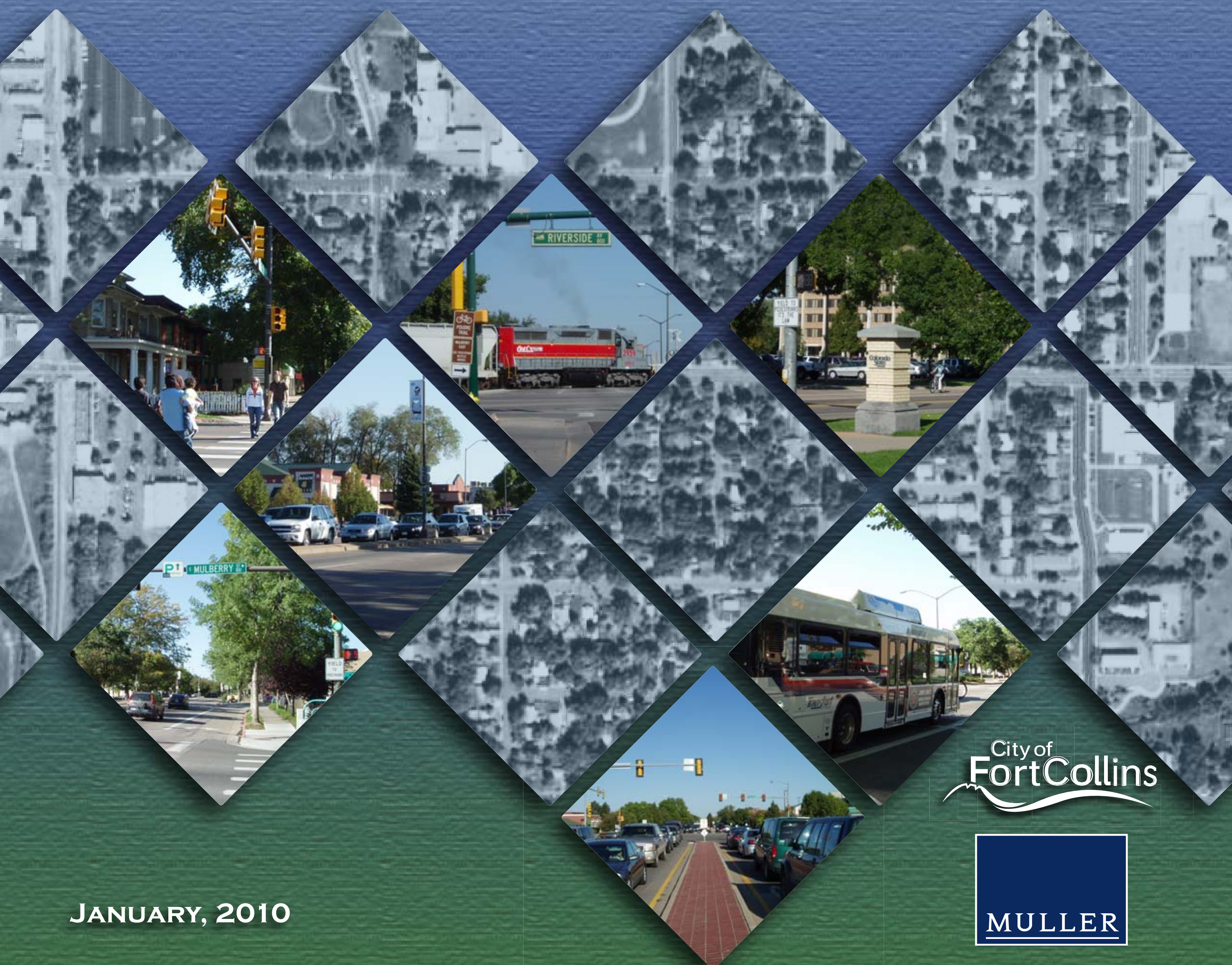
Fort Collins
Citywide Traffic Signal Timing Project

Final Report



City of Fort Collins

January, 2010

MULLER

FINAL REPORT

Fort Collins 2009 Traffic Signal Timing Program

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Executive Summary

Traffic signals are a part of everyday life whether one encounters them as a motorist, pedestrian, transit user or bicyclist. Most citizens encounter multiple traffic signals during their daily commute, shopping errands or recreational activities. Inefficient or improperly functioning traffic signals create untold amounts of frustration and angst to those who use them on a daily basis. Optimization of signal timing is one of the most cost-effective tools available to transportation professionals to improve the performance of the street system. It is a proven method for deceasing vehicle fuel consumption, vehicle emissions and motorist delays.

The primary purpose of the Fort Collins Traffic Signal Timing Program was to improve traffic flow along Fort Collins' major corridors and improve the efficiency of traffic signal operations. Additionally, the traffic signal timing program aimed to reduced emissions and fuel consumption in accordance with the requirements of the Congestion Mitigation and Air Quality (CMAQ) funding program.

Figure ES-1 shows the study area for this project. The study area included 150 traffic signals along the City's 10 major signal timing corridors and also along five minor corridors. The limits of each corridor are listed below in Table ES-1. The downtown signals on Mason and Howes Street were excluded from this re-timing effort due to their concurrent conversion from one-way to two-way operation. City staff has already updated the signal timings for Howes Street and will be doing the same for Mason Street after it changes to two-way operation.

Table ES-1: Corridors Retimed

Major Progression Corridor	Limits	Number of Signals
Taft Hill Rd	Harmony Rd to Mulberry St	11
Shields St	Westbury Dr to Laporte Ave	16
College Ave (US 287)	Carpenter Rd to Hwy 1	36
Lemay Ave	Trilby Rd to Vine Dr	21
Timberline Rd	Trilby Rd to Prospect Rd	12
Harmony Rd	Shields St to Lady Moon Dr	9
Horsetooth Rd	Dunbar Ave to Timberline Rd	9
Drake Rd	Constitution to Timberline Rd	7
Prospect Rd	Shields St to Prospect Pkwy	5
Mulberry St (SH 14)	Shields St to Greenfields Ct	11
Minor Progression Corridor		
Riverside Ave/Jefferson St	N. College Ave to Mulberry St	2
Laurel St	Mulberry St to Shields St	3
Elizabeth St	Constitution Ave to Shields St	2
Remington St	Prospect Rd to Mulberry St	3
Ziegler Rd	Rock Creek to Council Tree	3

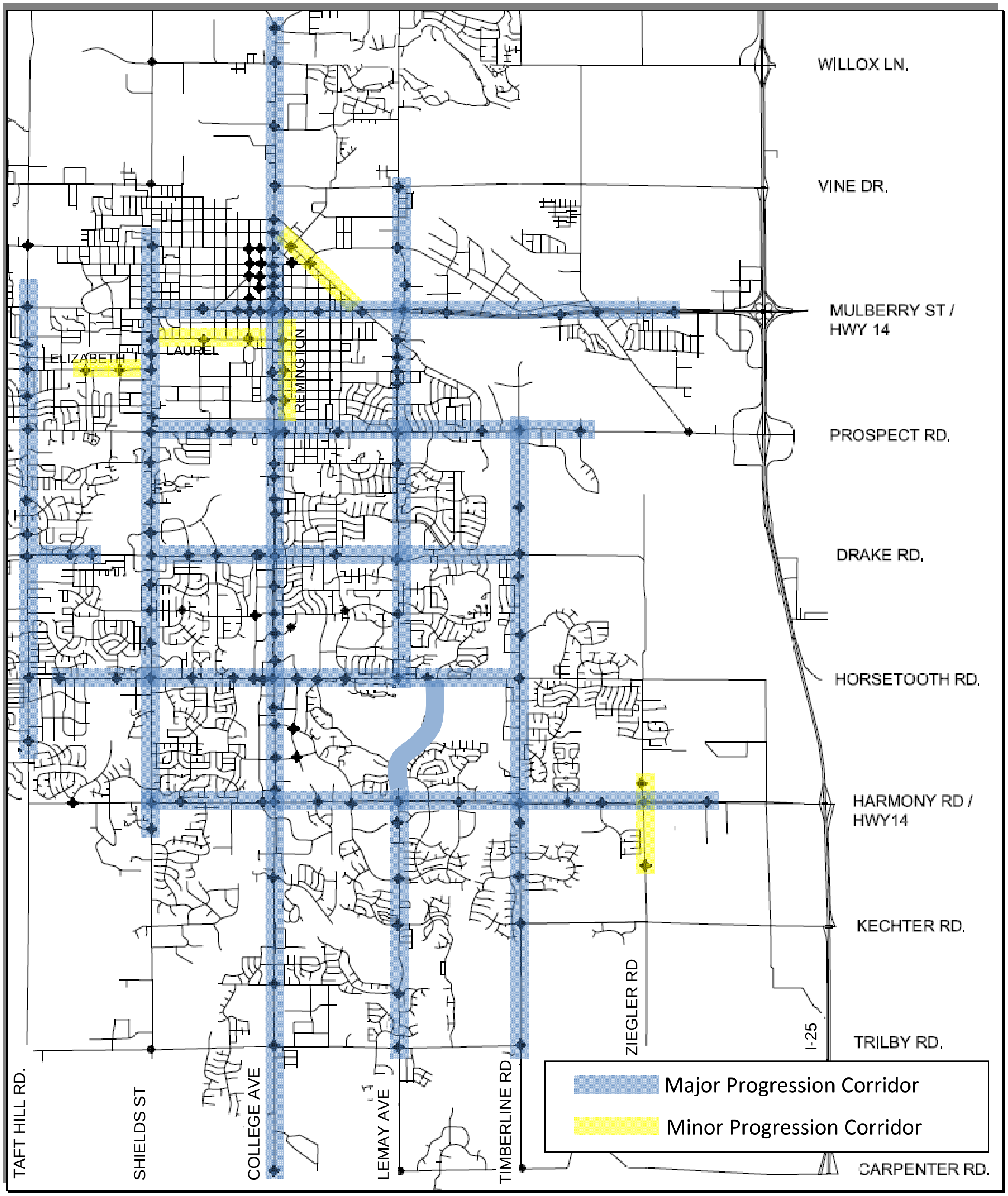


Figure ES-1: Fort Collins Traffic Signal Timing Program Area

Traffic flow conditions were evaluated during weekday and weekend time periods to determine the optimum timing plan by time-of-day and day-of-week. Table ES-2 shows the day-of-week and time-of-day periods when each timing plan is in operation. A few of the corridors operate on a slightly different schedule due to the unique travel characteristics of those corridors. These exceptions are shown on the Summary Reports in Appendix A.

Table ES-2: Time-of-Day Plans for Signal Coordination

Timing Plan	Day of Week	Hours of Operation
AM Peak	Monday – Friday	6:45 am – 11:00 am
Midday	Monday – Friday Saturday Sunday	11:00 am – 3:00 pm 9:30 am – 7:30 pm 10:30 am – 6:30 pm
PM Peak	Monday – Friday	3:00 pm – 7:45 pm
Off-Peak	Monday – Friday Saturday Sunday	6:00 am – 6:45 am and 7:45 pm – 10:30 pm 7:00 am – 9:30 am and 7:30 pm – 11:00 pm 7:45 am – 10:30 am and 6:30 pm – 10:30 pm

Project Benefits and Recommendations

A detailed “before-after” study was conducted to assess the performance of the signal re-timing project. Benefits were field measured by City staff by performing “before” and “after” travel-time runs along each of the ten primary corridors. Table ES-3 lists the system-wide benefits of the timing project in terms of travel time reduction, decreased fuel consumption, reduced emissions and monetary savings.

The annual project benefit of the signal re-timing effort is $17.98 million when considering fuel savings and travel delay savings for motorists. The resulting benefit-cost ratio for the project is 60:1. Further benefits of this project include an annual reduction of 1.2 million pounds of vehicle emissions, consisting of carbon monoxide, nitrogen oxides and hydrocarbons. The greatest reduction occurs with carbon monoxide (994,000 lbs). When CO is released into the atmosphere it combines with oxygen to form carbon dioxide (CO_2). CO_2 is a primary contributor to greenhouse gases. The calculated reduction in CO emissions results in a CO_2 reduction of 19.4 million pounds (8,800 metric tons) annually.

Table ES-3: System-Wide Benefits

	Vehicle Travel Time Reduction (Hours)	Fuel Consumption Reduction (Gallons)	Total Emissions Reduction (lbs)	Time and Fuel Cost Savings
Weekday Daily Benefit	2,591	3,596	4,276	$60,624
Weekend Benefit	2,223	1,655	1,969	$48,521
Annual Benefit*	776,200	1,003,000	1,193,000	$17,982,000

*Includes 255 weekdays and 52 Saturdays

There are several other performance measures that provide good indications of traffic flow. Table ES-4 shows the percent change in these measures as a result of the re-timing effort.

Table ES-4: Change in Traffic Flow Performance Measures

Performance Measure	AM Peak Period	Midday Peak Period	PM Peak Period	Off-Peak Period	Weekend Period
Reduced Vehicle Stops	12.1%	15.5%	18.2%	10.5%	19.5%
Reduced Motorist Delay	17.9%	12.8%	16.8%	18.8%	29.8%
Reduced Travel Time	5.3%	3.6%	6.7%	5.2%	8.5%
Reduced Fuel Consumption and Emissions	4.8%	4.2%	5.8%	4.6%	4.3%

It is worth noting that the performance measures listed in Table ES-4 only account for changes in "through-traffic" flow along the major corridors and do not account for changes in side street traffic operations. The off-peak period, in particular, has also realized additional benefits that are not accounted for due to the use of a shorter cycle length (85 seconds) than what was previously used (110 seconds) during this time period. In general, the shorter cycle length for the off-peak period has resulted in side street delay reductions of 20-25 percent.

The project final report also highlights a number of recommendations for future operational improvements at critical intersections. Improvements that are considered higher priority include:

- Add dual westbound left-turn lanes on Harmony Road at Lemay Avenue.
- Consider implementing flashing yellow arrow operation at nine intersections (See Section 5.1)
- Remove the westbound left-turn arrow from Drake Road to southbound McClelland Drive to reduce eastbound congestion on Drake Road.
- When funding becomes available, widen Harmony Road between College Avenue and Timberline Rd from 4 lanes to 6 lanes.
- Remove "split phase" signal operation at College Ave/Foothills Pkwy and at Laurel St/Howes St.

Section 5 of the report includes additional recommendations for operational and capacity improvements.

1 Introduction and Project Background

1.1 Project Need

Traffic signals are a part of everyday life whether one encounters them as a motorist, pedestrian, transit user or bicyclist. Most citizens encounter multiple traffic signals during their daily commute, shopping errands or recreational activities. Inefficient or improperly functioning traffic signals create untold amounts of frustration and anxiety to those who use them. The recent National Traffic Signal Report Card, published by the Institute of Transportation Engineers (see http://www.ite.org/reportcard/) assigned a grade of "C-minus" for the performance of signal timing throughout the United States.

The report states:

> *It is estimated that improper traffic signal timing accounts for **5 to 10 percent of all traffic delay**, or 295 million vehicle-hours of delay, on major roadways alone. …Congestion causes the average peak-period traveler an extra **38 hours of travel time** and an additional **26 gallons of fuel**, amounting to a cost of **$710 per traveler per year**.*

The report goes on to say:

> *A February 2007 Harris Interactive Poll found that traffic congestion and its accompanying delays are a fact of life for communities across the United States. **More than three-quarters of respondents answered that congestion is a moderate to serious problem in their community.** More than one-third (37 percent) said that traffic congestion is a serious problem in their community; one-quarter said traffic congestion is a serious problem that is not being addressed.*

The Signal Report Card also recommends that agencies optimize (re-time) their traffic signals every 3-5 years to account for changes in traffic flow, street modifications and signal control. Optimization of traffic signal timings is one of the most cost effective methods for improving travel efficiency and benefiting the end-user.

Prior to this project, the City of Fort Collins's last complete signal re-timing effort was done in 1998-1999. City staff updated the timings in 2005 but it was not a comprehensive re-timing effort and was hampered by several construction projects that were underway at the time. Over the past decade, the City's population has increased from 113,000 to 137,200 and development has expanded considerably in the southeast portion of the City. Additionally, several transportation improvement projects have been completed including: Harmony Road widening from Timberline to Ziegler; the extension of Timberline Road from Prospect to Mulberry, widening of the Harmony/Shields intersection, the widening of Ziegler Road from Harmony to Horsetooth, and the widening of Taft Hill Road south of Drake Road. The combination of these factors has caused travel patterns and travel demand to change, resulting in signal coordination plans that no longer matched current travel conditions.

1.2 Purpose of Project

The primary purpose of the Fort Collins Traffic Signal Timing Program was to improve traffic flow along Fort Collins' major corridors, while also maintaining efficient and safe travel for pedestrians and bicyclists. Additionally, the traffic signal timing program aimed to reduce emissions and fuel consumption in accordance with the requirements of the Congestion Mitigation and Air Quality (CMAQ) funding program. City staff also took the opportunity during this project to update the yellow, all-red and pedestrian clearance intervals at each intersection.

1.3 City of Fort Collins Signal System

The City of Fort Collins operates and maintains 177 traffic signals within its boundaries. These signals also include traffic signals on state highways that are owned by the Colorado Department of Transportation (CDOT) but maintained and operated by Fort Collins staff. Nearly all of Fort Collins' traffic signals are connected to their Siemens *i2* Advanced Traffic Management System (ATMS), which is used to remotely monitor and operate the traffic signals in a coordinated manner.

The City's field hardware consists of Type-170 cabinets and Naztec 2070 controllers operating on Siemens NextPhase firmware. Most traffic signals communicate with the City's ATMS over city-owned fiber optic cable or via wireless radio. The City also has 28 CCTV cameras and more than 150 system detectors that allow them to observe and monitor traffic flow on a real-time basis.

1.4 Project Scope

This traffic signal re-timing effort commenced in December 2008 and was completed 1-year later in December, 2009. The program included the development of traffic signal timing plans for 10 major corridors and 5 minor corridors. Figure 1 shows the limits of the retiming along each corridor. In all, timing plans were developed for 150 traffic signals for the following four time periods:

- Weekday AM Peak Period
- Weekday/Weekend Midday Period
- Weekday PM Peak Period
- Off-Peak Period (weekday/weekend early mornings and late evenings)

Additionally, City staff updated the yellow, red and pedestrian clearance intervals for all 180 traffic signals to bring them in conformance with the City's updated traffic signal timing guidelines. The project also included intersection turning movement counts by City staff, "before" and "after" travel time data collection to verify project benefits, and evaluation and documentation of those benefits.

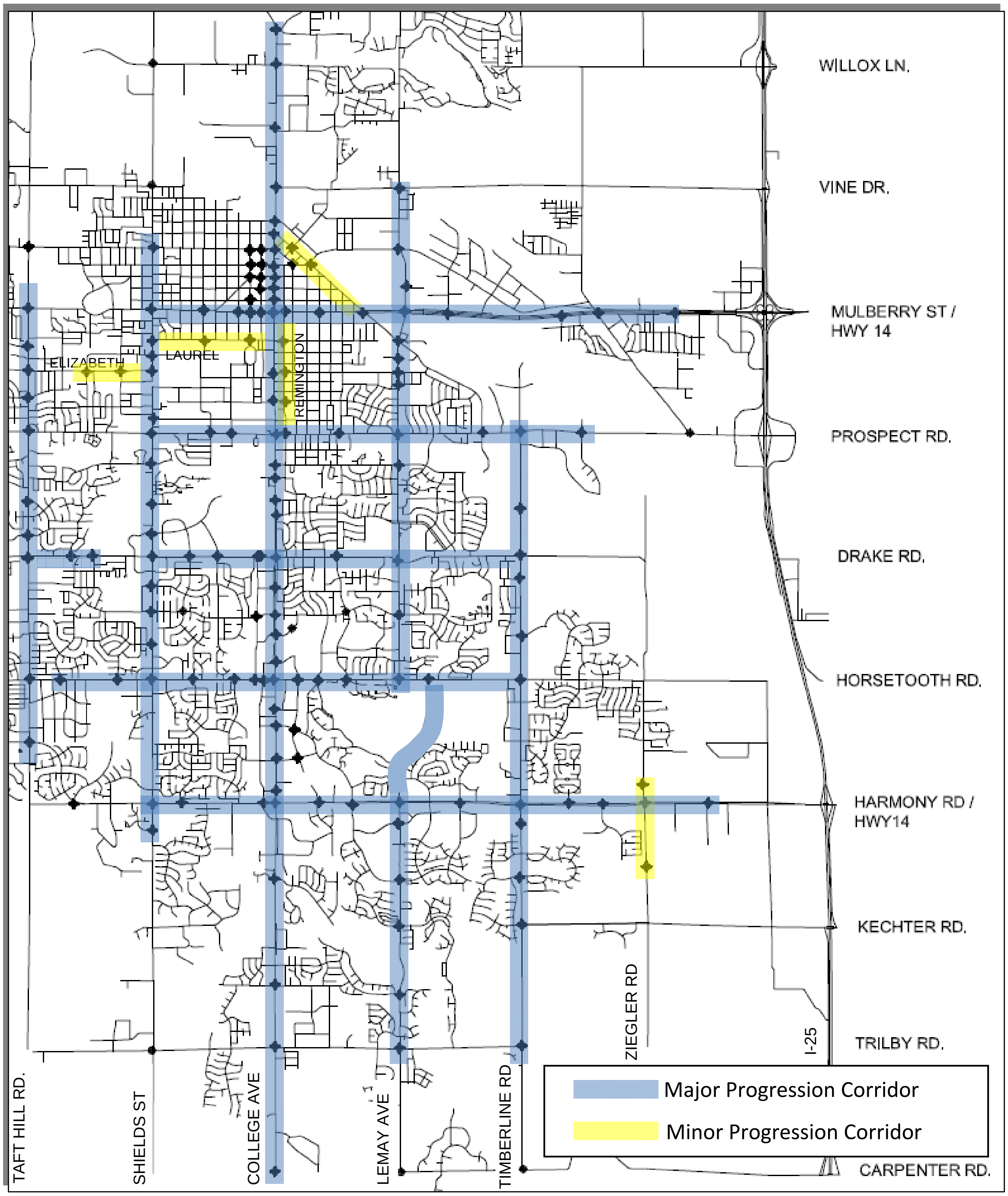


Figure 1: Traffic Signal Timing Program Area

2 Signal Timing Methodology and Analysis

Traffic signal coordination plans were developed for the ten major corridors shown in Table 1.

Table 1: Traffic Signal Timing Corridors

Primary Progression Corridor	Limits	Number of Signals
Taft Hill Rd	Harmony Rd to Mulberry St	11
Shields St	Westbury Dr to Laporte Ave	16
College Ave (US 287)	Carpenter Rd to Hwy 1	36
Lemay Ave	Trilby Rd to Vine Dr	21
Timberline Rd	Trilby Rd to Prospect Rd	12
Harmony Rd	Shields St to Lady Moon Dr	9
Horsetooth Rd	Dunbar Ave to Timberline Rd	9
Drake Rd	Constitution to Timberline Rd	7
Prospect Rd	Shields St to Prospect Pkwy	5
Mulberry St (SH 14)	Shields St to Greenfields Ct	11

Additionally, cross-coordination timing plans were developed for short routes along Ziegler Road north and south of Timberline Road, Elizabeth Street west of Shields, Laurel Street between Shields Street and College Avenue, Remington Street between Prospect Road and Mulberry Street and Jefferson/Riverside between N. College Avenue and Lemay Avenue.

Signal timing plans were prepared for the four time periods as shown in Table 2. The selected timing periods (time-of-day) for these plans were based on a review of the hourly traffic flow variations of the ten corridors. The AM and PM peak timing plans are in effect when traffic volumes are at their highest levels.

Table 2: Time-of-Day Plans for Signal Coordination

Timing Plan	Day of Week	Cycle Length	Hours of Operation
AM Peak	Monday - Friday	110 sec	6:45 am – 11:00 am
Midday	Monday – Friday Saturday Sunday	120 sec	11:00 am – 3:00 pm 9:30 am – 7:30 pm 10:30 am – 6:30 pm
PM Peak	Monday – Friday	120 sec	3:00 pm – 7:45 pm
Off-Peak	Monday – Friday Saturday Sunday	85 sec	6:00 am – 6:45 am and 7:45 pm – 10:30 pm 7:00 am – 9:30 am and 7:30 pm – 11:00 pm 7:45 am – 10:30 am and 6:30 pm – 10:30 pm

There are a few exceptions to the above time-of-day operations. They are:

- Harmony Road, Shields Street and College Avenue have extended times when they are in coordination during weekdays and weekends.

- Taft Hill Road and portions of Lemay Avenue, Mulberry Street and Timberline Road enter the off-peak timing plan at 7:00 pm instead of 7:45 pm on weeknights
- Both Mulberry Street and Harmony Road enter coordination at 5:30 am instead of 6:00 am on weekdays.

2.1 Data Collection

Traffic data for the signal timing program was provided by the City of Fort Collins. The following data was collected:

Daily Traffic Counts – Hourly traffic count data was provided for each approach to each signalized intersection. The data was collected during weekdays between 2006 and 2009. Supplemental data for Friday, Saturday and Sunday traffic was provided at one or more locations on each corridor in order to assess the relative proportion of traffic flow on weekends. Figure 2 illustrates the daily volume of traffic on each corridor. These volumes represent an average of 2 to 3 count locations along each corridor.

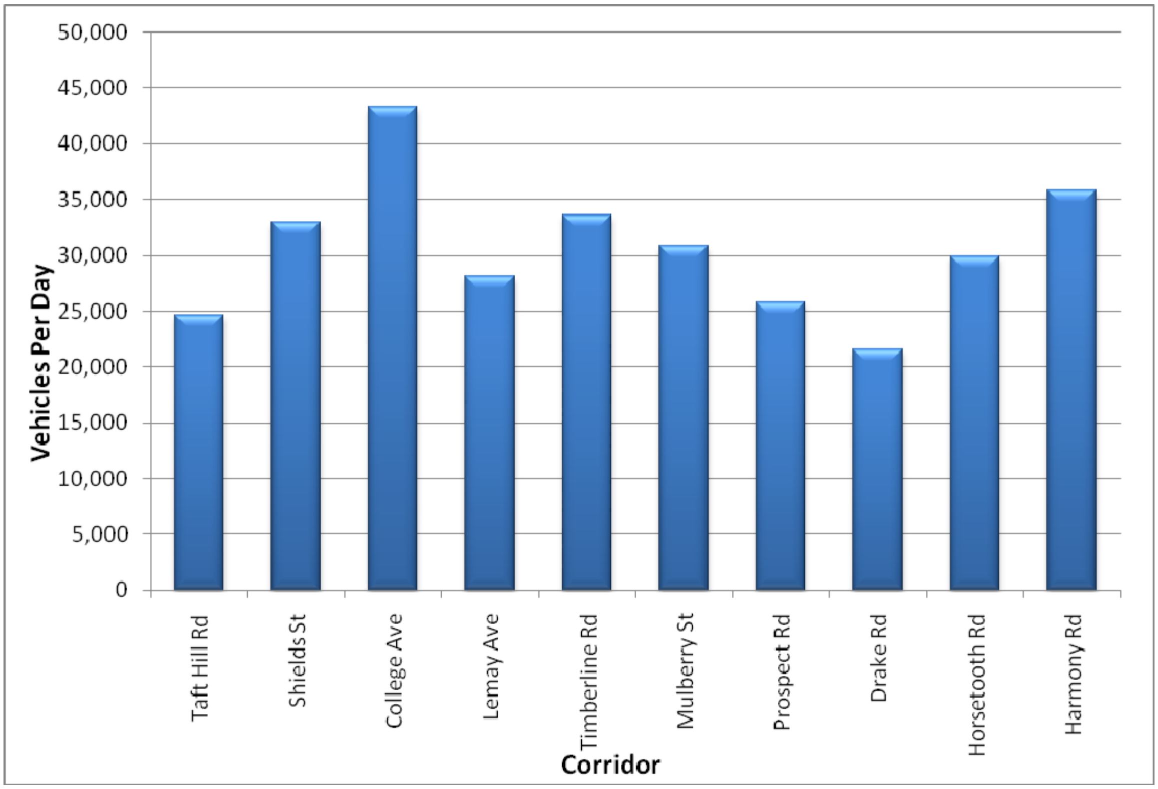


Figure 2: Average Daily Traffic on Major Corridors

The volumes range from 21,000 vehicles per day (vpd) on Drake Road to almost 43,000 vpd on College Ave. Daily volumes on the other eight corridors range from approximately 25,000 vpd to 35,000 vpd.

Figure 3 provides a comparison of the peak period traffic flows for which signal timing plans were developed. The data for this chart is a composite of the entering traffic flow at 14 major intersections along various corridors. The weekday PM peak period (generally occurring from 4:45 - 5:45 pm) experiences the heaviest volume of traffic flow and is noticeably higher than the weekday AM and midday peak periods. Saturday midday traffic is of similar magnitude as the weekday AM and midday peaks. The weekday off-peak period (7:45 - 8:45 pm) carries approximately 60% of the weekday midday peak flow. It should be noted that the volumes shown in Figure 3 represent an average of all the corridors and that each specific corridor has its own unique travel pattern and peaking characteristics. The timing plans developed and implemented were based on those specific conditions of each corridor rather than a composite of all corridors combined.

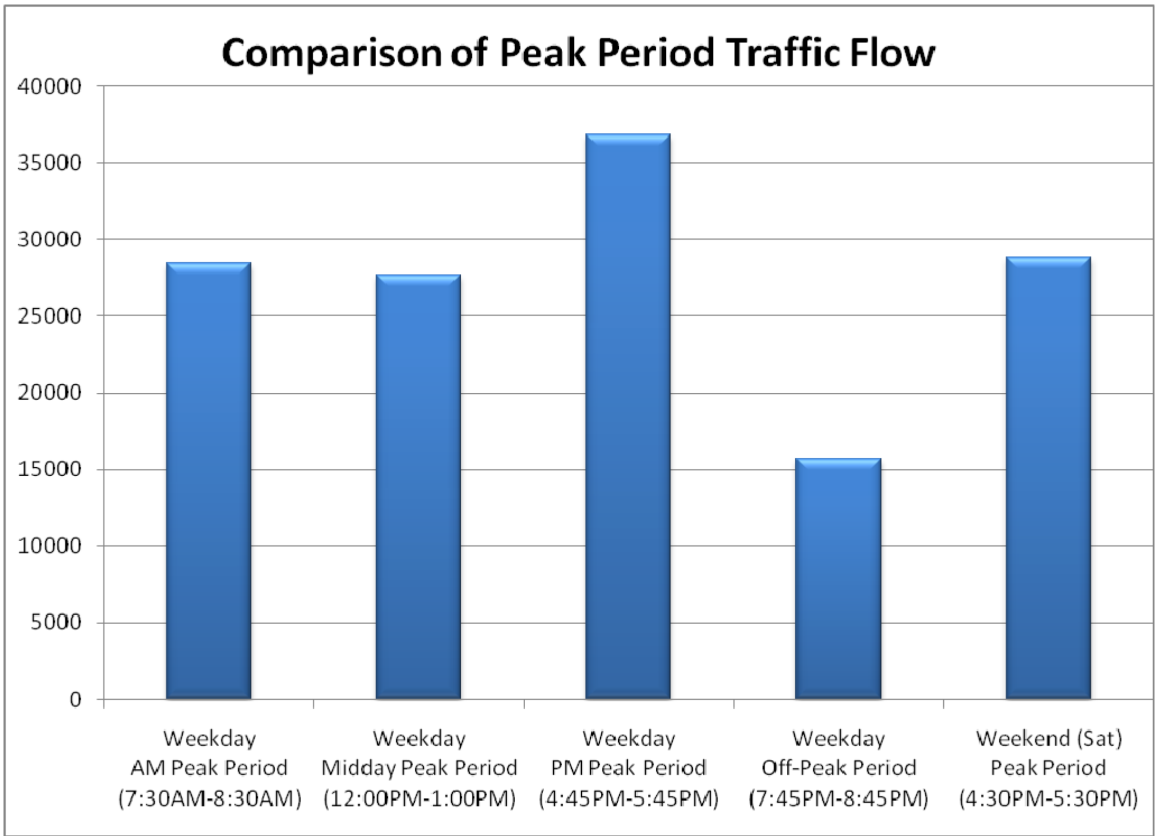


Figure 3: Comparison of Peak Period Traffic Flow

For each corridor, hourly traffic plots were also made to determine the peak periods of the corridor and verify directional flow characteristics. Hourly volume plots of each corridor are provided in the corridor timing notebooks. Figure 4 shows a composite plot of the combined daily volume variation for the 10 arterial corridors. Several system-wide observations made from the composite volume plot include:

- The weekday PM peak volumes are approximately 23% higher than the AM peak and about 28% higher than the noon peak.
- The AM peak period has three distinct peaks: 6:00, 7:00 and 8:00. The 6:00 am peak is likely a result of commuters leaving for their commute to the Denver metro area. The 7:00 am peak likely represents a segment of commuters that work an early shift and the 8:00 am peak represents typical commuter-oriented travel patterns.
- Saturday volumes are 10-20% higher than Sunday volumes.

- Sunday morning traffic tends to lag Saturday morning traffic by about 1-hour. Similarly, Sunday evening traffic drops-off about 1-hour sooner than Saturday evening traffic.
- Both Saturday and Sunday traffic peaks at 5:00 pm, with Sunday having a more distinct peak than Saturday.
- Traffic flow is at its lowest from 3:30 to 4:30 am during all days of the week.

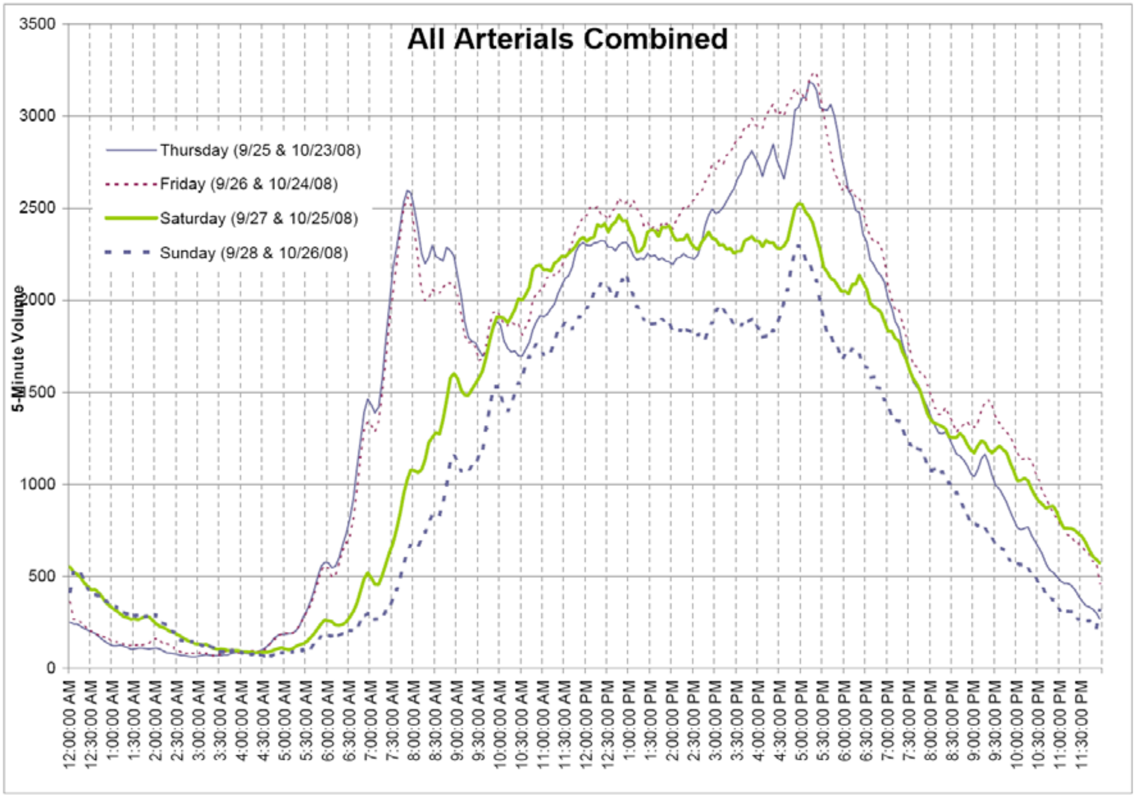


Figure 4: Composite Traffic Flow for Arterial Corridors

Turning Movement Counts (TMC) – Turning movement counts were collected by Fort Collins staff during the AM, midday and PM peak periods for each of the signalized intersections in the study area. The time periods for data collection were:

- 7:30 am – 8:30 am weekdays
- 12:00 am – 1:00 pm weekdays
- 4:30 pm – 5:30 pm weekdays

Turning movement counts were collected between 2006 and 2009 on a Tuesday, Wednesday or Thursday. The data were collected in 15-minute intervals and also included pedestrian movements in each crosswalk. For the off-peak period (weeknights from 7:45 – 8:45 pm) and weekend periods (4:30 - 5:30 pm), the midday traffic volumes were factored proportionally based on a relative volume comparison.

Before/After Travel-Time/Delay Runs – "Before" and "After" travel-time/delay runs were completed by Fort Collins staff for all ten arterial corridors. Travel-time/delay runs are critical to the success of a signal timing optimization project. Their purpose is two-fold:

1. The before data provides a detailed "picture" of the corridor's current performance and identifies areas of needed improvement.
2. Comparisons between the before and after data provide a performance measure to document benefits of the timing project.

For each corridor, a minimum of six travel-time runs were completed in each direction (12 total) and for each time period. The data collection periods included:

- Weekday AM period: 6:45 – 8:00 am
- Weekday midday period: 11:30 am – 1:00 pm
- Weekday PM period: 4:30 – 6:00 pm
- Weeknight off-peak period: 8:00 – 9:30 pm
- Weekend (Saturday) period: 11:30 am – 5:30 pm

Field Observations – In addition to collecting the above data, the Muller team also site-visited each corridor during each of the time periods to make qualitative observations with regard to corridor progression, intersection capacity, lane utilization, queuing, free-flow traffic speed, pedestrian movements, and any other unusual circumstances that affect traffic signal operations. This information was utilized in calibrating the timing model and in preparing the proposed timing plans.

2.2 Traffic Signal Timing Model Adjustments

The City of Fort Collins utilizes Trafficware's Synchro® traffic signal software application for developing coordinated traffic signal timing plans. The City provided Muller Engineering with base city-wide Synchro models that included the existing timings, lane geometry and volume data. Three timing models were provided to the Muller team: Weekday AM, Midday and PM. The Muller team used these models as the basis for preparing the new signal timing plans. Prior to optimizing the timing plans, the Synchro models were checked and calibrated against field observations and travel-time data to ensure a reasonable match with existing conditions. The calibration included the following changes:

- Progression speeds were adjusted where speeds varied from the posted speed limit,
- Lane utilization factors were modified where unusual imbalances in lane-use occurred (e.g. NB Left at Lemay/Horsetooth),
- Saturation flow rates were adjusted (e.g. the Highway Capacity Manual's CBD saturation flow rate adjustment factor of 0.90 was used for intersections within or near the CBD),
- The percentage of heavy vehicles was determined using CDOT data and applied to the SH 14 Truck Route corridor, ranging from 5% to 25%,
- Parking maneuvers were accounted for along College Avenue through downtown, and
- Minor volume balancing adjustments were made where there was an inexplicable change in link volumes.

2.3 Cycle Length Analysis and Timing Plan Optimization

Upon completion of the model calibration, the Muller team conducted cycle length analyses for each of the proposed timing periods. Muller evaluated cycle lengths over a range of 85 to 135 seconds. The 85-second cycle was the minimum cycle where pedestrian timing intervals could be satisfied at most intersections. The 135 second cycle was qualitatively determined to be the longest tolerable cycle length from a delay and queuing standpoint. Cycle lengths were evaluated in 5-second increments.

Synchro provides a "Performance Index" (PI) to assist in determining the most appropriate cycle length. The PI is based on an algorithm that minimizes system-wide stops and delays. The Synchro PI formula is:

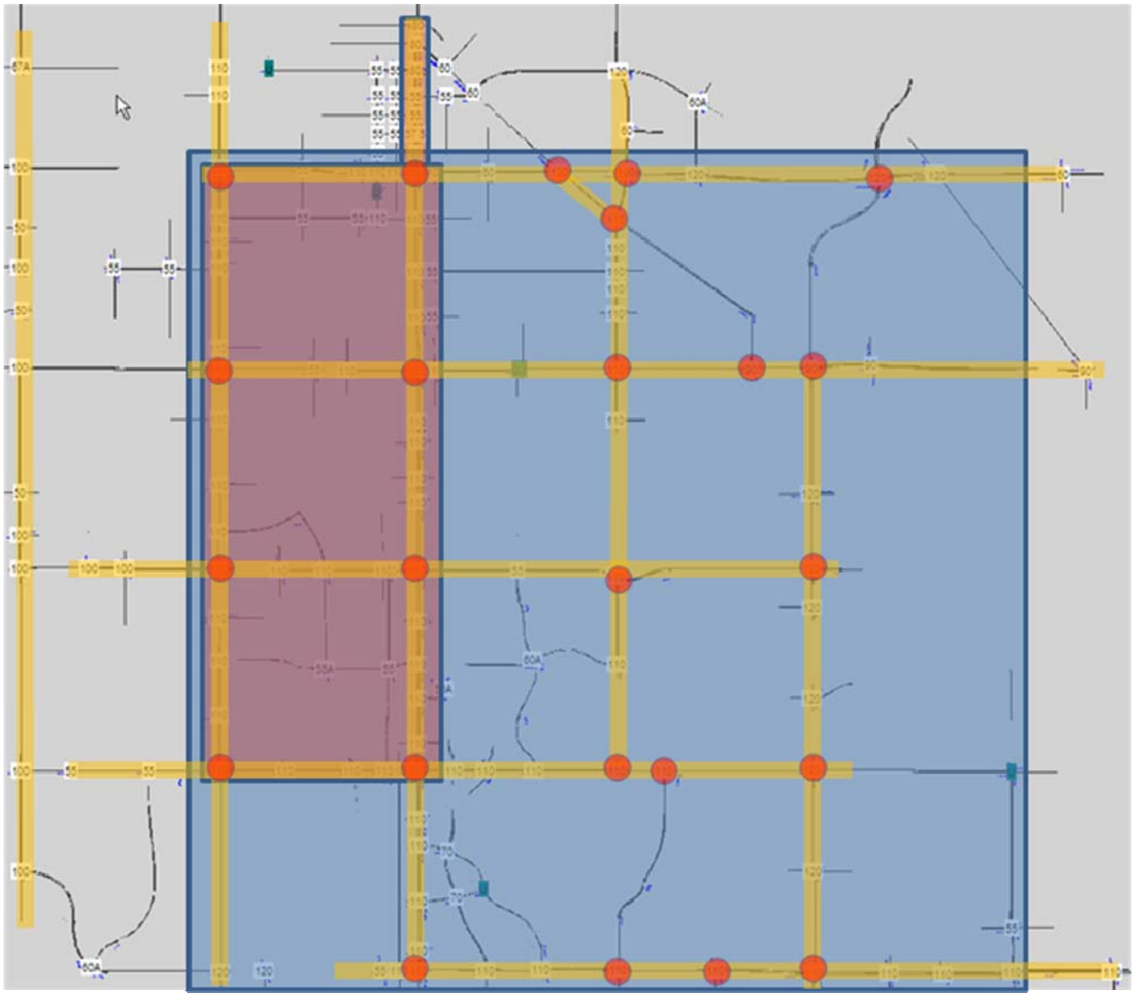
Performance Index (PI) = (Total Delay*3600 +Total Stops*10)/3600

In most situations, the above formula more heavily weights delay over stops, by a ratio of about 3:1. In order to give stops (i.e. progression) more balanced consideration, a sensitivity analysis utilizing factors of 20 and 30 for the "stops" multiplication factor (normally 10) was conducted. The increase in the stops factor from 10 to 30 only caused a slight change in the cycle length analysis results, but the project team still deemed that using the higher factor provided better weighting for selecting a cycle length more suited for progression.

Other factors that were considered in determining the best cycle length for each time period were: pedestrian crossing requirements, volume of pedestrians at critical intersections, queue storage, and cross-coordination with other corridors.

System Cycle Length versus Corridor Specific Cycles – The City's arterial street system is laid-out in a 5-mile by 5-mile grid that, by and large, lends itself to a single system-wide cycle length due to the need to provide cross-coordination at arterial-arterial intersections. There are some disadvantages, however, to using a single system-wide cycle, so the project team prepared a multi-step analysis process to evaluate the cycle length in both a system-wide and corridor specific fashion. Figure 5 illustrates the physical scope of each analysis.

- **System-wide Analysis:** This step included cycle length optimization of the 5 x 4 arterial grid (excluding Taft Hill Road) of 123 traffic signals. Taft Hill Road was excluded from this analysis because the crossing corridors have lower coordinatability factors, which allows Taft Hill Road to operate mostly independent from the other corridors.
- **Core Area Analysis:** The core area analysis focused on the key north-south progression corridors of Shields Street and College Avenue along with the crossing arterials of Horsetooth, Drake, Prospect and Mulberry. The logic behind this analysis is that this area includes the highest concentration of traffic signals and the most critical cross-coordination corridors.
- **Corridor Analysis:** The corridor analysis evaluated the optimum cycle length for each individual corridor without regard to crossing coordination. This was done to determine if a corridor had a strong proclivity for a cycle length that was significantly different than the optimum cycle produced by the system-wide and/or core area analysis.
- **Critical Intersections:** The "Natural" cycle for these intersections was examined to determine if the system, core and/or corridor cycle fell within an acceptable range of the natural cycle. In general, the selected cycle should be between 75% and 150% of the critical intersection's natural cycle.



Sy sis (123 Signals) | Core Area Analysis (51 Signals) | Corridor Analysis (10 Corridors) | Critical Intersection Analysis (24 Intersections)

Figure 5: Analysis Process

A matrix of the cycle length PI of each analysis scenario was prepared to facilitate cycle selection. Figures 6, 7 and 8 show the resulting cycle lengths for the AM, Midday/Weekend and PM periods. For the off-peak (night-time) period, a cycle length of 85 seconds was chosen for all corridors. *(Note: A separate cycle length analysis for the weekend peak traffic condition was completed and it yielded results that were very similar to the midday cycle length selection. Consequently, the project team decided to use the weekday midday timing plans for the weekend peak period.)*

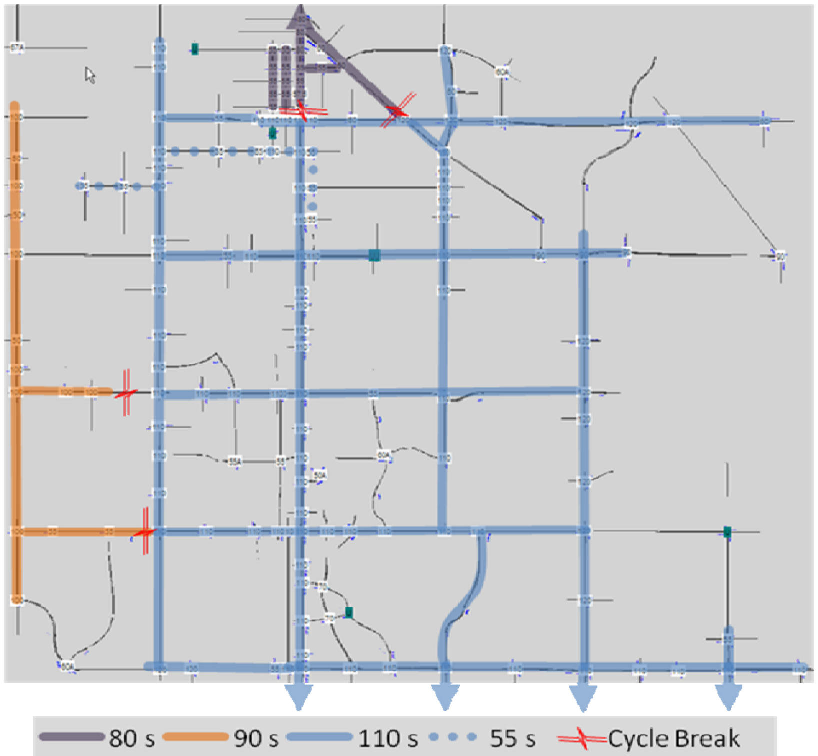


Figure 6: AM Peak Period Cycle Length Selection

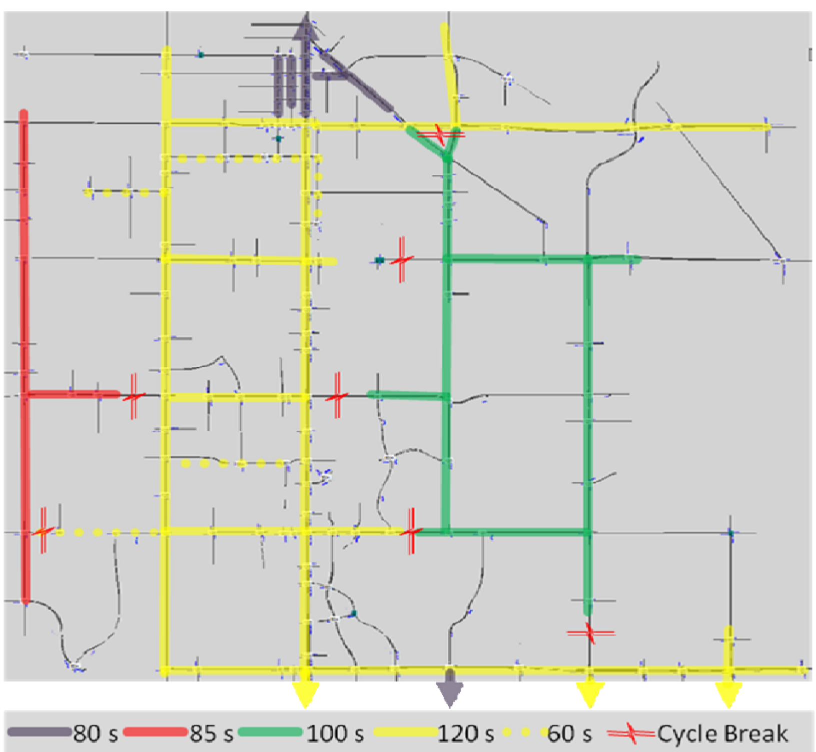


Figure 7: Midday Peak Period Cycle Length Selection

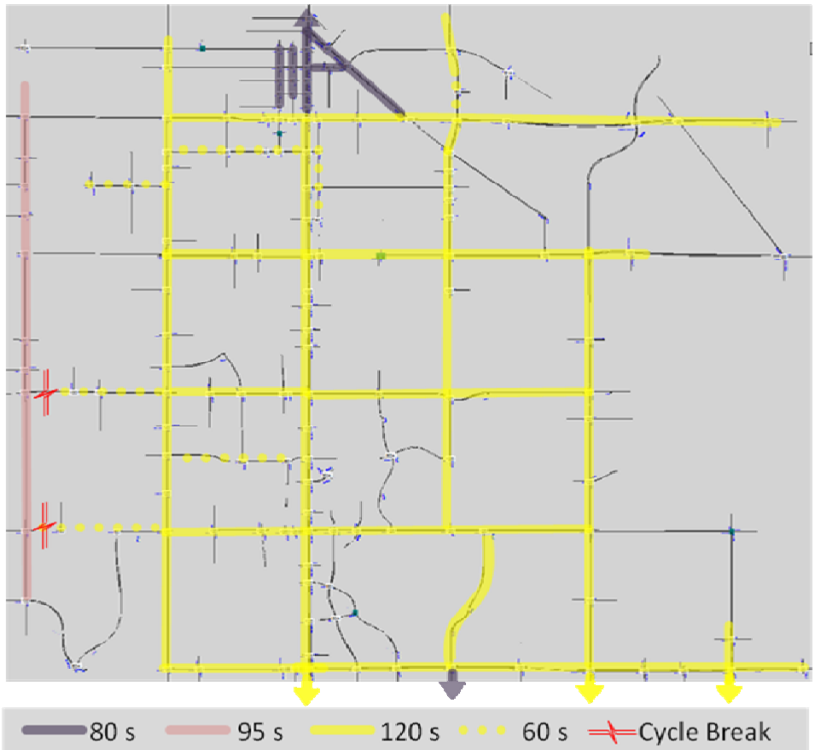


Figure 8: PM Peak Period Cycle Length Selection

Timing Plan Development – Development of the actual timing plans was an iterative process that included selection of intersection phase splits, offsets, phase sequencing and "hand-adjustments" of timing plans. The Synchro model optimizes these timing parameters; however, the Synchro optimization results are considered a "first-cut" in the process of developing good timing plans. Muller staff spent a considerable portion of time refining the Synchro timing plans based on our experience with other timing projects, our knowledge of the operation of each corridor and City staff input.

The software program, Tru-Traffic TS/PP®, was also used to refine offsets and phase-sequencing for each corridor. Tru-Traffic allows these timing parameters to be manually and/or automatically adjusted to optimize corridor timings and progression band-width. Figure 9 below shows an example of the time-space diagram produced by Tru-Traffic for the Taft Hill corridor. Similar diagrams were developed for all other corridors in each time period. The time-space diagrams provide a graphical representation of signal progression. They are also useful tools for evaluating the quality of progression and verifying field observations.

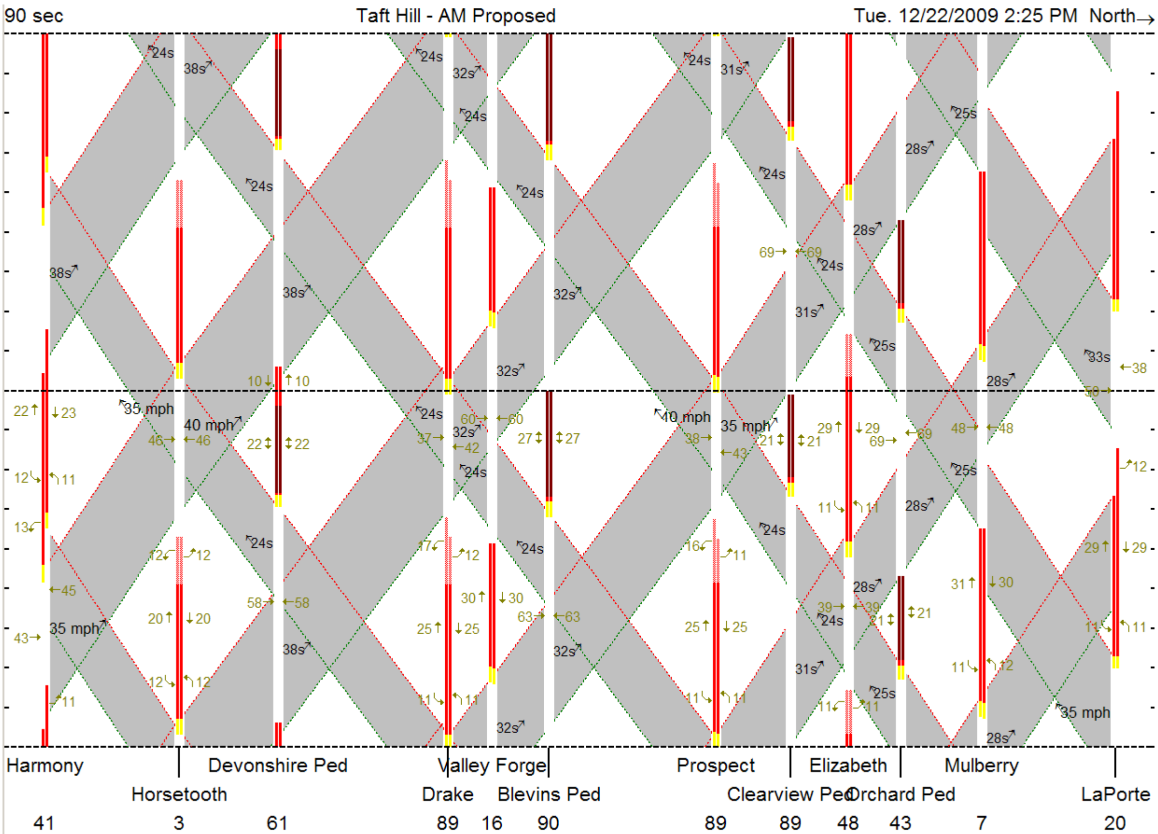


Figure 9: Tru-Traffic Time-Space Diagram for Taft Hill Road (AM Peak)

With a large citywide timing project such as the Fort Collins program, it is difficult to implement all of the corridor timings at once. As a result, the project team implemented the timings on a corridor-by-corridor basis. This creates a situation where some of the corridors may not have as good cross-coordination because the timings at critical crossing corridors have been previously set and are fixed. There are some natural break points in the grid system where coordination breaks can occur naturally because of large signal spacing gaps (e.g. Timberline between Prospect and Mulberry) or where there was a large change in through traffic due to heavy turning movements (e.g. Prospect/Riverside). Figure 10 illustrates the coordination zones that were used in the project and also the progression priority of the corridors.

As can be seen from Figure 10, north-south corridors were mostly favored over east-west corridors. The reasons for this are:

1. As a whole, the north-south corridors carry 15% more daily traffic than the east-west corridors
2. Intercity and intra-city travel is more oriented in a north-south pattern.
3. Train travel through Fort Collins is more disruptive to east-west corridors and, thus, traffic signal progression can be more easily maintained along north-south corridors.

Mulberry Street and Harmony Road are also primary progression corridors due to their connection to I-25 and their servicing of commuter travel patterns.

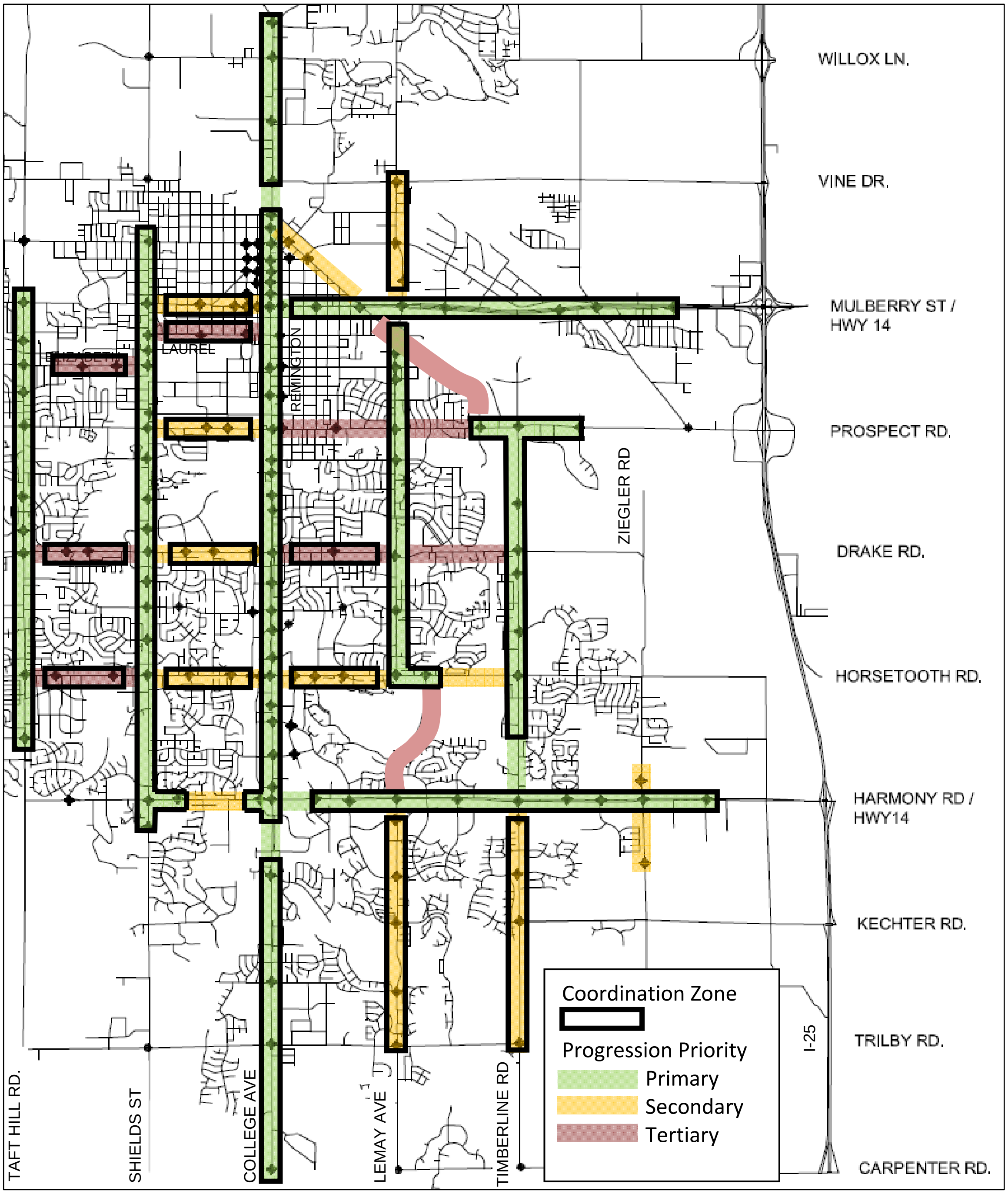


Figure 10: Coordination Zones and Progression Priority

Development of the corridor timing plans was done in the following sequence:

1. The first corridor to be re-timed was Harmony Road from Mason Street through Lady Moon Drive. In order to not disrupt coordination along College Avenue, the existing offset at College/Harmony was locked and the offsets for the other signals along Harmony were adjusted accordingly. The Synchro models were used to develop the

initial offsets, phase splits and phase sequences. Phase splits were hand-adjusted within Synchro to optimize critical movement delay and capacity. Tru-Traffic was then used to fine-tune offsets and phase sequences in order to maximize through-traffic progression. Synchro and Tru-Traffic were used in the same manner for each of the corridors mentioned below.

2. Timberline Road and South Lemay were the next corridors to be retimed. Offsets at Harmony/Lemay and Harmony/Timberline were locked based on the previous timings developed for Harmony Road. Lemay, north of Harmony Road, was considered a coordination break point due to the signal spacing between Harmony and Horsetooth, so the timings for Lemay north of Harmony were not "locked-in" to the Harmony Road timings. Timberline Road timings were also mostly independent from east-west corridor timings with the exception of the two Prospect Road signals east and west of Timberline. Timberline north of Prospect Road was also considered a coordination break due to the signal spacing between Prospect Road and Mulberry Street.

3. Mulberry Street, east of College Avenue, and Lemay Avenue, from Stuart Street to Vine Drive, were the next corridors to be re-timed. A temporary coordination break was inserted on Mulberry between College Avenue and Whedbee Street, and on Lemay between Stuart and Drake Road. Thus, the offsets for the new Mulberry and Lemay corridor timings were determined independently of the other corridors (note that once College Avenue was retimed, the offsets at each intersection along these two corridors were shifted by an equal amount to eliminate the coordination break on Mulberry Street between Whedbee Street and College Avenue).

4. Coordination plans were then developed concurrently for College Avenue, Shields Street and their crossing arterials (Horsetooth, Drake, Prospect and Mulberry) using Synchro. Offsets along College and Shields were then manually adjusted using Tru-Traffic to improve progression bandwidth. For College Avenue, the offset at Harmony/College was locked and all other offsets were referenced from that point. Offsets for Shields Street were also manually adjusted to improve bandwidth. Once the College and Shields offsets were determined, the offsets for all intersections along Shields were equally adjusted up or down to provide the best cross-coordination match for the east west corridors between Shields Street and College Avenue.

5. Cross-coordination along the east-west corridors between College and Lemay was the last piece of the coordination "puzzle" to be completed. The Lemay and Horsetooth corridors were given priority over Prospect and Drake coordination due to their higher traffic flows. As a result, signal progression along Drake and Prospect was not as favorable as the other corridors during a few of the time periods.

6. Independently from the other corridors, the Taft Hill timing plans were developed and implemented. The only cross-coordination with Taft Hill occurs with the two signals on Drake and on Horsetooth that lie between Taft Hill and Shields. Where feasible, these signals were "half-cycled" to minimize side street delay. Final timings were also prepared for the two traffic signals on Elizabeth (west of Shields), and for the three signals on Laurel (between College and Shields). The Elizabeth signals were coordinated with the signal at Shields/Elizabeth and the Laurel signals were coordinated between College and Shields.

3 Implementation and Fine-Tuning

3.1 Schedule and Process

The Muller team began implementation of new signal timing plans on March 24th, 2009. The implementation schedule was set to avoid implementing weekday peak period timings during the summer, when neither CSU nor Poudre Valley schools are in full session. During the summer months, off-peak weeknight timings for all corridors were implemented, as well as the weekend (midday) timing plans for several corridors. Table 3 below shows the implementation schedule.

Table 3: Corridor Implementation Schedule

Corridor (Limits)	Timings Implemented	Substantially Completed
Harmony Rd (Mason to Lady Moon)	3/24/09	4/22/09
Timberline Rd(Kechter to Prospect)[1]	4/6/09	5/20/09
Lemay Ave (Trilby to Oak Ridge)	4/22/09	4/24/09
Lemay Ave (Stuart to Vine)	4/29/09	6/3/09
Mulberry (Whedbee to Greenfields)	4/29/09	5/14/09
All-Corridors (Off-Peak/Weeknight Timings)	6/16/09	8/12/09
Shields (Westbury to Laporte)[2]	8/31/09	9/29/09
College Ave (Carpenter to Hwy 1)	8/31/09	11/18/09
Prospect (Whitcomb to Remington)	9/1/09	10/12/09
Horsetooth (Tradition to Lemay)	9/1/09	10/7/09
Drake (Worthington to Lemay)	9/1/09	9/30/09
Mulberry (Loomis to Mason)	9/1/09	10/6/09
Taft Hill Road (Harmony to Mulberry)	10/15/09	11/19/09
Laurel (Loomis to Howes) Elizabeth	11/18/09	12/10/09
Elizabeth (City Park to Constitution)	11/18/09	12/10/09
Drake and Horsetooth (Taft Hill to Shields)	12/16/09	12/18/09

Notes:
1. Included Prospect/Riverside and Prospect/Prospect Pkwy signals.
2. Included Starflower/Harmony signal.

The implementation process generally included the following steps:

1. Implement new weekday timings on Tuesday or Wednesday.
2. Verify cycle lengths and offsets at each intersection.
3. Communicate any needed corrections to Fort Collins traffic staff.
4. Begin checking individual intersections for any capacity/queuing problems and make necessary timing changes.
5. Check corridor progression for each direction of travel and each time period.
6. Recommend fine-tuning adjustments (splits/offsets) to Fort Collins staff.

7. Re-check corridor progression and local intersection operations during all time periods.
8. Adjust final timings as needed.

3.2 Fine Tuning

The key ingredient to a successful timing project is to spend the necessary time in the field observing traffic conditions and making necessary adjustments. Too often, new timings are implemented and not enough time is spent to verify and adjust the timings as needed. For this project, the Muller team spent seven months of field work implementing, adjusting and fine-tuning the timings. The above process typically transpired over a 2-4 week period for each corridor. Some corridors were fine-tuned more quickly and others had minor adjustments occurring over several weeks.

The fine-tuning process included adjusting splits to accommodate capacity or queuing problems with specific intersection movements, adjusting pedestrian crossing walk time (from 7 seconds to 4 or 5 seconds) at critical intersections, minor adjustments to offsets to reduce platoon stops, and, in some cases, adjusting the corridor progression speed to account for slower moving traffic.

There were two corridors in particular where progression speed adjustments were made during the fine-tuning process (note, the progression speed was adjusted for other corridors prior to implementation of the timing plans). Corridor progression speeds were lowered for the Harmony Road corridor during the midday and PM peak timing plans as it was found that traffic platoon often traveled 5-10 mph under the speed limit between Lemay Avenue and Ziegler Road. On East Mulberry Street, progression speeds were lowered from 50 mph to 45 mph between Link Lane and Summit View during the midday peak period. The change in progression speed also necessitated a change in the corridor cycle length from 100 to 120 seconds. The primary reason for this adjustment was the heavy presence of large trucks that use East Mulberry Street (SH 14) during the midday as a connection between I-25 and US 287.

4 Study Results

As mentioned in the introduction of this report, there are numerous benefits of traffic signal re-timing. Signal timing projects typically have one of the highest benefit-cost ratios for transportation projects. The primary benefits include reduction in travel time, fewer vehicle stops, decreased vehicle emissions (carbon monoxide, nitrogen oxides and hydrocarbons), decreased fuel consumption, and lower user costs to motorists. The benefits of a signal re-timing project impact individual motorists as well as the greater community and region at-large. Secondary benefits, which are more difficult to measure, can also include increased safety, reduced driver frustration and lower vehicle maintenance costs.

4.1 Method of Measuring Benefits

The primary benefits of signal re-timing can be measured through the collection of "before" and "after" travel-time/delay run data. Collection of travel-time data to verify signal re-timing benefits is a time-tested and well-proven method that is used by transportation agencies throughout the United States. Fort Collins staff utilized the software package PC-Travel to collect the travel-time data. Weekend "after" run data was collected by Muller Engineering using Tru-Traffic's GPS travel time data collection application. Tru-Traffic's reporting format is slightly different than PC-Travel's, but the performance measure data (travel time, delays, stops, speed, etc.) are essentially the same.

Fuel consumption was based upon the model developed by the University of Florida Transportation Research Center (TRC) and utilized by the TRANSYT traffic signal timing modeling software. The model is a linear estimate based on a combination of total travel, delay and stops. The TRC equation is:

$$\text{Fuel consumed} = K_{i1}\text{*Total Travel} + K_{i2}\text{*Total Delay} + K_{i3}\text{*Total Stops}$$

where model coefficients K_{ij} are functions of corridor cruising speed.

Emissions were calculated from the fuel consumption, based on the passenger car emission rates developed by the Environmental Protection Agency [Reference: http://epa.gov/otaq/consumer/f00013.htm]. The following equations were used to calculate Carbon Monoxide (CO), Nitrogen Oxide (NOx) and Hydrocarbons (HC):

CO = 449.5 grams/gallon of fuel
NOx = 29.9 grams/gallon of fuel
HC = 60.2 grams/gallon of fuel

The before-after data was assembled in spreadsheets to assess the change in performance measures for each corridor and to determine travel time, fuel and emission benefits. This process allows the City of Fort Collins to demonstrate the continued benefits of their signal timing program to CDOT, from which it received Congestion Mitigation and Air Quality (CMAQ) funding.

4.2 System-Wide Benefits

Using the procedures described above, the project team field-measured before and after travel-time data for the ten corridors in the project area. Benefits were calculated for weekday and weekend (Saturday) travel.

Traffic flow performance measures were calculated for each corridor and time period, and aggregated into system-wide values. Table 4 shows the percent change for each of these measures from the before condition to the after condition. The weekend period showed the greatest improvement, followed by the PM and AM peak periods. The changes shown in Table 4 were based on results of the before/after travel time runs. Due to City staffing budget limitations, weekend "after" travel time benefits were measured for only five of the corridors (Harmony Road, Timberline Road, Lemay Avenue, Mulberry Street and College Avenue). The weekday midday "after" travel time data was used to estimate weekend conditions for the remaining corridors because both time periods utilized the same timing plans. The weekend volumes were applied to the estimated weekend travel time results to determine the corresponding performance measures.

Table 4: Change in Traffic Flow Performance Measures

Performance Measure	AM Peak Period	Midday Peak Period	PM Peak Period	Off-Peak Period	Weekend Period
Reduced Vehicle Stops	12.1%	15.5%	18.2%	10.5%	19.5%
Reduced Motorist Delay	17.9%	12.8%	16.8%	18.8%	29.8%
Reduced Travel Time	5.3%	3.6%	6.7%	5.2%	8.5%
Reduced Fuel Consumption and Emissions	4.8%	4.2%	5.8%	4.6%	4.3%

Table 5 below shows the system-wide benefits in terms of vehicle travel-time reduction, decreased fuel consumption, emissions reductions and overall cost savings. Cost savings are based only on fuel consumption and travel time savings to motorists and do not include less tangible, but equally important, savings such as vehicle emissions. For this project a $15.96/hour value of time per person ($20.00 per vehicle assuming an average occupancy of 1.25 persons per vehicle) was applied for travel time savings. The value of time was based on the 2009 Urban Mobility Report, which is an annual report that evaluates the cost of urban traffic congestion throughout the United States [Reference: http://mobility.tamu.edu/ums/report/appendix_a.pdf]. Fuel costs of $2.45/gallon were based on the average price of unleaded regular gasoline for Fort Collins between September and November, 2009, as reported by American Automobile Association (AAA).

Table 5: System-Wide Benefits

	Travel Time Reduction (Hours)	Fuel Reduction (Gallons)	Total Emissions Reduction (lbs)	Time and Fuel Cost Savings
Weekday Daily Benefit	2,591	3,596	4,276	$60,624
Weekend Benefit	2,223	1,655	1,969	$48,521
Annual Benefit[1]	776,200	1,003,000	1,193,000	$17,982,000

Note:
1. Annual Benefit includes 255 weekdays and 52 Saturdays.

Overall, it is estimated that this signal timing project resulted in an annual cost savings of $17,982,000 to Fort Collins's motoring public. When divided by the cost of this study, the resulting benefit/cost ratio for this project is 60:1.

Emissions Reduction – Vehicle emissions consist of three pollutants: carbon monoxide (CO), nitrogen oxides (NOx) and hydrocarbons (HC). Table 6 below shows the breakdown of emissions reductions for each pollutant on a daily and annual basis.

Table 6: Reduction in Vehicle Emissions

Pollutant:	Carbon Monoxide (CO) (lbs)	Nitrogen Oxides (NOx) (lbs)	Hydrocarbons (HC) (lbs)	Total Emissions (lbs)
Daily Savings	3,562	237	477	4,276
Weekend Savings	1,640	109	220	1,969
Annual Savings[1]	994,000	66,000	133,000	1,193,000

Note:
1. Annual Savings includes 255 weekdays and 52 Saturdays.

As shown by Table 6, carbon monoxide has the largest reduction among the three pollutants. When CO is released into the atmosphere it combines with oxygen to form carbon dioxide (CO^2). CO_2 is a primary contributor to greenhouse gases. The calculated reduction in CO emissions results in a CO_2 reduction of over 8,800 metric tons annually. Applying a carbon offset value of $15 per metric ton translates into an annual cost savings of $176,000. [Reference: www.econeutral.com/buycredits.html].

4.3 Corridor Specific Benefits

In order to arrive at the system-wide benefits described above, a benefits evaluation for each individual corridor was conducted. Table 7 shows the detailed results for each corridor and Figure 6 graphically depicts the travel time and fuel cost savings by corridor.

Table 7: Corridor Specific Benefits (Annual)

Corridor	Vehicle Travel Time Reduction (Hours)	Fuel Consumption Reduction (Gallons)	Total Emissions Reduction (lbs)	Time and Fuel Cost Savings ($)
College Ave	44,127	66,055	78,556	1,044,372
Drake Road	10,959	43,792	52,080	326,461
Harmony Rd	165,165	139,947	166,432	3,646,167
Horsetooth Rd	79,577	76,183	90,600	1,778,197
Lemay Ave	93,268	212,514	252,732	2,386,022
Mulberry St	87,364	143,870	171,098	2,099,762
Prospect Rd	44,018	67,571	80,359	1,045,911
Shields St	126,036	114,158	135,763	2,800,406
Taft Hill Rd	10,527	11,321	13,463	238,269
Timberline Rd	115,203	127,625	151,778	2,616,737

As can be seen in Figure 11, the Harmony corridor realized the largest user benefit of the ten corridors that were retimed. The Drake and Taft Hill corridors saw the smallest improvements, partly because those corridors carry the least amount of traffic of the 10 corridors. Also, in the case of Drake Road, travel time was impacted because Drake's signal progression is interrupted by the higher priority north-south corridors of Shields, College, Lemay and Timberline. The other primary performance measures (vehicle travel time hours, fuel consumption and total emissions) reflect a similar pattern as that shown in Figure 11.

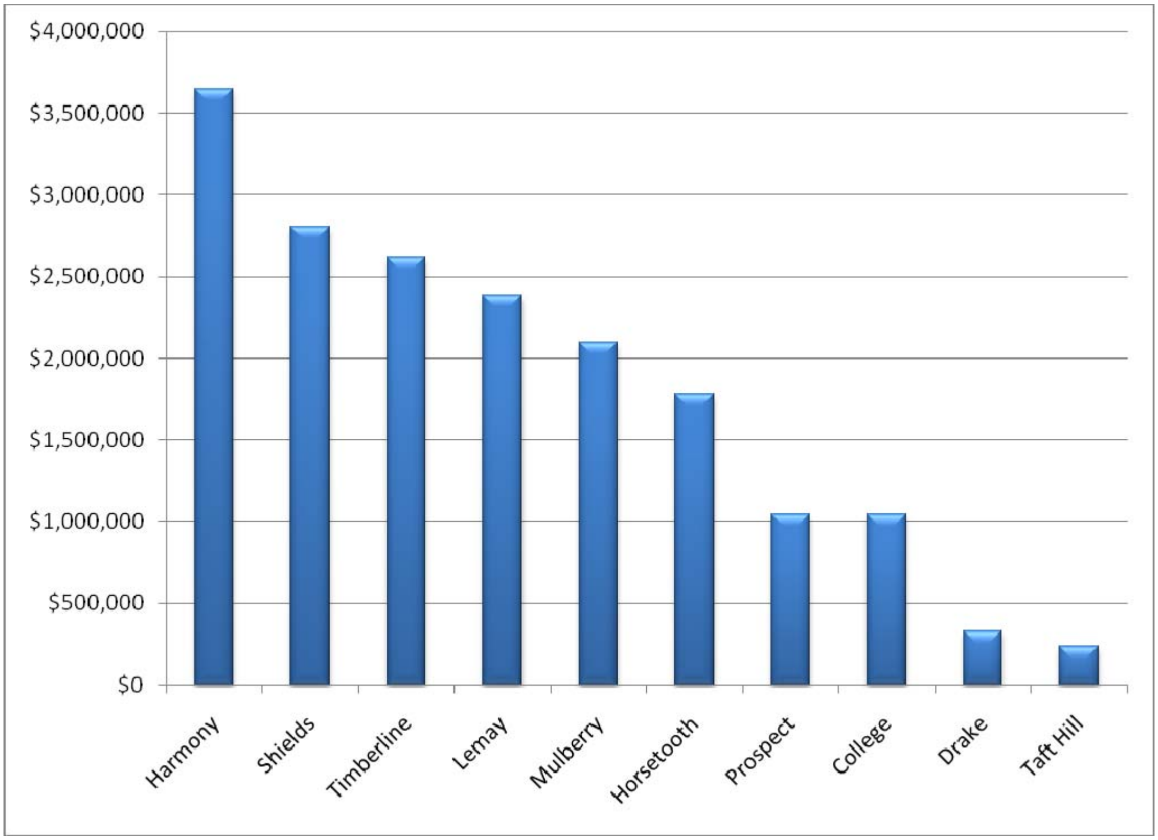


Figure 11: Annual Travel Time and Fuel Savings by Corridor

4.4 Hot Spot Improvements

During the course of conducting the before travel time runs, vehicle delays at all signalized intersections were recorded. Locations where through traffic delay exceeded 55-seconds were noted as potential hot spots for each time period. These delays were either caused by "hard stops" in the coordination plan that required vehicles to wait through the majority of the cycle to receive a green, or at locations where the approach was near or over capacity causing excessive delay. Delays were also recorded during the after travel time runs, and intersection approaches exceeding 55-seconds were noted.

Figures 12 through 15 show the comparison of the before and after hot spots. In general, several hot-spot traffic movements were mitigated with the new timings. In some cases, new hot-spot locations were created due to changes in the traffic timing patterns. Overall, however, the total number of hot-spot traffic movements was decreased in all time periods as noted in Table 8.

Table 8: Before/After Hot-Spot Comparison

Time Period	# of Hot Spot* Movements BEFORE	# of Hot Spot* Movements AFTER	Percent Reduction
AM Peak	9	8	11%
Midday Peak	17	12	29%
PM Peak	24	18	25%
Off-Peak (weeknight)	17	4	77%

* Intersection Through Movements Where Delay Exceeds 55-seconds/vehicle

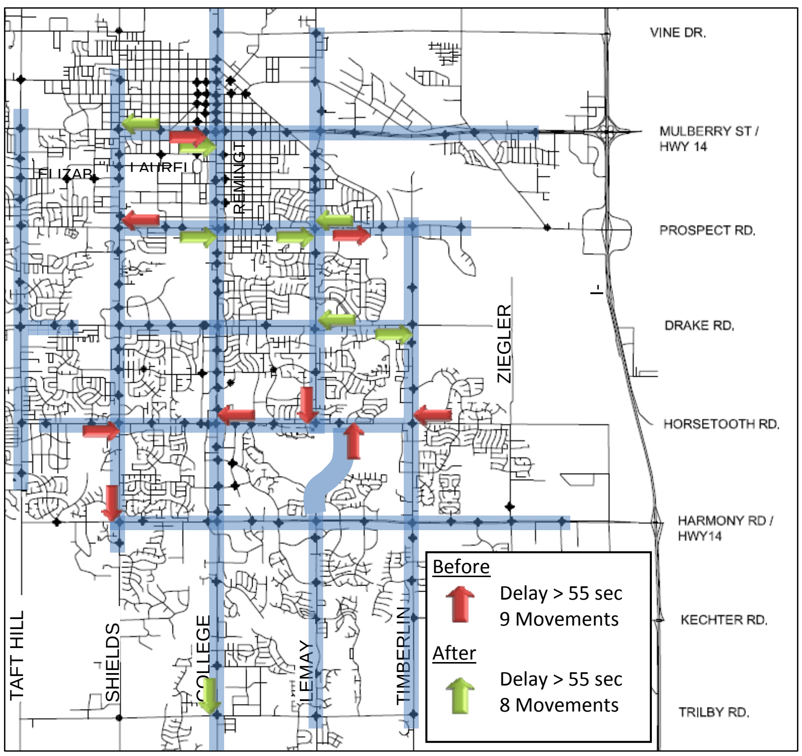


Figure 12: Before/After Hot Spot Locations in AM Peak Period

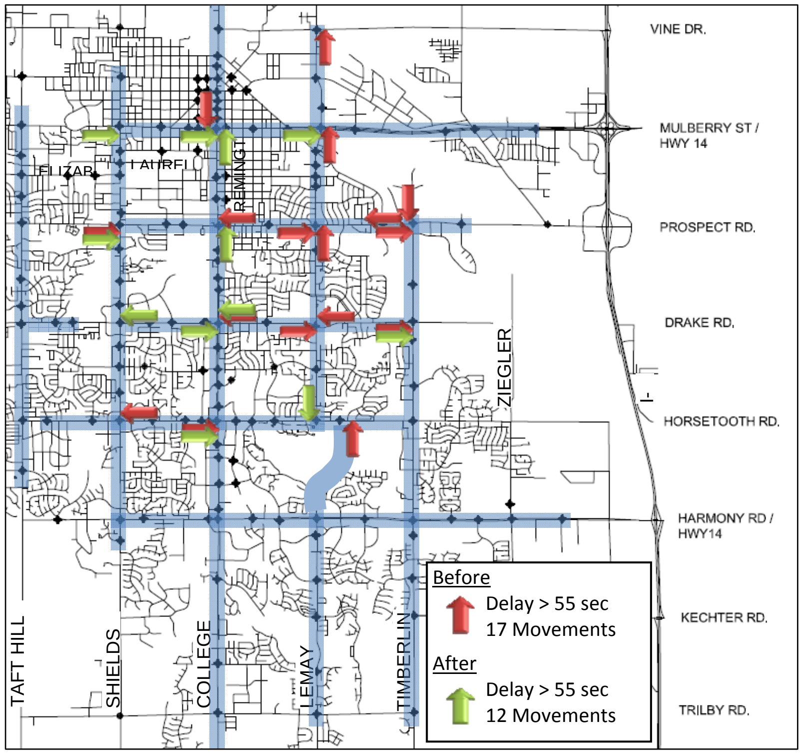


Figure 13: Before/After Hot Spot Locations in Midday Peak Period

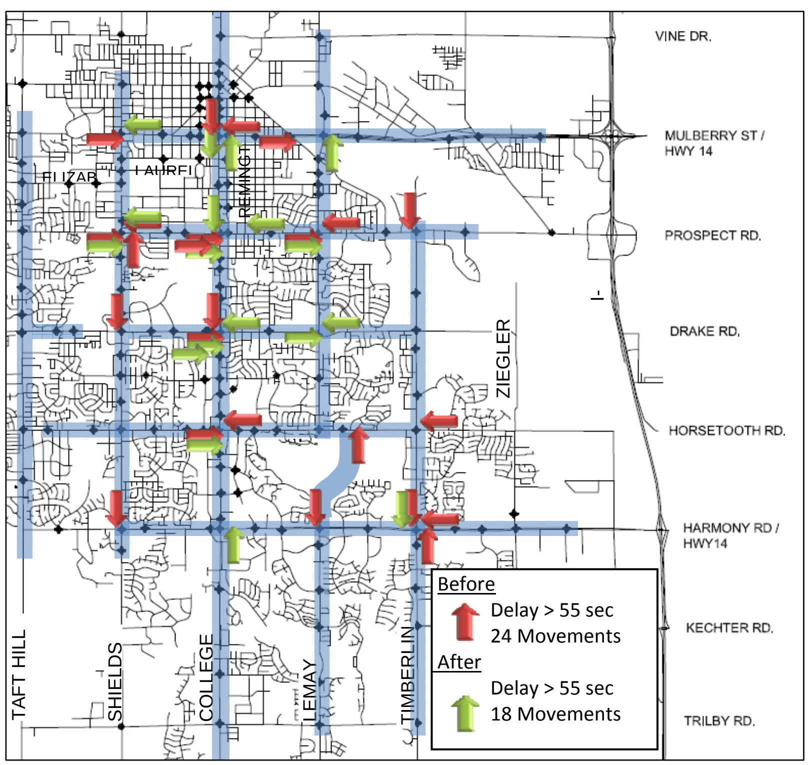


Figure 14: Before/After Hot Spot Locations in PM Peak Period

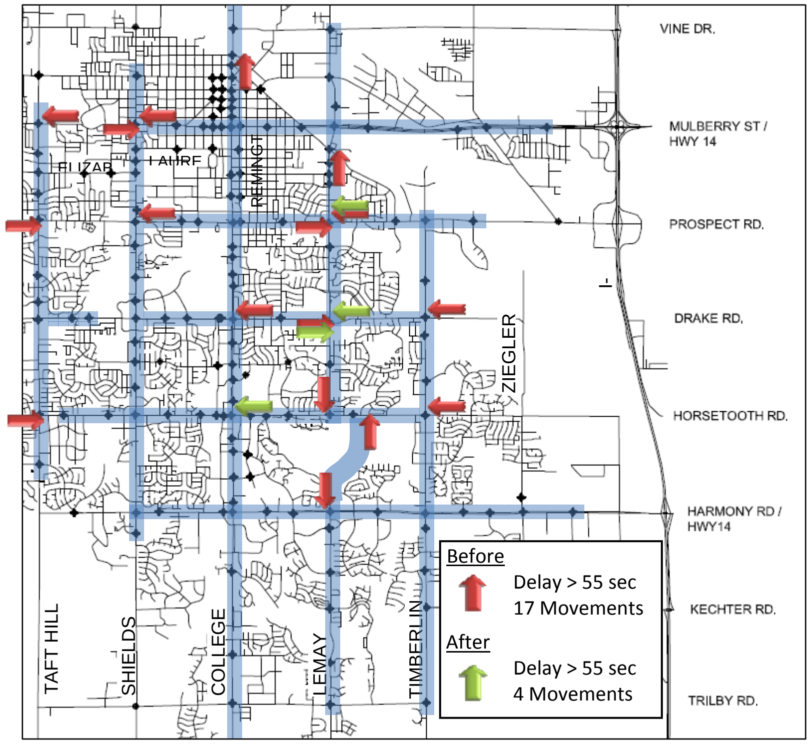


Figure 15: Before/After Hot Spot Locations in Off-Peak (Night) Period

5 Recommendations

5.1 Operational and Capacity Improvement Recommendations

During the course of the signal timing project, the Muller team noted a number of operational and capacity improvements that would be beneficial to improving traffic flow along each corridor. These include:

- **Use of Flashing Yellow Arrow Left-Turn Phasing –** Flashing yellow arrow (FYA) left-turn phasing has recently been approved for use by the 2009 Manual on Uniform Traffic Control Devices (MUTCD). FYA left-turn phasing offers the advantage of reducing delays to left-turning vehicles and can also improve corridor progression because lead/lag left-turn phasing can be implemented with FYA, unlike protected/permissive phasing which requires the use of leading left-turn phasing. Based on Muller Engineering's review of the corridor timing plans, the following locations are recommended as potential candidates for FYA:
  - Boardwalk/College – N/S Lefts
  - Drake/College – N/S/E/W lefts
  - Boardwalk/Harmony – E/W lefts
  - JFK/Harmony – E/W Lefts
  - Snow Mesa/Harmony – E/W Lefts
  - Raintree/Shields – E/W Lefts
  - Riverside/Prospect – E/W Lefts
  - Horsetooth/Timberline – N/S Lefts
  - Stuart/Lemay – N/S Lefts
- **Signal Phasing at College Ave/Foothills Parkway –** Removing the split phasing for the east/west phases would improve intersection operations, by permitting east/west through traffic and pedestrians to cross College Avenue simultaneously. This improvement would allow the Foothills approaches to be serviced more efficiently and give any excess green time back to College Avenue.
- **WB Left Queue Storage at Prospect Road/College Avenue –** Prohibiting the eastbound left-turn at Prospect Road/Remington Street would allow the westbound left-turn lane at Prospect Road/College Avenue to be extended. Currently, the left-turn storage at College is approximately 110 feet, resulting in the left-turn traffic queuing into the westbound through lane during the PM peak hour. Extending the left-turn lane storage would improve intersection operations by allowing proper lane utilization for the westbound traffic and would not require the widening of Prospect Road.
- **WB Dual Left at Harmony Road/Lemay Avenue –** The westbound left-turn at this intersection is a very heavy movement in the Midday and PM peak hours (over 250 vphs). The left-turn operates near or at capacity during both time periods and currently has a long protected-only phase. Providing an additional left-turn lane would improve traffic flow for both the westbound left-turn and the eastbound through movements. Construction of the dual left-turn lane could occur in the existing median and would not require the widening of Harmony Road.
- **Signal Phasing at Drake Road/McClelland Drive –** Removing the westbound protected left-turn phase at McClelland Drive would improve progression for the eastbound through traffic, which operates at capacity during the PM peak period. The

removal of this phase would give more green time back to the eastbound through traffic, reducing the double stops at College Avenue. The left-turn arrow at Redwing Road should remain to provide clearance for the railroad tracks during preemption.

- **NB Right Turn Lane at Timberline Road/Kechter Road –** The intersection is over-capacity due to increased development in the southeast portion of Fort Collins. The problem is also exacerbated by school-related traffic from Fossil Ridge Junior High and Zach Elementary School. During the AM and PM peak hours there are 300 and 200 right turns per hour, respectively. Adding a northbound right-turn lane would result in a significant improvement to overall intersection operations at this intersection.

5.2 Major Capacity/Long-Term Improvements

Several capital intensive improvements were identified during the course of the Signal Timing Program. The recommendations below do not include a detailed analysis of the potential costs, impacts or overall feasibility of such improvements, but are based on operational analysis and general observations during the course of Muller's field work on the project.

- **Southbound Dual Left At Shields Street/Drake Road –** The southbound left at this intersection operates at or near capacity during the PM peak period. There are currently 255 vehicles turning left during the PM peak hour and left-turn queuing often exceeds the storage capacity of the left-turn lane. Providing the dual left-turn lane would improve traffic flow for both the southbound left turn movement and also the northbound through movement. Widening of Shields Street may require additional right-of-way and possible tree removal.

- **Turn Lane Improvements at Horsetooth Road/Timberline Road –** This intersection operates near or over capacity in the AM and PM peak periods due to high turning movements from Timberline Road onto Horsetooth Road. The NB and SB single left turn lanes each carry approximately 250 vph during the PM peak period, and the SB right turn volume is 280 vph in a shared through/right lane. Widening the intersection to include dual north/south left turn lanes and a dedicated SB right turn lane would greatly improve overall traffic flow through the intersection. Right-of-way may need to be acquired in the northwest quadrant. There appears to be sufficient right-of-way for widening in the northeast, southwest and southeast quadrants.

- **EB Dual Left at Mulberry Street/Lemay Avenue -** The eastbound left-turn at this intersection is a very heavy movement in the Midday and PM peak hours (over 200 vphs). This critical movement operates at capacity during both time periods, with a protected-only left-turn phase. Providing an additional left-turn lane would improve traffic flow for eastbound left-turns. Widening of Mulberry Street may require additional right-of-way and would be restricted by the existing bridge to the west spanning the Cache La Poudre River.

- **EB Right Turn at Horsetooth Road/College Avenue –** The eastbound through/right movement at this intersection operates at or near capacity during the AM and PM peak hours. Providing a right-turn lane would improve traffic flow for both the through and right-turn movements and would improve intersection operations by allowing proper lane utilization by the eastbound traffic. This would likely be a long-term improvement due right-of-way constraints and a ditch crossing on the southwest quadrant.

- **Grade-Separated Pedestrian Crossing at Drake Road/Redwing Road –** The clearance interval required for pedestrians using the Mason Trail Corridor is greater than the green time that would usually be needed for the northbound vehicular traffic on Redwing Road. Providing a grade-separated pedestrian crossing would allow any excess green time to be given back to Drake Road, thereby improving the traffic flow rate for the eastbound and westbound through traffic. This improvement is also identified in Fort Collins' Master Street Plan document.
- **WB Dual Left at Mulberry Street/College Avenue –** The westbound left-turn at this intersection is a very heavy movement in the Midday and PM peak hours (over 200 vph). The left-turn operates near or at capacity during both time periods and currently has only 110 feet of storage, with left-turn traffic often queuing into the through lane. The proximity of Remington Street to the east precludes extending the left-turn storage; therefore, providing an additional left-turn lane would improve traffic flow for the westbound left-turn movement. Widening of Mulberry Street may require additional right-of-way and possible tree removal/sidewalk reconstruction.
- **Widen Harmony between Timberline Road and College Avenue –** Harmony Road experiences heavy congestion during the PM peak period and lacks the capacity to handle the existing traffic between Timberline Road and College Avenue. As a long-term improvement, adding through lanes to Harmony would increase the traffic flow rate, thereby reducing congestion. Reducing congestion on Harmony would also allow more green time to be given to the heavy side street traffic at Lemay Avenue. Widening of Harmony Road may require additional right-of-way and tree removal.
- **N/S Dual Lefts at Horsetooth Road/College Ave –** The northbound and southbound left turns at this intersection are heavy in the Midday and PM peak hours (~ 200 vph). These left-turns currently operate at capacity during both time periods and queuing often exceeds the storage of the northbound left-turn lane during the PM peak period. Providing the dual left-turn lanes would improve traffic flow for both the north/south left-turn and through movements. Widening of College Avenue may require additional right-of-way and possible tree removal/sidewalk reconstruction.
- **Shields Street/Elizabeth Street Capacity Improvements –** The capacity of this intersection is constrained by three factors: the split-phase operation of east/west traffic, the heavy volume of northbound lefts, and the heavy flow of pedestrians crossing Shields Street. The combination of these factors causes this intersection to be a bottleneck for Shields traffic during the AM and PM peak periods. Removal of the split phase operation would likely require re-alignment of the east-west lanes, which may prove to be difficult due to right-of-way and land use constraints. A pedestrian grade separated crossing would also alleviate congestion but would also be difficult without property impacts on either side of Shields Street. Further study of this intersection should be conducted to determine if any of the above mentioned capacity improvements are feasible.

APPENDIX - A

Corridor Summary Sheets

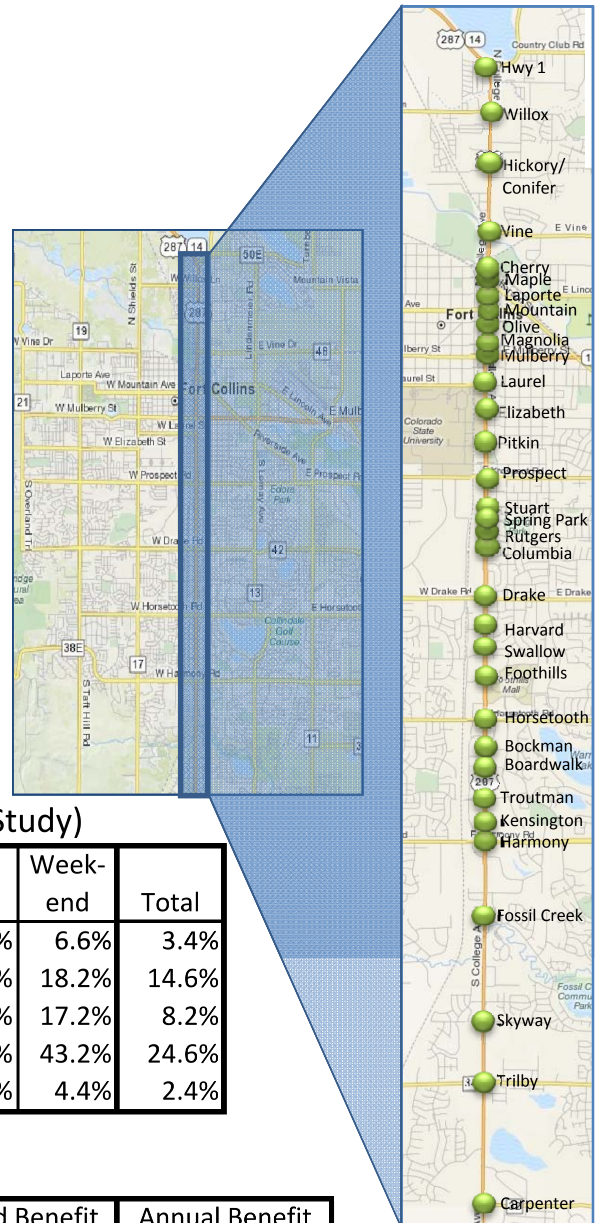
FORT COLLINS
CITYWIDE TRAFFIC
SIGNAL TIMING PROJECT

College Avenue

Hwy 1 to Carpenter

Corridor Snapshot

- Primary north/south corridor
- Serves mostly commuter and retail traffic
- Travel speeds vary greatly by time of day and location
- Congested intersections: Harmony, Horsetooth, Drake,
- Prospect, Laurel and Mulberry
- Corridor Length: 9.4 miles
- College carries approximately 36,000 vehicles per day at Fossil Creek, 25,000 vpd at Cherry and 43,000 vpd at Rutgers



Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	6:00-6:45 & 19:45-23:30
Saturday	85	7:00-9:30/20:30-24:00
	120	9:30 - 20:30
Sunday	85	7:45-10:30/18:30-22:30
	120	10:30 - 18:30

Signal Timing Results (From "Before/After" Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	-2.0%	-0.5%	3.3%	-3.6%	6.6%	3.4%
Decreased Stops	-6.5%	15.2%	18.9%	-40.0%	18.2%	14.6%
Increase in Average Speed	-3.4%	0.6%	8.7%	-6.6%	17.2%	8.2%
Signal Delay Reduction	-5.9%	-0.5%	9.4%	-11.9%	43.2%	24.6%
Decreased Fuel Use and Emissions	-1.6%	2.3%	4.5%	-8.7%	4.4%	2.4%

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	47	620	44,127
Fuel Consumption (Gallons Decrease)	147	551	66,055
Time and Fuel Cost Savings	$1,291	$13,755	$1,044,372
Emissions (Pounds Reduction)	174	656	78,556

Corridor Operational Improvement Recommendations

1. Consider converting protected/permissive left turn phasing to Flashing Yellow Arrow at:
   Boardwalk/College - N/S lefts
   Drake/College - N/S/E/W lefts
2. Remove E/W split phasing at Foothills/College.
3. Add dual N/S lefts at Horsetooth/College.
4. Prohibit EB left-turn at Prospect/Remington and extend WB left turn storage at Prospect/College.

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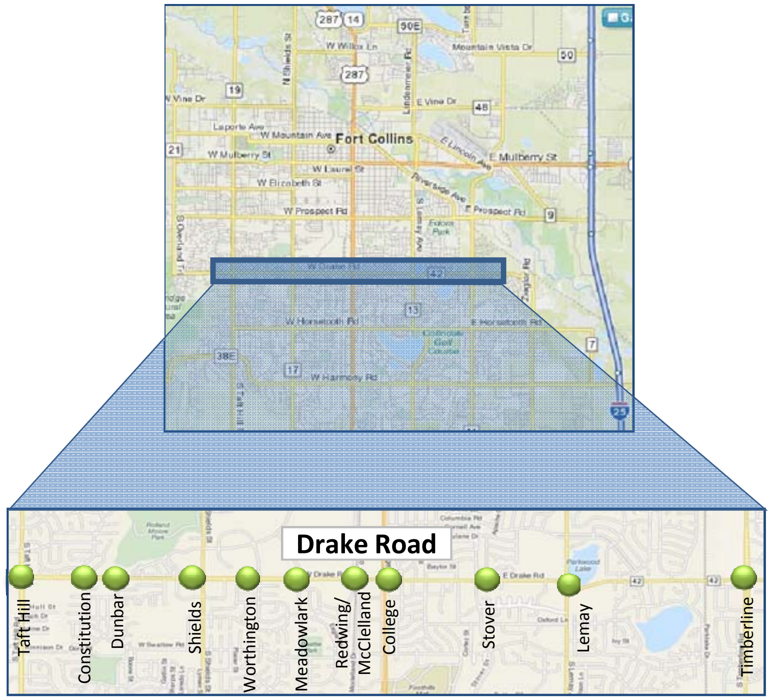
December, 2009

Drake Road

Taft Hill to Timberline

FORT COLLINS
CITYWIDE TRAFFIC
SIGNAL TIMING PROJECT



Corridor Snapshot

- Secondary east/west progression corridor
- Serves mostly intra-city trips
- Progression speeds 35-40 mph
- Congested intersections: Shields, College and Lemay
- Corridor Length: 4.0 miles
- Drake carries approximately 26,000 vehicles per day at Meadowlark and 20,000 vpd at Stover

Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	100/120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	6:00-6:45 & 19:45-22:30
Saturday	85	7:00-9:30/19:30-23:00
	120	9:30 - 19:30
Sunday	85	7:45-10:30/18:30-22:30
	120	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)[1]

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	6.6%	3.7%	-8.1%	10.3%	3.5%	2.3%
Decreased Stops	16.0%	7.4%	-14.7%	28.2%	8.2%	6.6%
Increase in Average Speed	7.7%	4.3%	-6.9%	12.4%	4.2%	3.1%
Signal Delay Reduction	17.7%	9.1%	-18.3%	27.3%	8.1%	5.6%
Decreased Fuel Use and Emissions	6.2%	3.1%	-5.0%	15.1%	1.8%	2.5%

Note: 1. Signal Timing Results based on travel time runs between Shields and Timberline

Corridor User and Community Benefits[1]

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	32	56	10,959
Fuel Consumption (Gallons Decrease)	165	33	43,792
Time and Fuel Cost Savings	$1,037	$1,192	$326,461
Emissions (Pounds Reduction)	196	39	52,080

Note: 1. Benefits based on travel time runs between Shields and Timberline

Corridor Operational Improvement Recommendations

1. Consider removing westbound left-turn phase at McClelland to improve eastbound progression (left-turn arrow at Redwing should remain for RR track clearance).
2. As a long-term improvement, provide grade separated pedestrian crossing at Drake/Redwing/McClelland.

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FORT COLLINS
CITYWIDE TRAFFIC
SIGNAL TIMING PROJECT

Harmony Road

Mason St to Lady Moon Dr

Corridor Snapshot

- Primary east/west Corridor Providing Access to I-25
- Serves mostly commuter and retail traffic
- Travel speeds vary greatly by time of day and location
- Congested intersections: Lemay, College and Timberline
- Corridor Length: 3.8 miles
- Harmony Road Carries approximately 34,000 vehicles per day at Snow Mesa and 38,000 vpd at Boardwalk

Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	5:30-6:45 & 19:45-23:30
Saturday	85	7:00-8:45/20:30-24:00
	120	8:45 - 20:30
Sunday	85	7:45-9:30/19:30-22:30
	120	8:30 - 19:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	6.7%	10.9%	14.4%	-8.0%	31.3%	21.9%
Decreased Stops	25.0%	28.3%	28.6%	-68.8%	55.2%	44.0%
Increase in Average Speed	7.2%	12.4%	17.5%	-9.0%	49.7%	26.2%
Signal Delay Reduction	22.5%	28.7%	32.4%	-41.6%	58.8%	47.6%
Decreased Fuel Use and Emissions	6.1%	9.0%	10.5%	-15.0%	17.1%	10.1%

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	434	1050	165,165
Fuel Consumption (Gallons Decrease)	420	630	139,947
Time and Fuel Cost Savings	$9,701	$22,548	$3,646,167
Emissions (Pounds Reduction)	500	749	166,432

Corridor Operational Improvement Recommendations

1. Consider converting protected/permissive left turn phasing to Flashing Yellow Arrow at:
   - Boardwalk/Harmony - EB and WB left
   - JFK/Harmony - EB and WB left
   - Snow Mesa/Harmony - EB and WB left
2. Add 2nd left-turn lane for WB left at Lemay.
3. As a long-term improvement, consider widening Harmony to 6 lanes between Timberline and College.

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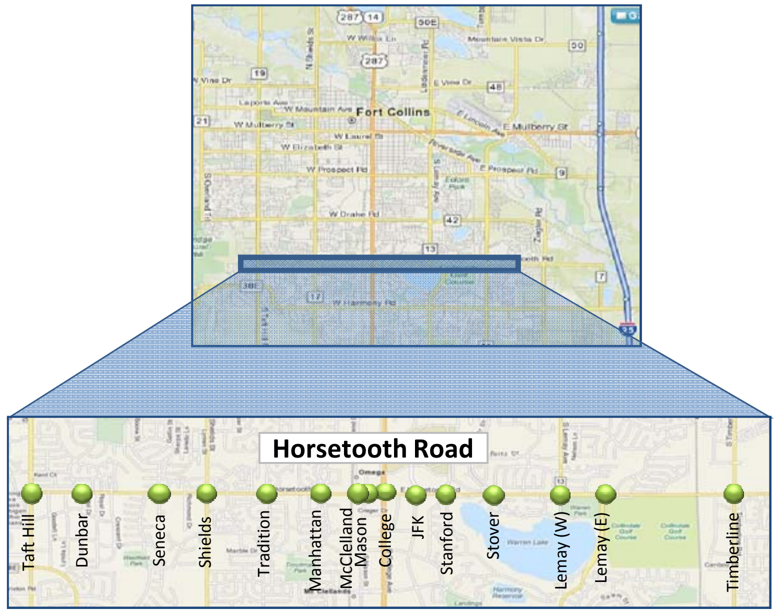
Horsetooth Road

Taft Hill to Timberline

FORT COLLINS CITYWIDE TRAFFIC SIGNAL TIMING PROJECT

Corridor Snapshot

- Primary east/west progression corridor
- Serves mostly commuters, and as an alternate route to Harmony
- Progression speeds 35-40 mph
- Congested intersections: College and Timberline
- Corridor Length: 4.0 miles
- Horsetooth carries approximately 24,000 vehicles per day at Tradition and 28,000 vpd at Stover



Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	100/120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	6:00-6:45 & 19:45-22:30
Saturday	85	7:00-9:30/19:30-23:00
	100/120	9:30 - 19:30
Sunday	85	7:45-10:30/18:30-22:30
	100/120	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)[1]

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	9.6%	0.5%	15.4%	3.2%	0.5%	5.0%
Decreased Stops	37.3%	3.9%	27.4%	11.1%	2.7%	13.2%
Increase in Average Speed	10.1%	-3.7%	16.5%	4.2%	0.4%	3.9%
Signal Delay Reduction	28.5%	-11.4%	31.5%	9.8%	-11.8%	3.0%
Decreased Fuel Use and Emissions	10.4%	-1.7%	10.4%	4.8%	-1.0%	3.0%

Note: 1. Signal Timing Results based on travel time runs between Shields and Timberline

Corridor User and Community Benefits[1]

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	309	13	79,577
Fuel Consumption (Gallons Decrease)	305	-29	76,183
Time and Fuel Cost Savings	$6,935	$189	$1,778,197
Emissions (Pounds Reduction)	362	-35	90,600

Note: 1. Benefits based on travel time runs between Shields and Timberline

Corridor Operational Improvement Recommendations

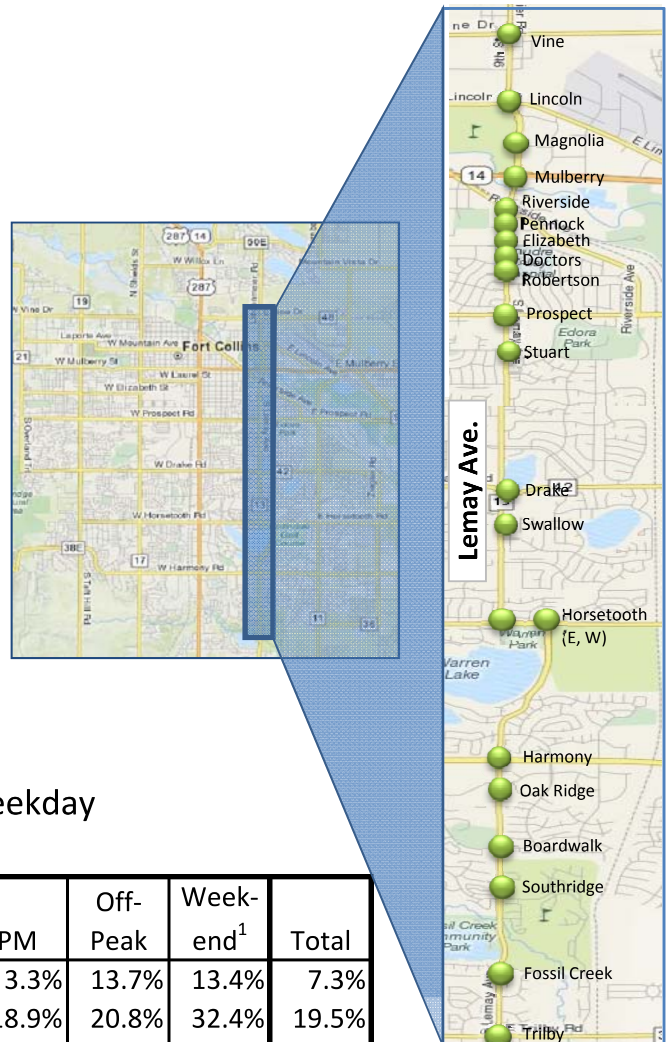
1. Add right-turn lane for EB right at College.

Lemay Avenue

Vine to Trilby

Corridor Snapshot

- North/south progression corridor
- Serves mostly commuter and local traffic
- Progression speeds 35-40 mph
- Congested intersections: Harmony, Drake and Mulberry
- Corridor Length: 7.1 miles
- Lemay carries approximately 15,000 vehicles per day at Oakridge and 29,000 vpd at Prospect



Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	100/120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	6:00-6:45 & 19:45-22:30
Saturday	85	7:00-9:30/19:30-23:00
	120	9:30 - 19:30
Sunday	85	7:45-10:30/18:30-22:30
	120	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end[1]	Total
Travel Time Reduction	3.9%	5.6%	3.3%	13.7%	13.4%	7.3%
Decreased Stops	-2.5%	14.3%	18.9%	20.8%	32.4%	19.5%
Increase in Average Speed	6.2%	6.4%	5.0%	15.5%	26.9%	16.4%
Signal Delay Reduction	36.7%	35.5%	27.0%	53.8%	53.5%	39.8%
Decreased Fuel Use and Emissions	5.9%	9.3%	7.3%	19.1%	8.9%	9.1%

Note: 1. Signal Timing Results based on travel time runs between Stuart and Vine

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	324	203	93,268
Fuel Consumption (Gallons Decrease)	805	141	212,514
Time and Fuel Cost Savings	$8,457	$4,415	$2,386,022
Emissions (Pounds Reduction)	957	168	252,732

Corridor Operational Improvement Recommendations

1. Consider converting protected/permissive left turn phasing to Flashing Yellow Arrow at:
   Lemay/Stuart - NB and SB left
2. Add 2nd left-turn lane for EB left at Mulberry.
3. Add 2nd left-turn lane for WB left at Harmony.

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FORT COLLINS
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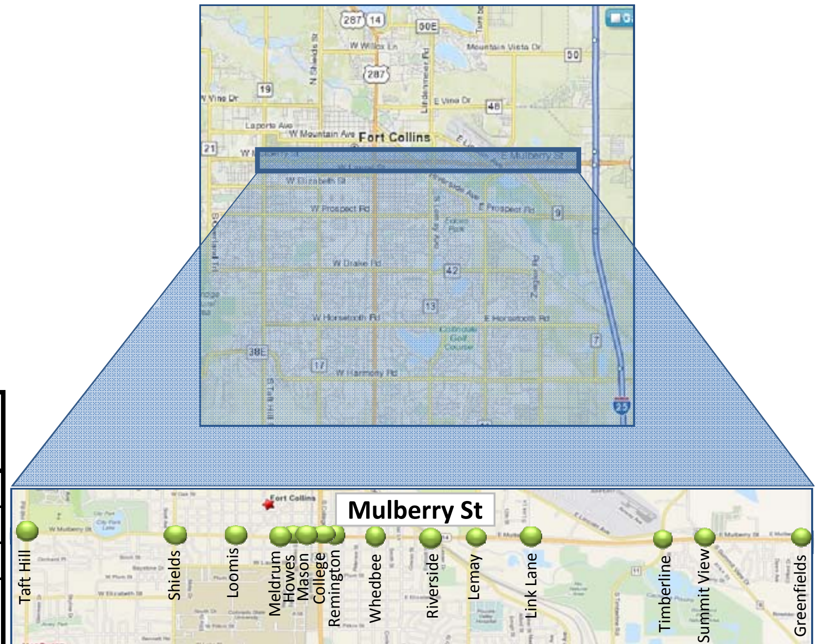
SIGNAL TIMING PROJECT

Mulberry Street

Taft Hill to Greenfields

Corridor Snapshot

- Primary east/west corridor providing access to I-25
- Serves mostly commuter traffic
- Travel speeds vary from 35 to 50 mph
- Congested intersections: Lemay and College
- Corridor Length: 5.3 miles
- Mulberry carries approximately 21,000 vehicles per day at Meldrum and 35,000 vpd at Link Lane



Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	120	11:00 - 15:00
PM Peak	120	15:00 - 19:00
Off-Peak	85	5:30-6:45 & 19:00-22:30
Saturday	85	7:00-9:30/19:30-23:00
	120	9:30 - 19:30
Sunday	85	7:45-10:30/18:30-22:30
	120	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	3.5%	9.6%	9.9%	7.1%	-4.3%	4.2%
Decreased Stops	13.3%	48.5%	32.4%	0.5%	21.4%	27.2%
Increase in Average Speed	2.5%	9.0%	12.1%	8.1%	-3.7%	1.5%
Signal Delay Reduction	8.1%	26.4%	21.9%	21.3%	-1.3%	15.7%
Decreased Fuel Use and Emissions	3.4%	13.5%	8.5%	5.9%	0.5%	5.0%

Note: 1. Signal Timing Results based on travel time runs between Shields and Greenfields

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	388	-223	87,364
Fuel Consumption (Gallons Decrease)	561	15	143,870
Time and Fuel Cost Savings	$9,138	-$4,430	$2,099,762
Emissions (Pounds Reduction)	667	18	171,098

Note: 1. Benefits based on travel time runs between Shields and Greenfields

Corridor Operational Improvement Recommendations

1. Add 2nd left-turn lane for EB left at Lemay.
2. Add 2nd left-turn lane for WB left at College.

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Prospect Road

Shields to Timberline

Corridor Snapshot

- East/west corridor providing access to I-25
- Serves mostly commuter traffic and trips to/from I-25
- Progression speed is 35 mph
- Congested intersections: College
- Corridor Length: 3.3 miles
- Prospect carries approximately 25,000 vehicles per day at Centre and 22,000 vpd at Lemay

Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	6:00-6:45 & 19:45-22:30
Saturday	85	7:00-9:30/19:30-23:00
	120	9:30 - 19:30
Sunday	85	7:45-10:30/18:30-22:30
	120	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	0.4%	8.1%	-0.3%	15.4%	7.2%	5.6%
Decreased Stops	1.5%	-8.0%	-3.2%	43.5%	-31.5%	-10.3%
Increase in Average Speed	0.2%	8.1%	0.4%	19.0%	8.8%	7.0%
Signal Delay Reduction	1.0%	18.2%	0.2%	33.7%	14.2%	11.2%
Decreased Fuel Use and Emissions	0.5%	3.1%	-0.4%	20.6%	-0.2%	3.6%

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	145	135	44,018
Fuel Consumption (Gallons Decrease)	266	-5	67,571
Time and Fuel Cost Savings	$3,552	$2,697	$1,045,911
Emissions (Pounds Reduction)	316	-6	80,359

Corridor Operational Improvement Recommendations

1. Consider converting protected/permissive left turn phasing to Flashing Yellow Arrow at:
   Prospect/Riverside - EB and WB left
2. Increase storage for WB left and right turns at College Avenue.

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FORT COLLINS
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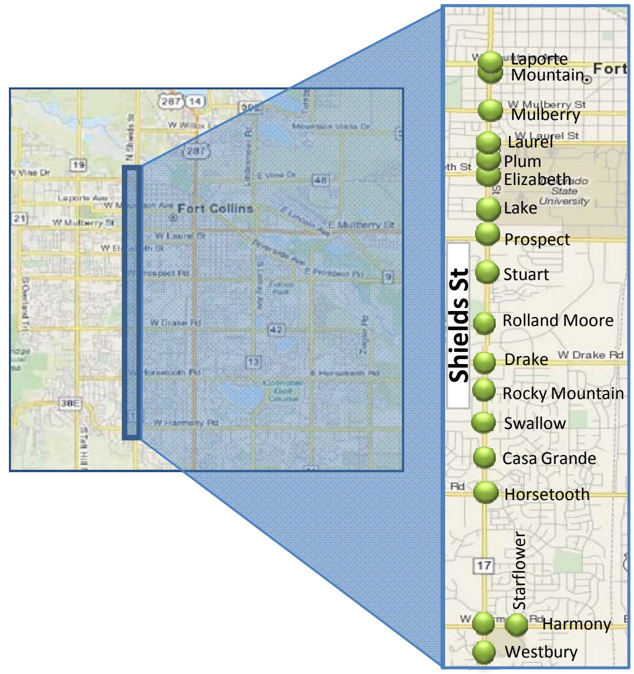
Shields Street

Westbury to Laporte

Corridor Snapshot

- North/south primary corridor
- Serves mostly commuter and CSU traffic
- Progression speed is 40 mph south of Propsect and 30 mph north of Prospect
- Congested intersections: Drake and Elizabeth
- Corridor Length: 4.5 miles
- Shields carries approximately 31,000 vehicles per day at Plum and 33,000 vpd at Swallow



Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	120	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	5:30-6:45 & 19:45-23:30
Saturday	85	7:00-9:30/20:30-24:00
	120	9:30 - 20:30
Sunday	85	7:45-10:30/18:30-22:30
	120	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)[1]

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	15.1%	-0.3%	10.8%	1.3%	-0.2%	4.1%
Decreased Stops	12.7%	5.7%	12.5%	23.0%	6.9%	9.2%
Increase in Average Speed	19.0%	0.5%	12.1%	1.9%	-0.3%	4.3%
Signal Delay Reduction	32.8%	0.6%	25.6%	4.0%	1.6%	10.5%
Decreased Fuel Use and Emissions	8.6%	0.8%	5.8%	4.5%	0.7%	3.6%

Note: 1. Signal Timing Results based on travel time runs between Harmony and Laporte

Corridor User and Community Benefits[1]

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	496	-10	126,036
Fuel Consumption (Gallons Decrease)	441	33	114,158
Time and Fuel Cost Savings	$11,008	-$126	$2,800,406
Emissions (Pounds Reduction)	524	40	135,763

Note: 1. Signal Timing Results based on travel time runs between Harmony and Laporte

Corridor Operational Improvement Recommendations

1. Consider converting protected/permissive left-turn phasing to Flashing Yellow Arrow at:
   Shields/Raintree - N/S lefts
2. Add 2nd left-turn lane for SB left at Drake.
3. Revise E/W geometry at Elizabeth to allow removal of split phase (long-term).

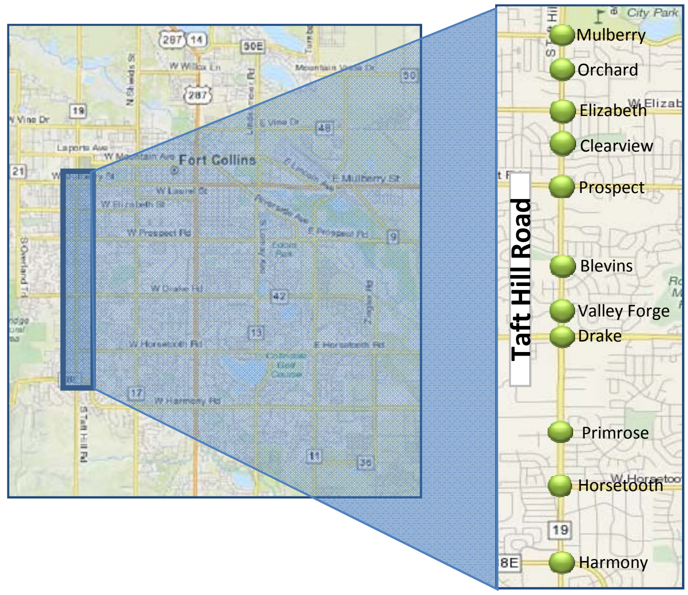
Fort Collins Citywide Traffic Signal Timing Project

Taft Hill Road

Harmony to Mulberry

Corridor Snapshot

- Primary north/south corridor
- Serves mostly local traffic
- Progression speeds 35-40 mph
- Corridor Length: 3.5 miles
- Taft Hill carries approximately 20,000 vehicles per day at Elizabeth and 21,000 vpd at Valley Forge



Timing Plans

Plan	Cycle Length (sec)	Time-of-Day
AM Peak	90	6:45 - 11:00
Midday	85	11:00 - 15:00
PM Peak	95	15:00 - 19:00
Off-Peak	85	6:00 - 6:45 & 19:00 - 22:30
Saturday	85	7:00 - 23:00
Sunday	85	7:45 - 22:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	5.7%	-1.6%	3.6%	-2.6%	-1.4%	0.4%
Decreased Stops	26.1%	-66.7%	36.6%	10.3%	-54.4%	-12.2%
Increase in Average Speed	6.5%	-1.1%	3.5%	-1.4%	-1.7%	0.3%
Signal Delay Reduction	28.5%	-9.1%	15.7%	-10.9%	-6.3%	1.9%
Decreased Fuel Use and Emissions	4.9%	-4.1%	3.5%	-0.2%	-1.2%	0.4%

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	46	-26	10,527
Fuel Consumption (Gallons Decrease)	50	-26	11,321
Time and Fuel Cost Savings	$1,052	-$575	$238,269
Emissions (Pounds Reduction)	59	-31	13,463

Corridor Operational Improvement Recommendations

1. Add 2nd SB left-turn lane at Taft Hill Road/Horsetooth Road.
2. Add turn arrow for the WB right-turn movement at Taft Hill Road/Harmony Road.
3. Widen Taft Hill Road from 2 to 4 lanes between Horsetooth Road and Harmony Road.

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Fort Collins
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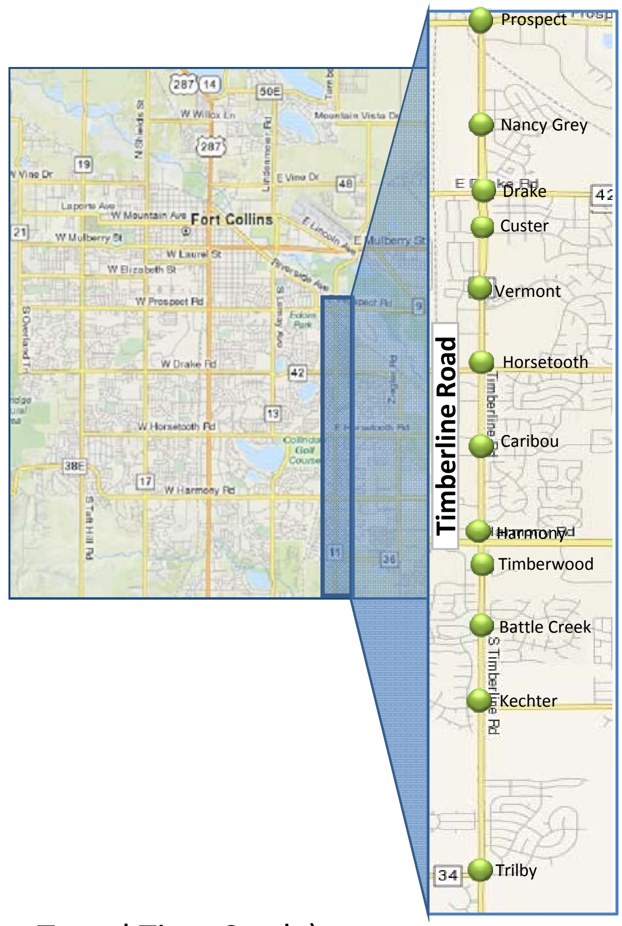
Timberline Road

Trilby to Prospect



Corridor Snapshot

- Primary north/south corridor
- Serves mostly commuter traffic
- Progression speed is 40 mph south of Drake and 45 mph north of Drake
- Congested intersections: Kechter, Horsetooth, Harmony
- Corridor Length: 5.0 miles
- Timberline carries approximately 18,000 vehicles per day at Battle Creek and 34,000 vpd at Vermont

Timing Plans

Plan	Cycle Length (s)	Time-of-Day
AM Peak	110	6:45 - 11:00
Midday	100	11:00 - 15:00
PM Peak	120	15:00 - 19:45
Off-Peak	85	6:00-6:45 & 19:45-22:30
Saturday	85	7:00-9:30/19:30-23:00
	100	9:30 - 19:30
Sunday	85	7:45-10:30/18:30-22:30
	100	10:30 - 18:30

Signal Timing Results (From "Before/After" Weekday Travel Time Study)

Measure of Effectiveness (MOE)	AM	Mid-day	PM	Off-Peak	Week-end	Total
Travel Time Reduction	6.7%	10.9%	14.4%	-8.0%	31.3%	11.0%
Decreased Stops	25.0%	28.3%	28.6%	-68.8%	55.2%	35.2%
Increase in Average Speed	7.2%	12.4%	17.5%	-9.0%	49.7%	12.2%
Signal Delay Reduction	22.5%	28.7%	32.4%	-41.6%	58.8%	39.8%
Decreased Fuel Use and Emissions	6.1%	9.0%	10.5%	-15.0%	17.1%	7.0%

Corridor User and Community Benefits

Performance Measure	Daily Benefit	Wknd Benefit	Annual Benefit
Vehicle Hours of Travel (Hours Reduction)	369	405	115,203
Fuel Consumption (Gallons Decrease)	437	311	127,625
Time and Fuel Cost Savings	$8,456	$8,855	$2,616,737
Emissions (Pounds Reduction)	520	370	151,778

Corridor Operational Improvement Recommendations

1. Add SB right-turn lane at Horsetooth.
2. Add 2nd left-turn lane for NB left at Horsetooth.
3. Consider Flashing Yellow Arrow operation for N/S lefts at Horsetooth.
4. Add NB right-turn lane at Kechter Rd.

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