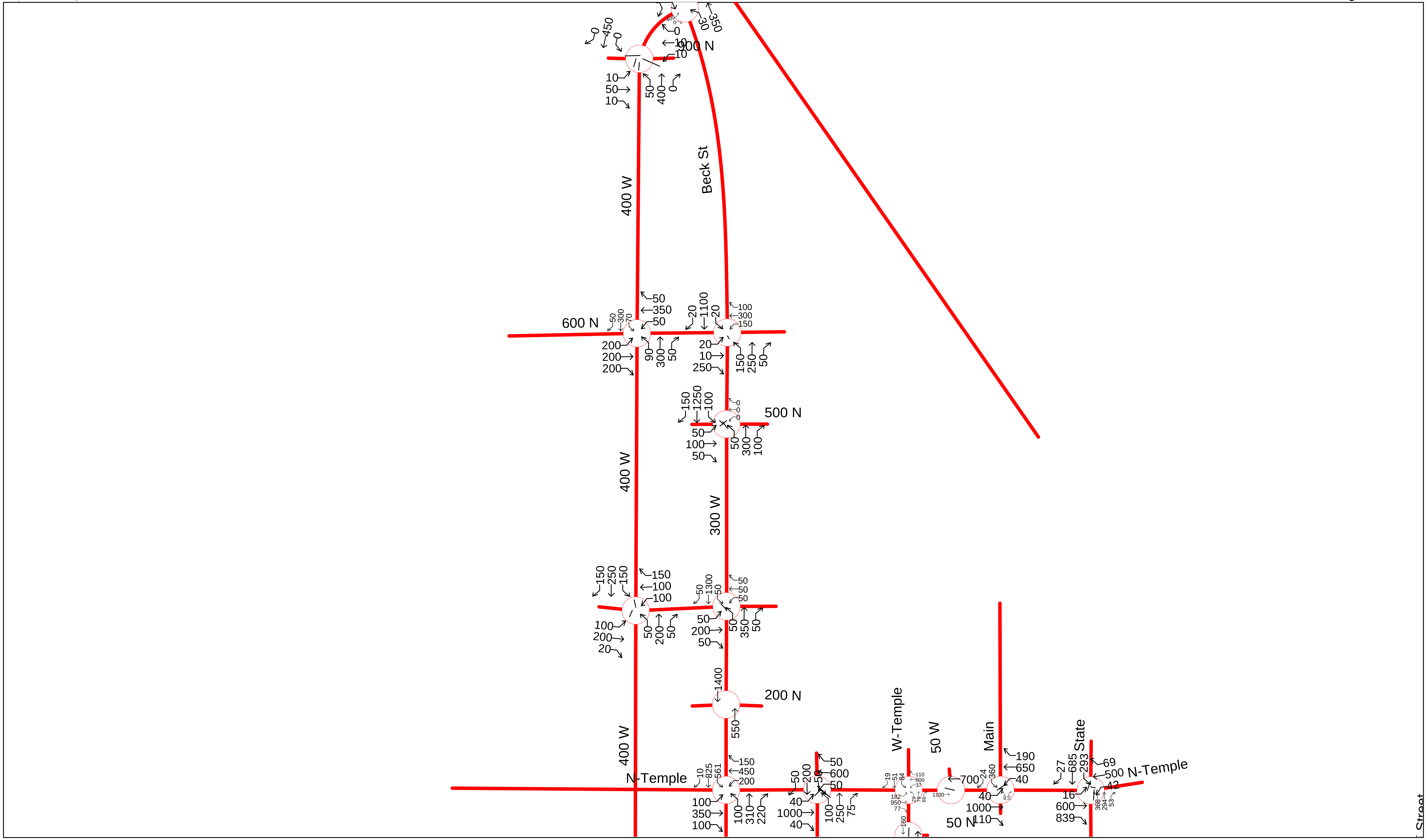
EXISTING TRAFFIC VOLUME COUNTS

APPENDIX B - TRAFFIC VOLUME COUNTS

Existing
Timing Plan: AM

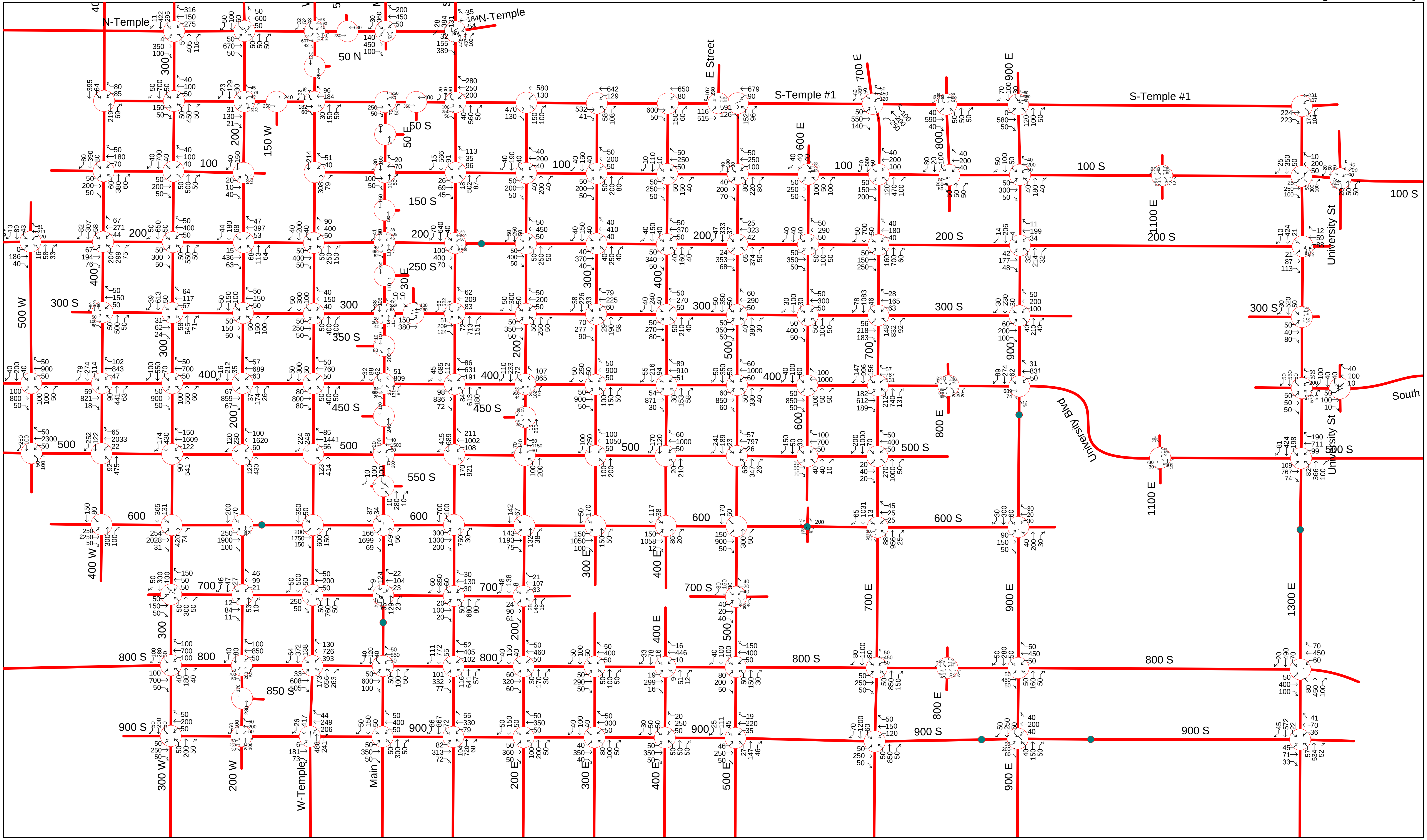


Existing
Timing Plan: AM



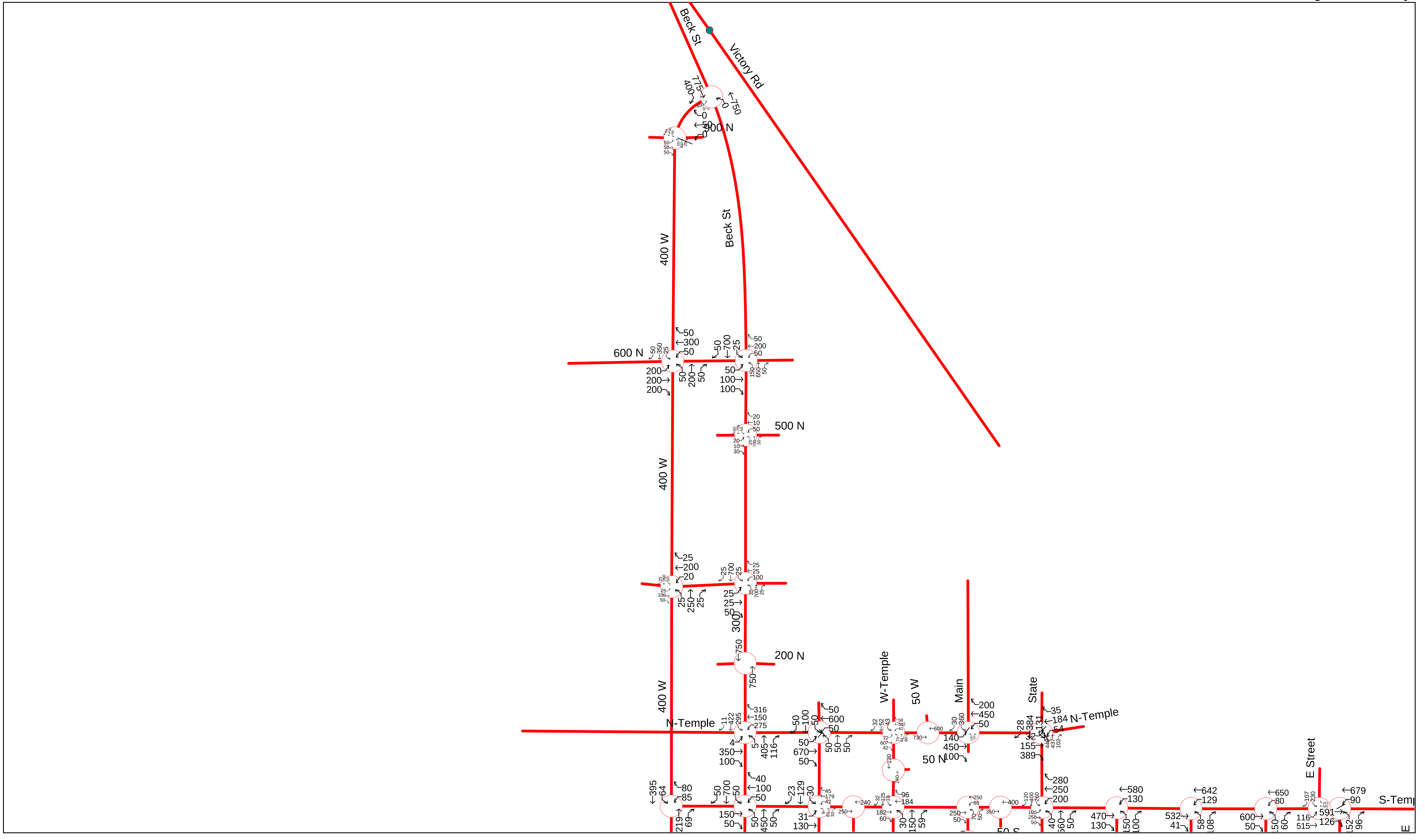
APPENDIX B - TRAFFIC VOLUME COUNTS

Existing
Timing Plan: Midday



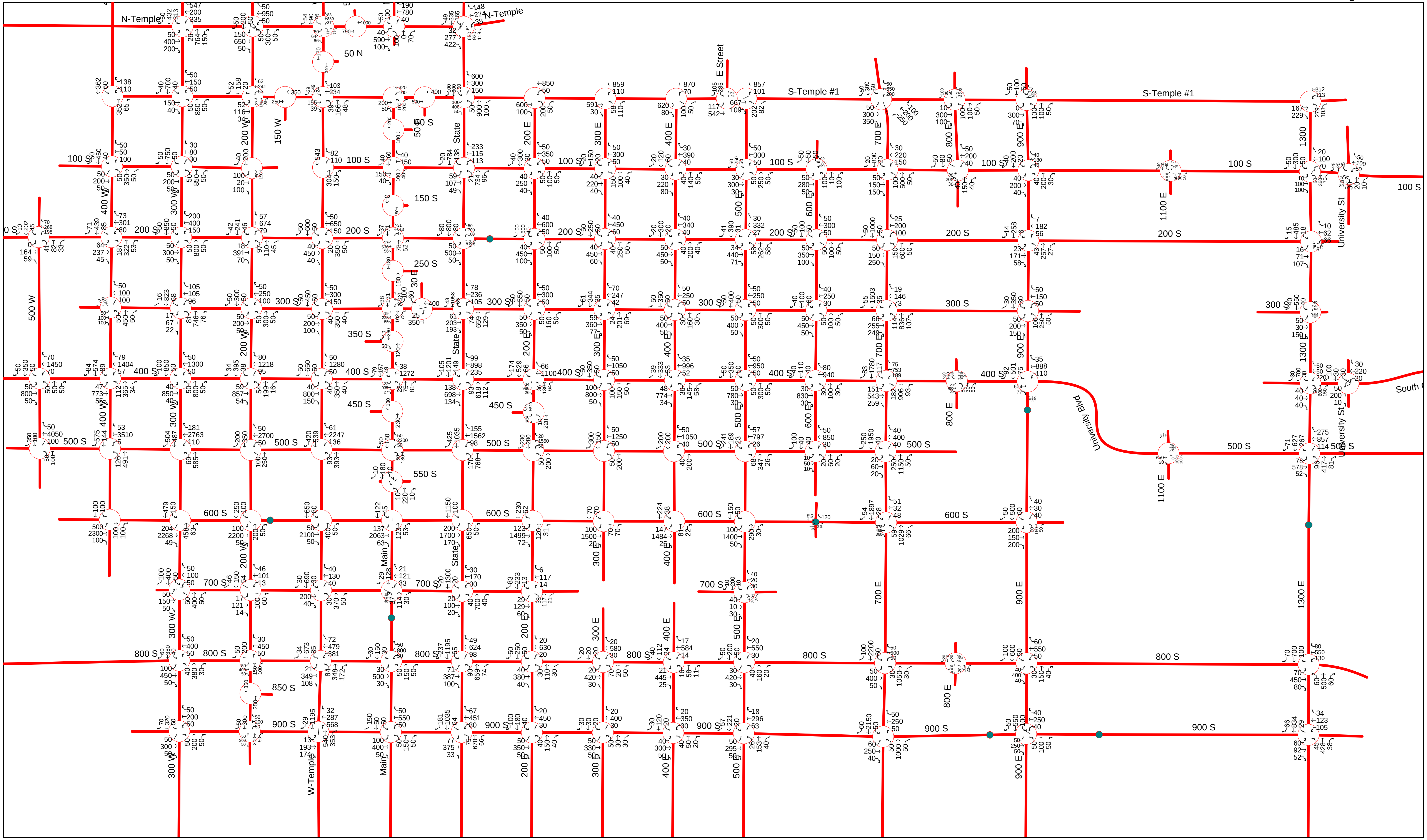
APPENDIX B - TRAFFIC VOLUME COUNTS

Existing
Timing Plan: Midday



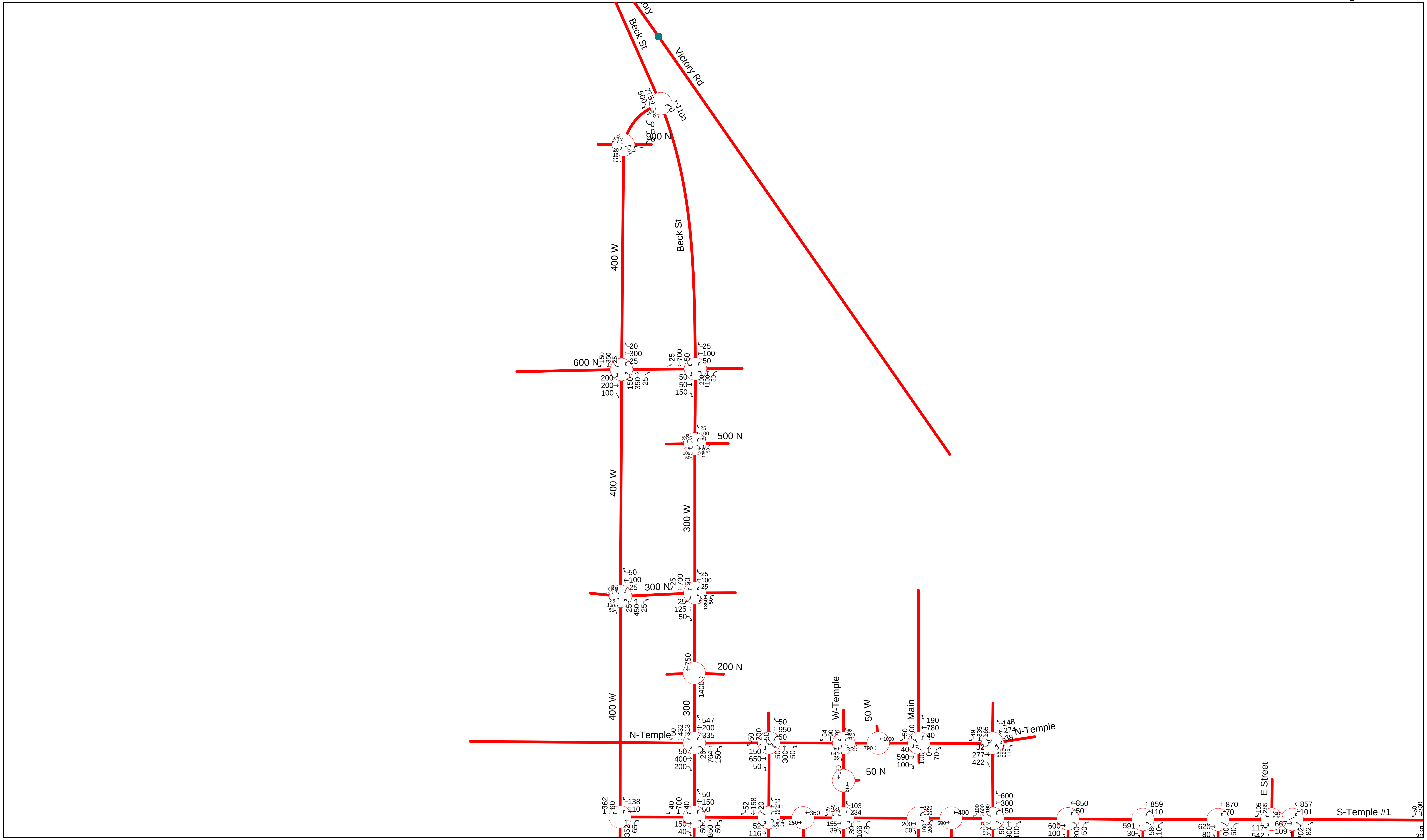
APPENDIX B - TRAFFIC VOLUME COUNTS

Existing
Timing Plan: PM



APPENDIX B - TRAFFIC VOLUME COUNTS

Existing
Timing Plan: PM

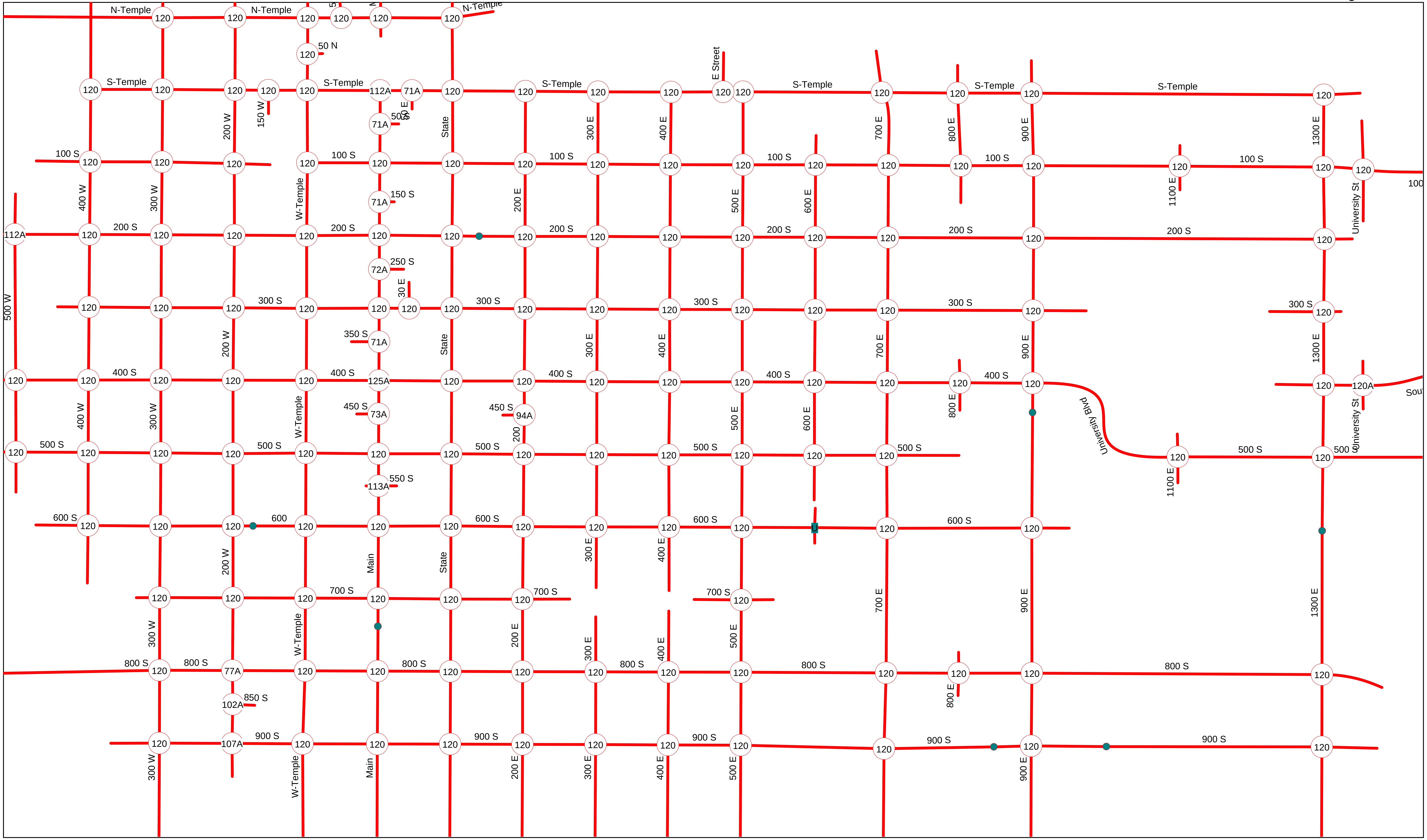


APPENDIX C

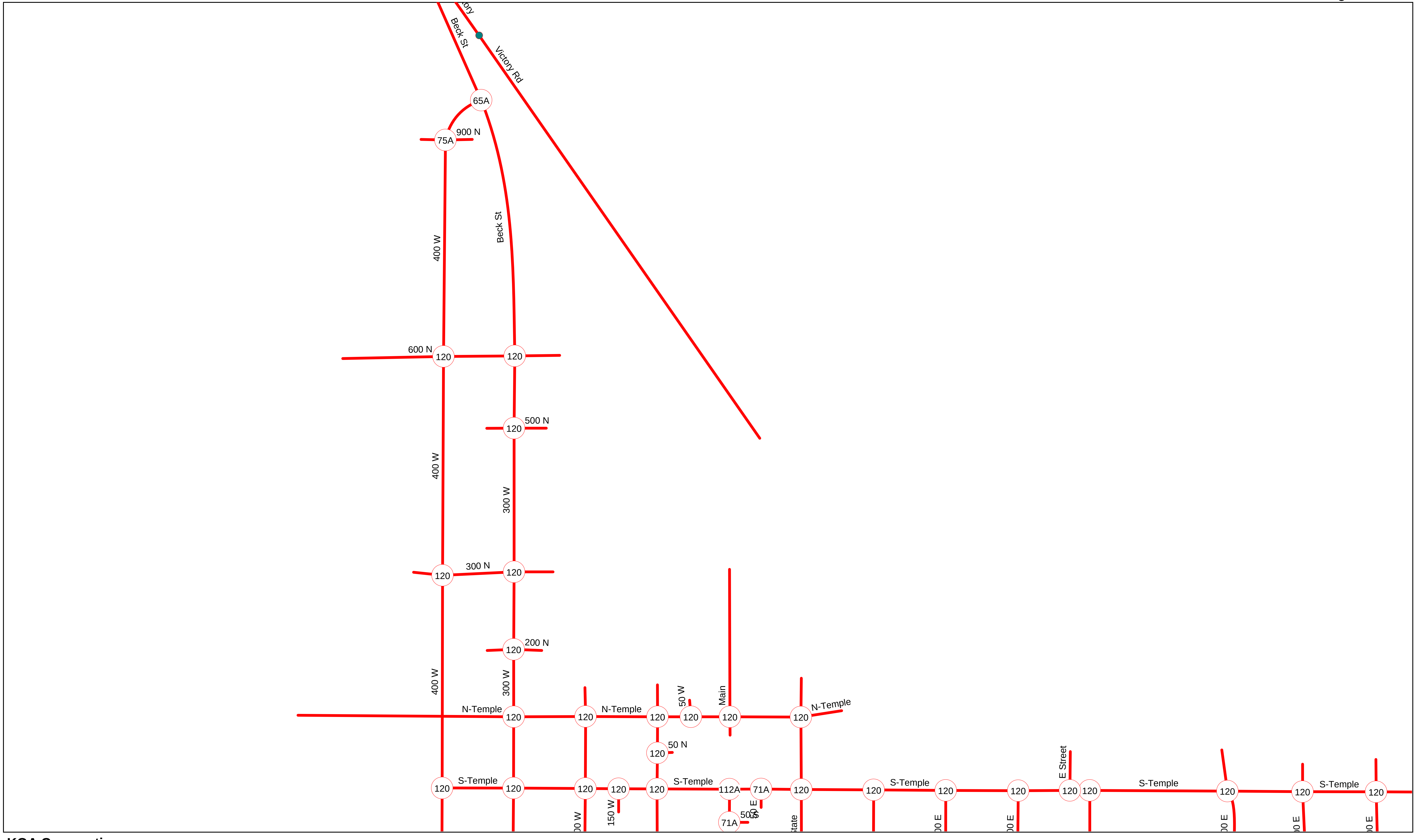
PROPOSED CYCLE LENGTH

Appendix C
PROPOSED CYCLE LENGTH

Optimized
Timing Plan: AM



KOA Corporation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Beck St
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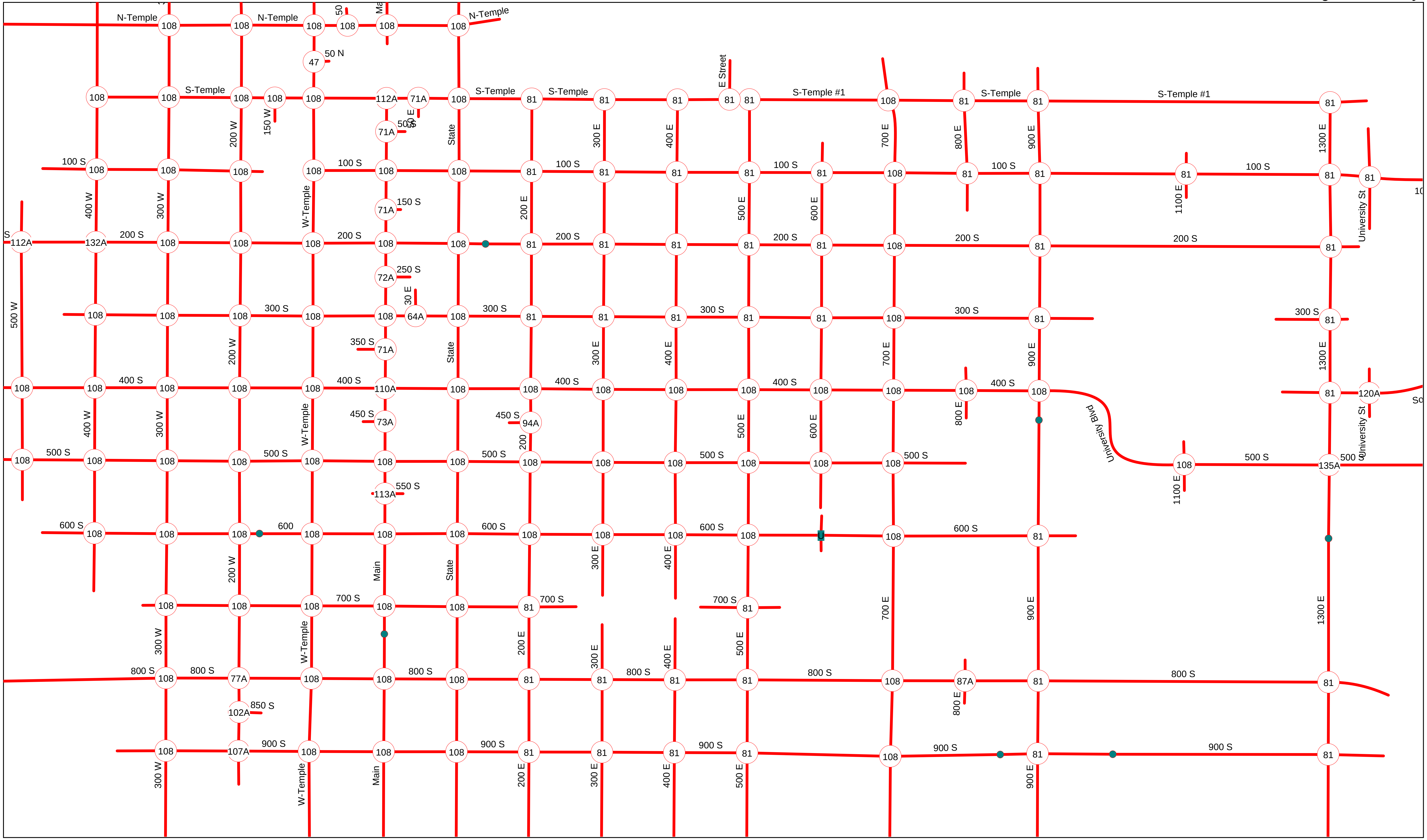
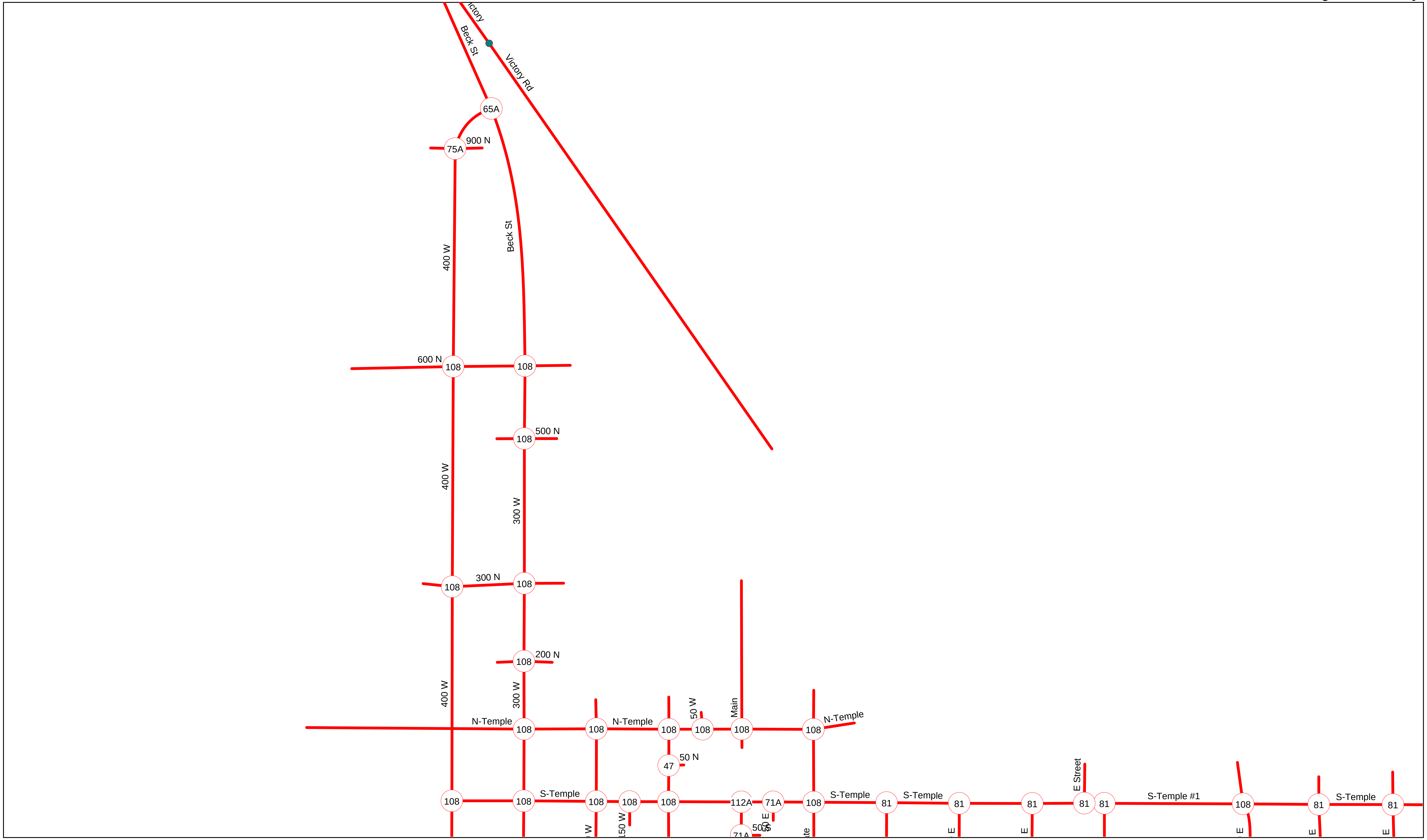
120
500 N
300 W
300 N
200 N
N-Temple
S-Temple
50 N
50 W
Main
150 W
112A
71A
State
E Street

Appendix C
PROPOSED CYCLE LENGTH

Optimized
Timing Plan: Midday



KOA Corporation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200 N
108
400 W
300 W
N-Temple
108
108
N-Temple
108
50 W
108
Main
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108
N-Temple
47
50 N
108
108
S-Temple
108
108
108
112A
71A
108
S-Temple
81
S-Temple
81
81
E Street
81
81
S-Temple #1
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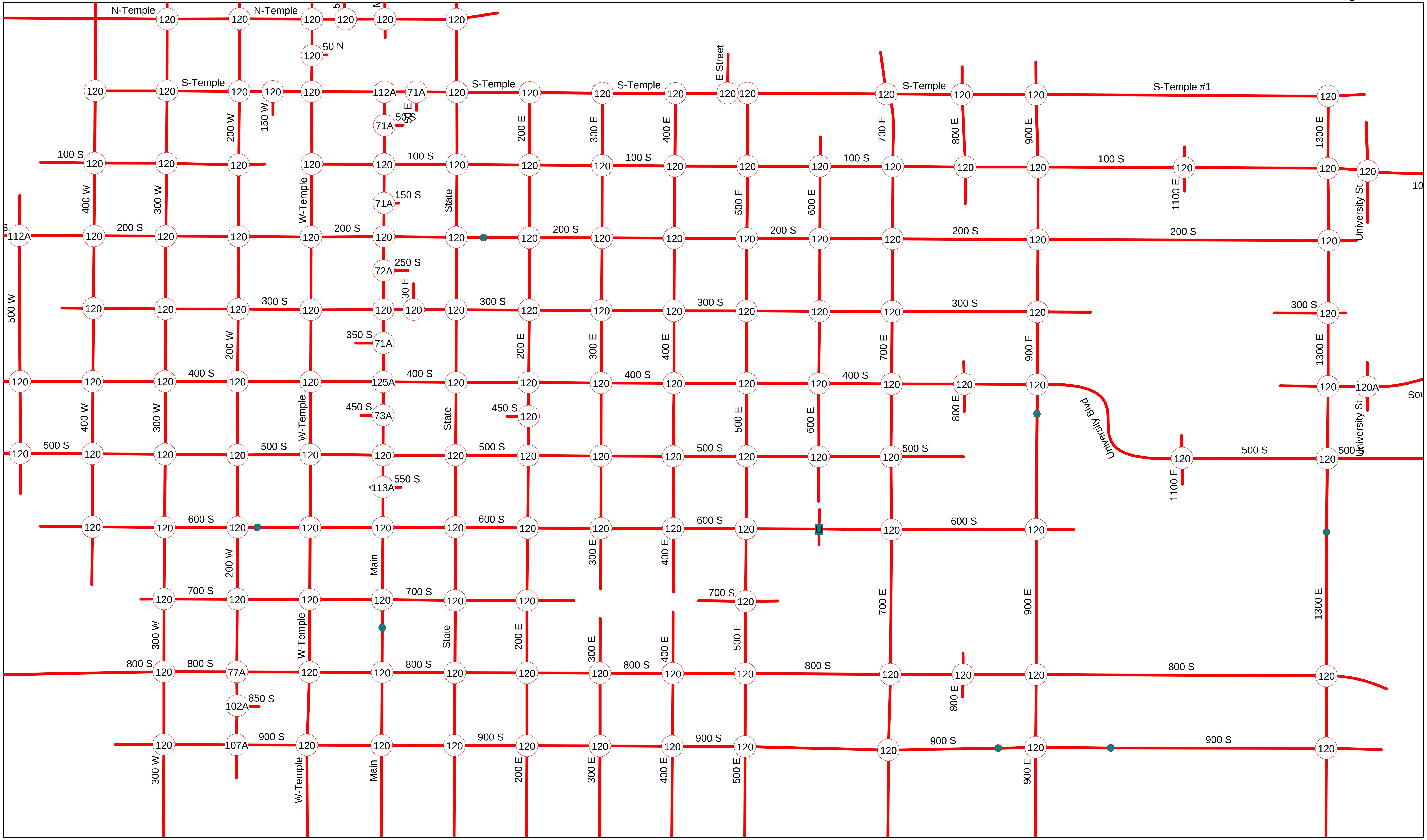
81
S-Temple
81
71A

Appendix C
PROPOSED CYCLE LENGTH

Optimized
Timing Plan: PM



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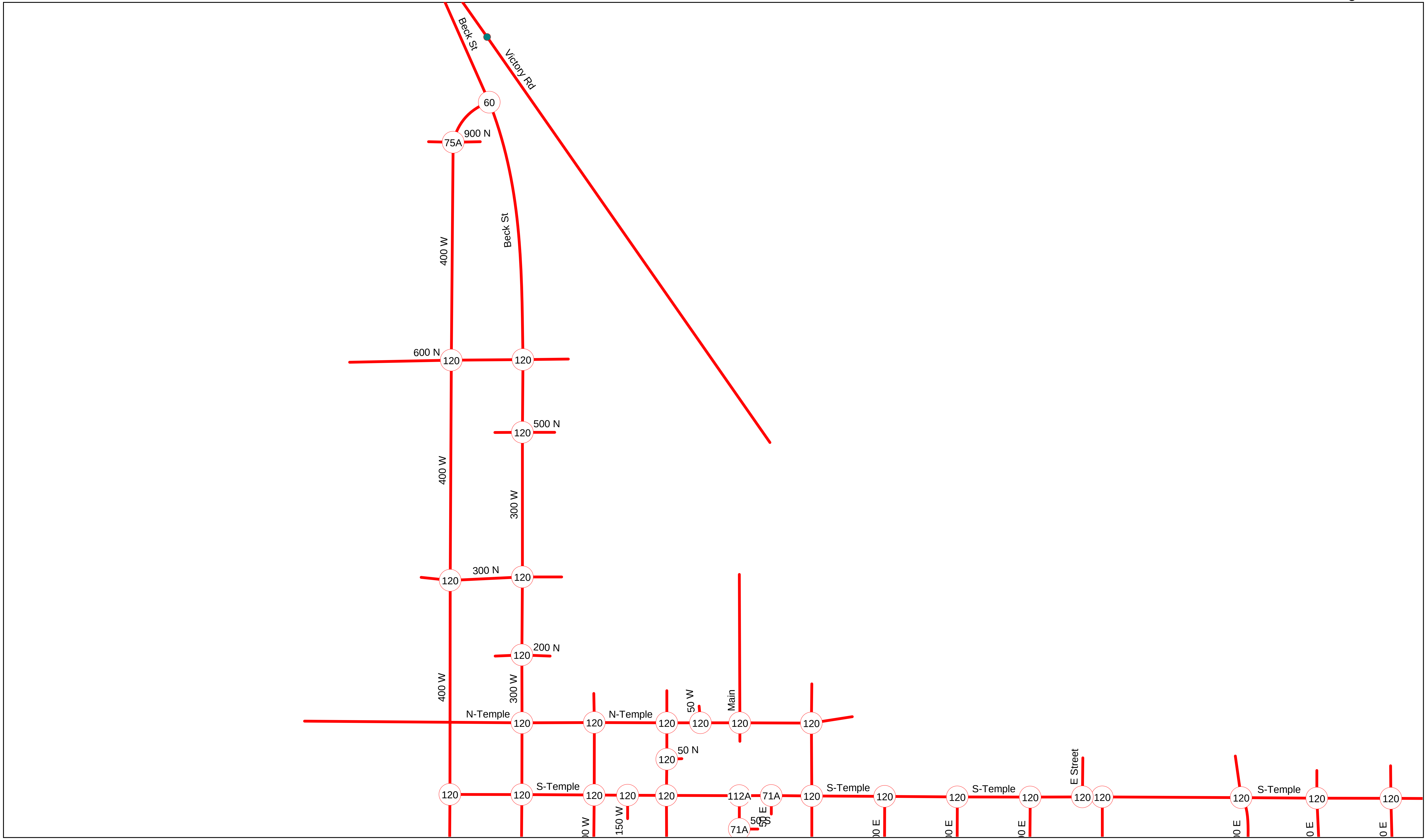
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300 W
300 N
200 N
N-Temple
50 W
Main
50 N
S-Temple
150 W
112A
71A
50 S
50 E
E Street

Travel Time Delay After Study Summary, AM

Corridor	Length (feet)	Length (mi)	Direction	From	To	Actual From	Actual To	Travel Time (sec)	Speed (mph)	No. of Stops	Total Delay (sec)
South Temple	11127	2.11	EB	300 West	1300 East	200 West	1200 East	395	19.4	4.3	139
	11127	2.11	WB	1300 East	300 West	1200 East	200 West	420	18.2	4.3	148
100 South	10361	1.96	EB	West Temple	University Street	Main St	1300 East	414	17.4	4.3	157
	10361	1.96	WB	University Street	West Temple	1300 East	Main St	488	14.6	6.3	225
200 South	9255	1.75	EB	500 West	900 East	450 West	700 East	470	13.5	4.7	210
	9255	1.75	WB	900 East	500 West	700 East	450 West	401	15.7	5	156
300 South	7934	1.50	EB	400 West	1300 East	300 West	700 East	336	16.5	3.3	110
	7934	1.50	WB	1300 East	400 West	700 East	300 West	389	14.8	4.7	166
800 South	12687	2.40	EB	300 West	1300 East	300 West	1300 East	541	16.2	5.7	229
	12687	2.40	WB	1300 East	300 West	1300 East	300 West	516	17	5	230
900 South	12686	2.40	EB	300 West	1300 East	300 West	1300 East	537	16.3	7.3	209
	12686	2.40	WB	1300 East	300 West	1300 East	300 West	459	19.3	4.7	156
400 West	11884	2.25	NB	600 South	900 North	600 South	900 North	586	14	5.7	276
	11884	2.25	SB	900 North	600 South	900 North	600 South	463	17.8	4.3	165
300 West	11092	2.10	NB	900 South	Victory Road	800 South	600 North	452	21.5	4	160
	11092	2.10	SB	Victory Road	900 South	600 North	800 South	404	23.7	3.3	120
200 West	7927	1.50	NB	900 South	North Temple	900 South	North Temple	331	17.7	4	122
	7927	1.50	SB	North Temple	900 South	North Temple	900 South	478	11.6	6.3	280
West Temple	7130	1.35	NB	900 South	North Temple	800 South	North Temple	379	12.5	4.7	182
	7130	1.35	SB	North Temple	900 South	North Temple	800 South	351	13.3	4.7	176
State Street	7933	1.50	NB	900 South	North Temple	900 South	North Temple	408	14.9	6	198
	7933	1.50	SB	North Temple	900 South	North Temple	900 South	226	25.5	2	47
200 East	7144	1.35	NB	900 South	South Temple	800 South	South Temple	230	18.1	3	72
	7144	1.35	SB	South Temple	900 South	South Temple	800 South	252	17	3	108
300 East	7127	1.35	NB	900 South	South Temple	900 South	South Temple	419	11.2	5	228
	7127	1.35	SB	South Temple	900 South	South Temple	900 South	280	16.9	3	107
400 East	7129	1.35	NB	900 South	South Temple	900 South	South Temple	320	15.7	3.7	134
	7129	1.35	SB	South Temple	900 South	South Temple	900 South	352	14.2	5	151
700 East	7132	1.35	NB	900 South	South Temple	900 South	South Temple	264	19.1	3	73
	7132	1.35	SB	South Temple	900 South	South Temple	900 South	246	19.7	3	72
900 East	7127	1.35	NB	900 South	South Temple	800 South	100 South	180	23	0.5	42
	7127	1.35	SB	South Temple	900 South	100 South	800 South	193	21.1	1.5	63

Travel Time Delay After Study Summary, Midday

Corridor	Data Year	Length (feet)	Length (mi)	Direction	From	To	Actual From	Actual To	Travel Time (sec)	Speed (mph)	No. of Stops	Total Delay (sec)
South Temple	2009	11127	2.11	EB	300 West	1300 East	200W	1200 East	425	18	5	145
		11127	2.11	WB	1300 East	300 West	1200 East	200 West	447	17.1	7	150
100 South	2009	10799	2.05	EB	West Temple	University Street	Main St	University Street	316	23.7	3.3	64
		10799	2.05	WB	University Street	West Temple	University	Main St	461	16	6.3	187
200 South	2009	10842	2.05	EB	500 West	900 East	450 East	900 East	503	14.7	6.7	209
		10842	2.05	WB	900 East	500 West	900 East	450 West	516	14.4	6.7	238
300 South	2009	9522	1.80	EB	400 West	1300 East	300 West	900 East	424	15.4	5.7	139
		9522	1.80	WB	1300 East	400 West	900 East	300 West	472	13.9	6	188
800 South	2008	12687	2.40	EB	300 West	1300 East	200 West	1250 East	476	16.8	5.8	187
		12687	2.40	WB	1300 East	300 West	1250 East	200 West	373	21.7	3.5	94
900 South	2008	10340	1.96	EB	300 West	1300 East	200 West	1100 East	352	20.2	4	92
		10340	1.96	WB	1300 East	300 West	1100 East	200 West	384	19.4	4	139
400 West	2008	8706	1.65	NB	600 South	900 North	500 South	600 North	389	15.4	3.7	165
		8706	1.65	SB	900 North	600 South	600 North	500 South	350	17.4	3.3	119
300 West	2009	11092	2.10	NB	900 South	Victory Road	800 South	600 North	439	17.3	5	171
		11092	2.10	SB	Victory Road	900 South	600 North	800 South	327	23.2	3	71
200 West	2009	7927	1.50	NB	900 South	North Temple	900 South	North Temple	429	12.8	6	222
		7927	1.50	SB	North Temple	900 South	North Temple	900 South	390	14	6.8	166
West Temple	2009	7130	1.35	NB	900 South	North Temple	800 South	50 North	390	11.9	5.7	200
		7130	1.35	SB	North Temple	900 South	50 North	800 South	395	12	5	210
State Street	2009	7933	1.50	NB	900 South	North Temple	900 South	North Temple	367	15.3	5	172
		7933	1.50	SB	North Temple	900 South	North Temple	900 South	246	22.5	3	58
200 East	2009	6350	1.20	NB	900 South	South Temple	800 South	North Temple	314	13	5	147
		6350	1.20	SB	South Temple	900 South	North Temple	800 South	263	15.5	4.3	99
300 East	2009	7127	1.35	NB	900 South	South Temple	900 South	50 South	352	13.8	5	134
		7127	1.35	SB	South Temple	900 South	South Temple	900 South	289	18.4	3.3	103
400 East	2009	7129	1.35	NB	900 South	South Temple	900 South	South Temple	355	14.2	5	162
		7129	1.35	SB	South Temple	900 South	South Temple	900 South	272	17.9	3.7	86
700 East	2008	7132	1.35	NB	900 South	South Temple	900 South	South Temple	248	19.6	2.7	72
		7132	1.35	SB	South Temple	900 South	South Temple	900 South	228	21.9	3	63
900 East	2008	7127	1.35	NB	900 South	South Temple	800 South	100 South	199	19.1	1.7	58
		7127	1.35	SB	South Temple	900 South	100 South	800 South	206	18.5	3	64

Travel Time Delay After Study Summary, PM

Corridor	Data Year	Length (feet)	Length (mi)	Direction	From	To	Actual From	Actual To	Travel Time (sec)	Speed (mph)	No. of Stops	Total Delay (sec)
South Temple	2009	11127	2.11	EB	300 West	1300 East	200W	1200 East	377	20.8	4	117
		11127	2.11	WB	1300 East	300 West	1200 East	200 West	384	19.8	5.3	104
100 South	2009	8374	1.59	EB	West Temple	University Street	Main St	1040 East	309	18.5	3.3	100
		8374	1.59	WB	University Street	West Temple	1040 East	Main St	364	15.8	3.7	155
200 South	2009	10054	1.90	EB	500 West	900 East	450 East	800 East	438	15.6	5	185
		10054	1.90	WB	900 East	500 West	800 East	450 West	464	15.2	5	207
300 South	2009	8733	1.65	EB	400 West	1300 East	300 West	800 East	404	14.9	4.7	159
		8733	1.65	WB	1300 East	400 West	800 East	300 West	576	10.5	7.7	301
800 South	2008	12687	2.40	EB	300 West	1300 East	300 West	1300 East	570	15.4	5	262
		12687	2.40	WB	1300 East	300 West	1300 East	300 West	488	17.8	4.3	191
900 South	2008	12689	2.40	EB	300 West	1300 East	300 West	1300 East	580	14.9	6.7	252
		12689	2.40	WB	1300 East	300 West	1300 East	300 West	564	16.2	6	245
400 West	2008	8706	1.65	NB	600 South	900 North	500 South	100 North	295	11.3	2.3	142
		8706	1.65	SB	900 North	600 South	600 North	500 South	293	20.9	2.7	79
300 West	2009	13925	2.64	NB	900 South	Victory Road	800 South	400 West	454	21	3.5	155
		13925	2.64	SB	Victory Road	900 South	400 West	800 South	396	24.2	2.3	110
200 West	2009	7927	1.50	NB	900 South	North Temple	900 South	North Temple	540	10.1	6.7	324
		7927	1.50	SB	North Temple	900 South	North Temple	900 South	362	15.3	5.3	141
West Temple	2009	7130	1.35	NB	900 South	North Temple	800 South	North Temple	440	11	6.7	245
		7130	1.35	SB	North Temple	900 South	North Temple	800 South	398	12.4	4.7	208
State Street	2009	7933	1.50	NB	900 South	North Temple	900 South	North Temple	265	21.1	2.7	67
		7933	1.50	SB	North Temple	900 South	North Temple	900 South	404	13.5	4.7	193
200 East	2009	6350	1.20	NB	900 South	South Temple	800 South	40 South	340	12.2	3.7	185
		6350	1.20	SB	South Temple	900 South	40 South	800 South	195	21.2	2	45
300 East	2009	7127	1.35	NB	900 South	South Temple	900 South	50 South	309	15.7	4	109
		7127	1.35	SB	South Temple	900 South	South Temple	900 South	315	15.7	3.7	116
400 East	2009	7129	1.35	NB	900 South	South Temple	900 South	South Temple	414	11.8	5	224
		7129	1.35	SB	South Temple	900 South	South Temple	900 South	302	16.8	3.3	129
700 East	2008	5546	1.05	NB	900 South	South Temple	800 South	100 South	167	23	1	51
		5546	1.05	SB	South Temple	900 South	100 South	800 South	229	17.2	2.7	96
900 East	2008	7127	1.35	NB	900 South	South Temple	800 South	100 South	223	17.7	1.7	69
		7127	1.35	SB	South Temple	900 South	100 South	800 South	310	12.3	3.7	166

APPENDIX E

SUMMARY OF TRAFFIC SIGNAL OPERATION SURVEY

Survey Questions	Tallahassee	Amarillo	Knoxville	Little Rock
1) How many signals does the City operate?	350	293	393	350
2) Do you have light rail in the City?	No	No	No	No
3) Do you have State controlled streets in downtown CBD area?	City operates all signals within city boundary	City operates all signals within city boundary	City operates all signals within city boundary	City operates all signals within city boundary
4) How many staff does the City have for signal operations and complaints?	4	7	10	4
5) Do you maintain you own signals?	Yes	Yes	Yes	Yes
6) Under what division (same as the traffic division?), approx how many technicians	9	7	9	6
7) Do you have a TMC? If no, Skip questions 8 through 10.	Yes	No	No	Yes
8) How many people work in the TMC – Supervisor, Operator, Engineer, Technician?	4	n/a	n/a	8
9) Do they also take care of communication problems, signal timing complaints	Yes	n/a	n/a	Yes
10) Hours of Operation – M to F or including weekends	Monday to Friday	n/a	n/a	Monday to Friday