Executive Summary

The Metropolitan Government of Nashville and Davidson County's Department of Public Works (MPW) identified seven corridors in the County that experience heavy traffic congestion and needed traffic signal timing improvements to improve traffic flow as well as air quality and fuel consumption. These corridors included a total of 223 signalized intersections:

- Corridor 1 - Gallatin Pike (49 intersections)
- Corridor 2 - Murfreesboro Pike (41 intersections)
- Corridor 3 - Bell Road and Hickory Hollow Parkway (16 intersections)
- Corridor 4 - Nolensville Pike and Harding Place (34 intersections)
- Corridor 5 - 21st Avenue South / Hillsboro Pike (28 intersections)
- Corridor 6 - West End Avenue / Harding Road (33 intersections)
- Corridor 9 - Lebanon Pike and Andrew Jackson Parkway (22 intersections)

To conduct this study — termed the Traffic Signal Optimization Study for the Metro Nashville Signal System — MPW received funding from the federal congestion mitigation and air quality (CMAQ) program via the Nashville Area Metropolitan Planning Organization (MPO).

The CMAQ program was established in 1991 by the Intermodal Surface Transportation Efficiency Act (ISTEA) and was reauthorized in the Transportation Equity Act for the 21st Century (TEA-21). The CMAQ program funds transportation projects and programs that reduce transportation-related congestion and emissions in nonattainment areas (areas where air pollution levels exceed air quality standards) and maintenance areas (areas that meet and maintain air quality standards and are redesignated as attainment).

Since Davidson County is designated a maintenance area for the one-hour ozone standard and nonattainment for the eight-hour standard, it receives an annual allocation of CMAQ funds to be distributed by the MPO. This project is part of the Nashville Area MPO's CMAQ program and was wholly funded by this program at a cost of $750,000.

The consultant team MPW selected to conduct this study was Kimley-Horn and Associates, Inc., with Stammer Transportation Engineering, Inc. and Bowby & Associates, Inc. as part of the team. The project scope included significant data collection efforts, an assessment of existing conditions, identification of potential improvements, development of timing plans for each period of the day including weekdays and weekend, and field implementation of the proposed timing plans. In addition, the project included the development of MPW's Traffic Signal Timing and Phasing Policy, development and presentation of a two-part training program for MPW staff, travel time and delay studies, air quality analyses, and complete project documentation.

Results from the signal timing effort included a 20 percent reduction in delay for the seven corridors, with the greatest delay reduction of approximately 37 percent along the Nolensville Pike and Harding Place corridors. Benefits in reduced fuel consumption also were realized with this project. A reduction of nearly 6 percent in fuel consumption along the seven corridors was achieved. Furthermore, improvements in air quality were achieved. Volatile organic compounds were reduced by 3 percent, nitrogen oxides by approximately 1 percent, and carbon monoxide by nearly 1 percent. The total project achieved a one year benefit-to-cost ratio of 21:1. However, newly implemented signal timing plans prove to be beneficial for a time period longer than one year. In other words, the useful life for signal timing plans is three years. Therefore, the three year benefit-to-cost ratio increases to 62:1.

In conclusion, this signal timing optimization program proved to be beneficial in three distinct areas:

- Reduction in traffic congestion for Davidson County motorists
- Environmental improvements (i.e., improvements in air quality and a reduction in fuel consumption)
- Fiscally beneficial (i.e., the benefits greatly outweigh the costs)
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Project Background and Scope

Project Background

The Metropolitan Government of Nashville and Davidson County, Department of Public Works, Engineering Division (MPW) selected the Kimley-Horn and Associates, Inc. team to perform a traffic signal optimization study for seven arterial corridors within the metro Nashville signal system that includes 223 signalized intersections. The consultant team included staff from Kimley-Horn, Stammer Transportation Engineering, Inc., and Bowlby & Associates, Inc. MPW selected the Kimley-Horn team for this project and issued a notice to proceed in June 2004. The seven corridors studied were generally completed individually beginning with corridor 4 (Nolensville Pike/Harding Place). The project was completed in April 2006.

This project is part of the Nashville Area Metropolitan Planning Organization’s (MPO’s) transportation improvement program (TIP) and was funded through the congestion mitigation and air quality (CMAQ) program, which was established in 1991 by the Intermodal Surface Transportation Efficiency Act (ISTEA) and reauthorized in the Transportation Equity Act for the 21st Century (TEA-21). The CMAQ program was established to fund transportation projects and programs that reduce transportation-related congestion and emissions in nonattainment and maintenance areas. Davidson County is designated a maintenance area for the one-hour ozone standard and a nonattainment area for the eight-hour standard. Therefore, it receives an annual allocation of CMAQ funds to be distributed by MPO. This project is part of the Nashville Area MPO’s CMAQ program and was wholly funded by this program at a cost of $750,000.

Project Scope

The project involved studying the following seven arterial corridors throughout the county (see Figure 1):

- Corridor 1, Gallatin Pike with 49 intersections
- Corridor 2, Murfreesboro Pike with 41 intersections
- Corridor 3, Bell Road/Hickory Hollow Parkway with 16 intersections
- Corridor 4, Nolensville Pike/Harding Place with 34 intersections
- Corridor 5, 21st Avenue South/Hillsboro Pike with 28 intersections
- Corridor 6, West End Avenue/Harding Road with 33 intersections
- Corridor 9, Lebanon Pike/Andrew Jackson Parkway with 22 intersections

Figure 1, Project Location Map

The major components of this project included:

- Development of a traffic signal timing and phasing policy for MPW
- Training program for MPW staff
- Data collection
- Existing conditions evaluation
- Timing plan development
- Field implementation and fine tuning
- Travel time and delay study
Traffic Signal Timing and Phasing Policy and Training Program

Traffic Signal Timing and Phasing Policy

Kimley-Horn prepared a traffic signal timing and phasing policy for MPW. This document was developed by collecting and evaluating traffic signal timing and phasing policies, standards, and guidelines from various resources — the Federal Highway Administration (FHWA), the Institute of Transportation Engineers, and the Tennessee Department of Transportation (TDOT). In addition to these resources, a survey was conducted of peer agencies including the following:

- Chattanooga, Tennessee
- Knoxville, Tennessee
- Memphis, Tennessee
- Atlanta, Georgia
- Birmingham, Alabama
- Lexington — Fayette County Unified Government, Kentucky
- Louisville — Jefferson County Metro Government, Kentucky
- Newport News, Virginia
- Miami — Dade County, Florida
- Fort Worth, Texas
- Vacaville, California
- South Carolina Department of Transportation
- North Carolina Department of Transportation
- Kentucky Transportation Cabinet

By using the knowledge gained in the standards and peer agency review, policy standards were then developed for MPW for vehicle green times, vehicle clearance interval times, pedestrian times, left-turn phasing, split phasing, and pedestrian phasing. Kimley-Horn and MPW then collaborated to determine which standards best suited the needs of Nashville and Davidson County. The policy document was finalized and accepted in October 2004 (see Figure 2).

Training Program

Kimley-Horn developed and facilitated a two-day training course for MPW staff on Kimley-Horn’s approach to traffic signal timing procedures and on the applications and uses of the Synchro® and SimTraffic® software. Staff from Bowlby & Associates provided a training session on the air quality analysis and the MOBILE6® software.

The training sessions were conducted in September and October 2004 with nine members of the MPW staff attending.

Data Collection

This project required a tremendous amount of data to be collected. This was accomplished by staff from Stammer Transportation Engineering, Kimley-Horn, and MPW. The data collected included the following elements:

- Existing signal timings and operational settings
- As-built traffic signal plans or file drawings (where available)
- Signal controller user’s manuals, coding sheets, and software
- Aerial photography
- Turning movement counts for each intersection (AM, mid-day, and PM counts, two hours each)
Kimley-Horn then performed an operational analysis for each intersection in each corridor. The capacity analyses were consistent with the Highway Capacity Manual 2000 methodology when comparing improvement options. Existing and proposed signal phasing and sequencing were analyzed as well as identifying other possible operational improvements, such as pavement marking changes, geometric improvements, signal control equipment additions and/or upgrades, etc. Consideration was given to compliance issues with the FHWA Manual on Uniform Traffic Control Devices, 2003 Edition (MUTCD). This information was compiled in a technical memorandum that was submitted to MPW on a per corridor basis.

Timing Plan Development

New timing plans were developed for each corridor using the data previously collected. Typically, four timing plans were developed for each system — an AM, mid-day, PM, and off-peak plan. Consideration also was given to seasonal, special events, or weekend timing plans where appropriate. For example, a timing plan for Gallatin Pike and Rivergate Parkway was developed for the holiday shopping season in the Rivergate Mall area.

The development of the timing plans began with an evaluation of each corridor and its system boundaries. Each corridor was broken into multiple systems or zones to ensure the signals within each zone would operate in the same coordination pattern. The zone boundaries were established by Kimley-Horn with input from MPW staff. A number of criteria were used including ADT and turning movement count data, intersection spacing, cycle length requirements, driver expectancy, Synchro® coordination factors, coupling indices, and existing features.

Existing Conditions Evaluation

Prior to developing the new signal timing plans, it was important to understand and validate the existing conditions in each corridor. By using the data collected in the field and knowledge of the existing conditions observed in the field, a network was built for each peak period using Synchro®. All assumptions used in developing the models were documented and discussed with MPW staff, and all electronic files were provided to MPW staff. The existing conditions of the signals along each corridor were analyzed in a manner consistent with the Highway Capacity Manual 2000 methodologies.
Once the zones were established, cycle lengths were determined for each zone and for each proposed timing plan. This was accomplished by the use of Synchro® cycle length evaluations, knowledge gained from field observations, and professional judgment. Proposed cycle lengths were discussed with MPW staff and documented in a memorandum submitted to MPW.

After the cycle lengths were determined, the optimal phase split times were established. This data was entered into the Synchro® model and then the phase sequences and offsets were evaluated to maximize the arterial greenband widths, thus reducing vehicle stops and delay. Greenbands were adjusted to accommodate the directional split of traffic on the arterial roadway for the AM and PM timing plans, while the mid-day and off-peak timing plans were generally optimized for two-way progression on the arterial roadway. MPW staff reviewed the proposed timing plans and approved them prior to field implementation.

The final component to the timing plans was the time-of-day clock settings for the new timing plans. This determines the optimal timing plan for each hour of a typical weekday and weekend day and were made by evaluating the 24-hour ADT tube count data and from field observations. These recommendations were submitted to MPW staff and approved prior to implementation.

The final step prior to field implementation of the new timing plans was to prepare coding sheets for each intersection. Kimley-Horn transferred the proposed timing plans from the Synchro® model into a format compatible with MPW’s traffic signal controller software database programs. This data was recorded on coding sheets that were developed by Kimley-Horn in Excel® to replicate the traffic signal controller software input screens. This resulted in coding sheets for MPW’s Peek 3000 series of signal controllers and the TCT LMD 8000 series of signal controllers (see Figure 3). Coding sheets were submitted to MPW prior to field implementation in an electronic format. MPW then entered the new timing plans into the traffic signal controller database.

Field Implementation

Field implementation began with downloading the newly developed timing plans to each traffic signal controller. Kimley-Horn and MPW made field observations to determine the effectiveness of these timing plans over a course of several days for each corridor. Observations were made during all time periods of the day, during each timing plan, and at transition times between timing plans. Using time-space diagrams, each timing plan was verified for its effectiveness (see Figure 4). These field observations served as a quality control measure for the new timing plans, and as a way to fine-tune the timing plans. Potential changes were evaluated on site by Kimley-Horn and discussed with MPW. Changes were then typically made by MPW staff from the central office, which included offset adjustments and split allocation changes. Less common changes were time-of-day clock settings and cycle lengths.

The field implementation observations and edits made while in the field were documented in a memorandum submitted to MPW. The Synchro® model also was submitted to reflect the implemented timing plans.

Project Results

To quantify the results and to evaluate the effectiveness of the newly implemented timing plans, a before and after travel time study was conducted. This study provided actual travel times along the arterial roadways — not the theoretical output from the model. Prior to implementing
the timing plans, multiple sets of travel time data were collected during the AM, mid-day, and PM peak periods for each of the arterial roadways in each corridor. This process was repeated several weeks after the timing plans were implemented and the results from these sets of data were analyzed.

**Travel Time Study**

The travel time study provided the data necessary for a delay study, a fuel consumption analysis, and an air quality analysis. For each corridor, delay reductions were calculated for each arterial roadway for each of the three peak periods in each direction. For the project as a whole, the individual amounts of delay were summed for before and after conditions. The percent change in delay for the entire project was approximately 20 percent. A similar study was made on fuel consumption changes due to the improved traffic signal timings.

The delay reductions for the project ranged from approximately 37 percent to 5 percent by corridor (see Figure 5). Five of the corridors studied showed delay reductions above 20 percent. For corridor 4 (Nolensville Pike and Harding Place), the improved signal timing plans yielded dramatic improvements in reduced delay as well as emissions and fuel consumption. This corridor is a major arterial roadway that provides access to the Nashville central business district from the southern portion of Davidson County. The significant improvements realized for this corridor benefit a large number of motorists who commute along this route.

The individual corridor results also indicate that two of the corridors — corridor 5 (21st Avenue/Hillsboro Pike and Blakemore Avenue/Wedgewood Avenue) and corridor 6 (West End Avenue/Harding Road) — did not benefit from the revised timing plans as much as the other five corridors. This may be explained by the nature of these two corridors. They are either near or at capacity during
the peak periods of the day, both have sections with closer than desirable intersection spacing, and have high amounts of pedestrian activity. Also, a shorter cycle length was implemented on portions of these two corridors. This decreased side street delay, but may have increased delay on the arterial roadway. Pedestrian timings were reviewed and modified along the corridors as per the new MPW Traffic Signal Timing and Phasing Policy, which enhanced safety. This policy is based upon new national standards for calculating pedestrian clearance times that were implemented with this project. This results in more time being allocated for the pedestrian crossings and the side street vehicles, which results in increased vehicle delay on the main street. Pedestrian traffic is significant in these corridors and these modifications to accommodate pedestrians and the negative impact on the motorists is warranted. This type of balance of pedestrian and vehicle accommodations is typical for urban corridors.

**Air Quality and Fuel Consumption Analysis**

Bowlby & Associates provided the fuel consumption analysis and the air quality analysis for this project. The results of the fuel consumption analysis for the whole project was a reduction of 5.7 percent. By using the data from the travel time study, an air quality analysis was conducted by using the MOBILE6® software and methodologies from the U.S. Environmental Protection Agency. For the entire project, volatile organic compounds were reduced by 3.0 percent, nitrogen oxides by 1.2 percent, and carbon monoxide by 0.7 percent. Figure 6 illustrates the fuel consumption and air quality percent reductions for each corridor.

It is expected that the actual emissions reductions will be higher than the predicted emissions reductions because MOBILE6® is not a truly "modal" model and does not have the ability to estimate changes in pollutant emissions that result from changes in modal (i.e., acceleration and deceleration) activity on a specific corridor. The new signal timing plans have reduced the number and duration of acceleration and deceleration events on the study corridors and the emissions reductions resulting from

![Figure 6, Fuel Consumption and Air Quality Percent Reductions for Each Corridor](image-url)
eliminating or reducing these modal events could be significant. However, these emissions reductions can not be accurately predicted using MOBILE6®.

**Economic Analysis**

Based on the results from the delay study, fuel consumption analysis, and the air quality analysis, an economic evaluation was conducted for the project to determine what benefits arose from the implementation of the new signal timing plans. The benefits studied included a reduced road user cost from reduced delay experienced by the motoring public, air pollutants, and fuel consumption. To determine these economic benefits, Kimley-Horn studied the AM, mid-day, and PM peak periods of the weekdays because of the available travel time study. Therefore, economic benefits were not quantified for the nonpeak hours of the delay and is not reflected in this analysis.

To calculate the cost savings resulting in the reduction of delay by the motoring public, a dollar value was assigned to the delay. The United States Department of Transportation provides data for this purpose. Using this data, analyses were made for each corridor in the project, and these results were tallied to yield a benefit in terms of reduced delay for the entire project. For a one-year period this benefit was calculated to be $14,770,900.

Economic benefits also were realized for the reduced emissions that resulted from the improved signal timing plans. This was calculated by assigning a cost to each of the three pollutants, as documented by FHWA. For the entire project, over a one-year period the benefit was found to be $33,655.

Similarly, the economic benefit was determined for the reduced fuel consumption. A conservative value of $2.00 per gallon of fuel was used for this analysis. For the whole project, this was found to be $637,630 for a one-year timeframe.

By using an engineering fee for this project, a benefit-to-cost ratio was calculated. The benefits were the sum of the delay, emissions, and fuel benefits over a one-year timeframe totaling $15,442,180. The cost was the contract value for the project — $750,000. This yielded a one year benefit-to-cost ratio of 21:1. However, the newly implemented signal timing plans will be used and prove to be beneficial for a time period longer than one year. Typically the useful life for signal timing plans is believed to be three years. A recent ITE Journal article states, “At a minimum, an operating agency should budget to retime traffic signals at least every three years.” Therefore, the three-year benefit is $46,326,550, while the cost remains only $750,000. This yields a three-year benefit-to-cost ratio of 62:1. Figure 7 shows the breakdown of the benefit-to-cost ratio for each corridor:

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Conclusions

The implementation of the traffic signal timing optimization study for the MPW Nashville signal system has proven to be beneficial to Davidson County motorists based upon the project results discussed. Hence, the traffic signal retiming effort has been a cost-effective way to improve traffic flow along the project corridors such that it has reduced travel times, delays, and vehicle stops. Furthermore, this project has achieved fuel consumption and emissions reductions, both of which are improvements to the environment. In addition, this project has proven to be financially beneficial in that the yearly benefit of the signal retiming effort greatly outweighs the cost (i.e., a yearly benefit-to-cost ratio of 21:1). In essence, this program has achieved the goals outlined in the federal CMAQ program as authorized in TEA-21.

Figure 7. Benefit to Cost Ratio