The Parallel Flow Intersection: A New Two-Phase Signal Alternative

THE CONTINUOUS FLOW INTERSECTION HAS RECEIVED INCREASING INTEREST AS AN EFFECTIVE AT-GRADE CAPACITY SOLUTION TO CONGESTION. THE PRIMARY GOALS OF THIS AND OTHER HIGH-CAPACITY DESIGNS ARE TO REDUCE SIGNAL PHASES, CYCLE LENGTH AND CONFLICT POINTS. A TWO-PHASE INTERSECTION DESIGN CALLED A PARALLEL FLOW INTERSECTION, OR PARAFLOW, IS ANOTHER ALTERNATIVE FOR IMPROVING PERFORMANCE.

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INTRODUCTION

Many intersections are congested in burgeoning metropolitan areas, and the problem is worsening as motorists demand ever-greater vehicle mobility. Rather than throw up their hands in the face of limited funds and increasingly stymieing regulations, transportation professionals have been daring to curb congestion and the deteriorating performance of roadway networks in more inventive ways.

This feature introduces a signalized two-phase intersection design patented by the author (U.S. Patent No. 7,135,989). The parallel flow intersection, or paraflow, is another solution for improving roadway junction capacity. For the purposes of this writing, a high-capacity intersection is defined as an intersection providing a satisfactory level of service (LOS) for each conflicting high-demand approach. Thus, a four-leg conventional intersection with high-demand conflicting movements would require four separate phases per signal cycle.

Achieving high capacity at an intersection is accomplished by reducing phases, cycle length and conflict points. More traditional high-capacity designs, such as the median crossover U-turn (or "Michigan left") and jughandle, have been used successfully where space is available, but size and cost limit their widespread application.

Transportation professionals continue to be challenged to safely increase the capacity of existing urban arterial intersections within confined spaces and at an acceptable cost. The paraflow is presented as a possible solution to satisfy these objectives at many more intersection locations than have been previously considered.

The paraflow is similar to the continuous flow intersection (CFI) in that left turns cross over opposing travel lanes during the cross-street through movement phase.[1] This process of concurrent left-turn and through movements permits the larger volume through traffic to proceed with no lost time due to protected left-turn phases. Unlike the CFI, however, the paraflow accomplishes this operation with bypass turn lanes parallel to the cross-street center lanes, resulting in a smaller intersection with different characteristics.

DESCRIPTION

Figure 1 illustrates the general layout of a four-leg, two-phase paraflow intersection. The paraflow shares the basic geometry of a conventional intersection with the addition of a turn bypass roadway along the cross street that then intersect to form a bypass junction. The bypass roadway removes left-turn conflicts from the main junction, allowing the signal to operate with two phases for each repeating cycle.

Center left-turn lanes are provided between the main and bypass junctions in the same location as in a conventional intersection. The left-turn lane storage requirements for length and number of lanes are determined by analyzing traffic flow and physical site constraints. A channelizing island is constructed at the end of the center left-turn lanes to provide positive guidance to drivers turning onto the bypass roadway. This feature is necessary to prevent drivers from inadvertently turning into the main junction.

The bypass roadway is located generally adjacent and parallel to the cross street with a length somewhat greater than the center left-turn lane storage need. Separation between the bypass roadway and cross street is necessary to avoid driver discomfort caused by having opposing traffic on both sides and the sensation of traveling the wrong way. A minimum separation of 1.8 meters (6 feet) should be provided with a yellow-painted raised median.

Rebboundable posts or bollards should be installed on the divider to create more obvious separation. Where space is available, wider separations applying grass or

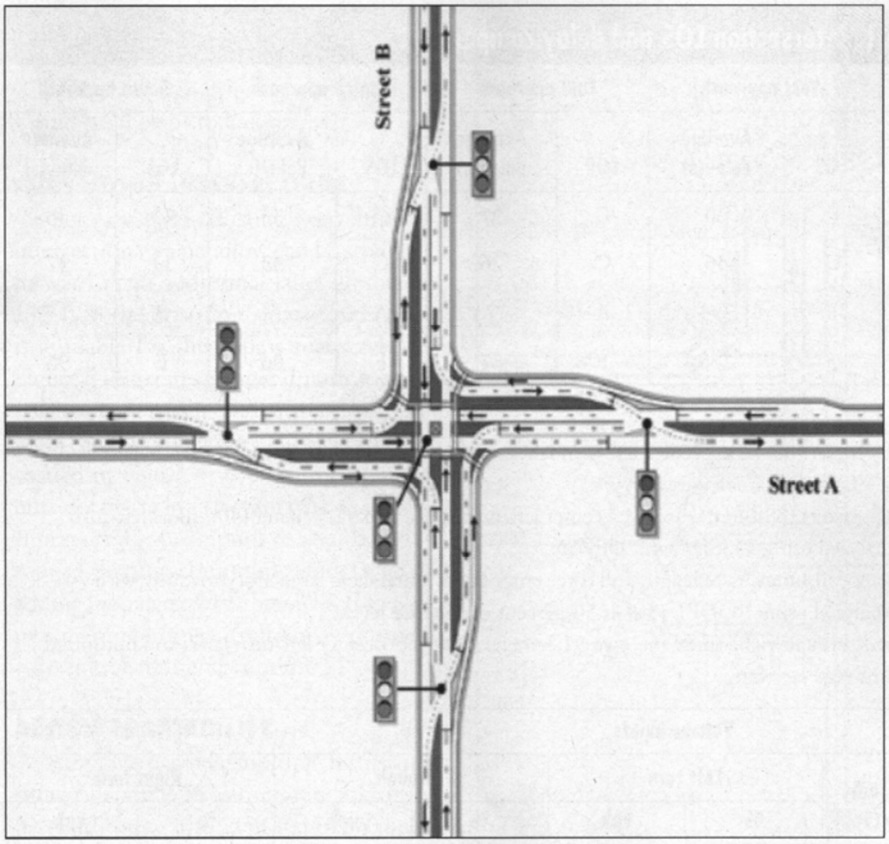


Figure 1. Layout of a four-leg, two-phase paraflow intersection.

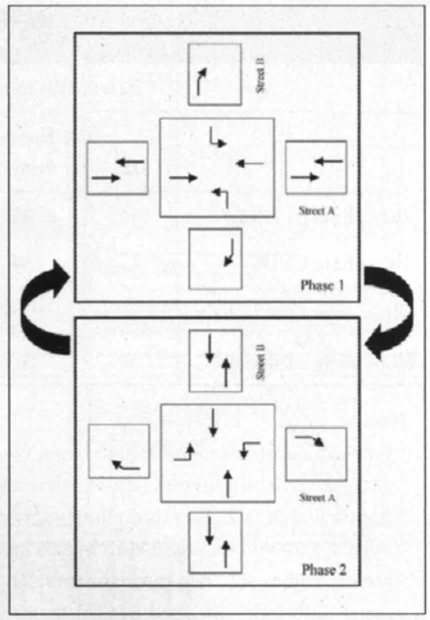


Figure 2. Signal phasing diagram for a four-leg, two-phase paraflow intersection.

landscaping can provide even better bypass junction geometry and can be more visually pleasing. A paved shoulder between the bypass left-turn lanes and raised divider also can be considered to offer even greater separation and a space for emergency stopping. The bypass roadway will add a minimum of 9.2 meters (30 feet) to the roadway cross-sectional width on the approach side and, with dual turn lanes and desirable lateral separation from the main roadway, 15.9 meters (52 feet) would be necessary.

OPERATION

The paraflow signal cycle basically consists of two phases; however, the main junction signals must be coordinated with the bypass junction signals based on traffic volume distribution and distance between junctions. Although bypass junction signal operation could result in multiple phases, the main junction signal will have only two phases per cycle.

Through traffic delay is reduced substantially compared to conventional intersections because additional green time is provided by operating through and left-turn phases concurrently. However, unlike at a CFI, where left turns are intended to stop only once, left-turning vehicles at a paraflow are stopped multiple times, resulting in more total left-turn delay at a paraflow than at a CFI.

Figure 2 shows the general signal phasing for a four-leg, two-phase paraflow intersection. In the first phase, the driver passes through the approach bypass junction and proceeds into the center left-turn lane, then is stopped by the main junction left-turn signal.

In the second phase, the left-turning driver turns onto the bypass roadway and continues to the departure bypass junction. Right-turning drivers pass through the approach bypass junction by traveling onto the bypass roadway and then merging onto the departure roadway. Through movements travel on a straight route in the same manner as a conventional intersection, passing through the three coordinated signalized junctions.

PERFORMANCE COMPARISON

Capacity analyses performed by the author suggest that the paraflow is very efficient compared with other intersection types. This feature presents the results of one such analysis expressed in terms of LOS and average vehicle delay for an intersection with a total approach volume of 6,375 vehicles per hour (vph) and 30-percent left-turn volume. The intersection analyzed had four approaches with two through lanes on each approach and 55-percent directional volume distribution on the major road.

The intersection types chosen for this comparison were: paraflow; CFI; three-lane modern roundabout and conventional intersection. The paraflow and CFI were modeled in the microsimulation program VISSIM (Version 4.0; PTV America Inc.), the modern roundabout using RODEL (Version 1.0; RODEL Software Ltd.) and the conventional intersection with Synchro (Version 6.0; Trafficware, Ltd.). Given that the different software results are not directly comparable, the trial results can be used to give only a general indication of relative performance.

The results of the comparison shown in Table 1 illustrate the potential performance gain of two-phase signals. Given the traffic volume inputs of the trial, the paraflow and CFI were at LOS C. On the other hand, the modern roundabout and conventional intersections produced LOS F. Both the paraflow and the CFI showed similar results at 80 percent and 75 percent less delay than the conventional and modern roundabout intersections, respectively.

Table 1. Intersection LOS and delay comparison.

	Intersection total		West approach		East approach		North approach		South approach	
	LOS	Average delay(s)	LOS	Average delay(s)	LOS	Average delay(s)	LOS	Average delay(s)	LOS	Average delay(s)
Two-phase paraflow[a]	C	32	C	30	C	27	C	35	D	36
Two-phase CFI[b]	C	34	D	36	C	26	C	33	D	37
Three-lane roundabout[c]	F	119	F	293	A	7	A	5	B	11
Conventional signal[d]	F	163	F	275	F	81	F	96	F	96

Notes:
[a] For each approach, two through lanes, two 91.5-meter (300-foot) center left-turn lanes, two 91.5-meter (300-foot) left-turn bypass lanes and one right-turn bypass lane. Analyzed using VISSIM v4.0 software.
[b] For each approach, two through lanes, two 91.5-meters (300-foot) displaced center left-turn lanes, two 91.5-meter (300-foot) left-turn bypass lanes and one right-turn bypass lane. Analyzed using VISSIM v4.0 software.
[c] For each approach, two through lanes, 91.5-meter (300-foot) flare length and three entry lanes. Three-lane circulatory roadway with 70-meter (230-foot) inscribed circular diameter. Analyzed using RODEL v1.0 at 50-percent confidence level.
[d] For each approach, one through lane, one shared through/right-turn lane, two 91.5-meter (300-foot) center left-turn lanes and optimized actuated-uncoordinated. Analyzed using Synchro v6.0 software.

Volume inputs

	% truck	Approach volume (vph)	Left turn %	Left turn vph	Through %	Through vph	Right turn %	Right turn vph
Major road (west)	3	2,500	30	750	60	1,500	10	250
Major road (east)	3	1,375	30	413	60	825	10	137
Minor road (north)	3	1,250	30	375	60	750	10	125
Minor road (south)	3	1,250	30	375	60	750	10	125
Total		6,375						

SAFETY

Safety at intersections is generally a function of vehicle speed and the number and severity of conflict points. A conventional intersection has 32 conflict points, of which 16 are the most severe crossing type. Crashes at conventional intersections often are at high speeds and, when combined with crossing maneuvers, result in a higher probability of fatality or serious injury.

On the other hand, the modern roundabout is indisputably the safest intersection, with very low travel speeds and only eight conflict points (less severe merge and diverge types). By comparison, the paraflow has 28 conflict points, of which 12 are the crossing type (see Figure 3). In addition to reduced crossing conflict points, all turn movements at the paraflow are protected and removed from the main junction.

PROPERTY ACCESS

The paraflow intersection does limit access to corner properties compared to a conventional intersection. Potential solutions are to allow left turns from the bypass roadway and/or left turns at the bypass junction onto the bypass roadway. In combination, these modifications would permit full access at driveways located on the bypass roadway. However, the presence of driveways on the bypass roadway or anywhere within the intersection limits increases the risk of stopped vehicle incidents that could, in turn, cause intersection movements to become blocked.

PEDESTRIAN CONSIDERATIONS

The paraflow offers protected pedestrian crossings at the main junction, with the crossing made in three separate signal phases: cross the near bypass roadway; cross the main roadway; and cross the far bypass roadway. At the main junction, channelizing traffic islands offer pedestrians refuge for safer crossing; at bypass junctions, the crossing will vary depending on the junction treatment. The combination of fewer lanes to cross between waypoints, one-way traffic at each crossing and no permitted left turns should make for a safer crossing at a paraflow than a conventional intersection, but at the expense of much more pedestrian travel time.

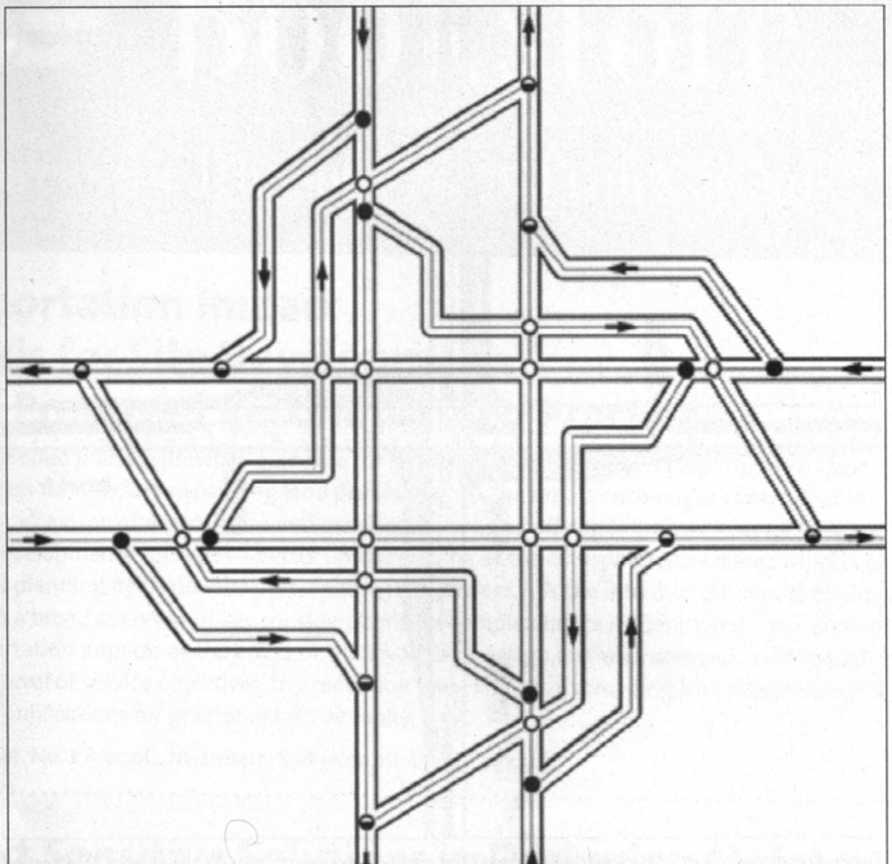
Given relatively long duration phases, separate pedestrian phases at a paraflow should not be necessary, unlike conventional intersections where all lanes on a leg must be crossed in a single phase, often requiring a separate activated pedestrian phase. A paraflow needs additional signal heads; thus assuming a four-leg conventional intersection requires four pairs of pedestrian signal heads, the paraflow would need eight total pairs.

CONVERTING INTERSECTIONS

Converting an existing conventional intersection to a paraflow can be straightforward if no additional lanes are being added to the existing roadway and space is available for the bypass roadways. As Figure 4 illustrates, longer duration work (such as new pavement construction) beyond the existing pavement limits (shown shaded in Figure 4) is performed on the outsides of the intersection without interrupting traffic operations or requiring detours. Less time-consuming work (such as adding loop detectors, channelization and pavement markings) could be performed with minor traffic disruption.

DESIGN ADAPTABILITY

Paraflows can take multiple forms and prove adaptable to various site and traffic conditions. Although the main junction is primarily limited to the at-grade signalized layout, the bypass junctions can receive a variety of treatments. The basic forms of paraflow intersections are four-leg, two-phase; four-leg, three-phase; and three-leg (T-type), two-phase. The major street bypass junction can take three forms: fully signalized, merge on the left (no signal in departing direction), or grade-separated. For minor-street bypass junctions, more options are available, including modern roundabout or stop-controlled treatments.



LEGEND	Four-leg, two-phase Paraflow	Conventional four-leg signalized Intersection
● Diverging	8	8
○ Crossing	12	16
◓ Merging	8	8
Total	28	32

Figure 3. Conflict diagram for a four-leg, two-phase paraflow intersection.

POTENTIAL RISK FACTORS

Without the benefit of a paraflow in operation to evaluate real-world performance, not all foreseeable problems possibly can be identified at this time; however, a few concerns are noted for consideration.

The bypass roadway is generally expected to be near-parallel with the cross street, forming a junction resulting in an undesirable intersection angle. Two problems emerge with this geometry: poor stopping sight distance (SSD) and wrong-way turn potential.

Short SSD is a concern with the driver stopped on the bypass roadway looking over the right shoulder to confirm that vehicles have stopped on the cross street departure lanes before entering the junction intersection. The bypass junction geometry can be adjusted to mitigate this problem by increasing the angle of intersection of the bypass roadway with the cross street. This is best accomplished by providing more lateral separation between the bypass and cross street roadways. Another method is to create a jughandle-like intersection by curving the bypass roadway away from the cross street, then forming the intersection.

Wrong-way movement potential is related to the bypass junction geometry as well, in that the high skew angle intersection creates a greater potential for driver confusion, leading to travel in the wrong direction of the cross street. Increasing the angle of intersection between the bypass roadway and the cross street in combination with clear markings and signage would reduce this risk.

Another risk factor is the loss of electrical power to the signal. Given the number of signalized movements and internally-conflicting routes within the intersection, signal malfunction could present a serious problem. Electrical backup means (generator or battery-powered light-emitting diode heads) would be necessary to protect against this situation.

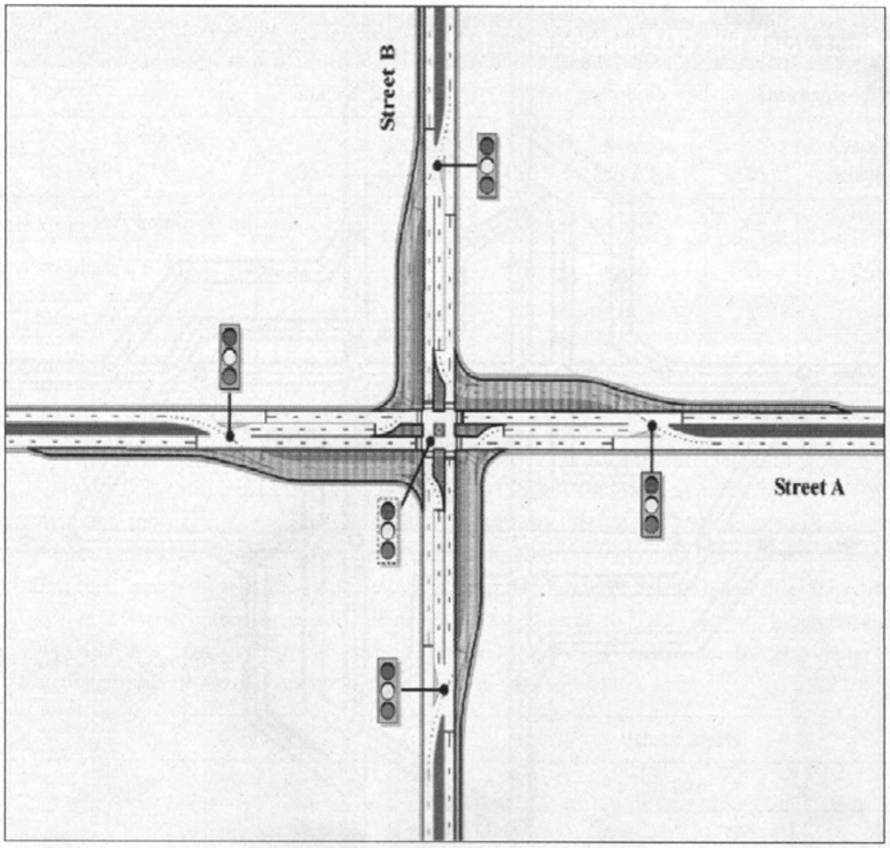


Figure 4. New pavement (shown as shaded areas) and signals necessary to convert the existing intersection to a paraflow intersection.

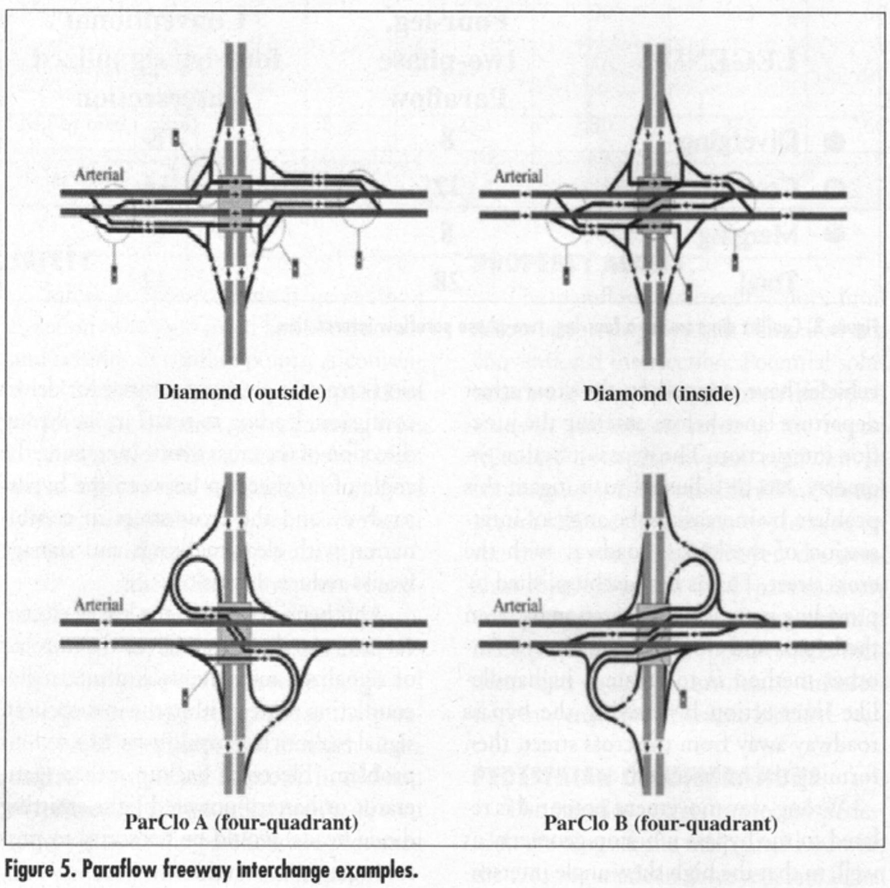


Figure 5. Paraflow freeway interchange examples.

Blocking within the intersection is an important concern, and measures would be necessary to reduce the effect of a crash or breakdown. Providing shoulders or other pullover space would help minimize the duration of interruption, and "no blocking" pavement markings combined with signage can be applied at critical crossing points.

A final risk factor is the improper turn where a driver might miss the turn opportunity and make an incorrect turn. With a CFI, this risk can occur for a left turn due to the center-turn lane displacement. Improper right turns are a greater risk with the paraflow, although the right-turn lane is not displaced as far as the CFI center-turn lanes. Effective signage and other wayfinding devices should minimize this risk for both intersection types.

PARAFLOW INTERCHANGE

The paraflow can be constructed as a freeway interchange either in diamond or partial cloverleaf (ParClo) forms (see Figure 5). The paraflow diamond interchange types are either inside or outside variants. The diamond interchange types retain the basic paraflow geometric design, in which the left turns from the freeway ramps connect to bypass roadways that are generally parallel and adjacent to the arterial.

The inside paraflow diamond places the opposing center left-turn lanes end to end at the bridge such that the arterial left turns travel directly onto the freeway entrance ramps, resulting in three two-phase junctions. The outside type separates the arterial center left-turn lanes such that left-turning vehicles turn onto the bypass roadways and then proceed onto the freeway ramps, also resulting in three two-phase junctions.

The use of a particular diamond variant is dependent on the site, with the outside type needing more arterial length but with lower structure cost than the inside type. For instance, the outside paraflow diamond could prove beneficial for converting existing conventional spread diamond freeway-over interchanges by modifying bridge end-spans to place the bypass roadways.

A paraflow ParClo can be a ParClo-A (two- or four-quadrant), ParClo-B (two- or four-quadrant), or single-loop ParClo. The ParClo-A and ParClo-B four-quadrant types can be configured such that the center left-turn lanes of the cross street are brought to a single signal at the bridge; a conventional ParClo requires two signalized ramp intersections on the cross street. The two quadrant and single-loop paraflow ParClo can be configured to form normal T-type paraflow intersections for two-phase operation where three-phase signals normally are necessary.

CONCLUSION

The parallel flow intersection has the potential to assist transportation agencies in reducing congestion at some of today's high demand intersections with less impact and at lower cost than conventional and other unconventional intersection designs. The layout expands a standard signalized intersection with the addition of turn bypass roadways parallel to the cross street.

This design appears to be intuitive and safe to drive, reduces property impacts and is flexible in application compared to other unconventional intersection alternatives. An important consideration for agencies desiring to improve capacity at existing intersections is the ease of converting to a paraflow without complicated construction phasing or temporary detours. The paraflow can be adapted in a variety of ways to fit site requirements with four- and three-leg intersection types, a variety of bypass junction treatments and freeway interchange types. The paraflow should be regarded as another option for agencies to expand the application of two-phase signals to even more intersections than previously considered. ■

References

1. Goldblatt, R.F. Mier and J. Friedman. "Continuous Flow Intersections." *ITE Journal*, Vol. 64, No. 7 (July 1994): 35–42.

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P.E., is principal of Quadrant Engineering LLC, a paraflow consulting practice. He is the inventor and patent holder (U.S. Patent No. 7,135,989) of the paraflow intersection. He also is a senior transportation engineer with TranSystems Corporation and has more than 20 years of experience in the planning and design of urban and rural streets and freeways.