TITLE: Analyzing System Travel Time in Arterial Corridors with Unconventional Designs Using Microscopic Simulation

AUTHORS: Jonathan D. Reid, Parsons Brinckerhoff
Joseph E. Hummer, North Carolina State Univ.

INTRODUCTION

Many metropolitan areas in the United States are experiencing explosive vehicular volume growth on major arterials. Several decades of steady increases in vehicle miles traveled (VMT), heightened freeway congestion and expanded urban centers have all increased the traffic-carrying importance of major arterials. This places a greater modern-day burden on these arterials to carry more long-distance vehicle trips and greater volumes. Paramount to providing optimal traffic operations is the ability of roadway designs and traffic signal systems to progress traffic along these major arterials.

This paper analyzes and compares traffic operations along a typical arterial under conventional and alternative geometric designs. The analysts compare two "unconventional" or "alternative" arterial designs to the conventional the two-way left turn lane (TWLTL) arterial design most prevalent across America. The analysts studied the alternative designs for their potential to provide an overall reduction in system travel times and other critical traffic operation measures of effectiveness (MOE's).

This paper only focused on the traffic operations of each corridor and ignored other issues such as design safety, driver expectation, right-of-way requirements and construction costs. Other operational or social-economic impacts outside of traffic operations and travel time (e.g., safety, pedestrian, land use impacts etc.) are beyond the scope of this research. Some guidance to these impacts can be obtained in other published materials on this subject matter.

The endeavor of this paper is application driven. The results are intended to model the traffic operations and travel time impacts of the alternative designs presented, which is needed as they are used in only spot locations (or not at all) across the country. The authors encourage further study into the theory of these design implications on arterial traffic operations.

ALTERNATIVE ARTERIAL DESIGNS CONSIDERED

The analysis compared two alternative arterial design strategies to the traditional TWLTL and divided highway designs, which constitute the vast majority of multi-lane arterials built in the United States. The two alternative arterial designs considered were the Median U-Turn Crossover design (MUT) and the Super-Street Median Crossover design (SSM).

A recent study of several alternative intersection geometric designs modeled capacity and delay measures of effectiveness of alternative geometrics (including the MUT and SSM designs) at *isolated* intersections (1). The report identified the MUT geometry as having the potential to improve intersection stopped delay. One of the unanswered questions raised in this report was, "Do the increased opportunities for progression offered by the unconventional alternatives that reduce signal phases result in still greater efficiency than the demonstrated herein for individual intersections? In particular, how well would a super-street, made up of a series of three-leg median U-turn crossover intersections allowing each direction of an arterial to progress independently, perform?" (1)

This study seeks to answer precisely that question. It is also an effort to quantify the system-wide benefits (or disbenefits) of the MUT and SSM geometric designs over a *system* of signals, as common on urban and suburban arterials throughout the United States. The study uses the Federal Highway

Administration CORSIM traffic modeling software for its abilities to report precise measures of effectiveness and use stochastic processes for detailed network analysis (2). Boone and Hummer have shown that CORSIM can adequately model MUT designs, producing MOE's similar to field measurements (3). Other review of current literature is sparse because modeling capabilities and data input optimization methods have only recently been capable of large network analysis. The Boone and Hummer 1994 TRB publication indicated the need for the research and analysis provided in this paper (1).

The following paragraphs describe each of the geometric alternatives used in this analysis, including a brief description of geometric and signal operations, and a summary of the potential advantages and disadvantages associated with each alternative.

Traditional Continuous Center Turn Lane and Divided Highways

By far the most commonly arterial designs are the TWLTL and divided highway, which includes the use of multi-phase signals to provide for all movements at major intersections. The analysts considered the TWLTL and the divided highway designs to be essentially the same design, as they share the same operational characteristics at signalized intersections. Both are subject to multi-phase signals at all signalized intersections. The divided highway may introduce U-turns at the intersection, but the impact to the intersection operational capabilities in most cases is negligible.

The strengths of the TWLTL and divided highway designs include:

- provision for all direct movements at each intersection
- a standardized design familiar to drivers
- permitting direct access for most or all roadside development

The typical TWLTL arterial design consists of either five or seven lanes, with two or three through lanes in each direction and a center common left-turn lane. Multi-phase signals at major intersections can be semi- or fully-actuated to optimize effective green time for the major roadway. Many multi-lane arterials also use extensive surveillance and detection equipment to try to optimize through travel progression on the arterial. This is most effective for dominant directional flows if the traffic split is unbalanced, as is often the case on arterials leading into and out of a major commerce district or downtown areas during the rush hour commute.

There are some disadvantages to TWLTL and divided highway designs:

- Balanced arterial flows are difficult to progress through a series of closely spaced traffic signals.
- Intersections with heavy turn movements (particularly left turns) require additional movement capacity that diminishes the green time for through movements and minimizes bandwidth opportunities for progression.

The Median U-turn Crossover Design

The MUT design has existed for over 30 years, with its predominant use in the State of Michigan (4). The Michigan Department of Transportation (MDOT) currently has over 1,000 miles in service, and continues to design them. The key function of the MUT is that the design removes all left turn movements at intersections along the arterial. Left-turning vehicles from the cross street must turn right onto the arterial, make a U-turn at a crossover designed into the median of the roadway and pass through the cross-street intersection. Similarly, left turns from the arterial must travel “past” the cross street intersection, make a U-turn at a crossover, and then turn right onto the cross street. There are several variations of the MUT design, including placing U-turn crossovers on the arterial only, placing them on the cross street only, or both. The geometry depends on the availability of right-of-way or existing/planned land use at the intersection. Figure 1 depicts the most prominent MUT designs.

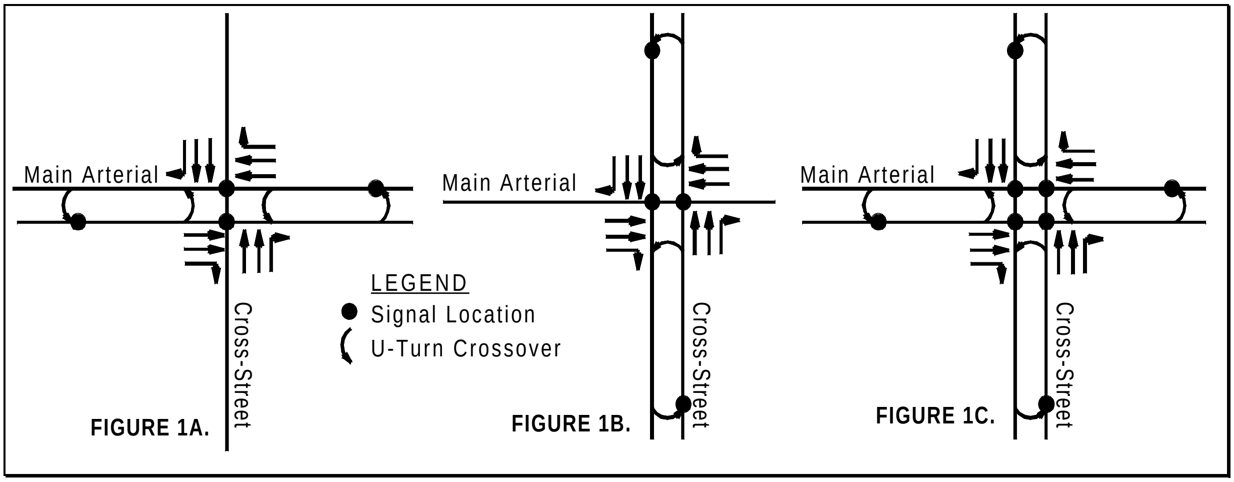

Figure 1 --Typical Median U-turn Crossover Designs

The removal of all left turns at the major intersections creates two-phase signal operation at all intersections. Boone and Hummer noted that the reduction in phases caused a reduction in cycle lengths (and there-by queue lengths) and increases progression opportunities on both roadways (1). In this analysis, signal optimization software selected a lower cycle length for the MUT alternative compared to the TWLTL design, each using the same volume conditions. Table 1 shows the system fixed-time cycle lengths chosen by SYNCHRO for each geometric and time-period scenario studied. A later section details the signal optimization process using SYNCHRO (4).

Table 1 -- SYNCHRO Optimal Cycle Lengths, sec.

Time Period	TWLTL	MUT	SSM
AM peak	160	110	120
Noon hour	90	60	60
Mid-day	80	60	60
PM peak	170	110	110

Compared to conventional protected signal operations at TWLTL intersections, a two-phase signal eliminates two signal lost periods per cycle, estimated at 3-4 seconds each depending on the length of the yellow and all-red phasing requirements and the width of the intersection.

This may seem as a proof of the obvious, that two-phase signal operations at intersections are more efficient than four-phase signals. However many transportation agencies argue that the penalty to left turns (the added travel distance) on the studied arterial alternatives negate the benefits from a reduction in the number of phases. The consequences of the U-turns are taken into account in the system-wide travel time comparison for the conventional versus alternative designs, detailed later in this paper.

The MUT design eliminates all permissive movements at the intersection, which may or not be permissive for high-speed conventional designs. Judgement is left to the local or state engineering agency to provide signalized (protected) or unsignalized (unprotected) control at the major U-turn crossover locations. States may review their policy allowing permissive left turns onto one-way facilities without major consequence to the efficient operations of these designs. Otherwise, the conditions are the same at unsignalized access points on any standard divided highway in the country. Note that additional signals at the crossovers may be added as needed according to crossover and arterial volume demands. It is then possible to synchronize these signals to provide perfect progression with the signals at the major intersection.

A summary of some of the advantages of the MUT design includes:

- The removal of left turns at the intersections allows for simple, two-phase signal operations.
- Two phase signals create more progression opportunities, and can be timed to allow perfect progression in at least one direction of travel (4)
- Potential reduction in delay to through volumes on the arterial
- Fewer intersection vehicular conflict points, and a probable reduction in left-turn or head-on collisions
- Greater potential for visual aesthetics

Noted disadvantages of MUT design include:

- Left turn vehicles must pass through the intersection twice (increased VMT) with the potential for increased delay to left turning vehicles -- particularly in low-volume conditions -- compared to the traditional multi-lane cross-section
- Greater possibility of driver confusion or error at critical (intersection) locations
- Requires twenty-five to fifty more feet of right-of-way than the conventional multi-lane arterial
- Generally less desirable to street-side businesses who rely on ease of access for “pass-by” trips

Super-Street Median Crossover Design

The SSM design is similar to the MUT design, but has some added features that allow for perfect progression of through traffic on the arterial in both directions (6). The SSM design features a break in cross-street traffic that allows the signals in both directions on the arterial to operate independently. As is the case for MUT designs, there are also several variations of SSM arterial designs, as illustrated in Figure 2.

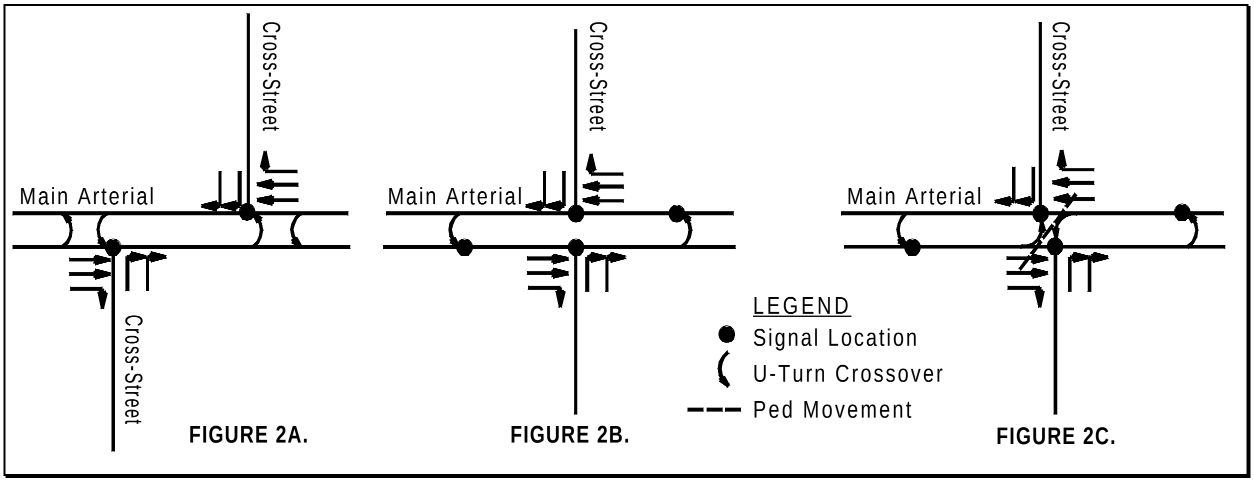

Figure 2 -- Super-Street Arterial Geometric Designs

When cross-street through-volumes are relatively low, it is advantageous to interrupt through cross street traffic on the arterial. Through trips require a right-turn onto the arterial, a left-turn via the median crossover, and then a right-turn onto the cross-street (Figure 2b). At higher volume cross street intersections, an offset SSM intersection design (Figure 2a) can move through traffic more efficiently. Left-turns from the arterial occur directly onto the cross street in Figures 2a and 2c.

While the super-street design and the potential for benefits to progression on the arterial appear feasible, to the author's knowledge no one has constructed an entire arterial section using super-street geometry.

Some of the advantages of the SSM design include:

- As with the MUT design, the intersections operate with simple, two-phase signals
- The independence of each signal at the cross-streets enables perfect progression on the arterial in *both* directions at any cross-street spacing. Each direction can even operate with differing cycle lengths

Disadvantages of the SSM design include:

- Potential for increased delay and more frequent stops for through traffic on the cross-streets.
- Potential confusion over the discontinuity in the cross-street
- Difficulty in providing the necessary capacity with high cross-street through traffic
- Some versions of the design are unfriendly to pedestrians, as pedestrians are forced to wait through two cycles or use unsignalized crossings
- Requires twenty-five to fifty more feet of right-of-way than the conventional multi-lane arterial
- Potentially harmful to roadside businesses which rely on "pass-by" trips

THE NORTHWESTERN HIGHWAY CORRIDOR

To test the three alternatives, the authors chose a typical suburban corridor. Controlling the traffic demands and major physical features such as cross streets, the authors were able to simulate all three alternatives and compare key MOE's. The arterial chosen as a basis for the arterial traffic model was Northwestern Highway, located in a northwest suburb of Detroit, Michigan. The primary reason for this choice was the availability of detailed traffic count data. The Michigan Department of Transportation (MDOT) performed an operational study for this corridor in 1995 to examine a future-widening project, and the authors obtained the data from that study.

The corridor is currently a MUT design, which aided in the modeling of the MUT alternative. The basic cross-section has four-lanes, with a six-lane section at the eastern end of the corridor. Typical median width is 80 feet, and the roadway lies within 180 feet of right-of-way. The section of the corridor modeled is approximately 2.5 miles long. There are five major (signalized) intersections on Northwestern Highway in study area. The speed limit on Northwestern Highway is 50 MPH and cross street speed limits range from 35 to 45 MPH.

The estimated ADT for the studied section of Northwestern Highway is 52,000 at the western end of the corridor and 60,000 at the eastern end, based upon the counts provided in the MDOT study. Directional flow is predominantly eastbound during the morning peak hours. However, the presence of many large offices and shopping developments along the corridor provides for balanced flows throughout the remainder of the day.

Another reason for the choice of corridor is the presence of varied intersection spacing. A criticism of studies based upon MUT designs in Michigan is that those arterials have equal one-mile or half-mile intersection spacing. This is due to the cardinal-direction grid-system of roads constructed in most of southeast Michigan, where MUT corridors are most prevalent. Due to the angular alignment of the Northwestern Highway corridor that cuts northwest to southeast across the directional grid system in the area, the corridor has varied signal spacing, ranging from 1,600 to 3,500 ft.

Northwestern CORSIM Model

The analysts modeled the corridor using the ITRAF input editor for CORSIM (7). For the MUT design alternative, the analysts' model followed the existing corridor as closely as possible, including all major intersections, U-turn crossover locations and most driveway locations. Some minor geometric modifications were necessary based upon the analysts' knowledge of CORSIM's difficulty in modeling closely spaced intersections and driveways. Also, the CORSIM model did not consider intersection angles at the cross street for reasons of simplification.

Figure 3 illustrates the link-node diagrams used as a basis for input into the CORSIM model. Only the western two intersections of the arterial are depicted to show the different node coordinates among the three alternative models.

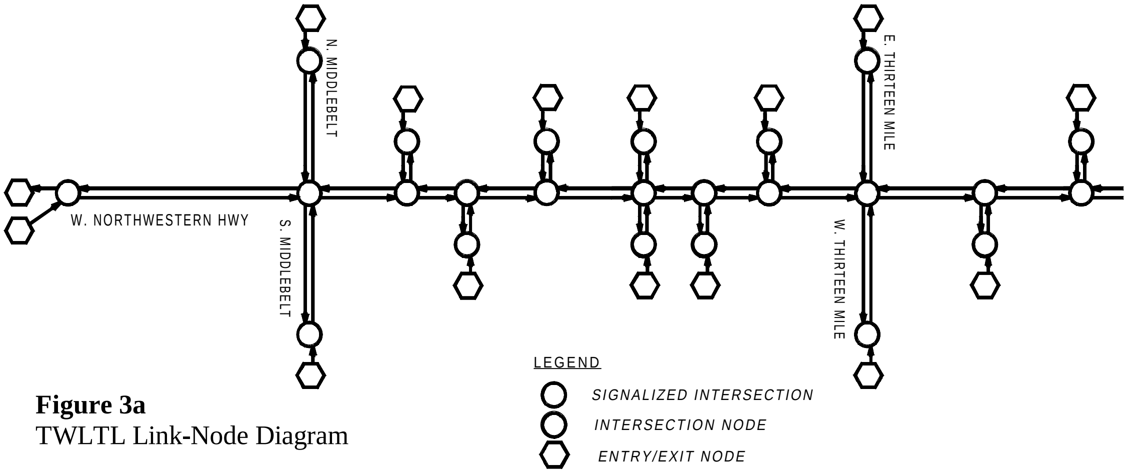

Figure 3a
TWLTL Link-Node Diagram

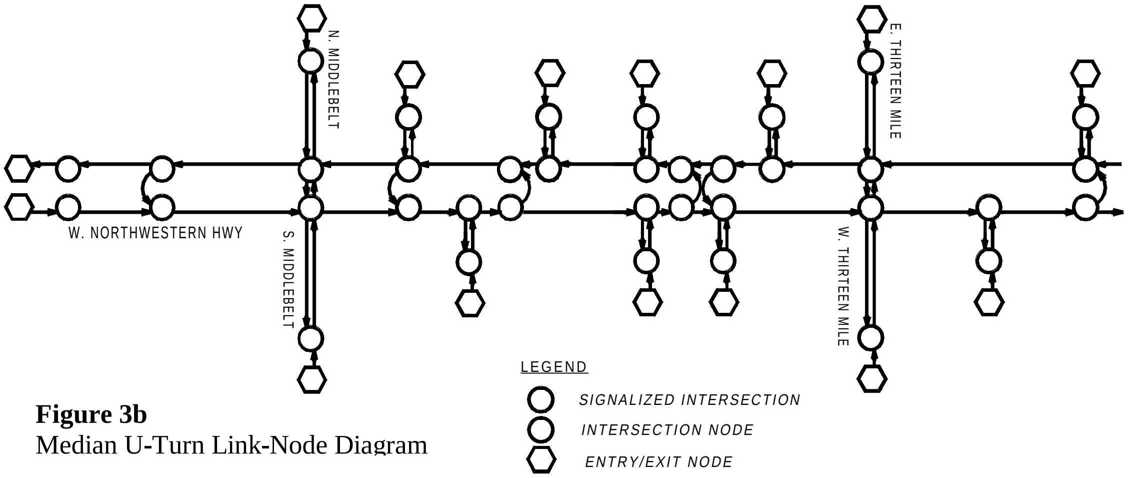

Figure 3b
Median U-Turn Link-Node Diagram

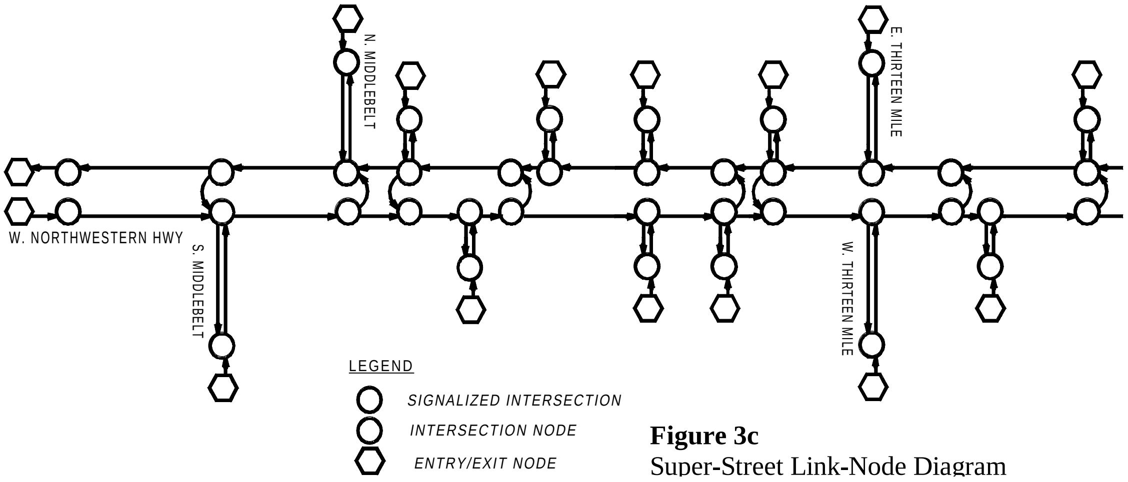

Figure 3c
Super-Street Link-Node Diagram

Figure 3 -- Geometric Alternative Link-Node Diagrams

The TWLTL simulation model assumed the same basic arterial and cross-street geometrics and driveway locations as the MUT. The analyst removed the median width in the MUT model, and included a center left-turn lane at all driveway and intersection locations. Because the CORSIM model does not allow opposite direction vehicles to share a common lane (as in the case with a continuous center turn lane), both directions were modeled with an exclusive left-turn "bay" at each intersection. In most cases, the bay extended the entire length of the link. Therefore, the arterial may appear to have six lanes in TRAFVU (the simulation graphic software included in the CORSIM software package), but has the same operational characteristics as the standard five-lane corridor.

The traffic simulation model for the SSM alternative used the designs in Figures 2a and 2b. Three intersections used the discontinuity geometry as depicted in Figure 2b. One used the offset design in Figure 2a. The busiest intersection used a standard MUT geometry due to very high through-trip and intersection volumes, and therefore was the controlling intersection for signal offsets along the system in both directions.

Construction of the Traffic Models

The analyst constructed each model in ITRAF to include entry and exit nodes at a fixed point in space. The fixed external-node coordinate system combined with fixed origin-destination volume model, allowed an equitable comparison between the arterial design alternatives, using system-wide MOE's. Specific comparisons of individual intersection or driveway delay were unimportant: the comparison sought was for overall system MOE's.

The authors used the Traffic Assignment feature of CORSIM to determine intersection volumes for each time period and volume scenario. The analyst manipulated the origin-destination volumes using a spreadsheet, and converted the volumes into proper CORSIM text format for insertion into the model. Presently, the Traffic Assignment environment determines only turning movement percentages at every intersection. CORSIM cannot fix the path of vehicles entering the system. Software engineers are aware of the need for true origin-destination modeling and are working to incorporate this feature in the next generation of the CORSIM software.

The roadway volumes inbound to the system originated from the intersection count data provided by the MDOT operational study. The known turning movements were helpful in assignment of realistic origin-destination paths for the corridor. Land-use information collected from a visit to the site and arterial photography of the corridor helped determine driveway volumes used in the analysis scenarios. Existing land-uses, grouped by size into several major categories formulated a basis for assigning trip rates based upon the ITE Trip Generation Manual (8). The known driveway roadway and driveway inputs aided in determining an origin destination matrix based upon the available outbound trips, so that the inbound and outbound trips were equal for the system. The reader should keep in mind that the methodology used in generating the trip rates for each scenario is not as important as the fact that each of the three geometric scenarios used the same volume input scenario.

The authors used this methodology to generate traffic for four time periods including:

- the morning peak-hour period (8:00am to 9:00am)
- the noon-hour period (12:00pm to 1:00pm)
- the mid-day period (2:00pm to 3:00pm), and
- the afternoon peak-hour period (5:00pm to 6:00pm)

Further, within each time period the authors employed four different “volume scenarios” by varying the intensity of the driveway volumes and through-trip percentages. The analyst defined a through trip as a trip that originated on Northwestern at either end of the corridor and preceded through the entire 2.5-mile corridor without turning onto any cross street or driveway. Through trip percentages used ranged from ten to twenty-five percent. These through-trip assumptions used are unfortunately typical for a suburban arterial corridor with much retail and commercial development. The analysts did not want to bias the analysis in favor of the MUT and SSM alternatives by assuming higher percentages of through trips. The lower through-trip percentages serve as a test of the lower limits of the geometric alternatives, which favors the traditional TWLTL design. Table 2 shows the variation of volumes in each volume scenario by showing movement and intersection volumes for a typical intersection during the AM time of day. Figure 4 illustrates the highest volume scenario turning movement arterial volumes for each geometric alternative.

Table 2 – Turning Movement Volume Variation by Volume Scenario

	EASTBOUND NORTHWESTERN			**WESTBOUND NORTHWESTERN**			**NORTHBOUND THIRTEEN MILE**			**SOUTHBOUND THIRTEEN MILE**			**INTRSECT TOTAL**
SCENARIO	*LT*	*THRU*	*RT*	*LT*	*THRU*	*RT*	*LT*	*THRU*	*RT*	*LT*	*THRU*	*RT*	*TOTAL*
1	319	1,915	224	200	1,061	146	24	225	63	64	173	46	4,460
2	106	2,228	65	134	1,292	134	24	225	63	64	173	46	4,614
3	290	2,051	196	193	1,309	153	21	225	66	67	173	43	4,787
4	55	2,462	20	120	1,565	98	21	225	66	67	173	43	4,915

The analysts formulated the intersection signal timing and offsets for each geometric alternative using SYNCHRO. The analyst chose the SYNCHRO model for its ability to optimize timings and offsets for an arterial network and output the results into a CORSIM file. Also, SYNCHRO has become a widely used signal optimization package recently in North Carolina, and is used by the NCDOT. The ability to optimize signal timing for the highest volume scenario in each time period was paramount to an equitable comparison of key MOE’s.

Three “dummy” SYNCHRO roadway models created (one for each geometric alternative) contained each signalized intersection within the given corridor, using the same node numbering scheme as the CORSIM model. The analyst used SYNCHRO to optimize each arterial network cycle length in ten-second intervals between 60 and 180 seconds. As noted previously, Table 1 shows the optimal cycle lengths chosen for each alternative.

Intersection parameters included protected, lead-only left turns for the continuous left-turn scenario alternative, which is consistent with general signal timing practice for high-volume corridors. The analyst included overlap phasing based upon the length of the corresponding left-turn phase. Each alternative allowed right turns on red at most locations.

A unique situation arose in simulating the median U-turn and super-street alternatives. In the field, these designs allow left-tuns on red at each crossover location. The coding in CORSIM does not allow for this situation. The analysts modified the approach geometry at each median crossover to “trick” the model into thinking the downstream node is to the left while coding it for a right turn movement. Therefore the left turn movements took advantage of the “right-turn-on-red” capabilities in CORSIM.

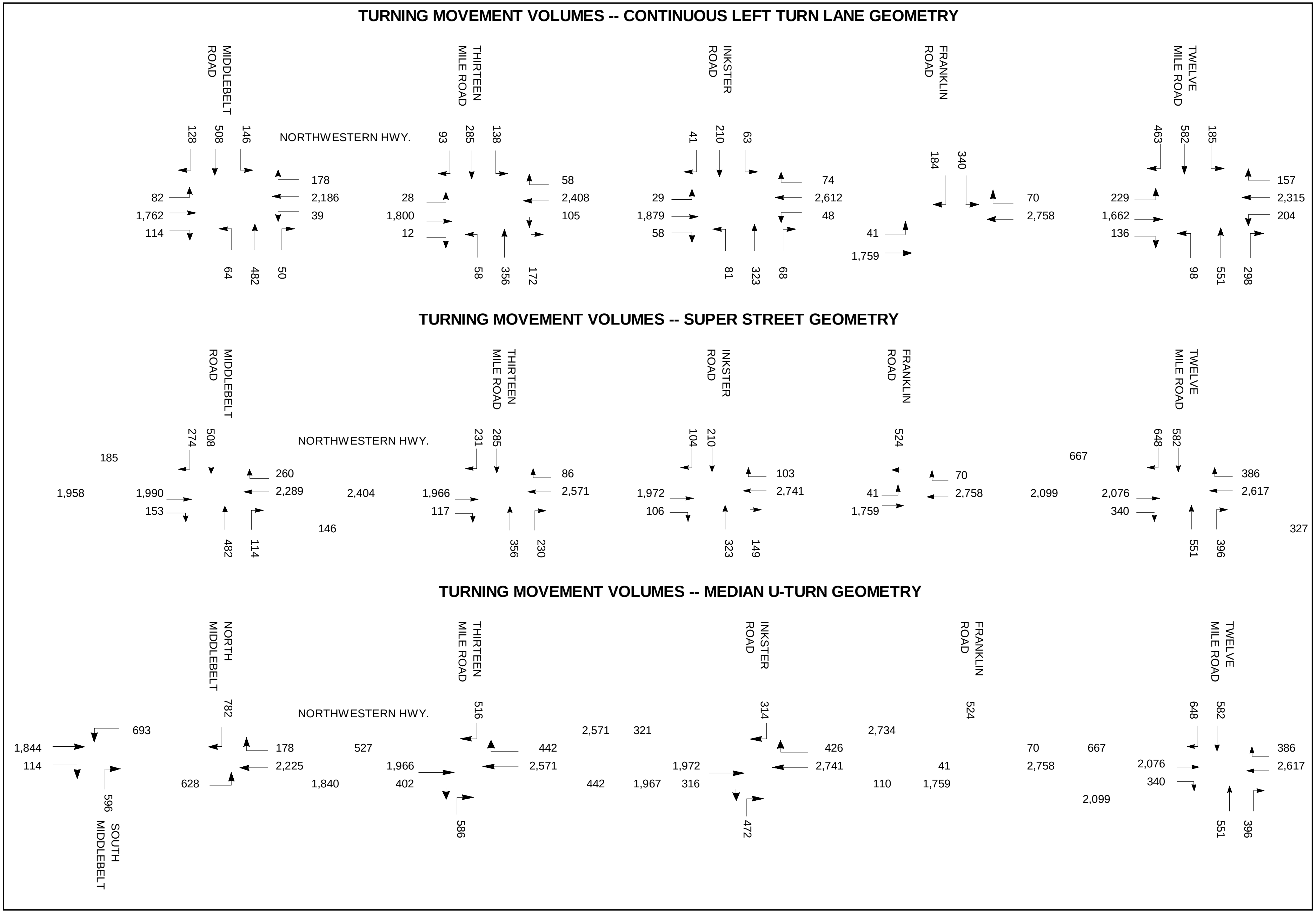

Figure 4 -- Highest Volume Turning Movement Count by Geometric Alternative

Each CORSIM run was 30 minutes, formed using three ten-minute intervals. The middle time-interval included a peaking factor for traffic volumes, so that peak queuing conditions would be included in the run results. The final experiment had 144 half-hour long CORSIM runs in a full factorial experiment design with three replications. There were three levels of geometry, four levels of time of day and four levels of through volume scenarios. The authors used the same random number seeds for the three replications in all 48 cells.

In order to verify that the travel time results produced in the CORSIM analysis did not consider only system travel time at the sacrifice of individual movements in the analysis of the alternatives, the analysts scanned the output results for the highest-volume scenario to find individual movements with triple-digit delays (i.e. beyond level of service F operations). The search did not include through movement delays on the arterial. The conventional design had 21 driveway or cross-street locations with 100-plus seconds average delay. The MUT design had 6 such locations (none new compared to the conventional design), and the SMM design had 9 such locations, also at locations with 100-plus seconds average delay under the conventional design. This verified the analyst's assumption that the improvement in system-wide travel times was a benefit to all movements along the corridor.

The complete report on this subject includes the results of the individual movements' delay by alternative. There were no overly delayed movements in the analysis results for any of the alternatives. Further, the methodology in optimizing the arterial network did not overtly favor arterial travel times by sacrificing cross-street delay. This information is absent from the paper, and will be integrated in the final form.

ANALYSIS RESULTS

The analyst tested several measures of effectiveness using analysis of variance (ANOVA) to determine the importance of arterial geometry related to system travel time, average stops per vehicle and average speeds for the network (9).

Results by Geometry

The ANOVA results for system travel time, number of stops and average speed indicated that the arterial geometry was a significant factor at a 99.99 percent level of confidence for each dependent variable. Table 3 provides mean values of the system travel time, average number of stops and average speeds for each geometry. Each cell in Table 3 represents the mean from 48 CORSIM runs.

Table 3 -- Average System MOE's by Geometry

ALTERNATIVE GEOMETRY	SYSTEM TIME, VEH-HRS	AVERAGE NO. OF STOPS PER VEH	AVERAGE SPEED, MPH
TWLTL	251.0	1.76	19.6
MUT	207.7	1.94	24.4
SSM	225.9	2.17	22.5

The results indicate that the MUT and SSM geometric designs improved both system travel time and average speed compared to the TWLTL design. The MUT system showed a seventeen-percent decrease in system travel compared to the TWLTL design, while the SSM showed a ten- percent decrease. Average speeds for the system also increased nearly twenty-five percent for the MUT alternative and nearly fifteen percent for the SSM compared to the TWLTL design.

The average number of stops increased for both the MUT and SSM designs. These alternatives should have increased stops because of the increased turning movements required for left-turning vehicles, and through vehicles in the case of the SSM design.

Multiple Factor Interactions

ANOVA results indicated that the two-factor interactions including geometry were significant to the 99.99 confidence level for all three dependent variables of interest. Table 4 summarizes the results for geometry by time of day, with each entry in the table representing the mean from 12 CORSIM runs.

Table 4 -- Two-Way Interactions: Moe's By Geometry and Time of Day Factors

GEOMETRY BY TIME OF DAY	TOTAL SYSTEM TIME, VEH-MIN	AVERAGE NUMBER OF STOPS	AVERAGE SPEED, MPH
AM PEAK			
TWLTL	302.1	1.95	14.5
MUT	254.3	1.98	22.4
SSM	282.7	2.36	18.2
NOON			
TWLTL	136.4	1.45	25.9
MUT	136.9	1.75	28.5
SSM	142.4	1.84	27.4
MID-DAY			
TWLTL	162.4	1.53	24.6
MUT	158.8	1.82	27.3
SSM	164.3	1.86	27.0
PM PEAK			
TWLTL	402.8	2.08	13.3
MUT	280.5	2.19	19.2
SSM	314.0	2.59	17.3

The results in Table 4 show that the MUT and SSM alternatives produced a reduction in travel time and an increase in average speeds during the A.M. peak and P.M. peak hours, when the volumes in the system volumes were greatest. This is consistent with the authors' hypothesis that the alternative designs can more efficiently handle high volumes of traffic in a corridor during peak hours.

The results of the off-peak MOE comparisons may be even more important than the peak hour comparisons. During the noon and mid-day hours analyzed, the system travel times of the MUT and SSM designs were very similar, and even showed a slight increase in system speed. This is important because the conventional wisdom holds that the MUT design is less efficient during the off-peak hours because of extra delay to left-turning vehicles. However, these study results indicate that the MUT and SSM designs operated with similar efficiency to the TWLTL during the off-peak hours.

The analysts also looked at the geometry by volume scenario two-way interactions. Table 5 summarizes the results for geometry by volume scenario, consisting of 12 runs per entry in the table.

Table 5 -- Two-Way Interactions: MOE's by Geometry and Time of Day Factors

GEOMETRY BY VOL. SCENARIO	TOTAL SYSTEM TIME, VEH-MIN	AVERAGE NUMBER OF STOPS	AVERAGE SPEED, MPH
VOLUME 1			
TWLTL	255.8	1.9	17.6
MUT	191.1	1.9	24.9
SSM	220.3	2.1	22.6
VOLUME 2			
TWLTL	239.1	1.6	21.6
MUT	201.3	1.8	25.5
SSM	224.7	2.2	23.2
VOLUME 3			
TWLTL	248.4	1.8	18.4
MUT	209.8	1.9	24.2
SSM	219.8	2.2	21.8
VOLUME 4			
TWLTL	260.4	1.7	20.6
MUT	232.8	2.1	22.9
SSM	238.9	2.2	22.5

Three-Way Interactions

Although ANOVA results indicated that the three-way interactions are significant to 99.99 percent confidence level, a graphical analysis of the three-way interactions did not produce any discernable pattern of significant interactions. The graphical analysis showed the U-shape pattern by time of day without a discernable variation by geometry or volume scenario.

CONCLUSIONS

The results of the analysis of TWLTL, MUT and SSM designs using CORSIM for a typical suburban arterial corridor indicate that the MUT and SSM alternatives have the potential to improve system travel time and speeds in the corridor during the busiest hours of the day. The analysis has also shown that these alternative designs do not compromise system travel times during the off-peak hours of the day. As expected, the TWLTL design had consistently fewer stops per vehicles than the MUT and SSM designs, which require a longer left turning path with more stop opportunities.

Some questions remain as to the practical application of the alternative designs, particularly the SSM as no one has built an entire corridor with it. The MUT alternative is a far more polished design, as is utilized heavily in Michigan. Both the MUT and SSM designs require wider right-of-way than the TWLTL and will have to overcome the fears of adjacent business owners. While there are questions about driver expectations, the MUT design has become familiar to most drivers in Michigan. Signing for this design is also increasingly evolving to become more user-friendly.

In creating the model for the SSM design, some interesting questions arose, including traffic control at the signalized intersections. The use of dual right turns is a potential hazard with right-turns on red. Use of left turn on red at the median crossover locations needs further operational research. In the SSM design, high U-turn volumes combined with right turn volumes from the cross street during the same signal phase also needs research.

Overall, though, if highway agencies are attempting to design or improve suburban arterial corridors such as the one modeled in this paper, they should consider the MUT and SSM as design alternatives. Reductions of an average of 17 percent in peak period travel times, without extra traffic lanes, are too large to dismiss without consideration. In addition, the CORSIM model and the SYNCHRO signal optimization package are adequate to examine alternative designs without expending large amounts of staff time.

ACKNOWLEDGMENTS:

Special thanks to David Shade from the Michigan Department of Transportation, for providing the count data for Northwestern Highway. MDOT, North Carolina State University or any other public agency did not subscribe the content of this paper. The authors assume responsibility for accuracy in setting up the CORSIM and SYNCHRO models, interpretation of the simulation outputs and the statistical analysis that contributed to the paper analysis and conclusions.

REFERENCES:

Boone, J.L., and J.E. Hummer, *Unconventional Design and Operation Strategies for Over-Saturated Suburban Arterials*. Final Report. NCDOT, Raleigh, N.C., June 30, 1994

TSIS User Reference Guide. Version 4.2. Office of Safety and Operations R&D, FHWA, McLean, Va., Feb. 1998

Hummer, J.E., and Boone, J.L., Calibrating and Validating Traffic Simulation Models for Unconventional Arterial Intersection Designs. *Transportation Research Record 1500*, TRB, 1995

Savage, W.F., *Directional Median Crossovers*. Traffic Engineering, vol. 44, no. 11, August 1974

SYNCHRO User Reference Guide. Version 3.02. Trafficware, Berkley, CA, 1993

Kramer, R.P., "New Combinations of Old Techniques to Rejuvenate Jammed Suburban Arterials" *Strategies to Alleviate Traffic Congestion*, *Proceedings of the 1987 National Conference*, Institute of Transportation Engineers, Washington, DC, 1988.

ITRAF User's Guide. Version 2.0, Oak Ridge National Laboratory and FHWA, Oak Ridge. TN, undated.

Trip Generation Manual, 5th Ed. Institute of Transportation Engineers. Washington, DC. 1998

SAS Procedures Guide. Version 6, 3rd ed. Sas Institute, Inc., Cary, N.C. 1990