Maricopa County Enhanced Parkway Alternatives Study

James M. Witkowski, PhD, James Beier, EIT

Abstract

This project evaluated the traffic operations performance of unconventional alternative intersection designs for the new "Arizona Desert Parkway" concept developed by the Maricopa Association of Governments and the Maricopa County Department of Transportation as part of the *I-10 Hassayampa Valley Roadway Framework Study* (2007). Phase 1 of the project evaluated and compared the traffic operations performance of conventional at-grade intersections along a hypothetical 12-mile corridor to that of a corridor consisting of indirect left-turn intersections (Michigan left-turns). Phase 2 added the evaluation and comparison of "Continuous Flow Intersections" to the assessment, and Phase 3 added continuous flow right-turn lanes to the indirect left-turn intersections. The Synchro/SimTraffic software was used to create a microscopic traffic simulation of the corridor with the alternative intersections designs. Performance measures consisting of total delay, delay per vehicle, vehicle travel time, total stops, and stops per vehicle were used to evaluate and compare alternatives at the corridor and individual intersection levels of analysis. Traffic volumes were established to test the alternatives against varying levels of congestion and to estimate the daily and hourly capacity of the corridor for each alternative design. Results of the study included the following:

- The Michigan Left Turn (MLT) concept increased the capacity of the corridor by 45 to 50 percent over the use of conventional intersection design.
- The hourly through lane capacity of an MLT intersection is on the order of 975 to over 1,025 vehicles per hour per lane in comparison to the typical 600 to 675 vehicles per hour per through lane for a conventional arterial intersection.
- The daily capacity of an 8-lane MLT parkway is on the order of 90,000 to 106,000 vehicles per day in comparison to the 62,000 to 73,000 vehicles per day for a roadway consisting of conventional signalized intersections.
- The MLT parkway design is capable of providing both a high level of capacity, a high level of roadside access, and a much safer travel environment.
- The capacity of a 6-lane MLT roadway exceeds that of an 8-lane conventional roadway, and a 4-lane MLT roadway is the equivalent of a 6-lane conventional roadway.
- The through lane capacity of a Continuous Flow Intersection (CFI) is only slightly higher than an MLT intersection.
- The strength of the CFI in comparison to the MLT design is in the ability of the CFI to accommodate high volumes of left and right-turns at lower levels of delay.
- The addition of the continuous flow right-turn lanes to the MLT intersections significantly reduced delay and improved traffic operations for both right and left-turns.

STUDY OVERVIEW

Long range transportation studies[1] in the Phoenix metropolitan area have identified the need for non-freeway facilities capable of providing significantly greater travel capacity than that provided by conventional major urban arterials while providing flexible roadside access. Various unconventional design and access refinement alternatives have been proposed to provide additional travel capacity without employing full grade-separations at intersections with arterial cross-streets. These design alternatives can provide the benefit of increases in intersection capacity while maintaining the potential for direct driveway access to each quadrant of the intersection. These design alternatives have also demonstrated significant safety benefits over conventional intersection designs[2].

These unconventional design alternatives generally focus on the provision of simple two-phase traffic signal operations at intersections by eliminating the left-turn movement at the main intersection and accommodating it elsewhere. The Maricopa County Department of Transportation commissioned a study to assess the traffic operations and capacity characteristics of various intersection design alternatives that could be applied to the new “Arizona Desert Parkway” concept. The initial phase of the study evaluated and compared the traffic operations benefits of employing indirect or Michigan left-turn (MLT) intersections to conventional intersection design along a hypothetical eight-lane parkway corridor[3]. In Phase 2, the study included a comparison of continuous flow intersections (CFIs) to both the conventional intersection design and the MLT intersection[4], and in Phase 3 the study added the use of continuous flow right-turn (CFRT) lanes to MLT intersections[5].

Traffic operations, traffic delay, and general roadway capacity measures were used to assess the differences between conventional intersections, MLT intersections, and CFIs. This study also analyzed the performance of a grade-separated single point urban interchange (SPUI) versus the other intersection design types at the intersection of two major eight-lane parkways. Exhibits 1 and 2 illustrate the design of the MLT intersection and the CFI intersection, respectively.

STUDY APPROACH

The approach for this study was to simulate the traffic operations for a hypothetical 12-mile long parkway corridor consisting of a six mile high intensity development urban section, and a six mile lower intensity suburban area. The high intensity urban condition consists of the following characteristics:

- The parkway is represented as an eight-lane divided roadway between intersections, with intersection turn lanes commensurate with the type of intersecting roadway.
- Major arterial intersections every mile with traffic signal control.

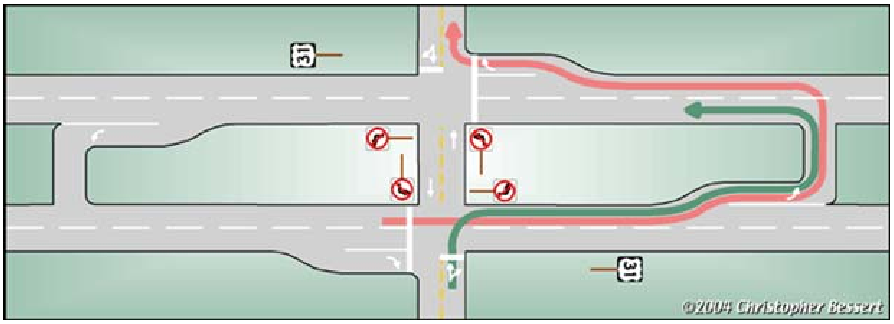
- Minor arterial intersections at half-mile spacing between the major arterials with traffic signal control.
- Stop controlled collector roadway intersections at quarter-mile spacing between the major arterials and the minor arterials.

The division between the high-intensity urban and suburban conditions (Mile 6 roadway) is represented by another eight-lane divided parkway.

The lower intensity suburban condition consists of the following characteristics:

- The parkway is represented as an eight-lane divided roadway between intersections, with intersection turn lanes commensurate with the type of intersecting roadway.
- Major arterial intersections every two miles with traffic signal control.
- Minor arterial intersections at one mile spacing between the major arterials with traffic signal control.
- Stop controlled collector intersections at ½-mile spacing between arterial intersections.

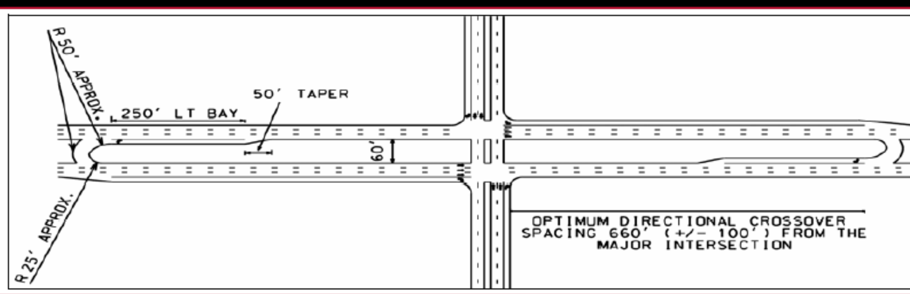
Exhibit 1
EXAMPLE OF A TYPICAL MLT INTERSECTION



Source: www.MichiganHighways.org

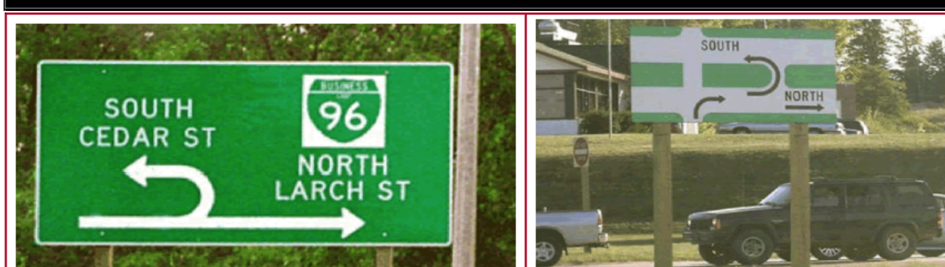
Source: www.Wikipedia.com

Figure 2. Typical schematics of MUTIT.



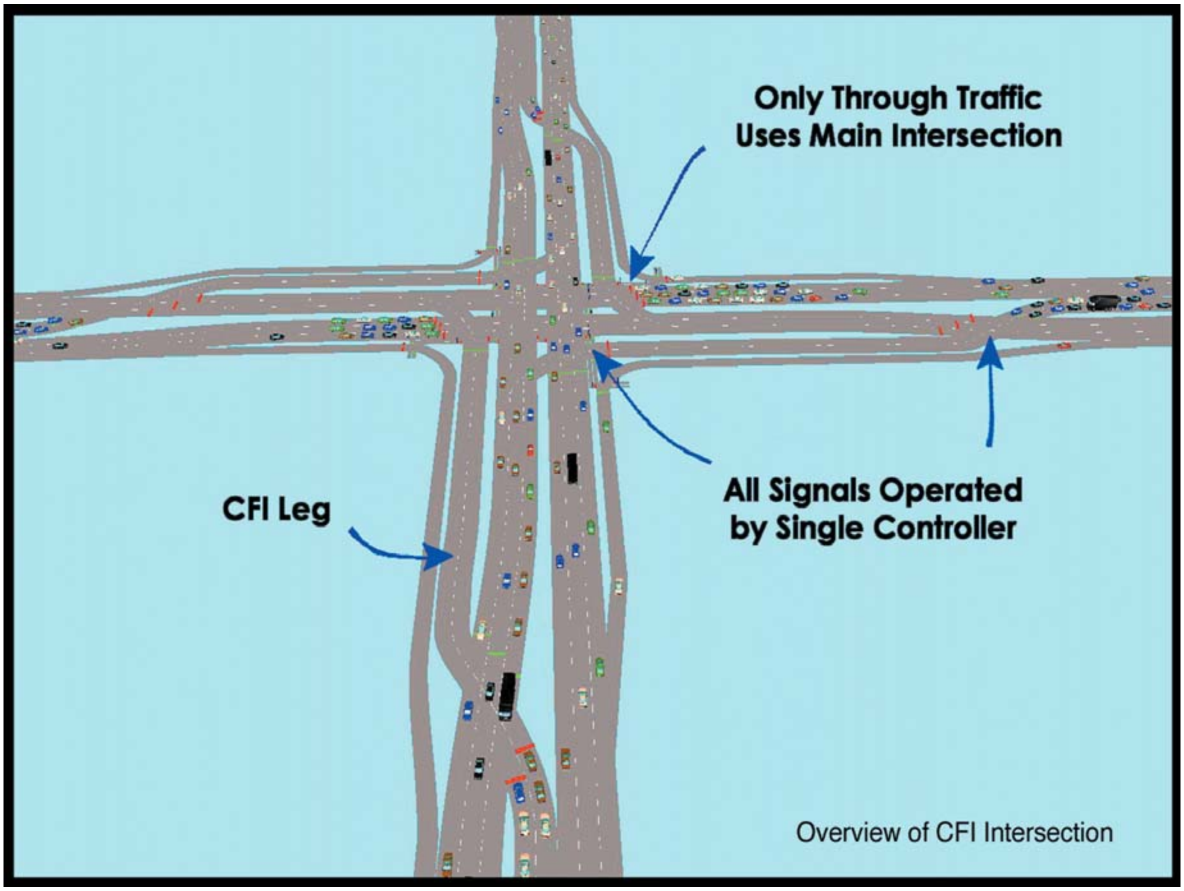
Source: Synthesis of Median U-Turn Intersection Treatment, Safety, and Operational Benefits, FHWA- HRT-07-033.

Figure 13. Examples of "innovative" signing plans for the MUTIT in Michigan.



Source: Synthesis of Median U-Turn Intersection Treatment, Safety, and Operational Benefits, FHWA- HRT-07-033.

Exhibit 2
EXAMPLE OF A CONTINUOUS FLOW INTERSECTION



Source: ABMB Engineers, Inc., Baton Rouge, LA. Reproduced with permission.

The traffic simulation was conducted using Synchro/SimTraffic, a traffic operations analysis software package developed by TrafficWare. Exhibit 3 provides a schematic of the general corridor configuration. The following general network scenarios represented the roadway configurations used to make the comparisons:

- Base Network – A network consisting of typical at-grade signalized and stop-controlled intersections consistent with the Maricopa County intersection design standards for each intersection type. The intersections provided exclusive left-turn and right-turn lanes consistent with the traffic demand, and protected left-turn movement signal timing.
- MLT Network – All of the intersections along the main parkway were converted to MLT intersections. U-turn opportunities were provided on the far side of the parkway intersection to accommodate the left-turn movements. At the Mile 6 parkway-parkway intersection, U-turn opportunities were provided on all four legs of the intersection. A median of a minimum 60 feet in width was assumed as part of the main parkway. Such a median is typical for the provision of U-turn

opportunities, and is required to provide adequate traffic operations for the U-turn movement.

- MLT Network with three intersections converted to CFIs (Mile 6, Mile 7, and Mile 10 intersections), while all other intersections remained as MLT intersections.
- MLT Network with three intersections modified to provide continuous flow right-turn (CFRT) lanes. The MLT/CFRT intersections were simulated at the same locations along the corridor as the three CFIs.
- MLT Network with a Single Point Urban Interchange (SPUI) at the parkway-parkway intersection – The parkway-parkway intersection was simulated with a grade separated SPUI, while the remainder of the intersections were MLT designs.

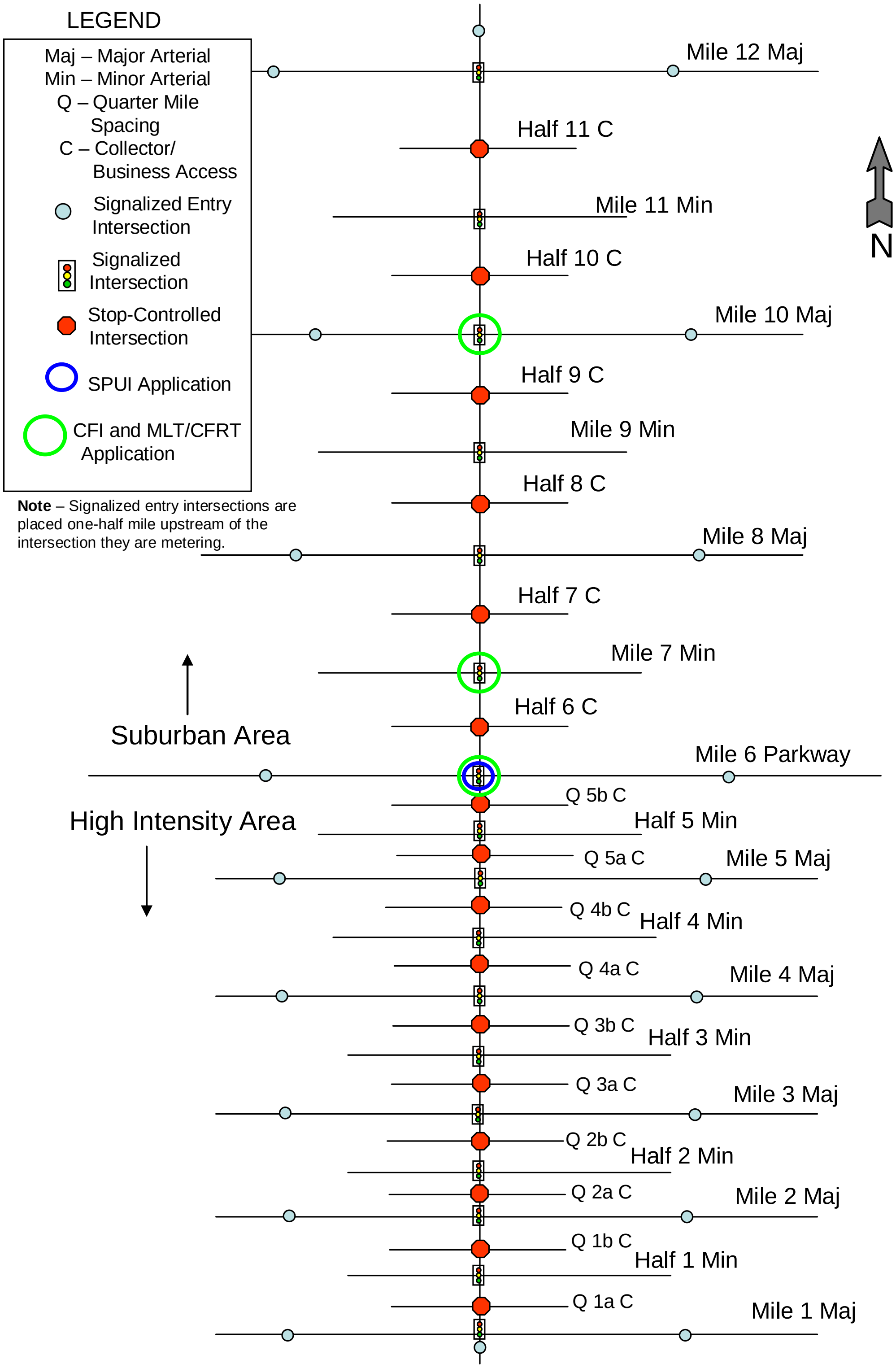
The traffic flow simulation study enabled the evaluation of traffic operations, including delay, travel time, and number of stops on the network alternatives. In addition, tests were constructed to estimate the capacity of the Base and MLT Networks.

TRAFFIC ANALYSIS AND SIGNAL TIMING

The analysis of traffic operations was conducted using the Synchro/SimTraffic software package developed by TrafficWare, Corporation. Synchro is a deterministic traffic operations, and traffic signal timing optimization software package. Synchro implements the methods of the 2000 *Highway Capacity Manual* for urban streets, signalized intersections, and unsignalized intersections. In addition to calculating capacity and level of service, Synchro can also optimize traffic signal cycle lengths, splits, and offsets for intersections along a corridor.

SimTraffic is companion micro-simulation software to Synchro. SimTraffic uses the Synchro data entry and the traffic signal timing generated by Synchro to create a stochastic micro-simulation of the entire roadway network under consideration. Each vehicle entering the network is tracked individually, and the traffic operations metrics are generated by compiling the individual vehicle information along each segment of the roadway. SimTraffic also creates an animation of the network showing each vehicle's journey and interaction with other vehicles.

Exhibit 3
GENERAL ROADWAY SCHEME FOR THE ANALYSIS



For this analysis Synchro was used for creating the network to be evaluated, data entry, and traffic signal optimization. Due to the complex nature of the traffic movements through the MLT network, SimTraffic was used to evaluate the traffic operations metrics and report the system performance of the alternatives. The simulation of each condition was executed five times using different random number seeds for each execution. The results of the five simulations were compiled and averaged to represent the final results for comparison of the alternatives being evaluated.

SimTraffic assumes random arrivals of vehicles on the first roadway segment entering a network. From that point on, vehicle arrivals at intersections are dictated by the traffic signal timing of upstream signals and the vehicle travel speeds on the network. Typically, random arrivals of vehicles at an intersection will result in higher estimates of vehicle delay than with a condition where arrivals are metered by upstream signals in a coordinated signal system. Therefore, in order to reduce the effects of random intersection arrivals on the analysis, entry intersections were used on each of the parkways and major arterials. The entry intersections are the first intersections encountered by traffic on these roadways in the simulation, thus eliminating the random arrivals at the next downstream intersection. Entry intersections were assumed to be one-half mile upstream of the parkway intersections. The locations of the entry intersections are also provided in Exhibit 3. The delay and traffic operations conditions at these entry intersections were not included in the performance metrics for the analysis of alternatives.

The parkway corridor in the MLT condition was simulated as two parallel one-way streets. This allows for proper simulation of the presence of the median and the directional median U-turns. In addition, it provides better simulation of the major signalized intersections. **It should be noted that an additional twenty seconds of delay was added to the left-turn movement in the MLT intersections to account for the additional time associated with the travel to/from the U-turn median opening on the parkway.**

As a method of providing a non-bias assessment and comparison of alternatives, Synchro was used to optimize traffic signal parameters for the simulations. Traffic signal cycle length, intersection splits, and offsets were optimized. The intersections along the main parkway corridor were assigned to the same zone for optimization of the cycle lengths and offsets. This provided the best condition for maintaining traffic progression along the main parkway as the entry intersections were not included in establishing the cycle lengths and offsets along the parkway. All of the intersections along the main parkway operated on the same cycle length, including the signalized U-turn locations.

In general, Synchro's signal timing algorithms tend to favor the highest traffic demand roadway, in this case the parkway, in establishing signal timing. The systemwide metrics used by Synchro may produce signal timings resulting in LOS F conditions on the cross street, if this reduces overall delay. The animation generated by the simulation, and Synchro/SimTraffic congestion parameters were reviewed to determine whether the optimized signal timings were resulting in what was considered unreasonable cross street congestion (for example, LOS F with over 150 seconds of delay per vehicle). In such cases, the signal timings were adjusted to provide more efficient cross street traffic operations. These and other efforts were made to provide the most efficient and realistic traffic operation possible with the demand volumes used in the analysis.

For the Base Network, all left-turn phases were protected only and were assigned as “lead” left-turns. SimTraffic default parameters for minimum headway, turn speed, and start-up delay were set to maximize left-turn lane throughput to provide the most efficient Base Case traffic operations possible. Minimum green times for pedestrians were not considered in the analysis, and pedestrian traffic was not included in the simulation of alternatives.

Traffic signal change plus clearance interval time was estimated for each intersection type based on the size of the cross street and the assumed intersection approach speeds for each roadway type. The equation for calculating the signal change plus clearance interval time presented in the Institute of Transportation Engineers, *Traffic Engineering Handbook*[6] was used for these calculations.

Signal timing at signalized U-turn locations was coordinated with the downstream traffic signal. Offsets were optimized to provide good progression and to allow efficient U-turn movement.

TRAFFIC VOLUMES

Traffic volumes for the Base Network and MLT Network conditions were established to represent peak-hour operational LOS D and LOS E (capacity) conditions along the simulated corridor at each intersection. The idea was to approximate the limits of the each corridor design to accommodate traffic demand which included high levels of cross street traffic demand. The Base Network Capacity traffic volume limits were estimated through an iterative process, which included increasing traffic volume on the network and optimizing signal timing, while attempting to minimize the occurrence of LOS F conditions in the network. No intersection approach was allowed to operate at LOS F. For the MLT Network, the cross street traffic volumes from the Base Network were held constant and the through volume on the MLT parkway was increased until LOS D and LOS E conditions were achieved along the corridor.

Conditions of 50 percent and 75 percent of the Base Network capacity volumes were also developed for a comparison of corridor operations during lower demand conditions. Typical traffic volumes for the Base and the MLT condition capacity analysis are provided in Exhibit 4.

TRAFFIC SPEEDS

The traffic speed input for each roadway type is provided in Exhibit 5. This represents the speed limit on each roadway type and the average travel speed for drivers under free flow traffic conditions. Vehicles in the simulation will travel faster or slower than the speed limit depending on the level of traffic congestion and the driver type speed factors used by SimTraffic.

PERFORMANCE AND ANALYSIS METRICS

The primary performance metrics for this analysis are **total delay (vehicle hours), delay per vehicle (seconds per vehicle), total stops, stops per vehicle, and total travel time in the system** as measured and compiled by the SimTraffic program. These primary metrics were summarized for the system as a whole and for individual intersections by intersection approach. The system consists of all roadway elements in the simulation excluding the entry intersections and entry intersection approaches. The **total number of vehicles entering the network** was used as a comparison between alternatives to ensure that the performance metrics were developed based on the same level of vehicular activity on the network. The following definitions are provided for clarity:

- **Delay** – SimTraffic calculates delay as the difference between the simulated travel time over a defined link distance and the "time it would take the vehicle with no other vehicles or traffic control devices" present.
- **Total delay** is the sum of the delay for each vehicle in the simulation.
- **Delay per vehicle** is the total delay divided by the total number of vehicles.
- **Total stops** is a count of vehicle stops by SimTraffic. Whenever a vehicle's speed drops below 10 ft/s, a stop is added. A vehicle is considered moving again when it speed reaches 15 ft/s.
- **Stops per vehicle** is calculated by SimTraffic by dividing the number of stops by the number of vehicles in the system.
- **Travel time** is a total of the time each vehicle was present in the simulation area. Travel time in SimTraffic includes time spent by vehicles denied entry to the system. Due to the traffic balancing procedure used to generate the input volumes for the simulation, denied entry vehicles were not a factor in the travel time estimations.
- **Total vehicles entering network** is the number of vehicles on the simulation network during the simulation, excluding entry intersection vehicles that do not travel on an approach to an intersection on the main parkway. Each vehicle is only counted once. This number will differ slightly for each random simulation, even when the same input volumes are specified.

Exhibit 4
AVERAGE TRAFFIC VOLUMES

Base Condition Traffic Volumes

Input Parkway Volumes (vph)

Cross Street Type	Left Turn (Average)	Thru (Average)	Right Turn (Average)	Total (Average)	U-Turn
Parkway	187	3,598	637	4,423	187
Major Arterial	210	3,787	315	4,312	394
Minor Arterial	110	3,945	343	4,399	195
Collector	62	4,229	70	4,362	106

Input Cross Street Volumes (vph)

Cross Street Type	Left Turn (Average)	Thru (Average)	Right Turn (Average)	Total (Average)	U-Turn
Parkway	211	1,966	713	2,890	212
Major Arterial	184	1,269	382	1,834	N / A
Minor Arterial	85	730	299	1,113	N / A
Collector	36	0	105	142	N / A

MLT Capacity Condition Traffic Volumes

Input Parkway Volumes

Cross Street Type	Left Turn (Average)	Thru (Average)	Right Turn (Average)	Total (Average)	U-Turn
Parkway	187	3,598	597	4,383	187
Major Arterial	210	3,751	305	4,266	394
Minor Arterial	110	3,924	316	4,349	195
Collector	67	4,170	67	4,305	106

Input Cross Street Volumes

Cross Street Type	Left Turn (Average)	Thru (Average)	Right Turn (Average)	Total (Average)	U-Turn
Parkway	211	1,965	603	2,780	212
Major Arterial	184	1,269	374	1,827	N / A
Minor Arterial	85	730	264	1,079	N / A
Collector	38	0	113	151	N / A

Exhibit 5
INPUT ROADWAY TRAVEL SPEED BY ROADWAY TYPE

Roadway Type	Link Speed (mph)
Parkway	45
Major Arterial	40
Minor Arterial	35
Collector	30

A methodology was devised to provide a comparison of intersection and network alternatives. Network comparisons were based on a summary of performance measures for all intersections in the network, excluding entry intersections. Intersection comparisons were developed by approach and by individual traffic movement. This was particularly useful in evaluating the impacts of the MLT and CFI intersections on the left-turn, right-turn and through movements at major signalized intersections.

TYPICAL RESULTS

The number of charts and tables summarizing the significant results of the three studies is far too numerous to be presented here. A few select tables and graphics are included below to provide a sense of how the simulation data were compiled for the comparison of alternatives. This information is provided in Exhibits 6 through 11.

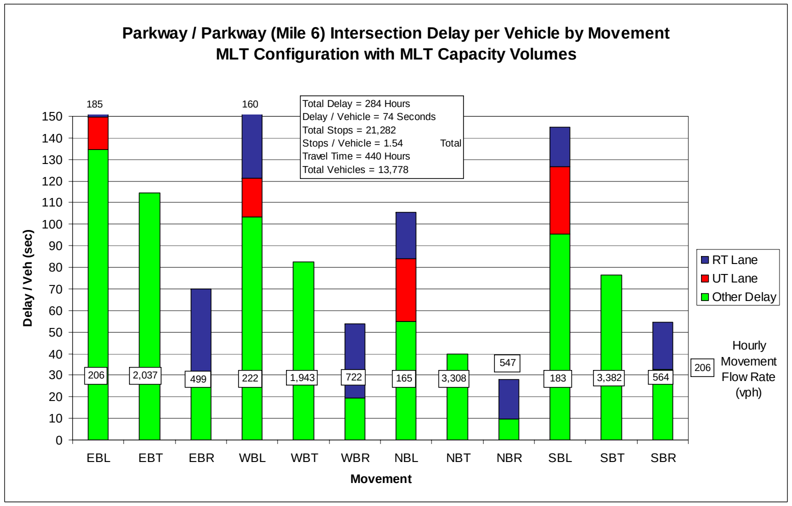
Exhibit 6
NETWORK PERFORMANCE MEASURES WITH BASE CAPACITY VOLUMES

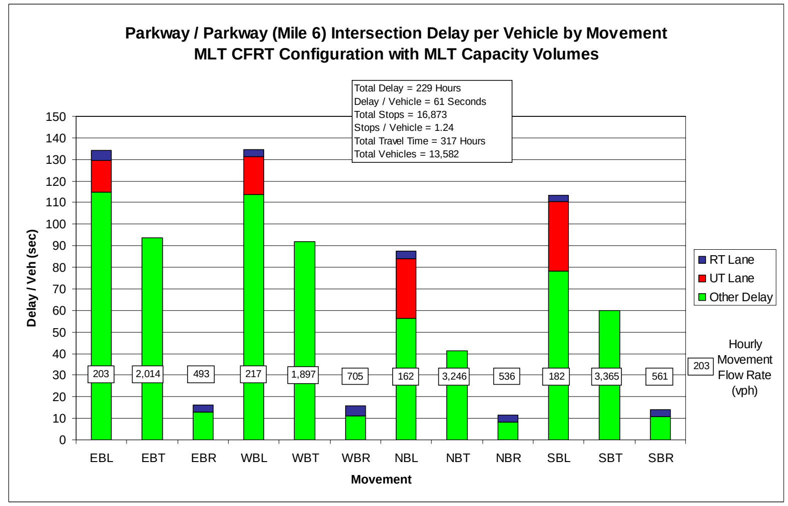
Base Capacity Volumes	Network			Comparison		
Performance Measure	Base Network	MLT Network	MLT Network w/ SPUI	Base to MLT % Diff.	Base to SPUI % Diff.	MLT to SPUI % Diff
Total Delay (hours)	2,560	1,706	1,710	-33.3%	-33.2%	0.2%
Delay per Vehicle (seconds)	148	98	98	-33.4%	-33.5%	-0.1%
Total Stops	142,571	112,347	109,805	-21.2%	-23.0%	-2.3%
Stops per Vehicle	2.29	1.80	1.75	-21.2%	-23.3%	-2.6%
Total Travel Time (hours)	5,136	4,610	4,587	-10.3%	-10.7%	-0.5%
Total Vehicles Entering Network	62,388	62,420	62,641	0.1%	0.4%	0.4%

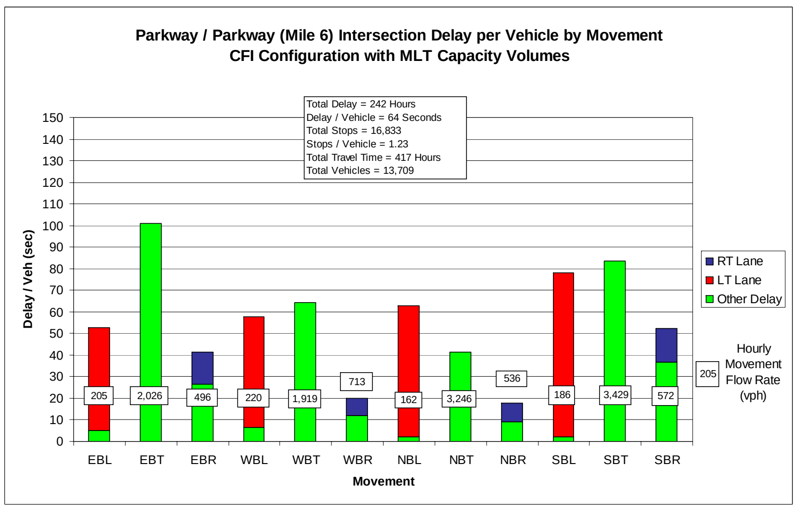
Exhibit 7
AGGREGATE INTERSECTION PERFORMANCE MEASURES WITH MLT CAPACITY VOLUMES

MLT Capacity Volumes	Mile 6, 7, & 10 Intersections			Comparison		
Performance Measure	MLT	MLT/CFRT	CFI	MLT to MLT/CFRT % Diff.	MLT to CFI % Diff.	MLT/CFRT to CFI % Diff.
Total Delay (hours)	632	537	495	-15.0%	-21.7%	-7.9%
Delay per Vehicle (seconds)	63	54	50	-14.3%	-21.6%	-8.4%
Total Stops	48,226	40,791	34,916	-15.4%	-27.6%	-14.4%
Stops per Vehicle	1.34	1.15	0.97	-14.7%	-27.5%	-14.9%
Total Travel Time (hours)	1,092	846	893	-22.6%	-18.2%	5.6%
Total Vehicles Entering Intersections	35,903	35,621	35,838	-0.8%	-0.2%	0.6%

Exhibit 8
PARKWAY-PARKWAY INTERSECTION (MILE 6) DELAY PER MOVEMENT BY INTERSECTION DESIGN ALTERNATIVE
(MLT Capacity Volumes)







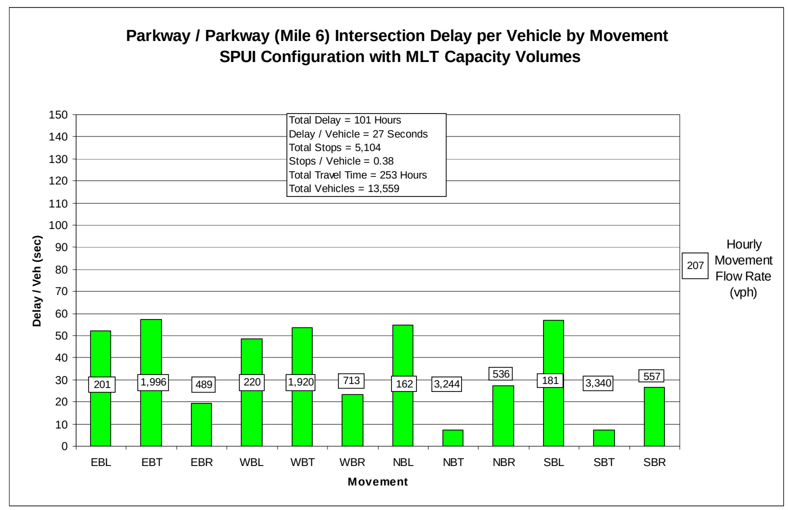
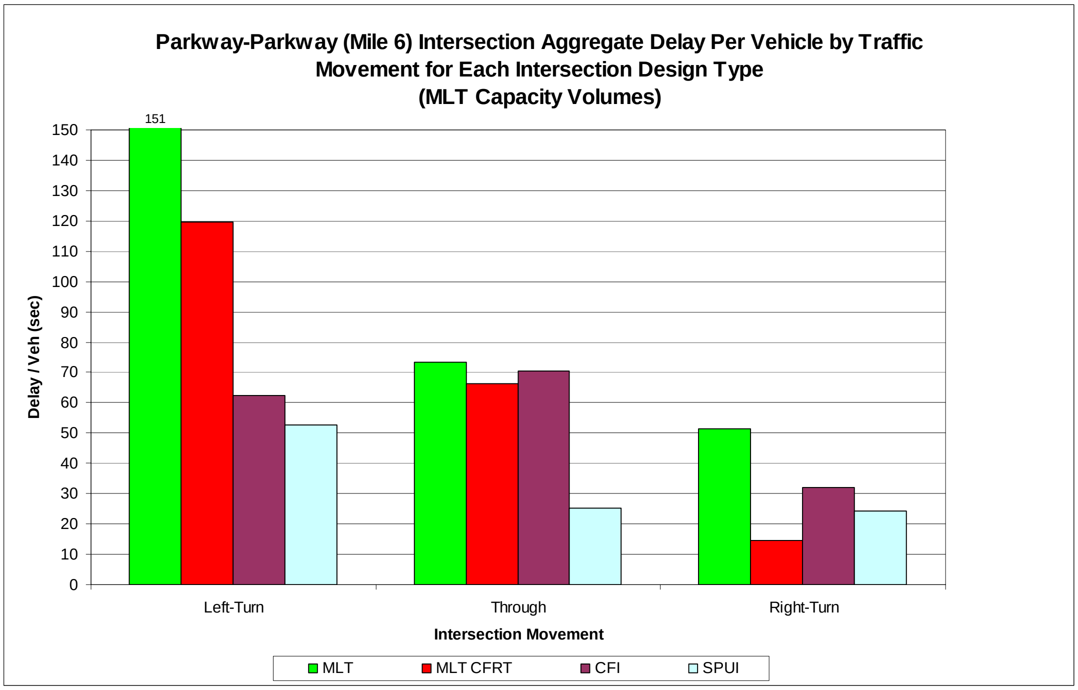


Exhibit 9
PARKWAY-PARKWAY (MILE 6) INTERSECTION AGGREGATE DELAY AND STOPS PER VEHICLE BY TRAFFIC MOVEMENT FOR EACH INTERSECTION DESIGN TYPE (MLT Capacity Volumes)



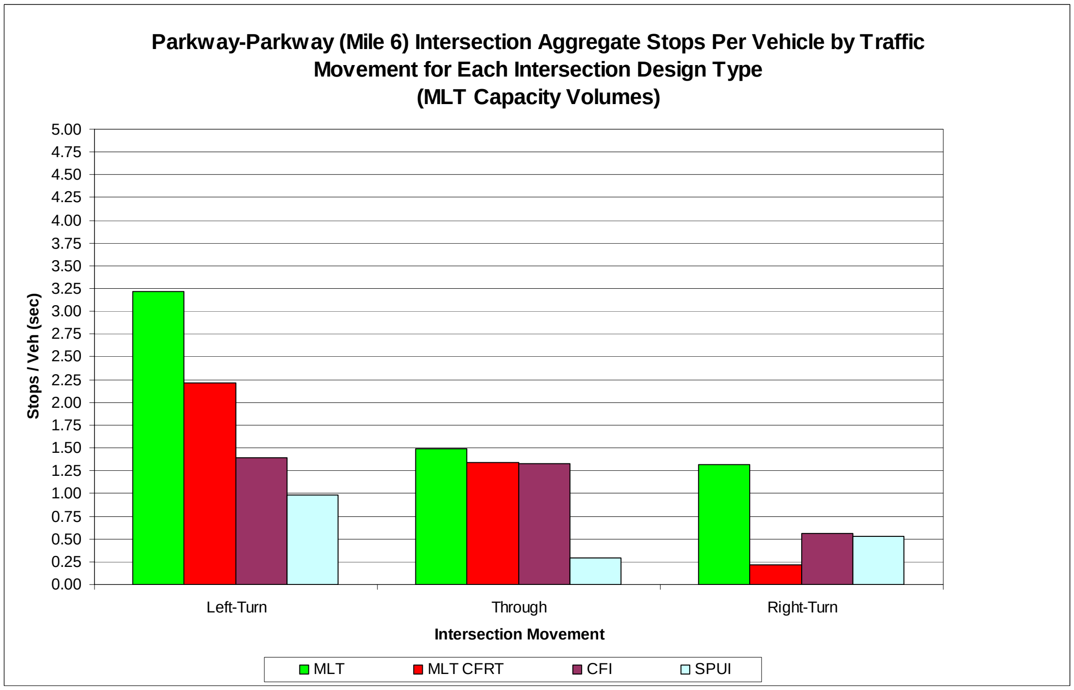
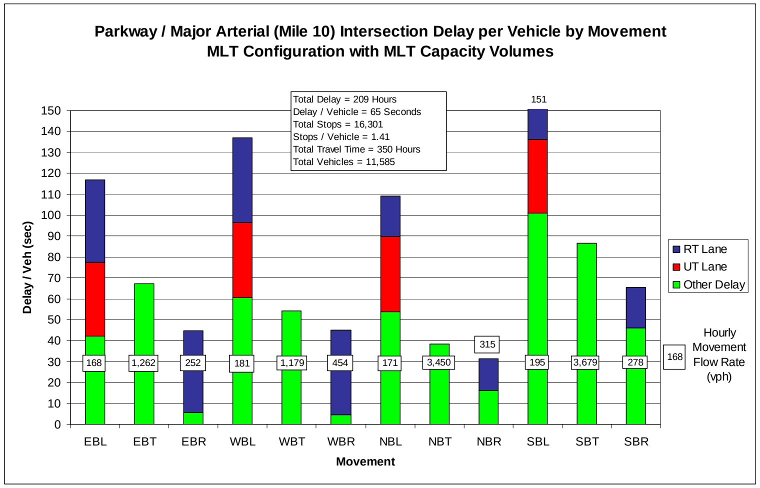
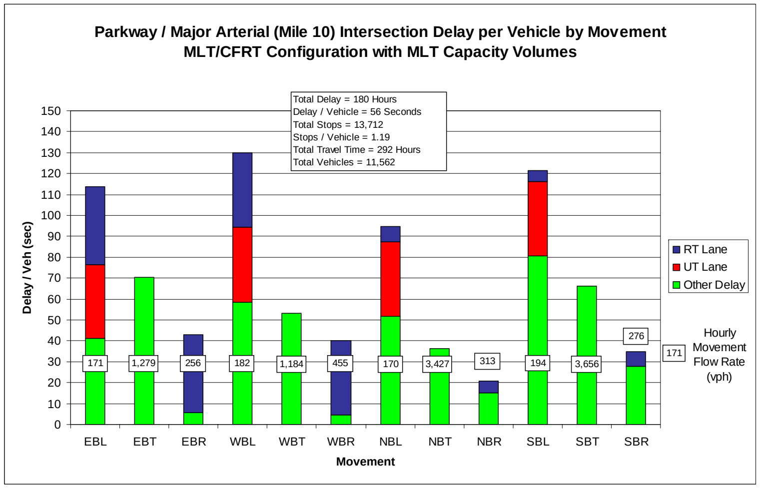


Exhibit 10
PARKWAY-MAJOR ARTERIAL INTERSECTION (MILE 10) DELAY PER VEHICLE BY MOVEMENT FOR EACH INTERSECTION DESIGN ALTERNATIVE
(MLT Capacity Volumes)





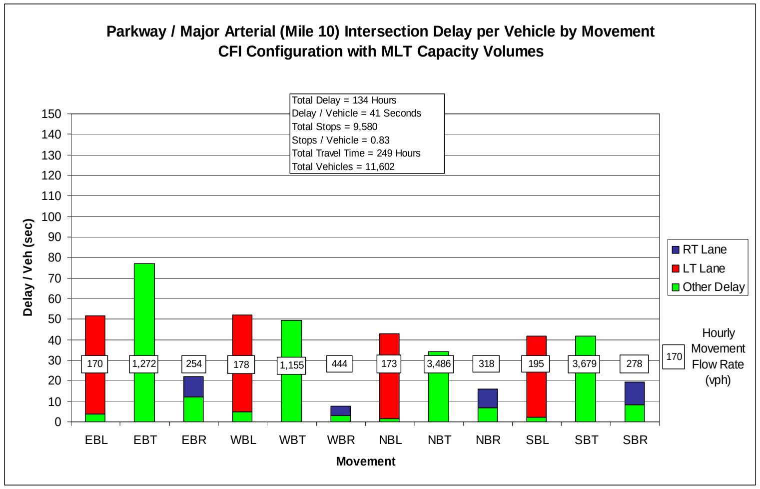
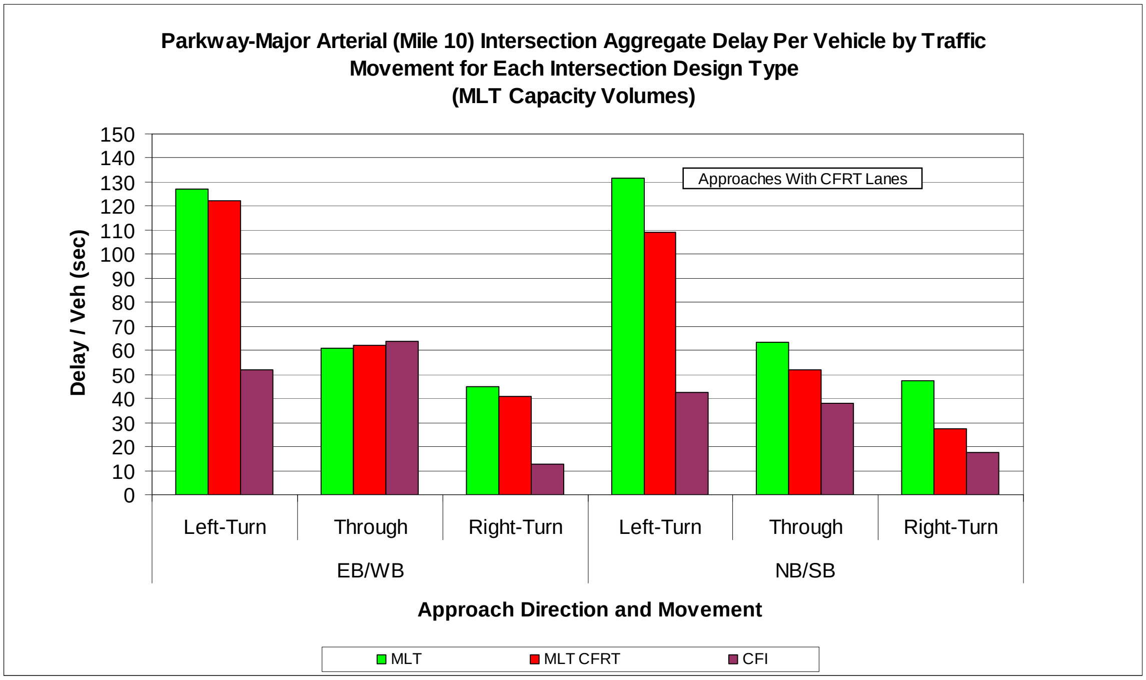
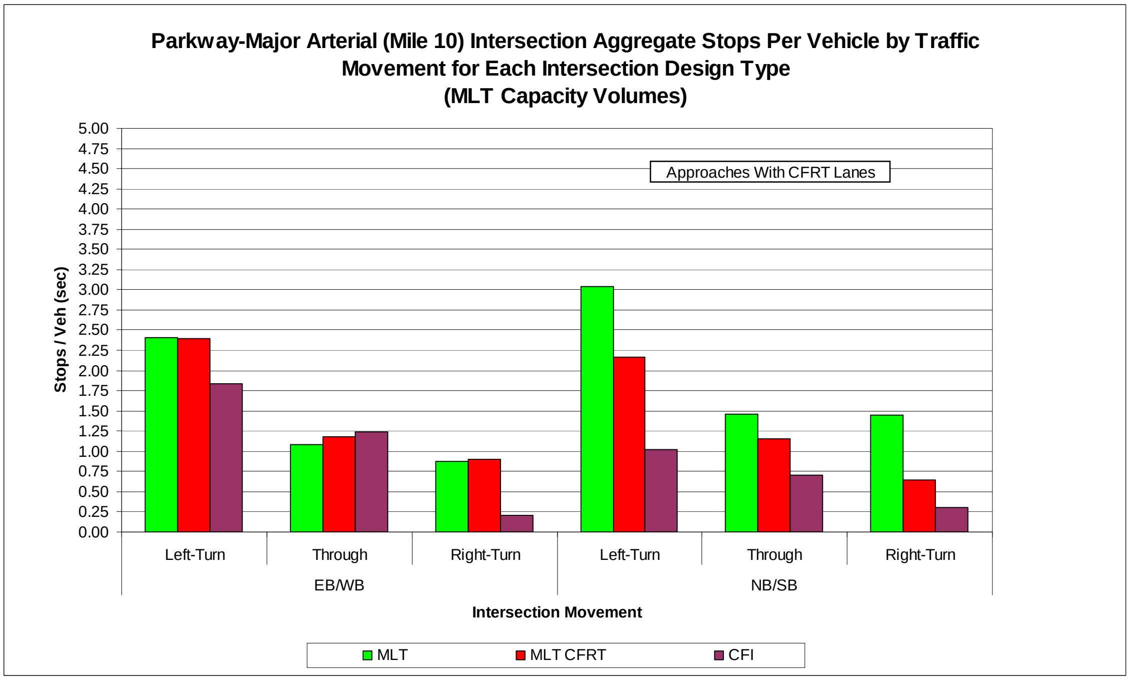


Exhibit 11
PARKWAY-MAJOR ARTERIAL (MILE 10) INTERSECTION AGGREGATE DELAY AND STOPS PER VEHICLE BY TRAFFIC MOVEMENT FOR EACH INTERSECTION DESIGN TYPE





SUMMARY OF RESULTS AND CONCLUSIONS

The following results and conclusions are based on the technical analysis conducted in this study. It should be noted that the results and conclusions based on the traffic simulation conducted for this study may be limited to the range of conditions applied and assumptions made in conducting the analysis, and cannot be generalized to all possible combinations of conditions.

- The capacity of the Base Network eight-lane divided urban parkway was estimated to be between 62,000 and 73,000 vehicles per day assuming that the peak-hour volume is between 10 and 8.5 percent of the daily volume, or 600 to 675 vehicles per hour per through traffic lane. The daily capacity estimate may be conservative in that the capacity of the right-turn lanes was not tested.
- The capacity of the MLT parkway was estimated to be between 90,000 and 106,000 vehicles per day assuming that the peak-hour volume is between 10 and 8.5 percent of the daily volume, or 975 to 1,025 vehicles per hour per through lane. The daily capacity estimate may be conservative in that the capacity of the right-turn lanes was not tested.
- The capacity of the MLT Network design was estimated to be 45 to 50 percent greater than the capacity of the Base Network.
- The results suggest that a six-lane MLT design should be capable of handling more traffic volume at signalized intersections than an 8-lane parkway with the Base Network design. A four-lane MLT roadway should be capable of handling approximately the same volume of traffic as a 6-lane Base Network design roadway.
- The MLT Network reduced <u>total network</u> delay by 33 percent, vehicle stops by 21 percent, and total network travel time by 10 percent in comparison to the Base Network design, assuming the Base Capacity traffic volumes.
- The MLT <u>parkway-parkway intersection</u> reduced <u>intersection</u> delay by 37 percent, stops by 32 percent, and travel time by 16 percent in comparison to the Base Network intersection design with the Base Capacity volume assumptions.
- The SPUI reduced <u>intersection</u> delay between 27 and 63 percent and <u>intersection</u> travel time between 22 and 41 percent in comparison to the MLT parkway-parkway intersection. The SPUI was more effective at reducing delay and travel time with the higher traffic volumes. The SPUI was slightly less effective when the high volumes were uniformly distributed by intersection approach.
- The impact of the SPUI on overall <u>network</u> travel time and delay reduction was isolated within one mile of the SPUI location on the MLT network.
- The introduction of the SPUI increased delay to cross street traffic attempting to enter the parkway at stop-controlled intersections immediately downstream of the SPUI location.

- The SPUI created traffic operations issues at the opposing stop-controlled U-turn locations immediately downstream of the SPUI, requiring conversion of one of these locations to signal control.
- The effectiveness of the MLT network to reduce delay and travel time at traffic volumes 75 percent of the Base Capacity levels was approximately the same as with 100 percent of the Base Capacity volumes in comparison to the Base Network. At 50 percent of the Base Capacity volumes, the MLT Network was significantly less effective in reducing delay and did not reduce travel time in comparison to the Base Network.
- At low traffic volumes the MLT design does not reduce network travel time because of the additional time spent by traffic making U-turns.
- The MLT Network was equally effective in reducing delay and travel time in both the high-intensity and suburban areas of the network with the Base Capacity volume assumptions. The travel time reduction was higher in the suburban portion of the network (14 percent versus 7 percent reduction).
- When traffic volumes were increased from the Base Capacity levels to the MLT Capacity levels, several of the stop-controlled U-turn locations required conversion to signal control. The volume threshold for conversion to signal control was not identified as part of this study.
- A U-turn opportunity was provided for each leg of the parkway-parkway intersection on the MLT Network. A single U-turn lane on each leg was shown to be as effective as dual U-turn lanes for U-turn volumes ranging from 374 to 465 vehicles per hour. Signal coordination and timing at the U-turn locations was such that the delay in the U-turn lane was approximately six seconds per vehicle and was only about six percent of the total delay per left-turning vehicle.
- The minimum midblock right-of-way requirements for an eight-lane MLT corridor are estimated to be approximately 200 feet assuming a 60-foot median.
- The minimum parkway-parkway intersection ROW width with the MLT intersection with dual right-turn lanes is approximately 225 feet, assuming the continuation of the full 60-foot median width through the intersection.
- The minimum ROW requirement for the SPUI intersection was estimated to be on the order of 214 to 220 feet for the intersection design assumed for this study. This assumed that three lanes in each direction were carried through the grade separated portion of the intersection, dual left-turn lanes on each approach, a single right-turn lane, and no through lanes on the intersection ramps.
- The capacity of an eight-lane divided roadway consisting of CFI intersections is estimated to be between 92,000 and 108,000 vehicles per day (vpd) assuming that the peak-hour volume is between 10 and 8.5 percent of the daily traffic. This result is considered somewhat conservative in that the capacities of the left-turn and right-turn lanes were not explored in this study, and these lanes operated under capacity with the assumed traffic volumes.

- Considering only the through movement at signalized intersections, the CFI design capacity is estimated to be approximately 1,000 to 1,050 vehicles per hour per through lane, which is slightly higher than the estimated 975 to 1,025 vphpl for the MLT design. The primary difference in through movement capacity of the CFI and the MLT intersection is that with the MLT intersection the left-turn movement volume must pass through the intersection, reducing the capacity for through traffic.
- The capacity of a CFI is estimated to be between 45 and 55 percent greater than the capacity of a conventional intersection design with multi-phase signal timing.
- The aggregate intersection performance measures indicate that the CFI reduced delay by 46 percent, reduced stops by 50 percent, and reduced travel time by 46 percent in comparison to the conventional intersection design. At the parkway-parkway (Mile 6) intersection the CFI reduced delay by 59 percent, stops by 69 percent, and travel time by 59 percent in comparison to the conventional intersection design.
- The CFI is similar to the MLT in terms of the treatment of the through traffic movement at the intersection. Both intersection designs provide simple two-phase signal timing for the through movement, significantly increasing through movement capacity in comparison to the multi-phase signal timing used with conventional intersection design.
- The primary reduction in delay, stops, and travel time with the CFI design is in the left-turn and right-turn movements in comparison to the MLT design. In the CFI, the left-turns only pass through the intersection configuration once as opposed to the MLT design where they pass through the intersection twice. The free flow right-turn lanes also provide significant advantage to the CFI design.
- The CFI generated better performance metrics than the SPUI for the Base Capacity volumes, which were the lowest volumes tested with the CFI design.
- The SPUI generated significantly better performance metrics than the CFI with the MLT Capacity and CFI Uniform Capacity volumes. The SPUI and the CFI provided comparable levels of delay with the MLT Uniform Capacity Volumes.
- The traffic operations performance improvements for the SPUI were as high as a 58 percent reduction in delay, a 69 percent reduction in stops, and a 39 percent reduction in travel time in comparison to the CFI design.
- The primary benefit of the SPUI design is the free flow operation of the grade separation for the major through movement of traffic on the parkway in the analysis.
- While it may be possible for the CFI to provide traffic operations characteristics similar to the SPUI at lower volume levels, this was not the case for the higher traffic volumes that approximated the capacity of the CFI intersection used in this study.

- A potential advantage of the CFI design over the SPUI is the ability of the CFI to accommodate high volumes of left-turn and right-turn movements with lower levels of delay than the SPUI.
- A disadvantage of the CFI design is the issue of providing access to adjacent properties on the corners of the intersection. The location of the left-turn lanes and the free flow right-turn lanes basically eliminates access within the limits of these lanes. Direct access should <u>not</u> be provided from the free flow right-turn lanes because of safety concerns. An alternative that has been used is to provide access to properties at the intersection via a frontage road system that connects to the main roadway down stream of the end of the free flow right-turn lane. Placement of the access point and design of the frontage road system would very much depend on the individual development plan for the adjacent property. These access points should be right-in, right-out only.
- The minimum right-of-way for an eight-lane divided parkway with CFI intersections consisting of dual left-turn lanes and a single free flow right-turn lane on each approach would be approximately 201 feet. This ROW is consistent with the estimated requirements for an MLT intersection corridor of approximately 200 feet, and is 24 feet less than the estimated 225 feet required for an MLT design at the parkway-parkway intersection.
- The inclusion of continuous flow right-turn lanes with the MLT intersection design provides a significant improvement in traffic operations over the MLT design, even when the CFRT lanes are only applied on two approaches of the intersection. This improvement in traffic operations is greatest when the CFRT lanes are used on all four intersection approaches where there are high volumes of left-turn and right-turn traffic.
- On an aggregate basis for the three intersections where the MLT/CFRT was simulated, the reduction in delay was 14 percent, stops 15 percent, and travel time 23 percent in comparison to the MLT intersection design.
- The MLT/CFRT intersection significantly improved traffic operations for both right-turns and left-turns in comparison to the MLT intersection. Where the CFRT lanes were only applied on two intersection approaches, the improvement in traffic operations was confined to the intersection approaches with the CFRT lanes.
- On aggregate for the three intersections tested, the MLT/CFRT reduced delay to left-turns by 15 percent and reduced delay to right-turns by 51 percent in comparison to the MLT design.
- The improvement in traffic operations of the MLT/CFRT in comparison to the MLT was greatest at the parkway-parkway intersection (21 percent reduction in delay for left-turns, and 72 percent reduction in delay for right-turns) where the CFRT lanes were employed on all four intersection approaches.
- At the parkway-major arterial intersection and the parkway-minor arterial intersection, where the CFRT lanes were employed on only two intersection

approaches, the improvement in traffic operations in comparison to the MLT design was confined to the approaches with the CFRT lanes. On the approaches with the CFRT lanes, the reduction in delay per vehicle was between 11 and 17 percent for the left-turn movements, and between 38 and 43 for the right-turn movements.

- While the CFI design performed better than the MLT/CFRT on aggregate for the three intersections tested, the improvement in traffic operations was much less than that estimated in comparison to the MLT intersection. The CFI provided an 8 percent reduction in delay and a 15 percent reduction in stops compared to the MLT/CFRT intersection.
- On aggregate the MLT, MLT/CFRT and CFI intersections provided virtually the same levels of delay for the through movements at the three intersections tested.
- On aggregate the MLT/CFRT and the CFI designs provided virtually the same levels of delay for right-turns at the three intersections tested, which was approximately a 50 percent reduction in delay in comparison to the MLT design.
- While the MLT/CFRT design did provide a significant reduction in delay for left-turns in comparison to the MLT design, the CFI design provided the lowest levels of delay for the left-turn movement, which was approximately 53 percent lower than that for the MLT/CFRT intersections on aggregate.
- The SPUI design provided the best overall traffic operations at the parkway-parkway intersection, which was primarily a result of the reduction in delay for the free-flow through movement at the intersection. The delay for the right-turns at the parkway-parkway intersection was lowest for the MLT/CFRT design, and the CFI performed nearly as well as the SPUI for the left-turn movement.
- While the addition of the CFRT lanes to the MLT design eliminated the advantage of the CFI for the right-turn movement and reduced the advantage of the CFI for the left-turn movement, the CFI still provided a significant advantage over the MLT/CFRT in terms of the traffic operations for left-turns. It should be noted that the delay estimates for left-turns through the MLT/CFRT intersection include an additional 20 seconds of travel time per vehicle associated with the additional travel distance for the U-turn maneuver.
- The MLT/CFRT design assumed a single right-turn lane along the parkway at signalized intersections. While this assumption reduced the number of turn-lanes on the parkway at the major intersections, the total right-of-way required remained the same as the MLT design, which assumed dual right-turn lanes. This is because of the addition of a right-turn acceleration lane on the parkway associated with the CFRT lane. The total right-of-way at the major intersections would remain at approximately 225 feet.
- The application of a CFRT lane with the MLT design presents similar challenges for access to adjacent properties as with the CFI design. Allowing direct access to adjacent properties from the CFRT lanes or from the right-turn acceleration lane is not practical from a safety standpoint, but access may be accomplished through the use of a frontage road system that connects to the main roadway

down stream of the end of the free flow right-turn lane. Placement of the access point and design of the frontage road system would very much depend on the individual development plan for the adjacent property.

- An additional safety consideration in the design and use of an MLT/CFRT intersection is associated with the prevention of access to the median U-turn from the upstream right-turn acceleration lane. This movement should be prevented to avoid a situation where right-turning vehicles attempt to weave across multiple lanes over a short distance to access the median U-turn. This is not an issue with the MLT intersection because the right-turn movement is controlled by a traffic signal and does not generally conflict with cross-street traffic.

ENDNOTES

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[1] *Interstate 10 – Hassayampa Valley Roadway Framework Study,* Maricopa Association of Governments, September 2007.

[2] Synthesis of Median U-Turn Intersection Treatment, Safety, and Operational Benefits,
FHWA- HRT-07-033.

[3] *MCDOT Enhanced Parkway Study*, Final Report, Maricopa County Department of Transportation, Contract No. 2005-076, August 2007.

[4] *MCDOT Enhanced Parkway Study: Phase 2 – Continuous Flow Intersections,* Final Report, Maricopa County Department of Transportation, Contract No. 2005-076, December 2007.

[5] *MCDOT Enhanced Parkway Study: Phase 3 – Refined MLT Intersection Analysis,* Final Report, Maricopa County Department of Transportation, Contract No. 2005-076, March 2008.

[6] Institute of Transportation Engineers, *Traffic Engineering Handbook, 5th Edition,* 1999, page 481.

AUTHORS INFORMATION

James M. Witkowski, PhD
Senior Transportation Manager
Morrison-Maierle, Inc.
8710 N. Thornydale Road, Suite 140
Tucson, Arizona 85742
520-572-5400 (phone)
520-572-5401 (fax)
jwitkowski@m-m.net

James Beier, E.I.T.
Transportation Engineer
Morrison-Maierle, Inc.
8710 N. Thornydale Road, Suite 140
Tucson, Arizona 85742
520-572-5400 (phone)
520-572-5401 (fax)
jbeier@m-m.net