Table 76. Summary of issues for median U-turn crossovers.

| Characteristic | Potential Benefits | Potential Liabilities |
|---|---|---|
| Safety | Potential major reduction in left-turn collisions.<br>Potential minor reduction in merging/diverging collisions. | None identified. |
| Operations | Potential reduction in overall travel time.<br>Reduction in stops for mainline through movements.<br>Mixed findings with respect to overall stops. | Mixed findings with respect to overall stops. |
| Multimodal | Number of conflicting movements at intersections is reduced. | Increased crossing distance for pedestrians.<br>Turning paths of the median U-turn may encroach in bike lanes. |
| Physical | None identified. | May be additional right-of-way needs depending on width of existing median. |
| Socioeconomic | None identified. | Access may need to be restricted within the influence of the median U-turn locations. |
| Enforcement, Education, and Maintenance | None identified. | Enforcement and education may be necessary to prevent illegal left turns at the main intersection. |

### 10.2.3 Continuous Flow Intersection

Continuous flow intersections (CFI), both full and partial, have recently been constructed in a small number of locations in the United States. Although too new for a full evaluation of the effect on operations and safety, continuous flow intersections are gaining in popularity. CFI are also sometimes referred to as crossover-displaced left-turn (XDL) intersections.

***Description***

A CFI removes the conflict between left-turning vehicles and oncoming traffic by introducing a left-turn bay placed to the left of oncoming traffic. Vehicles access the left-turn bay at a midblock signalized intersection on the approach where continuous flow is desired. Figure 91 shows the design of a CFI with crossover displaced left turns, and figure 92 illustrates some of the vehicle movements at such an intersection. As can be seen, the left turns potentially stop three times: once at the midblock signal on approach, once at the main intersection, and once at the midblock signal on departure. However, careful signal coordination can minimize the number of stops. Examples of implemented sites are shown in figures 93 and 94. Note that this section describes an at-grade CFI; a grade-separated version of the CFI was patented (U.S. Patent No. 5,049,000), but the patent expired in 2003.

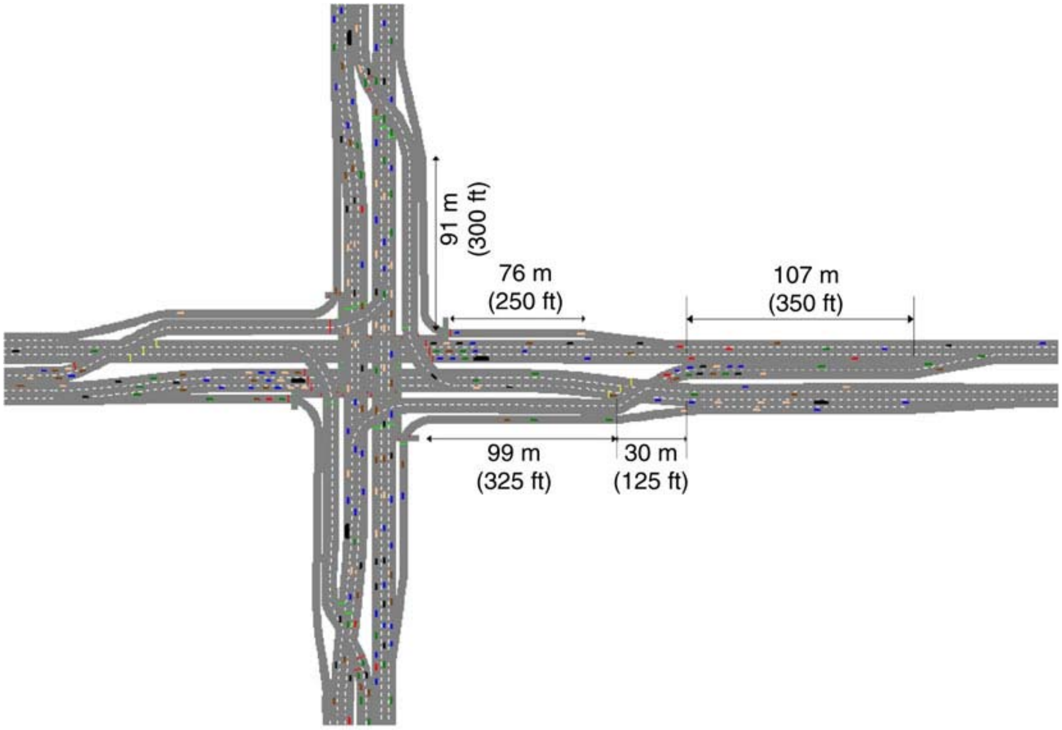
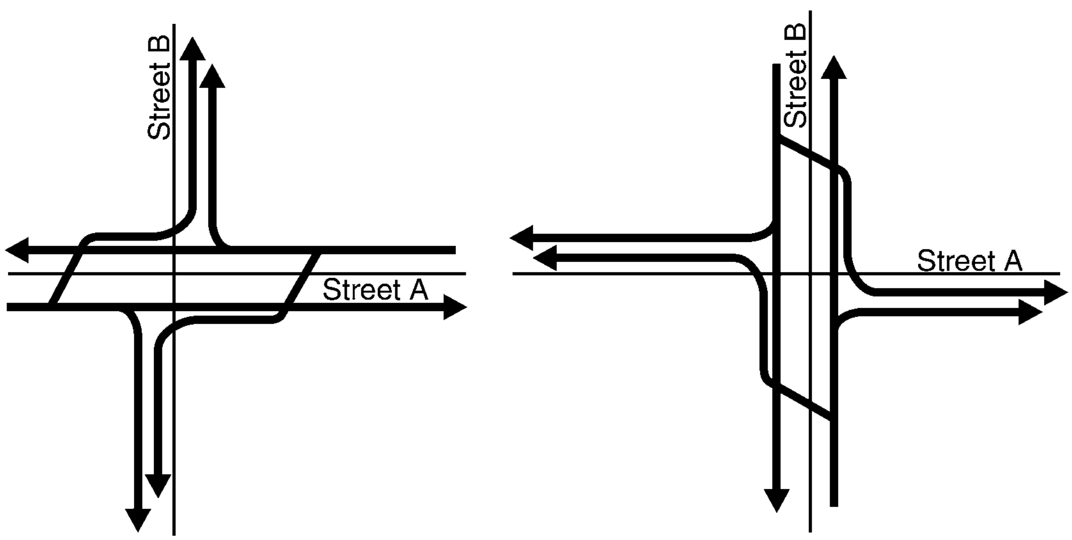



Figure 91. Diagram of a continuous flow intersection.(150)




(a) Turning movements from Street A.

(b) Turning movements from Street B.

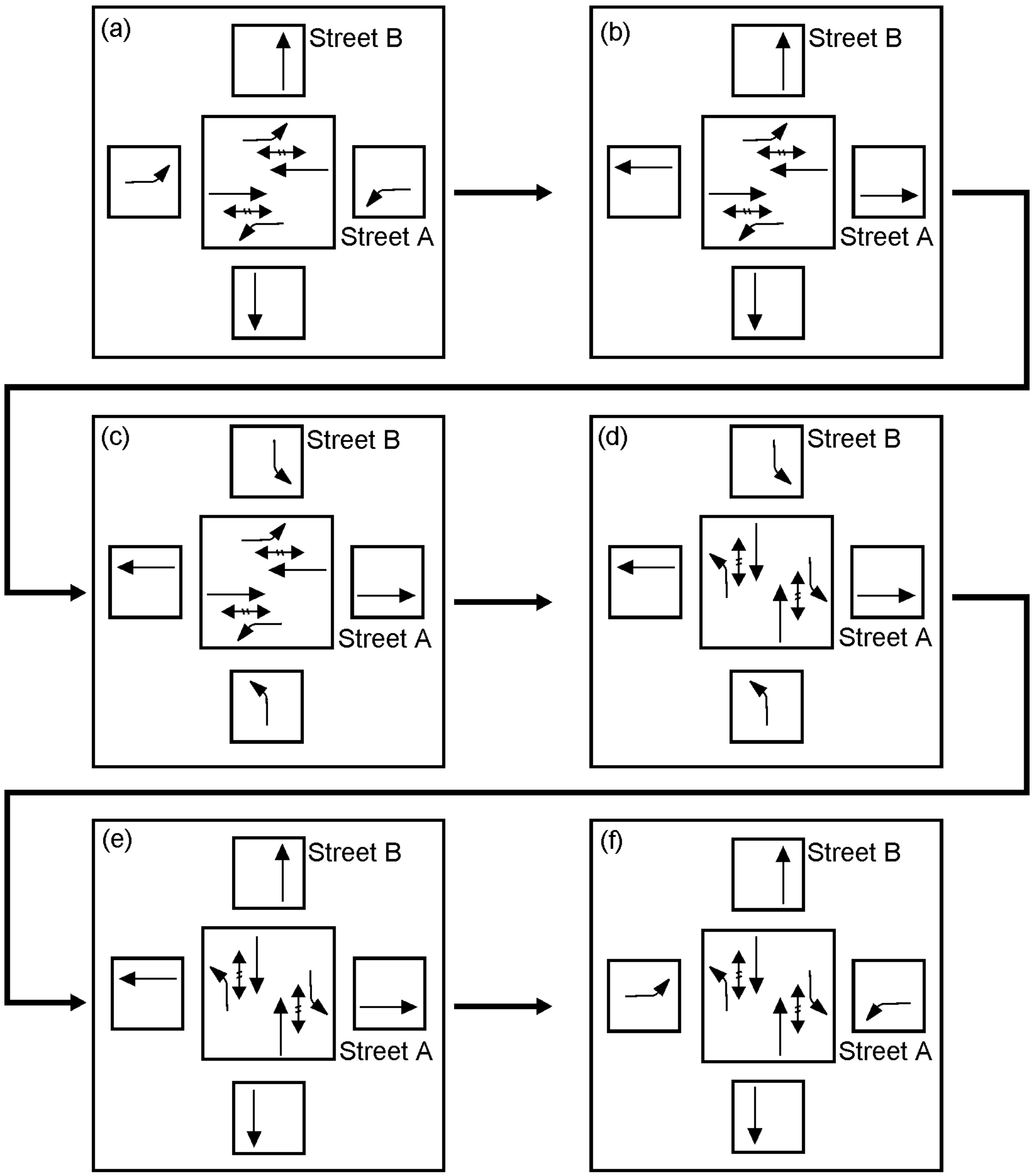
Figure 92. Vehicular movements at a continuous flow intersection.

Figure 93. Continuous flow intersection.

Photograph Credit and Copyright: Francisco Mier, 1999

Figure 94. Displaced left turn at a continuous flow intersection.[151]

The complete CFI design operates as a set of two-phase signals. As part of the first phase, traffic is permitted to enter the left-turn bay by crossing the oncoming traffic lanes during the signal phase serving cross-street traffic. The second signal phase, which serves through traffic, also serves the protected left-turn movements. Figure 95 shows the signal phase sequence used at a CFI.




a. Street A movements at the major intersection, left turns on the advance intersections on Street A, and through movements on the advance intersections on Street B.
b. Street A movements at the major intersection and through movements at all advance intersections.
c. Street A movements at the major intersection, through movements on the advance intersections on Street A, and left turns on the advance intersections on Street B.
d. Street B movements at the major intersection, left turns on the advance intersections on Street B, and through movements on the advance intersections on Street A.
e. Street B movements at the major intersection and through movements at all upstream intersections.
f. Street B movements at the major intersection, through movements on the advance intersections on Street B, and left turns on the advance intersections on Street A.

Figure 95. Signal phasing of a continuous flow intersection.[adapted from 150]

Intersections with high through and left-turn volumes may be appropriate sites for continuous flow intersections. There should be a low U-turn demand because U-turns are restricted with this design. Right-of-way adjacent to the intersection is needed for the left-turn ramps.

Left-turning vehicles make more stops than at conventional intersections, and may experience a slightly higher delay. Through traffic benefits greatly from this design.

***Safety Performance***

Safety improvements may be experienced by the left-turn movement due to the relocation of the turn lane; rear-end crashes with through vehicles may be reduced. Congestion-related collisions (mainly rear ends) may also decrease if stop-and-go conditions occur less often.

Table 77 shows the number of conflict points at a four-leg signalized intersection as compared to a continuous flow intersection. The number of merging/diverging conflict points is the same at a continuous flow intersection as compared to a conventional four-leg signalized intersection. All left-turn (crossing) conflicts are removed. However, the number of angle (crossing) conflicts would triple. Figure 96 shows the conflict point diagram for a continuous flow intersection.

Table 77. Number of conflict points at a four-leg signalized intersection compared to a continuous flow intersection with displaced left turns on the major street only.

| Conflict Type | Four-Leg Signalized Intersection | Continuous Flow Intersection |
|---|---|---|
| Merging/diverging | 16 | 14 |
| Crossing (left turn) | 12 | 6 |
| Crossing (angle) | 4 | 10 |
| Total | 32 | 30 |

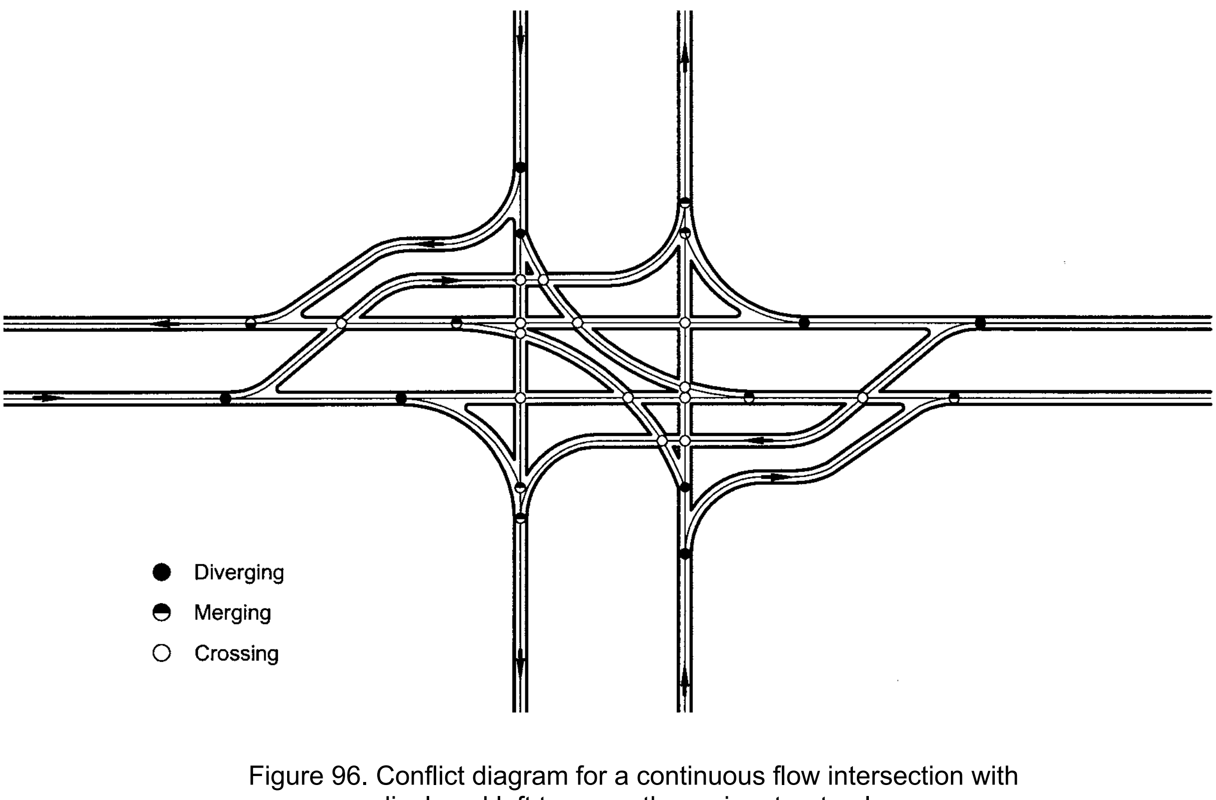



Figure 96. Conflict diagram for a continuous flow intersection with displaced left turns on the major street only.

Table 78 summarizes the expert opinion of the authors with regard to the safety benefits of changing a four-leg signalized intersection to a CFI.

Table 78. Safety benefits of converting a four-leg signalized intersection to a CFI: Expert opinion.

| Treatment | Surrogate | Finding |
|---|---|---|
| Convert signalized four-leg intersection to continuous flow intersection | Conflict points | Offers the potential for a major reduction in left-turn collisions<br>Offers the potential for a major increase in angle collisions |

### *Operational Performance*

The key operational benefit of this intersection is that multiphase signal operation is not required to provide protected left-turn movements. This benefits through traffic. Continuous flow intersections provide an at-grade intersection solution that can improve traffic operations beyond the capabilities of other conventional at-grade solutions.(152)

Jagannathan and Bared evaluated three different CFI configurations (four-leg intersection with displaced left on all approaches; four-leg intersection with displaced left on two approaches; and T intersection with displaced left on one approach) against a conventional intersection for a range of high entering volumes using VISSIM.(150) Operational benefits of the CFI were realized for all three CFI intersection configurations. For the case of the four-leg intersection with displaced left turns on all approaches, the following findings were documented:

- Average delay was reduced with the CFI by 48 to 85 percent compared to the conventional intersection, with the lower value applying to an undersaturated case and the upper value applying to an oversaturated case.
- The average number of stops with the CFI was reduced by 15 to 30 percent for under-saturated traffic flows and 85 to 95 percent for saturated traffic flow conditions at the conventional intersection.
- Queue lengths with the CFI were reduced by 62 to 88 percent compared to the conventional intersection, with the lower value applying to an undersaturated case and the upper value applying to an oversaturated case.

Goldblatt, Mier, and Friedman evaluated the performance of traffic at CFI designs by comparing it with the performance of conventional intersections under multiphase signal control.(152) Traffic demand was assumed equal on each approach leg to the intersection and turn movements were also assumed equal on each approach (15 percent left turns, 11 percent right turns). Traffic demand volumes for each approach were examined at 1,500, 2,000, and 3,000 vehicles per hour (veh/h). Key findings are as follows:

- At the 1,500 veh/h demand level, the demand was processed by both conventional and continuous flow intersections.
- At the 2,000 veh/h demand level, the capacity of the conventional intersection was exceeded (approximately by 20 percent) and the CFI serviced the entire demand.
- At the 3,000 veh/h demand level, the capacity of both the conventional intersection and the continuous flow intersection were exceeded. However, the capacity of the CFI nearly 50-percent greater than the conventional intersection.
- The advantages of the CFI are most pronounced when the demand approaches exceed the capacity of conventional designs and when heavy left-turn movements require protected phases.

In 1994 (the date of publication of Goldblatt, Mier, and Friedman), no known CFIs had been constructed.(152) Conclusions were drawn solely from operational simulation modeling. Actual operational experience with CFIs are not widely available, but should become more so as more CFIs are built and evaluated.

Abramson, Bergen, and Goldbatt also note the potential for improved arterial performance with CFIs.(153) Because left-turn signal phasing is effectively removed with a CFI, expanded green bands along the arterial can be achieved.

Simulation studies using a range of intersection configurations (number of through lanes on the major and minor street) and volumes from intersections in Virginia and North Carolina suggest mixed results in overall travel time through the intersection when compared to a conventional intersection: –1 to +25 percent during off-peak conditions, and –12 to +27 percent during peak conditions. The studies also show a general increase in the overall percent of stops when compared to a conventional intersection: +21 to +87 percent during off-peak conditions, and +12 to +49 percent during peak conditions.(145)

#### *Multimodal impacts*

Pedestrian safety is improved with the CFI design, according to Goldblatt et al.(152) Pedestrians cross at times when there are no conflicts with turning vehicles. Pedestrians do require two sequential signal phases to complete a street crossing. However, the layout and operation of the intersection may not be immediately apparent to pedestrians, particularly those with visual disabilities. As a result, pedestrians with visual disabilities may have challenges in way-finding through the intersection. The unconventional flows of vehicles will disrupt the audible cues that visually impaired pedestrians use; therefore, accessible pedestrian signals should be considered for use with this intersection configuration.

#### *Physical Impacts*

The footprint of a continuous flow intersection is greater than that of a conventional intersection because it requires right-turn lanes and acceleration lanes in each quadrant. It takes less space than an interchange, however.

#### *Socioeconomic Impacts*

According to Goldblatt et al., the construction cost of a CFI may be two to three times the cost of a standard intersection design due to increased right-of-way costs, and the need for additional, coordinated signal controllers.(152)

#### *Enforcement, Education, and Maintenance*

Additional potential roadblocks to continuous flow intersections include:

- Pedestrian acceptance (cross only at main intersection—no midblock crossing).
- Driver acceptance (vehicles may be opposed by traffic on both sides).
- Snow removal issues.
- Breakdown of vehicles.
- Providing access to adjacent parcels.
- With less intersection delay, improvements in air quality can be realized.

A public information campaign may be needed to educate drivers on the operation of the intersection. Abramson, Bergen, and Goldblatt provide a summary of a human factors study of continuous flow intersection operations.(153) Survey questionnaires were used to assess the learning curve of drivers utilizing a CFI in New York. Results indicated a positive response rate of 80 percent for first-time users of the design. After about a week of use, 100 percent of daily drivers expressed positive comments about the design. The basic conclusion is that unfamiliar drivers easily negotiate the intersection form and, after a short break-in period, nearly all drivers can become familiar and comfortable with the design. Key negative comments received in the survey dealt with adequate advance signing that must be provided. The authors detail the experience with one intersection only (and only one leg of the intersection had been designed as a CFI).

The use of extensive special directional signing is key to maximizing driver understanding and acceptance.

***Summary***

Table 79 summarizes the issues associated with CFI.

Table 79. Summary of issues for continuous flow intersections.

| Characteristics | Potential Benefits | Potential Liabilities |
|---|---|---|
| Safety | Left turns removed from main intersection. | None identified. |
| Operations | More green for through. | More stops and delay for left turns. |
| Multimodal | No conflicts during pedestrian crossing. | Two-stage pedestrian crossing.<br>Layout may not be immediately apparent, especially for visually impaired pedestrians. |
| Physical | Smaller footprint than interchange alternative. | Right-of-way needed.<br>Larger footprint than conventional intersection.<br>Access management. |
| Socioeconomic | Air quality. | Construction cost.<br>Access management. |
| Enforcement, Education, and Maintenance | None identified. | Public information campaign may be needed. |

### 10.2.4 Quadrant Roadway Intersection

A quadrant roadway intersection includes an extra roadway between two legs of the intersection (see figure 97). Drivers who wish to turn left from either the major or minor road will travel further to do so, but all left turns will be removed from the main intersection, as shown in figure 98. This design creates two additional intersections, which operate as three-phase signals, but the signal at the main intersection can operate as a two-phase signal, as shown in figure 99.

The signals at the quadrant ramps should be located a sufficient distance upstream of the main intersection to eliminate the potential for queue spillback. Reid identified a length of 150 m (500 ft) for his CORSIM evaluation.(154)