

CFI Guideline

A UDOT Guide to Continuous Flow Intersections

July 2013



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EXECUTIVE SUMMARY

According to Arthur C. Clarke, all new ideas pass through three phases – ‘it can’t be done’, ‘it probably can be done, but it’s not worth doing’, and finally ‘I knew it was a good idea all along’. This is a pattern that UDOT’s innovative Continuous Flow Intersection (or CFI) has followed and continues to follow in its implementation through the State of Utah.

With ten CFIs constructed in Salt Lake County between 2007 and 2013, and with several more in design or ready for construction, the CFI has become a standard transportation solution in the Salt Lake City area. Score one for “it was a good idea all along.” In the rest of the State, however, only one CFI has been constructed and there are few immediate plans for any additional CFIs. This leaves most of the state in the “is it worth doing?” or the “it can’t be done in our community” phases. Given the overwhelming success of the CFIs in Salt Lake and Utah County, current UDOT leadership feels that a reluctance to adopt the CFI in other areas of the State may be resulting in missed opportunities.

The major purpose of the *CFI Guideline* is to accelerate acceptance of the CFI throughout the State, and to formalize the critical design elements to help foster acceptance. The CFI Guideline promotes this goal by providing a detailed accounting of key concept principles, design variations, decision making factors, evaluation standards, design standards, and lessons learned from CFI implementations throughout the State. The consolidation of this information into a single resource demystifies the CFI, removes some elements of unknown risk, and provides design confidence that encourages implementation.

To date, the CFI’s success in Utah has been very good, if not excellent. With eleven CFIs constructed in six years (2007-2013), UDOT clearly recognizes the value that the

CFI concept provides for a very reasonable cost (usually < \$10 million). These costs compare favorably to grade-separated solutions or corridor widening projects that can cost 2 to 5 times more, or even to the similar costs of “interim solutions” that provide significantly less operational benefit. In addition to the excellent benefit-cost ratios, CFIs have shown safety improvements that include fewer conflict points, and a 30% to 70% reduction in travel times and intersection delay. All of these benefits are provided with minimal driver inconvenience, no out-of-direction travel, and new opportunities for access management/consolidation.

Of course these benefits do not imply that Utah’s CFIs have been without their flaws and controversies. As would be expected with any new concept, numerous lessons learned have occurred over the course of the past five years. Some lessons learned are found in the convergence of intersection geometry and signal timing (harmonizing crossover distances), while others address driver expectancy and comfort (signs and lane configurations). Some of the most important lessons learned are found

in long-term implications of maintenance (e.g. snow removal), public perception (e.g. design consistency), and opportunities for corridor application.

The lessons learned, collective design experiences, successes, and failures of implementing

Utah’s CFI concepts represent a wealth of information to be captured and made accessible. Gathering this information together and making it electronically accessible allows this wealth of information to be searchable, prolific, and easy to use. With easy access to this information, UDOT hopes that its project managers and design teams will consider the *CFI Guideline* as a call to action to evaluate, design, and construct more CFIs throughout the State. The money and time expended to gather this information into one place is an effort to encourage UDOT professionals, in all regions, to identify opportunities for CFI implementation in old and new locations – to consider retrofit intersections and

“Creativity can solve almost any problem. The creative act, the defeat of habit by originality, overcomes everything.”

— George Lois

new corridors alike.

The *CFI Guideline* is written specifically for project managers and design teams. Sections 1-3 of the CFI Guideline guide project managers through the process of deciding when and where to consider a CFI. Sections 2, 4 and 5 are written primarily for design teams. They contain the nitty-gritty details of CFI design, including rules of thumb, lessons learned, technical details, and section references to accepted design standards. Understanding that the CFI Guideline’s greatest potential benefit is in areas where CFIs are still a new concept, Section 6 is a messaging guide for project managers to foster greater public acceptance of the CFI

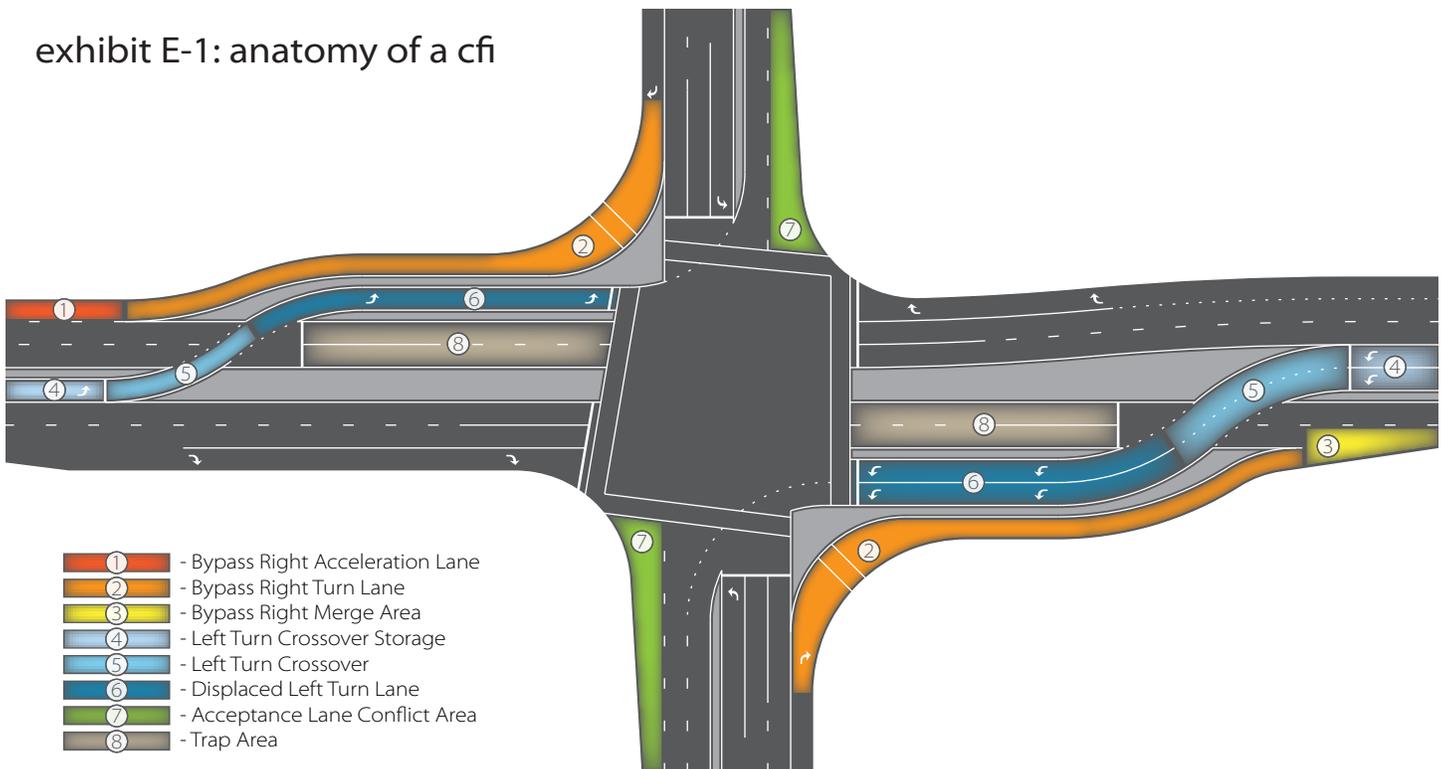
and other new concepts as well.

We hope that project managers and design teams will appreciate the CFI Guideline for the labor of love that it is – a guideline of best practices (not a straitjacket) and past innovations, and a starting point for continuing innovation on future projects.

“The good thing is, with innovation, there isn’t a last nugget. Every new thing creates two new questions and two new opportunities.”

— Jeff Bezos

exhibit E-1: anatomy of a cfi



SECTION 1 - CFI OVERVIEW & BASIC CONSIDERATIONS

CFI Concept Basics

To begin a discussion on CFIs, we must first address the fundamental CFI concept, which at its most basic level is a design strategy that removes one or more left turn signal phases from the conventional four-phase intersection. Eliminating left turn signal phase(s) is accomplished by directing the left turn vehicles across the opposing lanes of through traffic, in advance of the intersection, into a channelized lane (displaced left turn lane) to the outside of the opposing through traffic as illustrated in **Exhibit 1-1**. This crossover movement, or displaced left turn, occurs at a new signal located upstream of the main intersection. The crossover signal is strategically timed to turn green prior to the start of the through movement green phase at the main intersection. With ideal timing, left turning vehicles cross over, proceed toward the main intersection, and then continue on to make a left turn from the outside of the oncoming through traffic. Consequently, both the left turn and through movements (and in some cases right turns) are able to proceed simultaneously through the intersection, eliminating the need for dedicated left turn green time.

Opposing crossover movements are nearly always paired (e.g. north & south or east & west) in order to eliminate a left turn signal phase entirely. If one set of paired crossover movements are implemented, the intersection will usually operate with 3 phases. If crossover movements are implemented on all four approaches to eliminate both left turn signal phases, the intersection would then operate with 2 phases.

The green time saved by eliminating left turn signal phases at the main intersection is added to through movements, improving intersection capacity and reducing delay. Because this additional green time is theoretically added to the end of the through movement green phase (when vehicles are already traveling at speed), even small additions of green time can be very effective. In fact, these small additions of green time are so effective that displaced left turns at a CFI can potentially improve the capacity of an intersection between 30% and 70%, as identified in operational and observational studies performed by UDOT. **Exhibit 1-2** illustrates how eliminating left turn phases with a CFI translates to more green time at an intersection.

exhibit 1-1: anatomy of a cfi

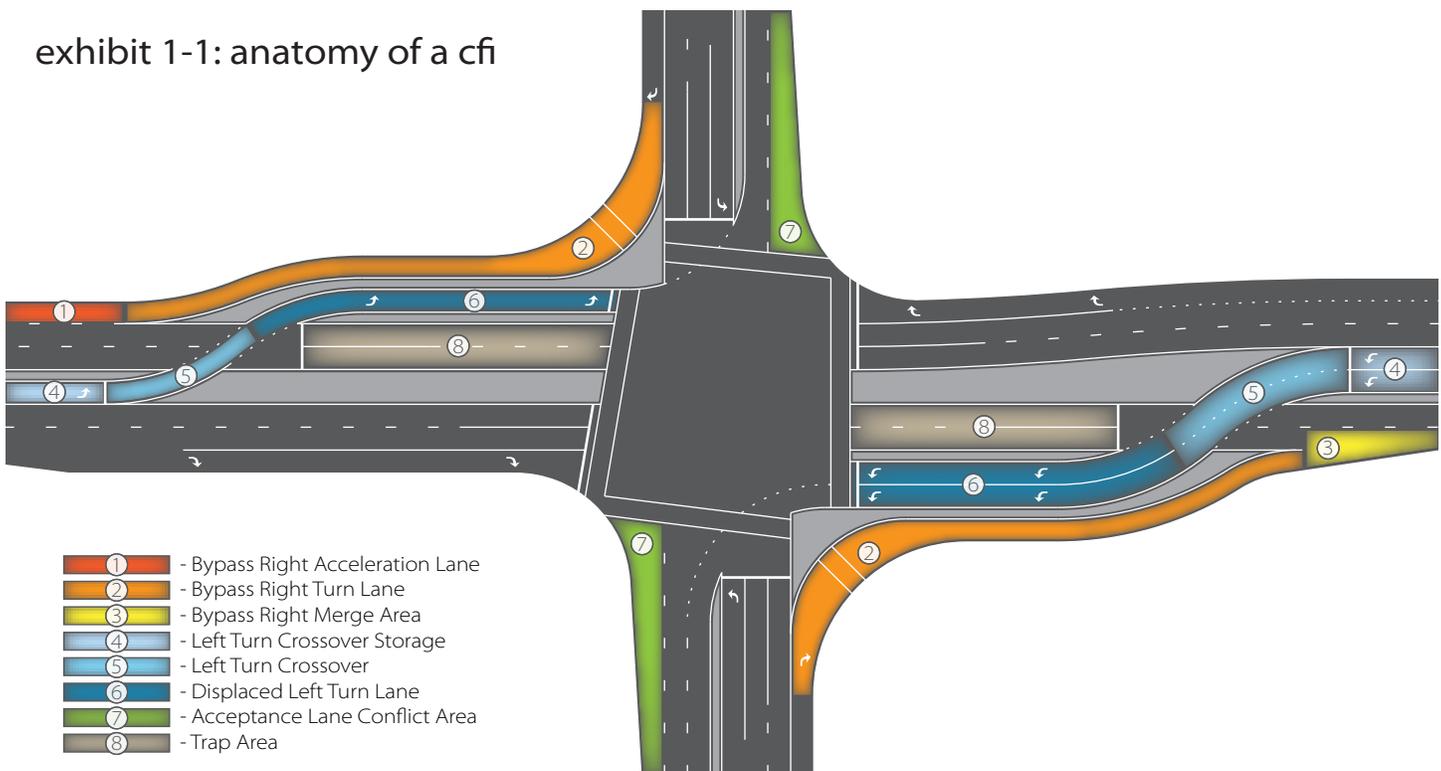
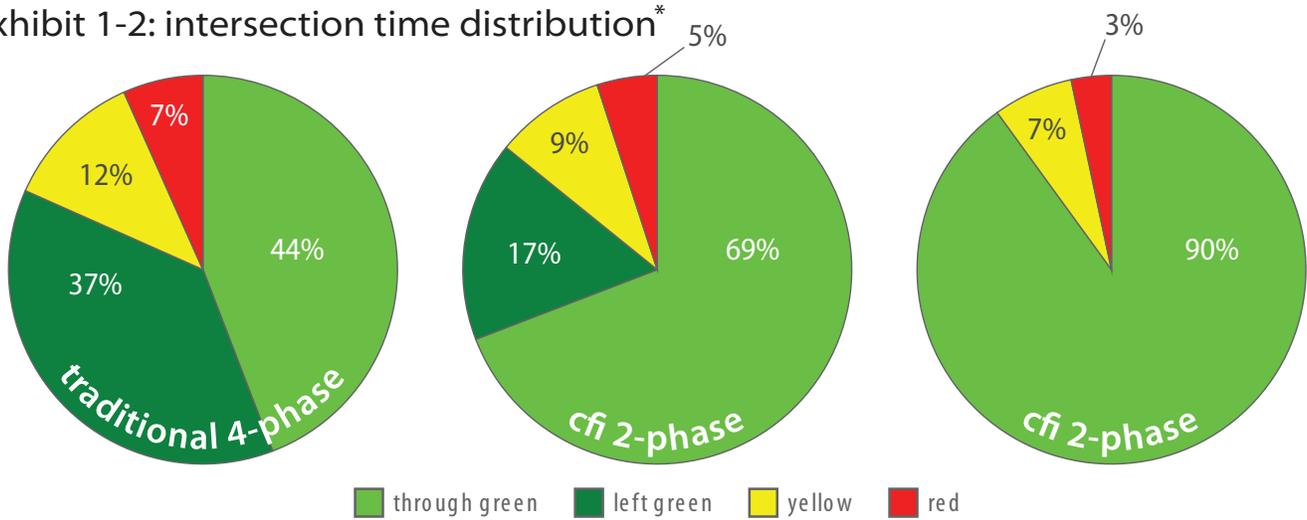


exhibit 1-2: intersection time distribution*



*Comparison based on sample 4-phase intersection with 120 second cycle length and typical UDOT timing standards

Bypass Right Turns & Receiving Lane Conflicts

To avoid potential conflicts with right turning vehicles crossing in front of the displaced left turn lane, a bypass right turn lane can be used to allow right turning vehicles to bypass the intersection. A bypass right turn lane veers to the right just before the intersection, and passes outside of the displaced left turn lanes until it clears the crossover location and merges back into traffic. Bypass right turn lanes are safe and efficient for right turn movements; however, they also significantly widen the intersection footprint, increasing impacts and costs. A CFI bypass right turn lane is illustrated in **Exhibit 1-3**.

Because left turn, through, and right turn movements

from opposing directions can all move simultaneously during the same green phase, potential for receiving lane conflicts exists between left turns and opposing right turn movements. These receiving lane conflicts are highlighted in **Exhibit 1-4**. If the number of left turn and opposing right turn lanes at a CFI equals the number of receiving approach lanes, then the turning vehicles must simply obey the law and avoid wide turns that take them outside of their designated receiving lanes. If there are not enough receiving lanes to accommodate all the turns, other measures are sometimes necessary in order to accommodate both opposing movements safely. These measures, which include right turn overlaps, are described in greater detail in the Section 2 - Conceptual Design.

exhibit 1-3: bypass right turn

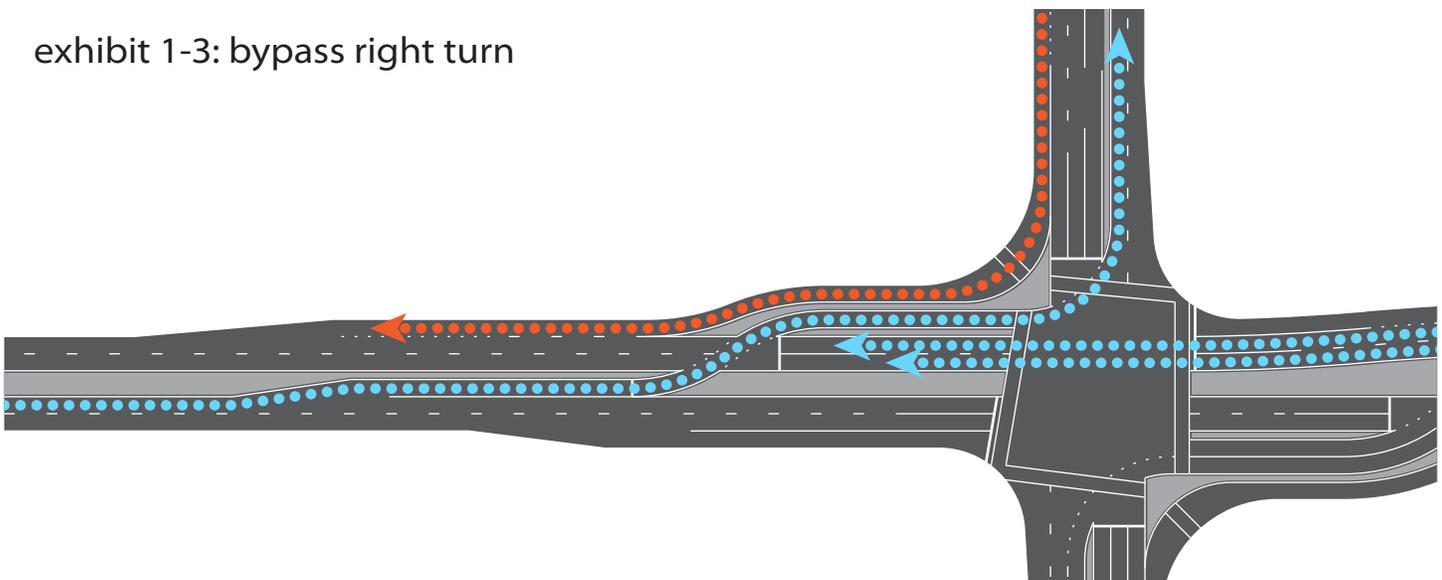
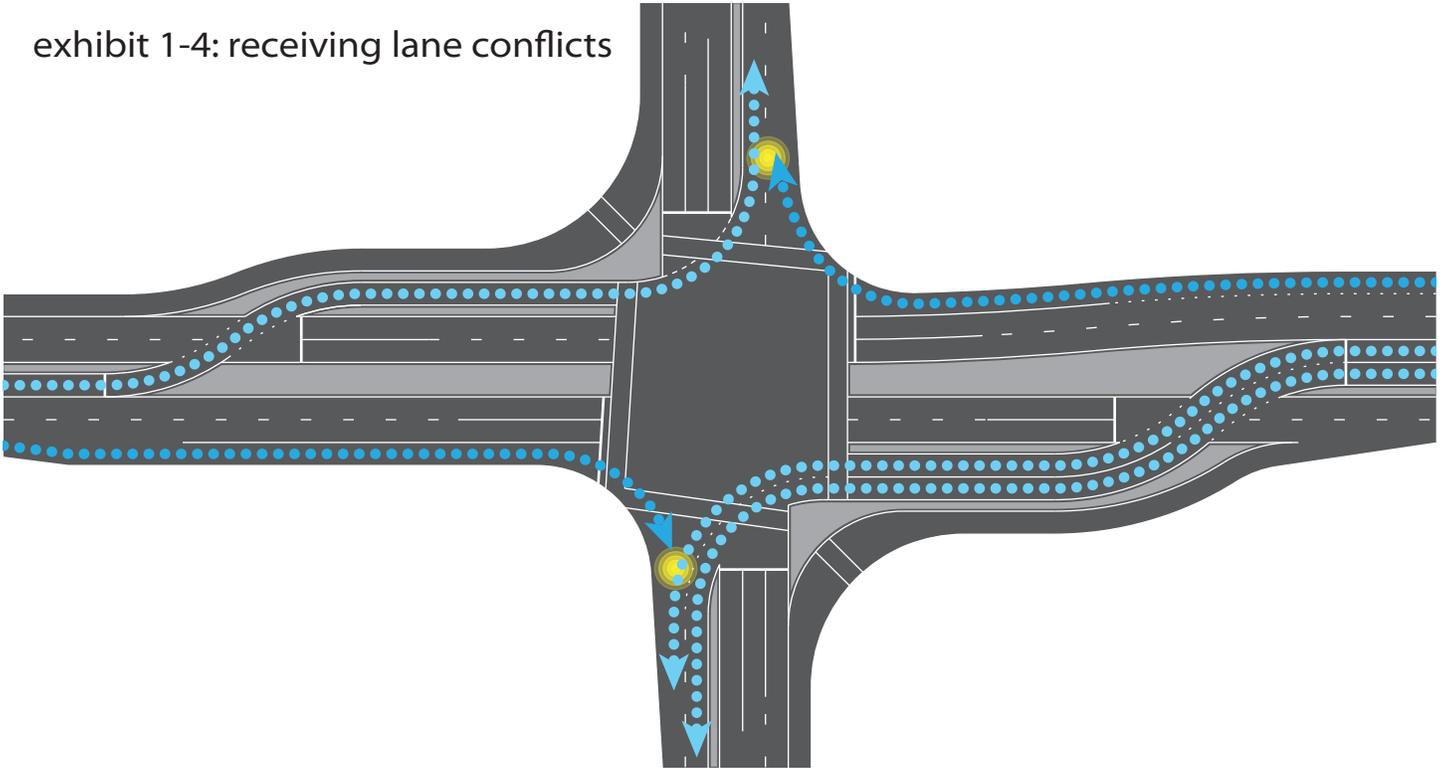


exhibit 1-4: receiving lane conflicts

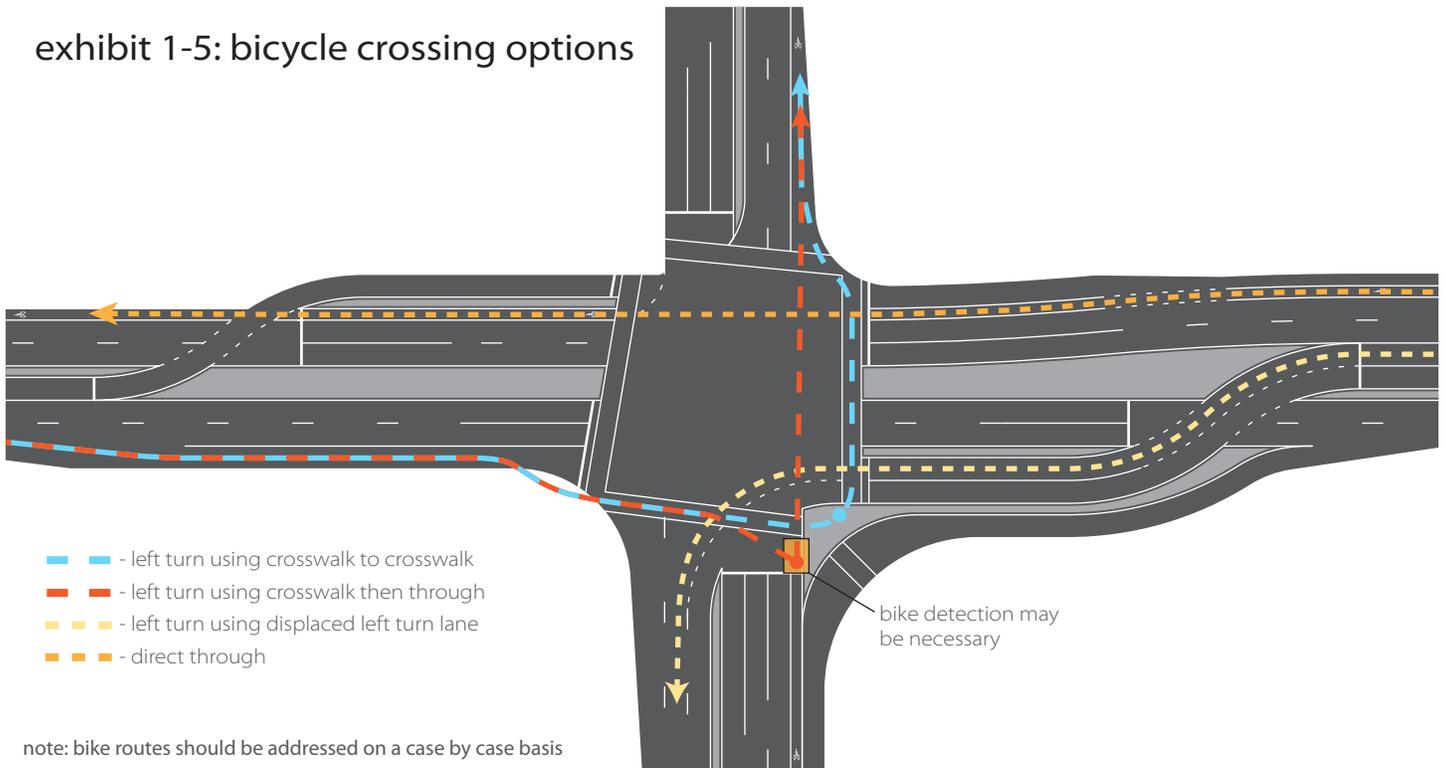


Bicycles and Pedestrians

The way in which bicyclists move through a CFI is really not much different from how they would move through a conventional intersection. The newness of the CFI concept, the lack of established convention, and the general lack

of experience with CFIs, however, encourages positive guidance to help bicyclists navigate a CFI. **Exhibit 1-5** illustrates some of the options available to bicyclists who wish to pass through a CFI, including the legal use of the crossover left turns for bicycle left turn movements.

exhibit 1-5: bicycle crossing options



note: bike routes should be addressed on a case by case basis

These illustrative options are not all inclusive and do not necessarily represent accepted UDOT conventions for CFI bicycle crossings, which should be addressed on a case by case basis and should consider signal timing, signing, striping, and detection needs.

Bicycle accommodations at a CFI should also acknowledge the different types of bicyclists likely to pass through the intersection. Some bicyclists are comfortable operating amongst vehicular traffic (road cyclists), and some bicyclists are less confident in these conditions (recreational cyclists). Different types of bicyclists require varying needs, which should be addressed during design. A more detailed discussion of potential provisions for bicyclists can be found in Section 4 - CFI Design Parameters.

He that will not apply new remedies must expect new evils, for time is the greatest innovator.

— Francis Bacon

Pedestrians typically cross CFIs at-grade. This is accomplished with either a controlled or uncontrolled pedestrian crossing for bypass right turn lanes, and a controlled crossing of the main intersection that occurs after the CFI left turns have finished their movement. Since the CFI has a larger footprint than many traditional intersections, pedestrian crossing times can be fairly long. These long crossing times can make half cycle lengths prohibitive and can complicate timing plans generally. Consequently, opportunities to eliminate crossings altogether (or to provide pedestrian structures) should be considered. Additional discussion of pedestrian considerations can be found in Sections 2 and 4.

CFI Medians

The median separation for displaced left turn lanes and left turn storage at CFIs are often an access impediment. Considered from another vantage point, it can also be considered an opportunity for access consolidation, depending on the surrounding context. To this end, a number of strategies have been developed to allow partial access at various points within the CFI. These strategies will be discussed in more detail, but generally provide left turn accesses at crossover locations and sometimes allow right-in right-out or left-in left-out

movements to/from bypass right turn lanes or displaced left turn lanes.

At the CFI, the median separations such as the ones between displaced left turn lanes and through lanes, and between displaced left turn lanes and bypass right turn lanes are often an access impediment. However, considered from another vantage point, these median separations can provide an opportunity for access consolidation, depending on the nature of surrounding development. Over the years, a number of strategies have been developed to allow partial access at various points within the CFI. The strategies, which include left turn access at the crossover locations and left and right turn access at the bypass right turn lanes, are discussed in more detail in Section 2.

Evolution of the CFI & Lessons Learned

Since the construction of UDOT's first CFI at 3500 South & Bangerter Highway (SR-154) in 2007, the design of the CFI in Utah has continually evolved. UDOT's first CFI was an evolution and improvement over the CFI concepts implemented elsewhere. With ten CFIs operational in Utah as of 2012, it might be tempting to think that the concept is now pretty well set in stone. In fact, nothing could be further from the truth. While there certainly are some general principles that apply to all CFIs, there is no one-size-fits-all CFI solution. In fact, we should probably repeat that phrase for additional emphasis. **There is no one-size-fits-all CFI solution.** More importantly, there are still plenty of potential innovations that can be applied to expand and improve upon current CFI designs if presented with appropriate constraints and opportunities. So, the CFI likely still has some room to evolve, even in Utah.

The Element of Cost and Innovation

In considering the past evolution of the CFI concept and the potential for ongoing evolution, the element of cost deserves special consideration. In many ways, a high-cost improvement alternative that takes a decade to fund and construct is inherently inferior to a more reasonably

priced improvement that can be funded in a much shorter timeframe. Regardless of whether current environmental procedures allow consideration of cost or not, the factor of cost is nevertheless crucial in selecting which alternatives will actually become funded construction projects. Cost is part of the reason why ten CFIs have been built in Utah between 2007 and 2012, and why CFIs have continued to evolve in Utah.

Cost was a factor in selecting the CFI as a solution over grade separated alternatives for Utah’s first CFI at 3500 South, and at other locations on Bangerter Highway. During the East-West Mobility Study, intersections along Bangerter Highway were identified as high delay locations and barriers to east-west travel. With the CFI at 3500 South as an example, the study recognized the potential for CFIs on the Bangerter Highway and Redwood Road (SR-68) corridors as compare to the limited capacity improvements expected from conventional improvements and the high costs and impacts of grade-separation. Based on this recommendation, UDOT has now constructed eight CFIs on Bangerter Highway with a cost less than that of two grade separated interchanges.

An example of how cost drove the evolution of crossover distances and bypass right turn lanes can be found in the design of the 3500 South and Bangerter CFI, and in

the design of subsequent CFIs on Bangerter Highway at 4100 South, 4700 South, 5400 South and others. At 3500 South, the CFI evolved from previous applications in other jurisdictions to provide relatively short crossover distances (only 300’ from the intersection) in order to avoid some significant property acquisition costs. While it was known from micro-simulation that these shorter crossover distances might not allow the CFI to serve left turns quite as well, it was nevertheless decided that the property acquisitions necessary to fully optimize the intersection were not worth the additional cost.

The CFI at 3500 South (and all previous versions in other jurisdictions) had bypass right turn lanes that allowed some right turns to bypass the intersection altogether. In subsequent CFIs, crossover distances were extended to optimize the traffic operations and bypass right turn lanes were eliminated to narrow the intersection footprint, avoid additional property acquisition costs, avoid utility conflicts, reduce grading and retaining requirements, and reduce the overall project costs. In making the decision to eliminate bypass rights, the performance of some right turn movements were sacrificed for a much smaller intersection footprint that cost about half of the 3500 South CFI.

Signs and signal variations have also evolved, largely

exhibit 1-6:
conventional
intersection

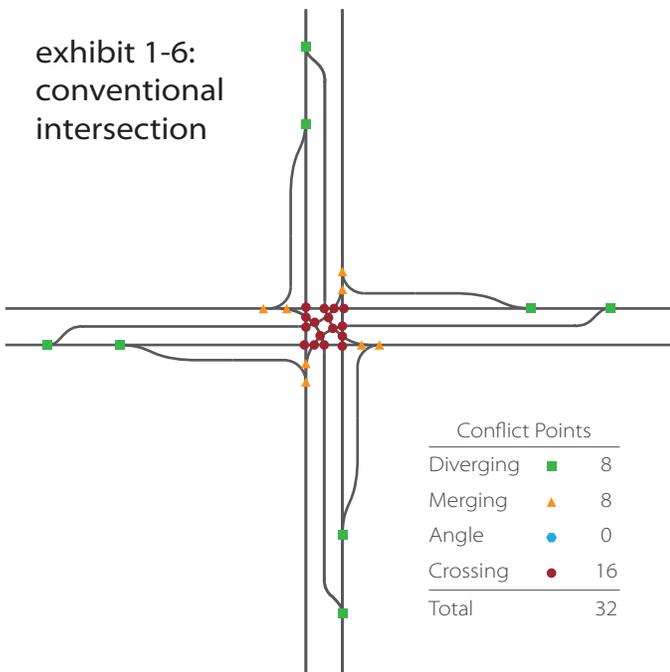


exhibit 1-7:
2-leg cfi

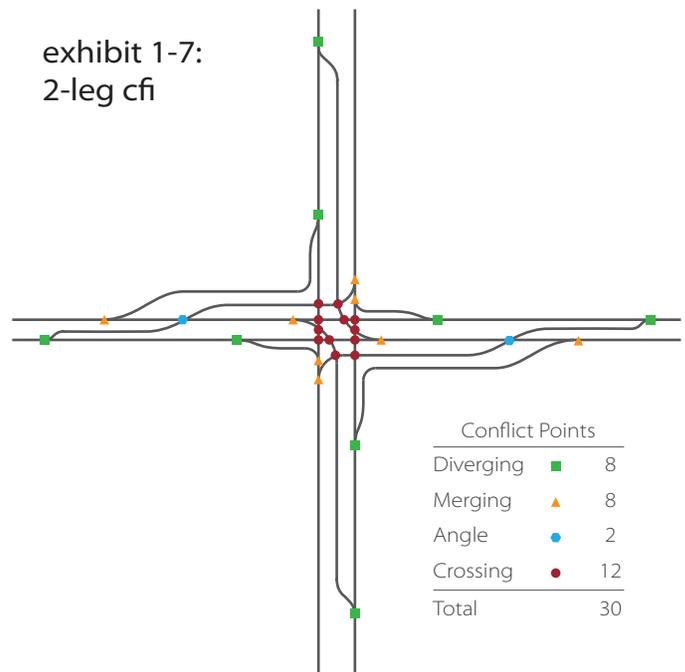


exhibit 1-8:
4-leg cfi

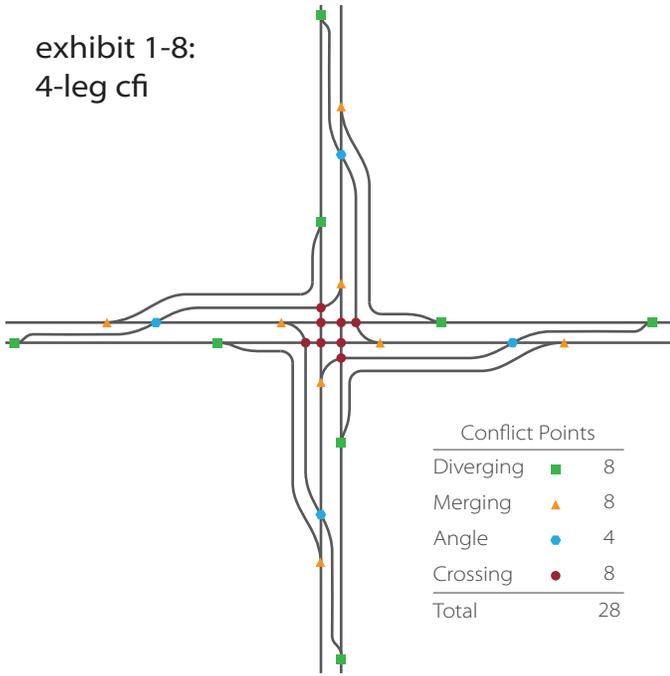
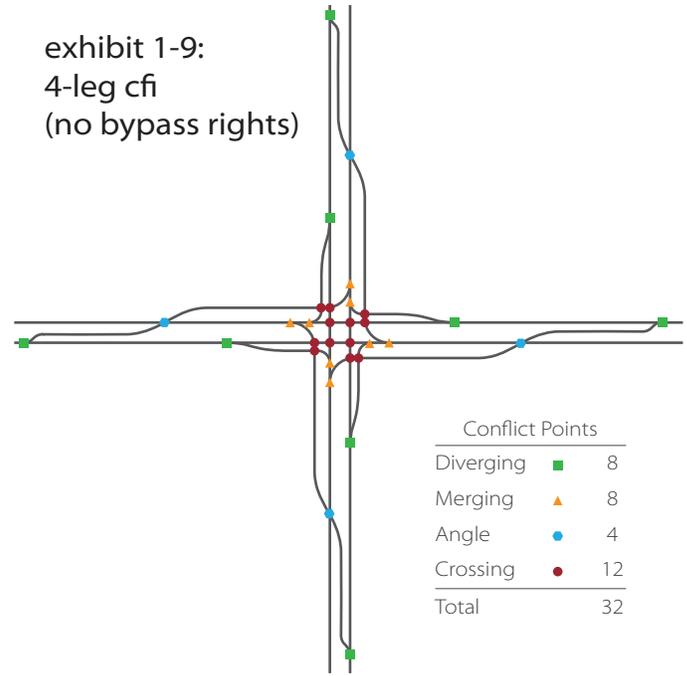


exhibit 1-9:
4-leg cfi
(no bypass rights)



as a result of the many different viewpoints of design professionals that have worked on each of the CFIs. While some design and timing strategies are clear betterments, some are merely individual preferences that have minimal impact on the operation of CFI intersections. Taken as a whole, however, these small differences, individual preferences, and minor inconsistencies tend to confuse drivers and reflect poorly on design consistency. Another lesson learned then, is that some **consistency of design is necessary in order to better manage a multitude of individual design preferences as well as driver expectations.**

Other lessons learned include attention to maintenance and snow removal, signal coordination within the CFI system and with upstream/downstream signals, construction MOT and signal turn-on coordination, managing public expectations, and communicating the benefits and reasons for implementation to the public, including an emphasis on demonstrating how post-construction operational performance meets or exceeds expectations.

Safety

One of the ways the CFI improves traffic safety in comparison to the conventional intersection is by reducing or spreading out the total number of conflict points at the intersection. **Exhibits 1-6 to 1-9** graphically compares

the number of conflict points at a conventional intersection to the ones at the CFI. The CFI eliminated conflicts are also the most dangerous conflicts at the intersection, e.g. left turn to through movement conflicts.

CFIs in Utah have been evaluated along with other CFIs throughout the country to determine whether CFIs are safer than other intersection types. Preliminary reports indicate that CFIs are about as safe for vehicular traffic as other intersection types. These same studies have noted that crash incidence tends to decrease somewhat after the first year of implementation. No significant studies have been performed for bikes and pedestrians, but most CFIs in Utah have been implemented on facilities like Bangerter Highway that limit ped crossings and prohibit bicycles.

CFI Strengths and Weaknesses

It is worth noting the common misconception that CFIs are implemented primarily to deal with high volume of left turning vehicles. While the CFI can certainly handle high volume left turns ($v > 700$ veh/h/ln at 6200 South and Redwood Road in Taylorsville, UT), the primary motive driving CFI implementation is the improved intersection capacity. As previously discussed, this is accomplished by eliminating the left turn signal phase in order to shift green time to through movements. Consequently, a CFI can still be an excellent option even when low volumes of left turns are concerned.

| Exhibit 1-10 | | Strength | Weakness | CFI STRENGTHS & WEAKNESSES |
|--------------------|----|----------|----------|---|
| Safety | 1 | ● | | Fewer collisions than traditional intersections (traditional) |
| | 2 | ● | | Lower collision severity vs. traditional |
| | 3 | ● | ● | Fewer conflict points than traditional, more than grade separated |
| | 4 | ● | | Fewer dangerous crossing conflicts than traditional |
| | 5 | | ● | Potential for wrong-way movements |
| | 6 | | ● | Potential for right turn and left turn conflicts |
| | 7 | | ● | Longer pedestrian crossings |
| | 8 | | ● | Signal in flashing mode or going dark |
| Traffic Operations | 9 | ● | | 30% to 70% increase in lane capacities |
| | 10 | ● | | Corridor applications equivalent to adding lanes |
| | 11 | ● | | Serves high volume facilities |
| | 12 | ● | | Compatible with high volume turn movements |
| | 13 | ● | | Increased capacity decreases congestion |
| | 14 | ● | | More green time |
| | 15 | ● | | Efficient 2-phase or 3-phase signal operation |
| | 16 | | ● | Complex signal operations |
| | 17 | | ● | Potential for ped crossing time to limit cycle length flexibility |
| | 18 | | ● | Potential for more user delay during light traffic periods |
| | 19 | | ● | No right turn on red without bypass right turn lane |
| Cost & Impact | 20 | ● | | Significant delay savings per dollar expended |
| | 21 | ● | | Delay savings exceeds cost in just a few years |
| | 22 | ● | | Visually context sensitive (at-grade solution) |
| | 23 | ● | | Lower cost vs. grade separation |
| | 24 | ● | | Smaller footprint vs. grade separation |
| | 25 | | ● | Larger footprint than traditional |
| Access | 26 | ● | | Highly compatible with access restricted corridors |
| | 27 | ● | ● | Access restriction, consolidation, and management |
| | 28 | ● | ● | Corner business access impacts |
| | 29 | ● | ● | Medians and vertical separators required |
| Public Perception | 30 | ● | | Direct left turn movements (not out-of-direction) |
| | 31 | ● | | Drivers adapt quickly to the concept |
| | 32 | ● | | Public acceptance historically high |
| | 33 | | ● | Potential for driver confusion |
| Design | 34 | | ● | Channelization complicates bike movements |
| | 35 | ● | | Flexibility of design (many variations) |
| | 36 | | ● | Additional drainage considerations required for channelization |
| Bike & Ped | 37 | | ● | Inconsistent signing may be consequence of flexible design |
| | 38 | ● | | Bikes & Pedestrians can be accommodated at grade |
| Maintenance | 39 | | ● | Peds may require 2-stage crossings, refuges, structures |
| | 40 | ● | | Increased capacity extends intersection life by decades |
| | 41 | | ● | Additional sign & signal maintenance |
| | 42 | | ● | Snow storage complications |
| | | | ● | Power backups |

There are enough similar misconceptions about the CFIs that some direct discussion of strengths and weakness is warranted. It should also be noted that different contexts can turn strengths into weakness, and vice-versa. Consequently, care should be taken in interpreting any catalog of strengths and weaknesses too literally. Context and traffic characteristics are powerful constraints that

can break common rules and sometimes require a more nuanced interpretation of strengths and weaknesses. **Exhibit 1-10** lists strengths and weaknesses of the CFIs as perceived by UDOT.

When should you consider a CFI?

The CFI is a flexible and robust intersection treatment that is appropriate to consider in a number of circumstances, but it is not appropriate in every circumstance. To date, UDOT has only applied the CFI in retrofit applications where no other at-grade alternative would suffice. It has also been most commonly applied on access restricted corridors. Future CFI applications need not be restricted to these limited circumstances. There are a number of other less-daunting situations that could justify a potential CFI implementation if considered in the appropriate context. There are also situations where a CFI just isn't practical, and it is important to be able to distinguish between the two.

The top two considerations for the appropriateness of a CFI are capacity and geometric constraints. The CFI is a strong candidate for improvement at an intersection if an existing or planned three or four-phase signal is approaching, at, or over capacity; and if conventional improvements are prohibitive on account of expensive ROW or intrusion to surrounding economic activity.

Capacity Considerations

With regard to capacity, the CFI best shows its ability to serve heavy traffic volumes when hourly per lane through and left turn volumes are too high to be served by a conventional intersection but not so high as to eliminate the use of signals altogether. Through volumes and left turn volumes that approach 70% of an hourly free flow lane capacity would likely warrant the consideration of grade separated alternatives instead of a CFI.

The four-approach CFI is the Cadillac of at-grade intersections and has the capacity to handle surprisingly high intersection volumes. If you have an over-capacity at-grade intersection, you should consider a CFI.

CFIs can also be effective in situations with high through volumes and lower left turn volumes. We have already noted the common misconception that CFIs are implemented primarily to deal with high-volume left turn movement, but should further note that when a 2-leg CFI is considered, the crossover lefts need not always be designed to serve the highest direction of left turns. In fact, several of the CFIs on Bangerter Highway in the Salt Lake Valley were implemented with crossover legs that served the northbound (NB) & southbound (SB) lefts, which had significantly lower turn movement volumes than the eastbound (EB) and (WB) lefts.

Other alternatives tend to compare favorably to CFIs (potentially making CFIs less attractive) when through volumes are moderate and left turn volumes are high. In these cases a CFI would still function well, but may not provide a distinguishing benefit over less access-intrusive options unless left turn volumes are exceptionally high. A good case in point for a CFI with low through volumes and high left turn volumes is the CFI at 6200 South and Redwood Road in Taylorsville, Utah. While NB & SB volumes on Redwood Road are some of the highest in the State, EB & WB through volumes are exceptionally light. However, the EB left (EBL) and the SB right (SBR) have exceptionally high turn movement volumes that could not have otherwise been served without implementing EB triple lefts and taking green time from the NB & SB through movement phases. In such cases, the phase time savings of the CFI is usually applied to the high side street left turn movements and major corridor through movements instead of to the lower side street through movements.

Since the largest left turn volumes at an intersection command the most phase time, a CFI configuration that eliminates the highest volume left turn phases will naturally free up the greatest amount of phase time for other movements. Despite this fact, CFI legs need not always be provided on the legs with the heaviest left turn movements. For one, the heaviest left turn movements don't always occur on opposing approaches of an intersection. Also, land uses adjacent to the heaviest movements may prohibit widening the roadway for displaced left turn lanes on account of impacts to the economic activity, accessibility, and prohibitive costs of property and right-

of-way acquisition. For these reasons, the crossover left turn approaches for many of the CFIs in Utah have been designed on approaches without the heaviest left turn volumes. In fact, most of the CFIs on Bangerter Highway have crossovers located on the access restricted Bangerter Highway approaches, and not on the heavily commercial non-crossover approaches. While these CFIs achieve less than maximum achievable capacities, they still provided enough capacity to meet improvement goals.

Context Considerations

The primary context considerations for a CFI are adjacent signals, utilities, ROW, and access.

The proximity of adjacent signals can provide an easy pass-fail criterion. When signals are too close, installing a new crossover signal may not even be possible. Even if the crossover is possible at an ideally spaced existing signal, the existing signal will be further complicated by the additional signal phases associated with the crossover. This addition of new signal phases and geometric constraints can result in operational failure at the crossover. The close proximity of existing signals can also create conflicts between CFI crossover storage and existing left turn storage in the opposite direction. In most cases, a minimum distance of a 1/4 mile between adjacent intersections is necessary to consider installing crossover lefts between the intersections. This distance may extend considerably if left turn volumes or through volumes are high.

The CFI usually requires some additional right-of-way in order to accommodate displaced left turn lanes and bypass right turn lanes. This can create impacts on adjacent property and on utilities. While neither property impacts nor utility impacts are fatal flaws, the need to mitigate these impacts raises the cost of CFI implementation. While the higher cost of implementation may still be justified based on anticipated operational benefits, consideration should be given to other alternatives that may provide similar benefits at a lower cost.

The final context consideration is access. This consideration could also be a pass-fail criterion in some cases, although there are enough access design variations to cover a considerable number of complicated access scenarios. These access scenarios are covered in detail in Section 2. Obviously, building CFIs on an access restricted corridor like Bangerter Highway is ideal.

Still, CFIs can be built in heavily commercialized areas (like the one at 5400 South & Redwood Road in Taylorsville, Utah), or on the side street legs of access restricted corridors (like the one at 4100 South & Bangerter Highway in West Valley City, Utah). Creative access considerations can allow implementation of a more robust intersection

improvement to adequately serve future traffic demands, at the same time creating access consolidation and access accommodation opportunities. The four-leg CFI at the intersection of 4100 South & Bangerter Highway is a good example of how creative access considerations supported the implementation of a four-leg CFI that will serve traffic for much longer than a 2-leg CFI concept would have been able to do, while still serving the access needs of important businesses. Creative access considerations thus directly support UDOT's final four goal of Strengthening the Economy.

While the consideration of cost in evaluating alternatives has gone somewhat out of vogue due to environmental cost consideration restrictions that prioritize other purpose and need criteria, cost has nevertheless been a factor in considering the CFI concepts constructed to date. The reason for this is the simple reality that cost is an excellent indiscriminate differentiator that considers many factors that accrue to cost all at once. It allows geometric complexity, access, ROW, and utility considerations to be considered simultaneously, at least as it relates to their respective cost elements. It also allows multiple alternatives to be compared from a cost benefit perspective so that public funds can be maximized. Although cost sometimes makes a strong argument, it need not be a tyrant, as more subjective considerations can still be made when costs are

Nothing will ever be attempted if all possible objections must be first overcome.

— Samuel Johnson

considered. Consequently, we highly recommend a cost/benefit based alternatives evaluation when considering CFIs or other innovative intersection alternatives.

Exhibit 1-11 provides a list of the CFIs that have been implemented to date.

Exhibit 1-11

UTAH CFI LOCATIONS

| No. | Intersection | City | 2-Leg | 4-Leg | Bypass Right Turn |
|-----|------------------------------|------------------|-------|-------|----------------------|
| 1 | 3500 S & Bangerter Hwy | West Valley City | ● | | ● |
| 2 | 6200 S & Redwood Rd | Taylorsville | ● | | ● |
| 3 | 5400 S & Bangerter Hwy | Taylorsville | ● | | |
| 4 | 4700 S & Bangerter Hwy | Taylorsville | ● | | |
| 5 | 4100 S & Bangerter Hwy | West Valley City | | ● | |
| 6 | 5400 S & Redwood Rd | Taylorsville | ● | | |
| 7 | 3100 S & Bangerter Hwy | West Valley City | ● | | |
| 8 | Sandy Pkwy & University Pkwy | Orem | ● | | |
| 9 | 6200 S & Bangerter Hwy | West Jordan | ● | | |
| 10 | 7000 S & Bangerter Hwy | West Jordan | ● | | |
| 11 | 13400 S & Bangerter Hwy | Riverton | ● | | ● |

SECTION 2 – CONCEPTUAL DESIGN

CFI Variations

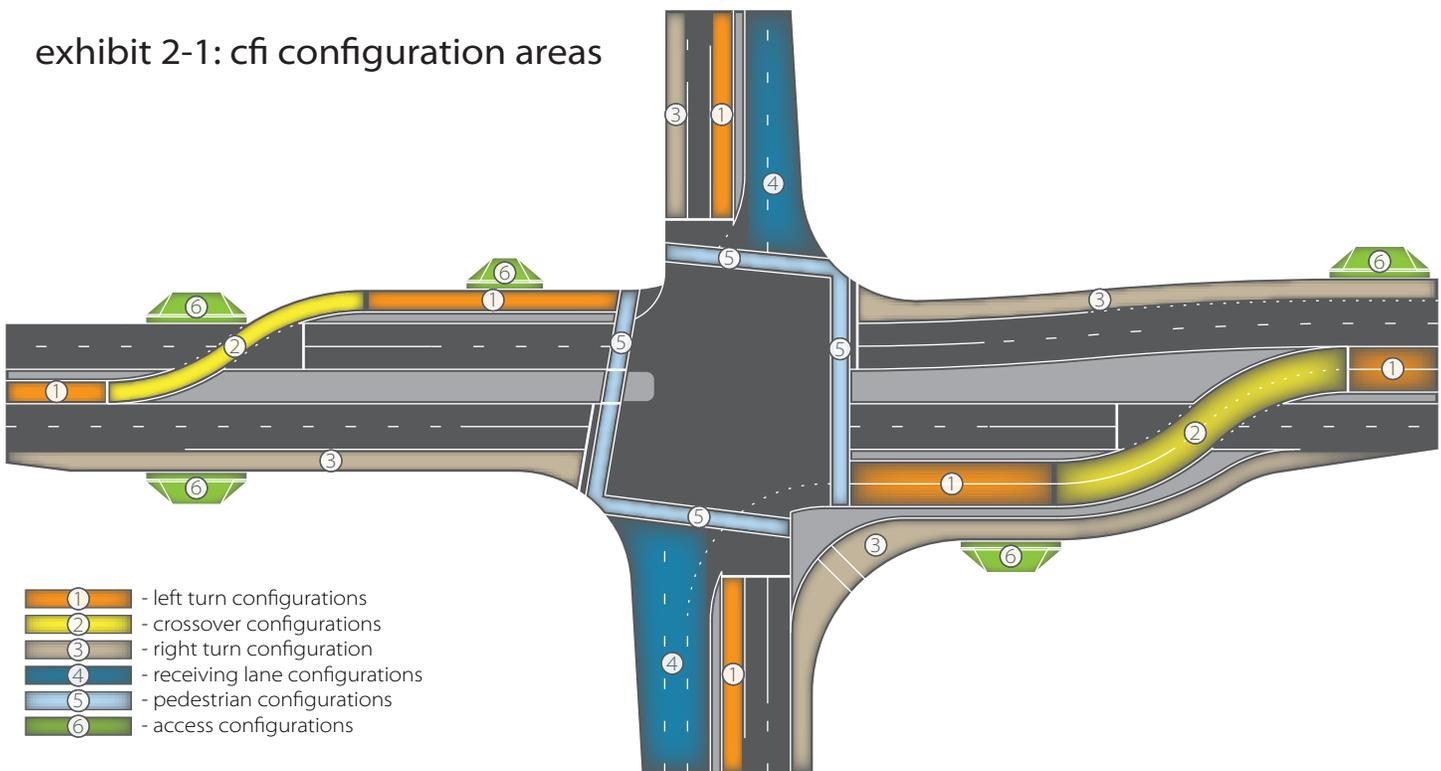
Planning level conceptual design flows naturally from the volumes and context considerations discussed in the previous section. To overcome the constraints presented by the capacity and surrounding context, CFIs can be custom configured in six basic ways listed below and illustrated in **Exhibit 2-1**:

1. Left turn configurations
2. Crossover configurations
3. Right turn configurations
4. Receiving lane configurations
5. Pedestrian configurations
6. Access configurations

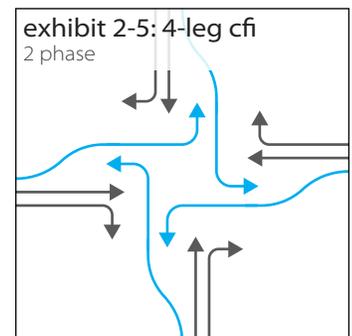
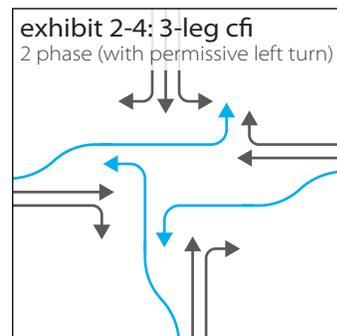
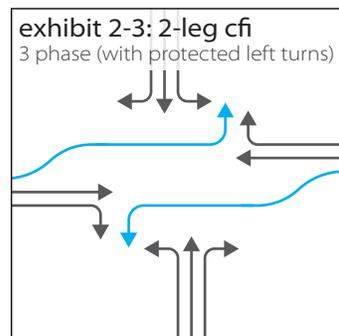
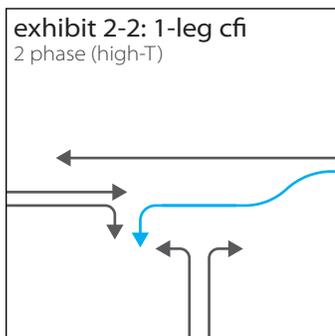
Configuring the Number of CFI Approaches

The number of CFI legs or approaches to be used is typically a function of the additional capacity required, with considerations for what the surrounding context will allow. The opposing crossover movements on each leg or approach of the CFI are nearly always paired (north & south or east & west) in order to eliminate a signal phase entirely. A single pair of opposing crossover movements (2-leg CFI or 2-approach CFI) reduces the signal cycle by one phase (3-phase signal), while two pairs of opposing crossover movements (4-leg CFI or 4-approach CFI) reduce the signal cycle by two phases (2-phase signal). The more signal phases reduced, the more efficient the signal will be. **Exhibits 2-2 to 2-5** illustrate various CFI approach configurations.

exhibit 2-1: cfi configuration areas



- ① - left turn configurations
- ② - crossover configurations
- ③ - right turn configuration
- ④ - receiving lane configurations
- ⑤ - pedestrian configurations
- ⑥ - access configurations



Since a single-leg CFI would not normally eliminate an entire signal phase, single-leg and triple-leg CFI's are rarely utilized. The exceptions to this general rule would be at a t-intersection, opposing a permissive left turn movement (which would need to remain permissive for perpetuity), or opposing a prohibited left turn (which would need to remain a prohibited turn for perpetuity). In these instances, a single crossover could eliminate an entire signal phase in one direction, although the benefits achieved may prove temporary with either permissive or prohibited lefts. A 3-leg CFI, where the left turn movement opposing one of the displaced left turn lanes is either permissive or prohibited, eliminates two left turn phases and operates as a 2-phase signal.

While increasing the number of CFI legs generally improves signal efficiency and operation, a greater number of CFI legs usually also increases right-of way, utility, and access impacts, which can drive up cost. Although a 4-leg CFI will generally perform better than a 2-leg CFI, a 4-leg CFI may be more than what is needed depending on the level of improvement required and the constraints dictated by the surrounding context.

Crossover Distance & Movement Configurations

The crossover configuration usually consists of determining how far to place the crossover from the main intersection, as well as determining the number and type of movements at the crossover location and the associated number of signal phases. As of 2013, the crossover locations for Utah's operational CFIs have been between 150 to 800 feet from the main intersection. Generally, the "sweet spot" for crossover distance is 500 to 600 feet from the intersection, with shorter crossover distances corresponding to lower crossover left turn demands, and longer distances corresponding to longer distances. All of the crossover signals implemented to this point have been two-phase signals with a crossover movement, a combined crossover/left-in access movement, or a crossover movement/signalized bypass right turn.

While 500 to 600 feet is a good rule of thumb, the crossover distance should ideally be derived from left turn requirements. For example, the time required for left turns to initiate their crossover movement, travel in the displaced left turn lane, and arrive near the stop line for the

displaced left turn movement is a function of the crossover distance. Since left turn, right turn and through vehicles on an approach move on the same green signal at a CFI, multiplying the time that it takes to travel this crossover distance by two also yields the potential maximum amount of time that the crossover signal can stay green without

Exhibit 2-6: Unguren equations

| equation | if these requirements are met | why this equation |
|--|--|--|
| $t = \frac{V_1 + V_2}{2a} + \frac{d_1}{V_1} + \frac{d_2}{V_2}$ | $d_1 > \frac{V_1^2}{2a}$ $d_2 > \frac{V_2^2}{2a}$ | crossover dist. (d_1) and opposing through movement dist. (d_2) are greater than the dist. required to accelerate to final speed |
| $t = \sqrt{\frac{2d_1}{a}} + \sqrt{\frac{2d_2}{a}}$ | $d_1 \leq \frac{V_1^2}{2a}$ $d_2 \leq \frac{V_2^2}{2a}$ | crossover dist. (d_1) and opposing through movement dist. (d_2) are less than the dist. required to accelerate to final speed |
| $t = \frac{V_1}{2a} + \frac{d_1}{V_1} + \sqrt{\frac{2d_2}{a}}$ | $d_1 > \frac{V_1^2}{2a}$ $d_2 \leq \frac{V_2^2}{2a}$ | crossover dist. (d_1) is greater than and opposing through movement dist. (d_2) is less than the dist. required to accelerate to final speed |
| $t = \frac{V_2}{2a} + \frac{d_2}{V_2} + \sqrt{\frac{2d_1}{a}}$ | $d_1 \leq \frac{V_1^2}{2a}$ $d_2 > \frac{V_2^2}{2a}$ | crossover dist. (d_1) is less than and opposing through movement dist. (d_2) is greater than the dist. required to accelerate to final speed |

Where:
 t = total potential CFI left turn split time (sec)
 V_1 = speed (ft/sec) in displaced left turn lane (typically less than V_2)
 V_2 = speed (ft/sec) of opposing through vehicles (typically posted speed limit)
 a = acceleration (ft/sec²), usually around 7 ft/sec²
 d_1 = distance (ft) for crossover left turn movement measured from crossover left turn stop bar to displaced left turn lane stop bar at main intersection
 d_2 = distance (ft) for opposing through movement measured from main intersection stop bar to stop bar at crossover left turn location

*Assumptions:
 1. This is an estimate of the potential split time (green + yellow + all red) for the CFI left turn based on distances and roadway speeds
 2. Final split time at implementation may vary
 3. Bypass right turn lane is part of design
 4. Side street turns do not get trapped at crossover left turn location as they are exiting the CFI
 5. Pedestrian crossing times do not limit the potential split time
 6. Vehicles start from a stop

making opposing through movements stop for a second time at the crossover signal. The Unguren Equations presented in **Exhibit 2-6** can be used to approximate the maximum CFI crossover (left turn) split times. The equations were derived based on the relationship between crossover distance, vehicle speed through the crossover, and travel time through the crossover.

As an approximation, the Unguren equation is a useful starting point for fine tuning signal timing in micro-simulation models and the development of signal timing plans. With the complexity of CFI operations, however, it can be expected to have its limitations. *Consequently, use of this equation should ALWAYS be paired with micro-simulation and field calibration to ensure that modeled and implemented signal timings are properly optimized for all relevant traffic conditions.*

The configuration of signalized turn movements at crossover locations is to some degree a function of access considerations. When accesses are consolidated, it is often convenient to locate them at the crossovers in order to provide safe and signalized access, particularly for left turn movements. Some potential configurations for signalized turn movements at the crossover locations are as follows:

1. Crossover only
2. Crossover/left-in
3. Crossover /left-in/u-turn

All of these configurations are 2-phase signals.

Right Turn Configurations

CFIs are usually configured either entirely with or entirely without bypass right turns, although some high volume right turn movements may require bypass right turns only for those movements. As discussed previously, a bypass right turn eliminates potential conflicts with right turning vehicles that would otherwise cross in front of the displaced left turn lane by providing a free right turn lane outside of the displaced left turn lane(s).

Since bypass right turn lanes increase the intersection footprint, they also tend to increase impacts and costs. The increased intersection width also increases pedestrian crossing distances and requires staged pedestrian crossings. Pedestrians first cross the bypass right turn lanes in a crosswalk that typically requires right turns to yield, and then wait at a pedestrian refuge island before crossing the remaining lanes in a signalized pedestrian crossing. The bypass right turn lane may also be signalized to require traffic to stop for pedestrians at high pedestrian volume intersections and at school crossings.

Exhibit 2-7 depicts a signalized bypass right turn lane at the 13400 South and Bangerter Highway CFI in Riverton, UT. Since the bypass right turn lane only conflicts with the pedestrian crossing, the signal can be pedestrian actuated and independent of main intersection signals. The bypass right turn lane may also be signalized prior to its point of entry into mainline traffic to allow safer merging of right turn vehicles and through traffic.

exhibit 2-7: signalized bypass right turn



CFIs without bypass right turn lanes have a smaller footprint, a reduced cost, and shorter pedestrian crossing distances. The main difference between the CFI with and without the bypass right turn lane(s) is that the CFI without the bypass right turn lane(s) requires mandatory prohibition of right turns on red for right turns that cross displaced left turn lanes. To discourage right turns on red across the displaced left turn lanes, dedicated right turn pockets are usually eliminated in favor of shared through/right lanes, and other design elements are added, including guide striping around the corner and extremely tight radii to discourage “wrong way” turns into the displaced left turn lanes. Since traditional “no right turn on red” static signs are frequently ignored by drivers, and since the consequences (potential collisions) of turning right on red while left turners are using the displaced left turn lane are bad, LED blankout signs are encourage to help draw the attention of drivers to the prohibited movement and to reinforce the prohibition of right turns on red.

Excluding bypass rights under conditions with a high volume of side street right turns reduces signal efficiency, making the elimination of bypass right turns infeasible. In such conditions, shared through/right lanes may not be able to serve all of the right turning traffic. Shared through/right lanes may also reduce through vehicle capacity, which may necessitate dedicated right turn pockets on non-CFI legs. These dedicated right turn pockets pose an important safety consideration since they alter driver perception of the right turn movement in a way that makes it more likely for prohibited “right turn on red” movements to occur at CFIs without bypass right turns.

Since right turns make their movement on the same green signal with left turns and through movements, potential movement conflicts in the receiving lanes may also occur at CFIs with more than two CFI legs. Some vehicles turning right on green may also need to stop at the crossover location in order to allow the crossover movement to occur since the CFI left turn movement at the crossover turns green while the side streets are green. With no bypass rights and a high volume of side street right turns, this can reduce the signal efficiency and coordination for through movements in the primary direction, depending on how many vehicles get “trapped” in this area between the main signal and the crossover signal (the Trap Area). It can

also reduce the capacity of the CFI left turns by limiting the amount of green time that can be provided since the through movement at the crossover location will have to turn green sooner to clear out the “trapped” vehicles to allow space for the mainline through movements. This phenomenon is particularly common among four-leg CFIs when bypass rights are not provided.

Exhibit 2-8: simplified Unguren equations

| equation | if these requirements are met | why this equation |
|--|-------------------------------|---|
| $t = \frac{V_1}{2a} + \frac{d_1}{V_1}$ | $d_1 > \frac{V_1^2}{2a}$ | crossover dist. (d_1) is greater than the dist. required to accelerate to final speed |
| $t = \sqrt{\frac{2d_1}{a}}$ | $d_1 \leq \frac{V_1^2}{2a}$ | crossover dist. (d_1) is less than the dist. required to accelerate to final speed |

Where:
 t = total potential CFI left turn split time (sec)
 V₁ = speed (ft/sec) in displaced left turn lane (typically less than mainline/posted speeds)
 a = acceleration (ft/sec²), usually around 7 ft/sec²
 d₁ = distance (ft) for crossover left turn movement measured from crossover left turn stop bar to displaced left turn lane stop bar at main intersection

***Assumptions:**

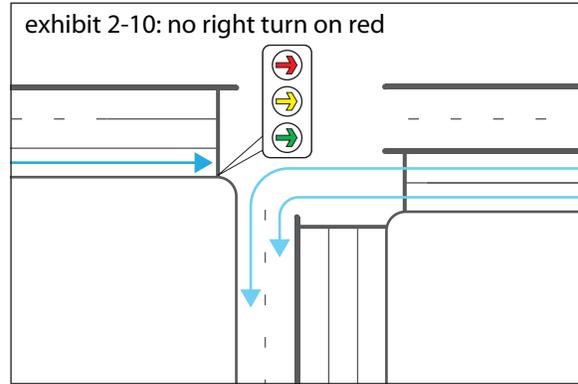
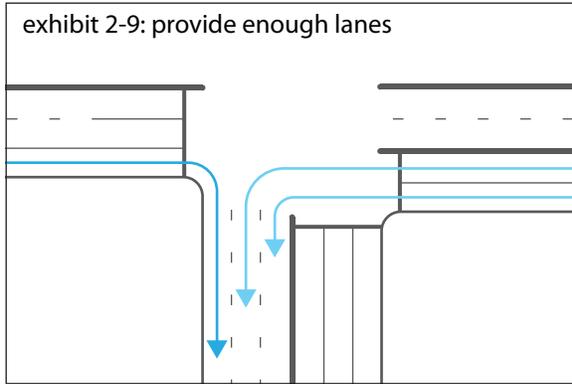
1. This is an estimate of the potential split time (green + yellow + all red) for the CFI left turn based on distances and roadway speeds
2. Final split time at implementation may vary
3. Bypass right turn lane is likely not part of design
4. Additional time from through vehicles from main intersection to crossover location cannot be provided to the crossover left turn
5. Pedestrian crossing times do not limit the potential split time
6. Vehicles start from a stop

When Trap Area impacts occur, the equation previously provided to describe the total potential CFI left turn split time would be simplified as follows:

The Simplified Unguren Equations for instances of Trap Area impacts are shown in **Exhibit 2-8**.

Receiving Lane Configurations

Because left turn, through, and right turn movements from opposing directions move together on the same green signal at a CFI, potential for receiving lane conflicts exists between left turns and opposing movement right turns. If there are enough receiving lanes to accommodate the



total number of turns (left and right) that concurrently use the receiving area, then receiving lanes may only need to be widened in order to make the turn movements more comfortable. Where possible, enough receiving lanes of sufficient width should be provided to accommodate all turns simultaneously.



Where enough receiving lanes to accommodate all turns cannot be provided, right turns will need to wait for left turns to finish their movement before proceeding. This delayed right turn movement has been accomplished using red right

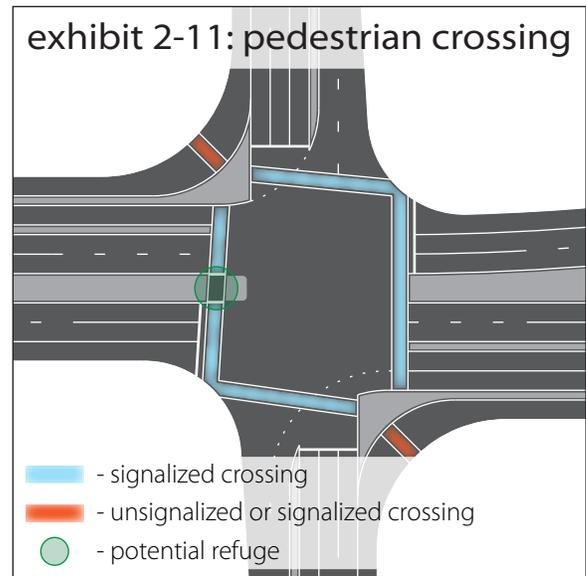
turn arrow indications and the same “no right turn on red” LED blankout sign employed in the no bypass right turn scenarios. A delayed right turn movement should not be used at locations with shared through/right lanes. **Exhibits 2-9 and 2-10** illustrate receiving lane configuration options at the CFI.

Design geometry for receiving lanes should be intuitive for drivers to follow, with appropriate lane widths, approach angles, corner radii, design geometry, striping, and signage. Design standards for these items are included in Section 4.

Pedestrian Configurations

While many of Utah’s CFIs have been designed with at-grade pedestrian crossings, in some cases pedestrian crossings have been eliminated at some or all intersection legs. While grade separated pedestrian crossings are costly, they are nevertheless tempting from a traffic operations standpoint. Removing pedestrians from the intersection via grade-separation simplifies signals and

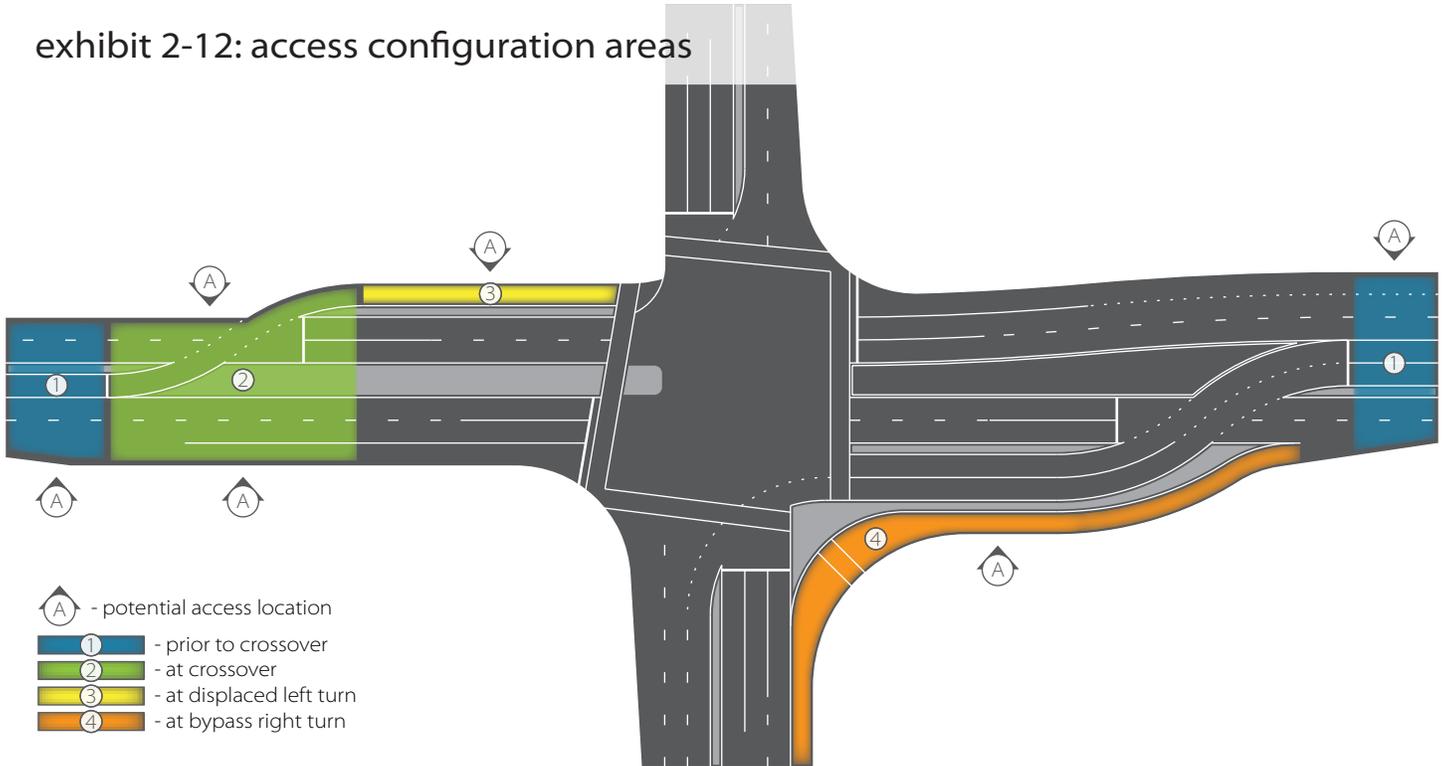
allows greater flexibility with signal timing. On the other hand, grade-separated pedestrian crossings increase the traveled distance and the effort required for pedestrians to cross the intersection. This sometimes leaves pedestrian crossing structures underutilized while pedestrians continue to risk at-grade crossings for the purpose of convenience. In case of overhead pedestrian bridges, care should also be taken to ensure that the structure doesn’t hinder a driver’s ability to see signal indications by blocking the view.



To more closely match the expectations and tendencies of pedestrians, at-grade crossings should be given due consideration. In addition to matching pedestrian expectations, at-grade crossings have the added benefit of avoiding many property impacts, utility impacts, and costs.

Pedestrian crossings of bypass right turn lanes usually require right turners to yield when pedestrians are in

exhibit 2-12: access configuration areas



the crosswalk. Depending on the design speed of the roadway and crosswalk visibility, flashers or other advanced warning signs/devices may be advisable. Pedestrian crossings of other movements are signaled with pedestrian call buttons and timed pedestrian phases. Signalized pedestrian crossings should be shortened whenever possible in order to allow maximum signal timing flexibility. Pedestrian crossings should also be considered when signalized access is provided at the crossovers as well.

Access Configurations

While constructing CFIs on access restricted corridors is ideal, CFIs can be built in heavily commercialized areas with appropriate access considerations. Creative access considerations can allow a more robust concept to be built, extending the life of the intersection. They can also create access consolidation opportunities that will serve traffic and the access needs of important businesses. Creative access considerations thus directly support UDOT’s goal of strengthening the economy.

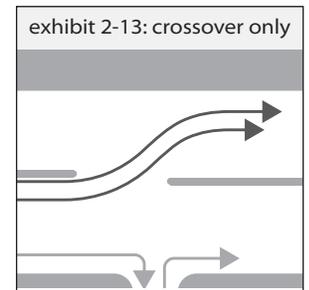
CFI access accommodations fall generally into four categories (see **Exhibit 2-12**):

1. Access accommodations at the crossover
2. Access accommodations prior to the crossover
3. Access accommodations at the displaced left turn
4. Access accommodations at the bypass right turn

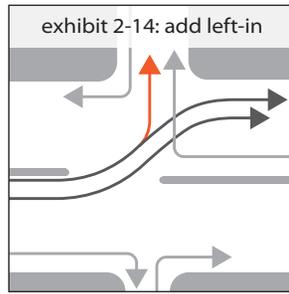
Crossover Access Accommodations

When accesses are consolidated, it is often convenient to locate them at the crossovers in order to provide safe and signalized access, particularly for left turn movements. As previously discussed, the most common access configurations at the crossover locations are as follows:

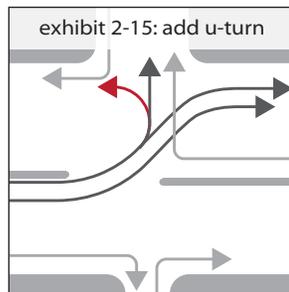
1. **Crossover only.** This is the most common over access used to date (see **Exhibit 2-13**). It provides no access whatsoever at the crossover location, and operates as a simple 2-phase signal. It is appropriate when no access is required or when left turn volumes are so high that the addition of access volumes might induce failure and/or excessive queuing.



2. *Crossover/left-in.* This access option shown in **Exhibit 2-14** allows left turns into a single access during the crossover movement, but no left turns out of the access. It operates on a simple 2-phase signal. When combined with right-in/right-out access beyond the crossover location, it can provide businesses with partially signalized $\frac{3}{4}$ access. If there are dual crossover lanes, the left turn movement must occur from the left most lane.



3. *Crossover/left-in/u-turn.* This option shown in **Exhibit 2-15** is similar to the crossover/left-in, but also allows a u-turn from the left most lane in order to serve business accesses impacted by crossover turn storage medians. It operates as a two-phase signal.



High volume left-out movements deserve special consideration if volumes are high enough to fill up the displaced left turn lane to any significant degree. Queued vehicles in the displaced left-turn area can disrupt the relationship between crossover distance and the time it takes to travel from the crossover to the main intersection – introducing new conflict points, reducing left turn capacity, and requiring additional signal timing considerations in order to accommodate the queued vehicles as well as the normal left turn volumes. It is also important to note that left-out movements will also be forced to take a left at the main intersection, making the movement useful only for those vehicles intending to turn left instead of going through or right at the main intersection.

Access Accommodations at the Bypass Right

Access accommodations at the bypass right turn are limited to right-in/right out movements, with similar cautions regarding right-in movements impeding the flow of other right-turning traffic. Right out movements are also yield movements which do not affect signal timing since there is usually no signal affecting right turn progression heading out of the intersection.

Access accommodations into displaced left turn lanes and bypass right turn lanes should be rare occurrences that are limited to one such access (at most) on each leg. Failure to manage accesses in these areas can create excessive friction that can cause the CFI operations to fail prematurely.

Access Accommodations Prior to Crossover

Access accommodations prior to the crossover are typically limited to right-in/right-out movements due to crossover storage medians. These medians could be eliminated to allow full access during off-peak hours of the day, but should be carefully considered in light of safety considerations prior to being removed.

Access Accommodations at the Displaced Left

Access accommodations at the displaced left turn are limited to left-in/left-out movements. If left turn access is allowed at the crossover, left-in access from the displaced left turn lanes is likely unnecessary. It is also potentially detrimental to the CFI operations since vehicles turning left from the displaced left turn lane will slow the flow of traffic and disrupt the left turn movement at the main intersection. Low volume left-out movements, on the other hand, yield before entering the displaced left turn area. This leaves queuing and delay to occur on the business property, outside of the CFI system.

SECTION 3 – TRAFFIC EVALUATION

VISSIM Modeling

No one size fits all CFI exists, particularly in retrofit applications where each of the previously discussed conceptual design variations has the potential to create different driver behaviors, travel paths, queues, and signal timing implications. To confidently evaluate these traffic characteristics with variable alternatives, the appropriate tools are required.

A traffic micro-simulation software provides reliability and flexibility to evaluate the various unique elements of a CFI. For this discussion, we will reference VISSIM, a commonly used and robust time-step and behavior-based micro-simulation software that simulates each transportation mode (train, bus, car, bike, or person) individually. Each mode is assigned relevant psycho-physical parameters according to a specific behavior profile. The different modes enter the model stochastically according to a randomly seeded algorithm and interact with each other based on predetermined geometry, routes, decision points, and intersection controls, to name a few. The variability of driver profiles, the random seeding of the model, and the ability to define complex geometries, routes, decision points, and signal controls all make it possible to emulate very life-like conditions using VISSIM.

Other less sophisticated analysis tools such as HCS, Cap-X, and Synchro are empirical tools which provide results based on specific variables and equations. This means that generally, for any given set of variables, the calculations will always produce the same results, regardless of the traffic behavior that is influenced by intersection spacing, queue spillback, weaving, or other complex traffic characteristics. While other micro-simulation tools such as SimTraffic (or older tools like CORSIM) are stochastically based, they sometimes lack the ability to accurately evaluate the operation of a CFI for a design-level analysis. While these may be very adequate for other intersection configurations, or even a high planning-level analysis of a CFI, experience has shown that these less robust tools are generally not flexible enough to accurately and confidently model the complex travel behavior which occurs at a CFI or other innovative

intersection.

VISSIM's robust features have made it UDOT's tool of choice for modeling complex traffic operations at innovative intersections like the CFI. This does not mean that other tools do not have value in other traffic analysis and optimization tasks, or that VISSIM is infallible due to its robustness and flexibility. On the contrary, VISSIM's robust flexibility can also be particularly dangerous if driver parameters, decision points, and network paths are not kept true to observed driver behaviors and traffic characteristics.

Unrecognized and unchecked deviations from observed behaviors and poor modeling practices lead to analysis that potentially misrepresents traffic operations by overstating the benefits of marginal improvements and understating the benefits of more robust improvements. Inaccurate measures of effectiveness (MOEs) alter traffic-based design recommendations, producing sub-optimal designs. And ultimately, the MOEs provided by micro-simulation analysis affect decision making – determining what alternatives will be built, what design features they will have, and how those features should be designed or sized. It is therefore critical that traffic models emulate real behaviors to provide confident results for making decisions.

Other Modeling & Analysis Tools

While tools like HCS, Cap-X, and Synchro/SimTraffic are not usually suitable for evaluation of final CFI (or other innovative intersection) alternatives, they may be appropriately used as preliminary screening tools to understand the relative operational performance of various alternatives. In using these tools for preliminary screening, it should be recognized that many critical features of operation will naturally be missing from these less detailed tools. Consequently, it is imperative that the traffic engineer responsible for interpreting screening results has an adequate understanding of the limits of these analysis tools so that operational performance results can be appropriately weighted to consider the limits or deficiencies of certain tools that may have a disproportionate impact on one alternative versus another.

Calibration and Validation of Models

An existing conditions micro-simulation model does not

become a credible basis for developing alternative models until it demonstrates the ability to mimic existing conditions faithfully. The calibration and validation of traffic models is necessary to ensuring that micro-simulation models do, in fact, emulate real traffic behaviors and characteristics. Every intersection is different. Lane geometries, driver behaviors, turn movements, turn storage areas, transition areas, origin destination routes, and signal timings are a little bit different for every intersection. Each of these traffic characteristics should be confidently replicated in the micro-simulation model based on field observations and data collection. In calibrating micro-simulation models, especially a high-capacity intersection like a CFI, special consideration should be given to observed traffic characteristics such as (to name a few):

1. Unserved peak hour traffic volumes
2. Observed queue lengths
3. Travel times
4. Lane utilization
5. Saturation flow rates
6. Friction areas
7. Origin destination paths and other critical paths

Once critical traffic characteristics have been identified, they can be replicated in the micro-simulation model at several different points. Some of the more common areas requiring calibration are:

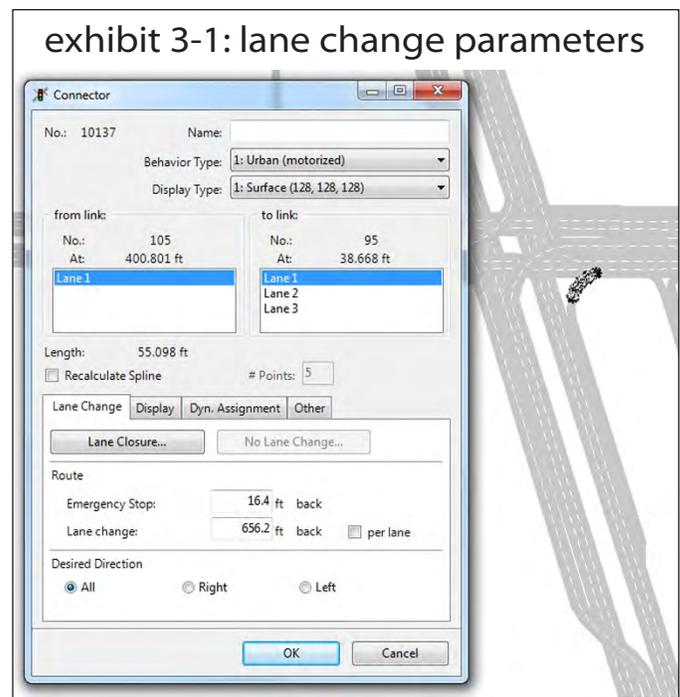
1. Individual route characteristics and lane change distances
2. Global link and lane change behaviors (saturation flow rate parameters)
3. Accurate signal timing & logic (RBC may not be enough in some instances, sometimes it may require software in the loop (SIL) to be more accurate)
4. Priority rules and conflict areas
5. Speed profiles, desired speed decisions, and reduced speed areas

The following details are intended to provide a general overview of these specific parameters as they might relate to special CFI considerations and are not intended to address all the options or strategies for calibrating a micro-simulation model. Furthermore, additional information should be sought and reviewed in the appropriate software

manuals to more fully understand these parameters and their functions in the software.

1. *Individual route characteristics and lane change distances.* Links and connectors provide the path-based connectivity through the network of a VISSIM model and the parameters governing lane change behavior. The Emergency Stop and Lane change parameters (**Exhibit 3-1**) are used to help control the lane change behavior for vehicles. Emergency Stop defines the last possible position for a vehicle to change lanes. Lane change defines the distance at which vehicles will begin to attempt to change lanes (e.g. a sign distance

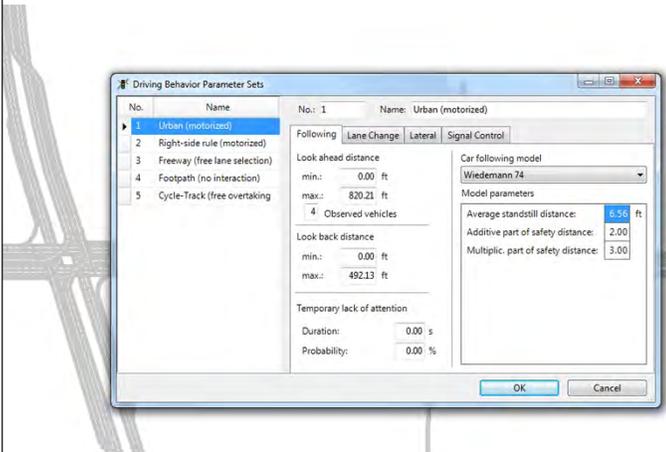
exhibit 3-1: lane change parameters



from a turn). If the per lane option is active, the given lane change value will be multiplied by the number of lanes the vehicle has to change to reach the connector. Additional care should be given to these settings with respect to the left turn crossover locations as well as the left turns at the main intersection.

2. *Global link and lane change behaviors.* Both the car following and lane change models in VISSIM use an extensive range of parameters (**Exhibit 3-2**). Some of these may be adapted by the experienced user to change basic driving behavior. As these parameters directly affect the vehicle interaction and can cause

exhibit 3-2: global link parameters



substantial differences in simulation results, only experienced users should modify, if necessary, any of these parameters. Particular attention should be given to these settings to appropriately calibrate link capacities for CFIs given their high capacity capabilities. Refer to the software user manual for additional detail and specifics for these settings.

3. *Accurate signal timing.* An elementary part of calibrating any traffic model includes inputting accurate signal timing. Because CFIs require some additional signal timing efficiency and often rely on more complicated ring and barrier structures with overlaps, special attention should be given to assuring signal timing operation is accurate for the CFI configuration, especially for the left turn crossovers. Some special areas of focus should include the ring and barrier structure, phase sequence, left turn phasing type, offsets, pedestrian and vehicle splits, overlaps, minimum green times, clearance intervals; passage/ minimum gap times, and reasonably expected signal optimization for alternative scenarios. Ultimately, consult with UDOT signal staff (or specific agency staff in other locations) to assure accurate operation.

4. *Priority rules and conflict areas.* Priority rules are used to model driver behavior (Exhibit 3-3) to more closely replicate decisions drivers make before crossing conflicting travel lanes (e.g. decision points).

Conflict areas (Exhibit 3-4), like priority rules, is another parameter in VISSIM that helps simulate yielding

behaviors (e.g. decision points). A conflict area can be defined wherever two links/connectors in the VISSIM network overlap.

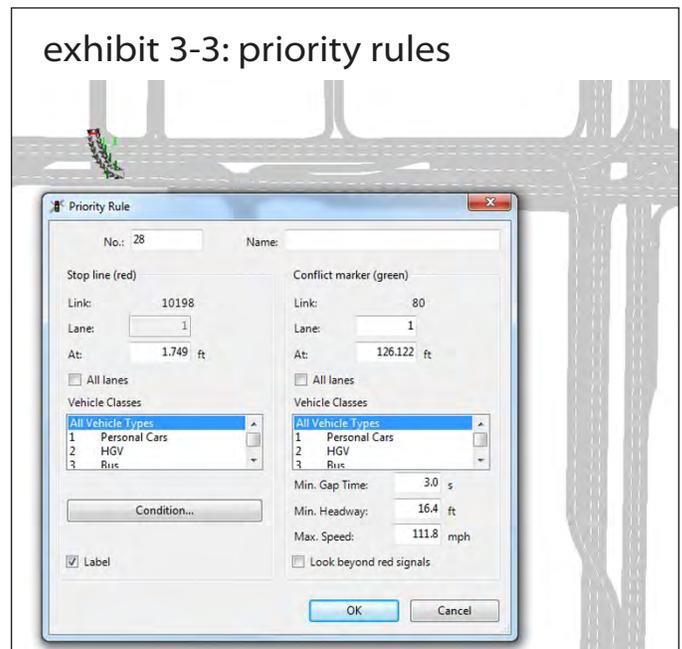
Both parameters are used to help control permissive movements and warrant additional attention when developing a CFI model, especially at unique CFI features. Refer to the software manual for details and direction on the application of these parameters.

5. *Speed profiles, desired speed decisions, and reduced speed areas.* It is important to define speed profiles accurately (for any evaluation performed in VISSIM), based on data collected from the field. This parameter can have a significant effect on travel time calibration and should be adequately considered during model development.

Locations particular to a CFI exist where speeds must be adjusted to account for the geometric layout. A desired speed decision (Exhibit 3-4) should be placed at a location where a permanent speed change should become effective. Consider appropriateness for use at crossover locations.

Reduced speed areas (Exhibit 3-6) change the vehicle speed profile over the portion of a link where it is placed - typically used where vehicles turn and only temporarily slow. Specific attention should be given at turning locations for a CFI where radii may be different than a typical intersection. Again, refer to the

exhibit 3-3: priority rules



software manual for details and application of these parameters.

Careful consideration and application of these parameters with validation will help improve the reliability and accuracy of CFI models, evaluations, and results.

Avoiding “Forced Calibration” of Models

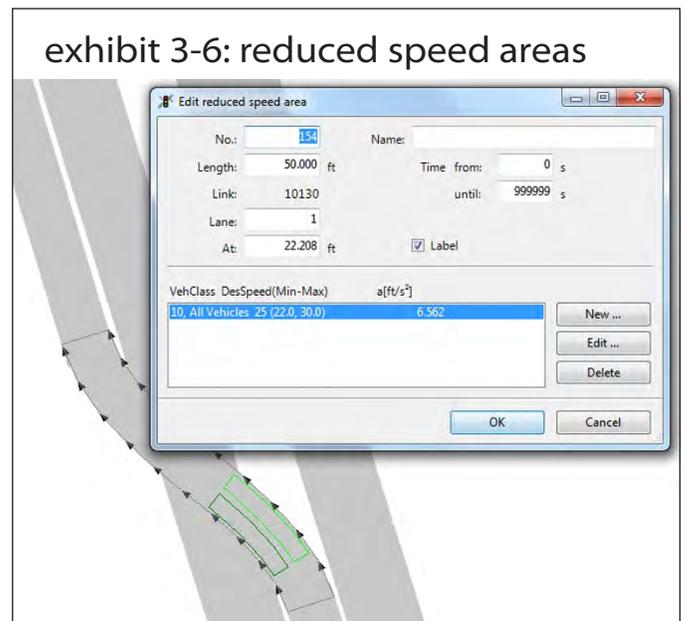
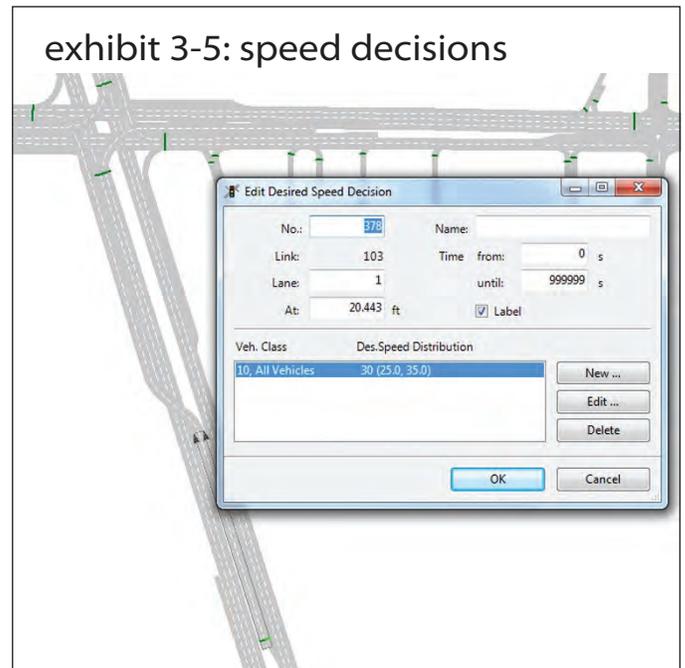
The calibration and validation of models can be a difficult

speed of the Reduced Speed Area parameter contrary to observed speed to either simulate queuing or show traffic demand being served, or (c) allowing conflicting vehicle movements to occur simultaneously in order to increase signal throughput.

Project managers and UDOT technical staff should be savvy to the process of calibration and validation along with common “forced calibration” shortcuts in order to ensure models are developed based on a realistic representation of actual traffic conditions. Simply, it is



and time consuming process, but it is also an extremely critical process to developing confidence in evaluation models. Consequently, it should be recognized that when budgets are tight and/or experience is lacking, frustrated attempts may be made to “force calibration” by changing parameters that are not true to actual driver behaviors, roadway geometries, or traffic characteristics. For example, a driver traveling in the inside most lane on multi-lane arterial will not typically, and consistently, make a decision to change lanes and turn right a mere 300’ from the intersection. Consequently, a micro-simulation model developed with a 300’ lane change distance for right turns originating in the far left lane with the sole intent to induce congestion, lengthen travel times, or meet validation criteria would be considered inappropriately calibrated. Some additional examples of “forced calibration” could, but are not limited to, include: (a) changing the Desired Speed Decision parameters along a corridor from the observed free flow speeds to conform to corridor throughput or travel times, (b) changing the



important to be able to assess the reliability of the model to accurately evaluate improvement scenarios.

Furthermore, it is important to remember that calibration precedes validation. After initial efforts are made to calibrate a model, thorough validation helps confirm the accuracy of the model (its ability to replicate field traffic conditions) and builds confidence in the tool's ability to accurately evaluate other traffic scenarios. Often, the process of calibration and validation is iterative in an effort to align the traffic operations in the model to those observed in the field.

Data Collection

The type and reliability of data collected is critical to the model calibration and validation process. In order to ensure proper model calibration and validation, consider collecting the following data:

1. *Average Daily Traffic (ADT)*. Every traffic count is a snapshot in time. ADT data is helpful to validate the other data to be collected based on historical patterns and for comparisons to other traffic forecasting tools like regional travel demand models.
2. *Turn movement counts*. Ideally, all turn movement counts for a study area should be collected on the same day (or for multiple days). Attention should be given to the accuracy of the data collection depending on the needs of the evaluation (e.g. 15 minute bins). The process to review, balance, and input the traffic volumes into the model is one of the first steps in creating a reliable micro-simulation model.
3. *Queue lengths*. Observing queue lengths provides a visual check to gauge congestion that can be useful in calibrating the micro-simulation models to the existing conditions. Observing queue lengths every 15 minutes during the count can also help identify

extending queues that could indicate unmet traffic demand. This unserved traffic would then be added to turn movement counts in the micro-simulation model in order to more accurately replicate existing congestion.

4. *Saturation flow rate*. This information can be helpful to understand driver behaviors that affect congestion and translate them into the micro-simulation model as headways, following distances, and other driver parameters.

5. *Roadway geometry*. Substandard lane widths and other geometric features such as merges and lane drops are common areas of friction for replication in the micro-simulation model.

6. *Driveways*. In heavily commercialized areas, driveways can have a significant impact roadway friction. Col-

lecting driveways can also be helpful for understanding access opportunities and for messaging potential improvements to adjacent property owners.

7. *Signal timing*. Correctly modeling traffic signal timing plans is critical to replicating existing conditions.
8. *Travel times*. Travel times can be very useful, when collected at the same time as the other data, to validate the traffic model. Regardless of whether travel times are collected using drivers, GPS, or Bluetooth technology, it is important to ensure that enough data is collected to provide a reliable and confident data set from which to base travel time run estimates. The Student's T distribution can be used to determine the required sample size based on the standard deviation of the results.
9. *Video collection*. Video recorders can be used to collect turn movement counts and driveways. Having a video record is also very useful in identifying criti-

Questions for evaluating calibration techniques:

1. **Is it reasonable to expect drivers to behave in this way?**
2. **Does this technique represent actual driver behavior at the location during the time of day being evaluated?**
3. **Are there other driver behaviors, roadway geometries, or traffic characteristics that may also contribute to the observed behavior?**
4. **How will the proposed calibration method affect the evaluation of alternatives?**

cal weave movements, origin destination routes, traffic splits, lane utilization, and other important travel characteristics. Video recorders can also be set to record not just turn movement counts, but other critical movements as well. In path based models like VISSIM, knowing and mimicking these routes can be important to emulating actual traffic behavior.

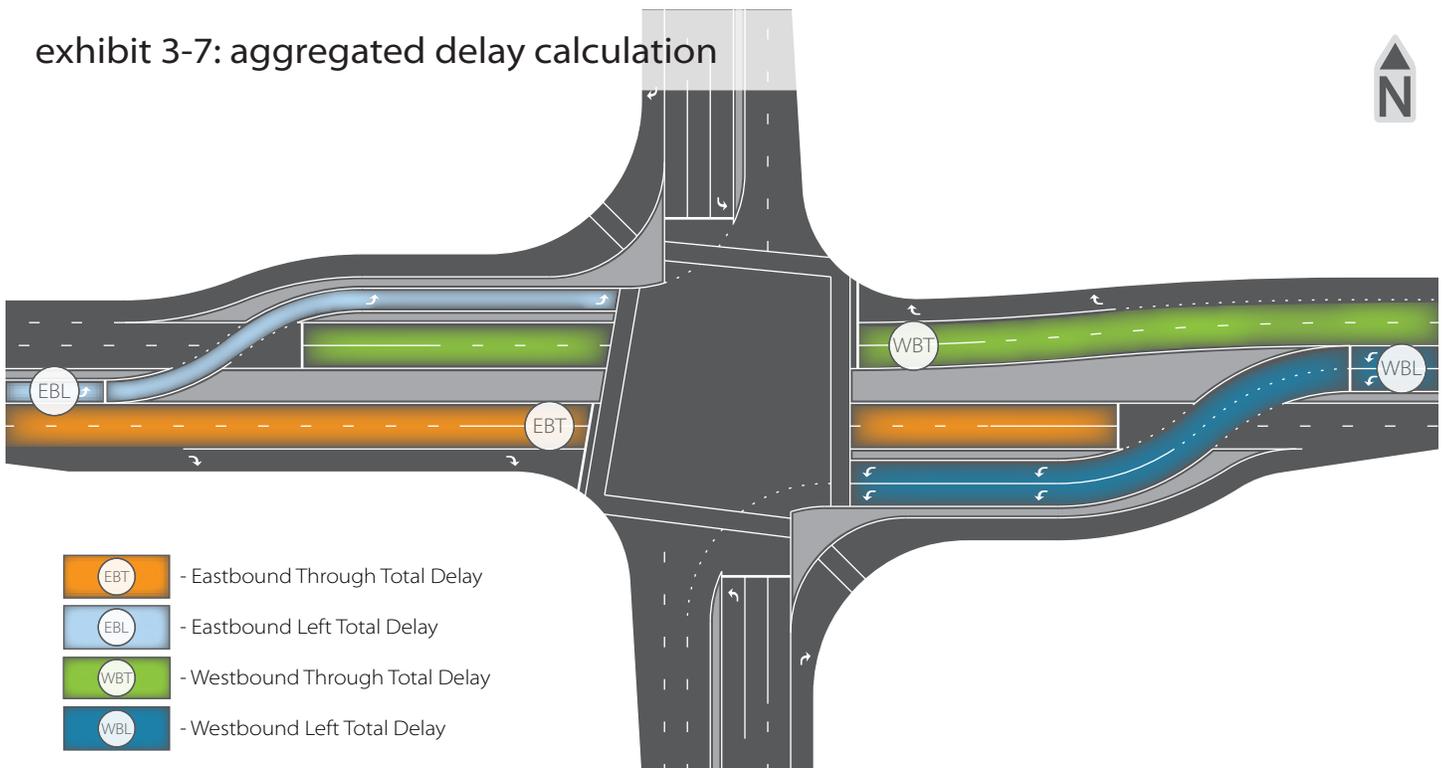
CFI Measures Of Effectiveness

Even though multiple signals are usually required to operate a single CFI intersection, the delays for all of the movements at these signals are typically aggregated into a single delay measure for each movement. For example, the delay for a northbound crossover movement would be added to the northbound left turn delay at the main intersection (which is usually close to zero) to provide a single aggregate delay for the entire northbound left turn movement. Similarly, southbound through delay at the main intersection would be added to the southbound through delay at the crossover movement (also close to zero) to provide a single aggregate delay for the entire southbound through movement. This method of aggregating delay allows a good “apples to apples” comparison between a traditional intersection and a CFI alternative. The suggested method for calculating delay

at a CFI is elaborated in **Exhibit 3-7**.

Evaluation standards can vary depending on the owners standards or requirements, the funding source, the environmental processes required, and/or the federal/state agencies involved. It should go without saying that consideration should be given to any requirements necessary prior to proceeding with evaluation efforts. However, a discussion about those requirements and any potential risks or nuances associated with the evaluation of a CFI is a valuable discussion early in the process.

exhibit 3-7: aggregated delay calculation



SECTION 5 – CFI IMPLEMENTATION & CONSTRUCTION

Maintenance of Traffic (MOT)

As with other construction projects, the safe and efficient movement of traffic through CFI construction zones helps to maintain a positive public perception while limiting impacts to businesses and the traveling public. UDOT contractors have developed an effective construction MOT strategy that allows all through traffic lanes and most turn lanes to stay open during peak traffic and daytime hours and reduce impacts to businesses and the traveling public. For much of the construction period, traditional left turn lanes can remain operational while utilities are relocated and the displaced left turn lanes are constructed outside of the existing intersection footprint. This additional pavement can then be used to shift lanes, as necessary, to construct improvements within the existing travel way. Construction activities such as pouring medians, pavement resurfacing, striping, and signal transitions have typically been completed with night work over single nights or weekends. **Exhibit 5-1** and **Exhibit 5-2** show examples of lane closures and traffic operations during construction.

Opening a New CFI

With the introduction of new concepts like the CFI, it is

exhibit 5-1: construction



important to make a positive first impression and avoid early confusion with premature openings. Transitioning signals and opening a CFI for operation without fully completing construction work is not advised - despite the inevitable pressure from contractors to do so. Items that have regularly been missing at signal transition and turn on include: missing or non-operational signal detection, improper signal head placement, incomplete striping and pavement markings, missing signs, incomplete sections of critical roadway or sidewalk, and missing pedestrian

exhibit 5-2: night construction



call features. These omissions are not trivial. They cause inefficient CFI operation on opening day and sometimes for extended periods of time. They contribute to driver confusion that endangers all road users and have sometimes resulted in close calls for potentially life threatening collisions. They risk setting a poor precedent and expectation on how the intersection should operate, particularly with regard to prohibited movements, generate myriads of complaints, and generally tarnish the public perception of UDOT’s opening day execution.

The engineer in charge of the CFI implementation should make sure that all traffic control devices are in place and tested prior to transitioning signal systems and opening a new CFI for public use. A checklist covering required items for signal transition and intersection opening is provided in **Exhibit 5-3** to help engineers in charge hold contractors accountable for the completion of these items prior to intersection opening.

Signal Detection

Properly functioning detection is critical for efficient traffic operations at a CFI, like most signalized intersections. For CFI and non-CFI approaches, stop bar detection

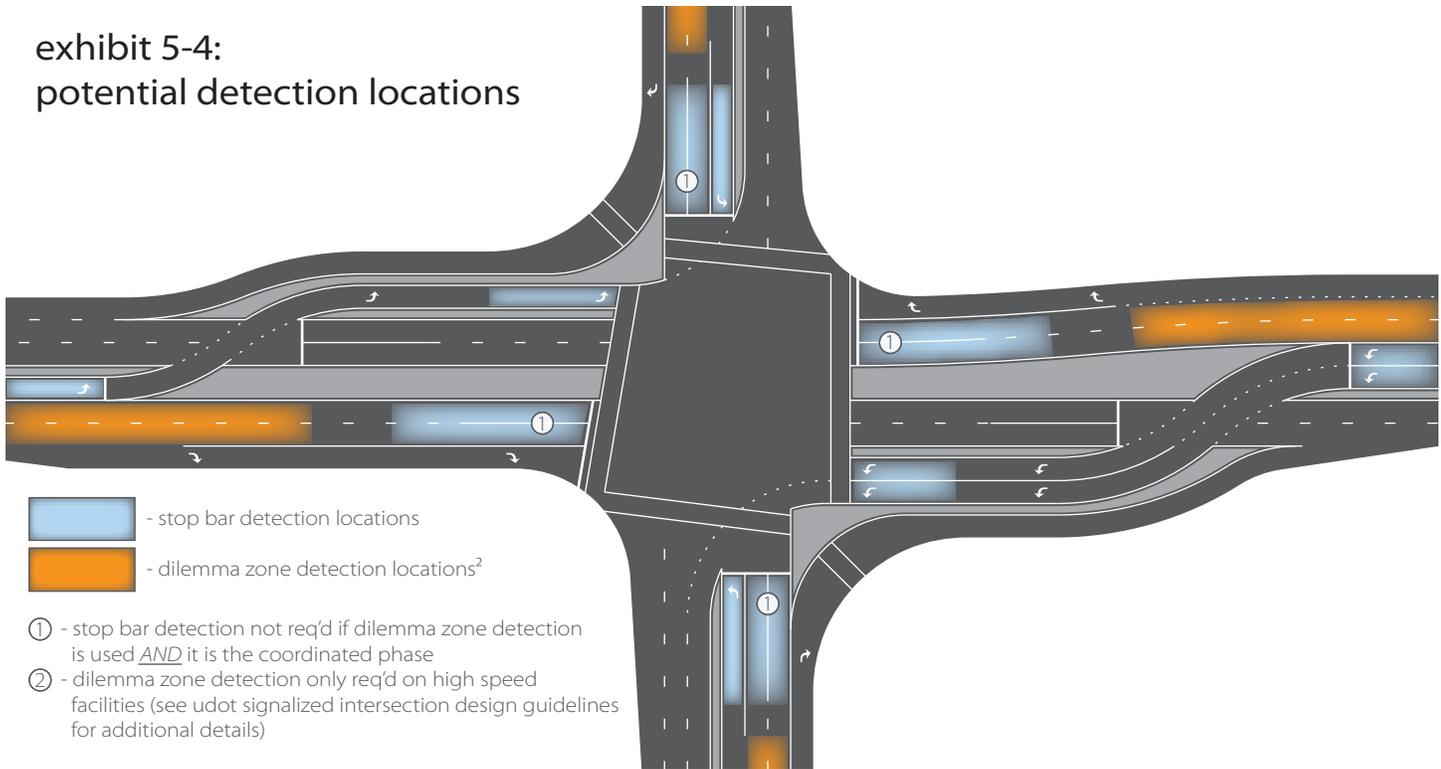
is usually provided to monitor the presence of vehicles and extend the green time for through and left turn movements. If two approaches will always operate in coordination (considering all time of day plans), stop bar detection may be eliminated to allow the controller to accommodate other phases which may be necessary. Advanced, dilemma zone detection for through lanes on higher speed facilities is recommended and operates as it does at a typical intersection. At crossover locations, stop bar detection is used for the crossover left turn lane. Stop bar detection is not required for opposing through traffic at the crossover location because it operates with an overlap that only turns red when the crossover is occurring. Stop bar detection at the main intersection is also required for the displaced left turn lane. This allows the green time to be extended to serve left turn demand or to call the left turn phase in order to clear trapped vehicles in the displaced left turn lane. **Exhibit 5-4** depicts the typical detector influence areas for the CFI.

In addition, it is important to test detection (regardless of the type of detection used) before opening a new signal to traffic to help assure accurate operation at opening so

Exhibit 5-3
CFI OPENING DAY CHECKLIST

| | | | |
|-------------------|----|--------------------------|---|
| Roadway | 1 | <input type="checkbox"/> | Mast arm mounted and other CFI signage must be installed as per the design |
| | 2 | <input type="checkbox"/> | CFI medians and channelizing islands must be constructed as designed |
| | 3 | <input type="checkbox"/> | CFI pavement markings must be provided as designed |
| | 4 | <input type="checkbox"/> | All construction equipment must be removed from the intersection |
| | 5 | <input type="checkbox"/> | All travel lanes and driveways must be opened to traffic and cleared of any debris |
| | 6 | <input type="checkbox"/> | Any preexisting pavement markings must be cleared from the intersection before restriping |
| Signal & Lighting | 6 | <input type="checkbox"/> | Construction of sidewalks and curb ramps must be complete |
| | 6 | <input type="checkbox"/> | Signal poles and mast arms as specified must be installed and grounded at designed locations |
| | 7 | <input type="checkbox"/> | Specified signal heads must be installed and aligned as shown in the design, and tested |
| | 8 | <input type="checkbox"/> | Pedestrian push buttons and signal heads must be installed as designed, and tested |
| | 9 | <input type="checkbox"/> | LED blankout signs must be installed as designed and specified, and tested |
| | 10 | <input type="checkbox"/> | Specified signal detection must be installed at appropriate locations, tested and operational |
| | 11 | <input type="checkbox"/> | Specified controller cabinet must be tested at the TOC, have all equipment, and operational |
| | 12 | <input type="checkbox"/> | All aspects of signal timing must be tested and approved by signals engineer |
| | 13 | <input type="checkbox"/> | Conflict monitor and MMU must be configured, tested, and approved by signals engineer |
| | 14 | <input type="checkbox"/> | CCTV, priority, and preemption equipment must be installed as designed, and functional |
| UDOT Approval | 15 | <input type="checkbox"/> | Design specified luminaires must be installed and operational |
| | 15 | <input type="checkbox"/> | Signal must be connected to the TOCs ATMS network |
| | 16 | <input type="checkbox"/> | Contractor must ensure conformity with UDOT’s Innovative Intersection Specification |
| | 17 | <input type="checkbox"/> | Contractor must get approval of the UDOT resident engineer and signals engineer before the signal turn-on |

exhibit 5-4:
potential detection locations



as to not confuse drivers with unoperational movements.

Signal Timing Guidance

In order to provide the flexibility necessary for efficient CFI operation, the use of advanced signal technology is crucial. Intersection operations for a CFI require the use of overlaps to optimize coordination between crossover signals and the signals at the main intersection. Overlaps allow several non-conflicting phases to operate simultaneously, even when the phases cross the barrier in the NEMA ring and barrier structure. Adequate hardware is necessary, that will accommodate the necessary phases and overlaps, for the CFI to operate efficiently and as intended.

Even though the signal timing strategy may vary between 2-leg and 4-leg CFIs, the basic CFI signal timing principles that drive efficiency of operation remain the same. At the CFI, efficiency in signal operation is achieved by simultaneously providing safe passage for left turns and through movements from opposing approaches. This is achieved by displacing left turns to the outside of conflicting through movements in advance of the intersection and reallocating green time to heavier through movements. Another component of the efficiency

gain at the CFI is to ensure that the left turn signal at the main intersection turns green as the vehicles approaching from the upstream crossover signal arrive at the main intersection. To accomplish perfect coordination between the crossover and main intersection signals, strategic overlaps and timing are implemented. It is worth noting that the CFI can still operate well without perfect crossover green coordination, but it has been UDOT's goal to optimize this coordination whenever possible.

Exhibit 5-5 provides an example of the UDOT signal timing strategy for a 2-leg CFI using four rings, and **Exhibit 5-6** provides the UDOT signal timing strategy for a 2-leg CFI using 2 rings. Lastly, **Exhibit 5-7** provides the signal timing strategy for a 4-leg CFI using 2 rings. Contact UDOT Traffic Operations Center (TOC) at (801) 887-3710 for assistance with signal timing implementation in Utah.

Currently, most NEMA cabinets, and controllers, only support 16 total channels or signal phases. UDOT has used the two ring structure shown below and 16 overlaps at the 4-leg CFI intersection at 4100 South & Bangerter Highway. The other 2-leg CFIs operate off the two ring structure within the 16 channel limitation.

exhibit 5-5:
2-leg cfi signal timing (four ring)

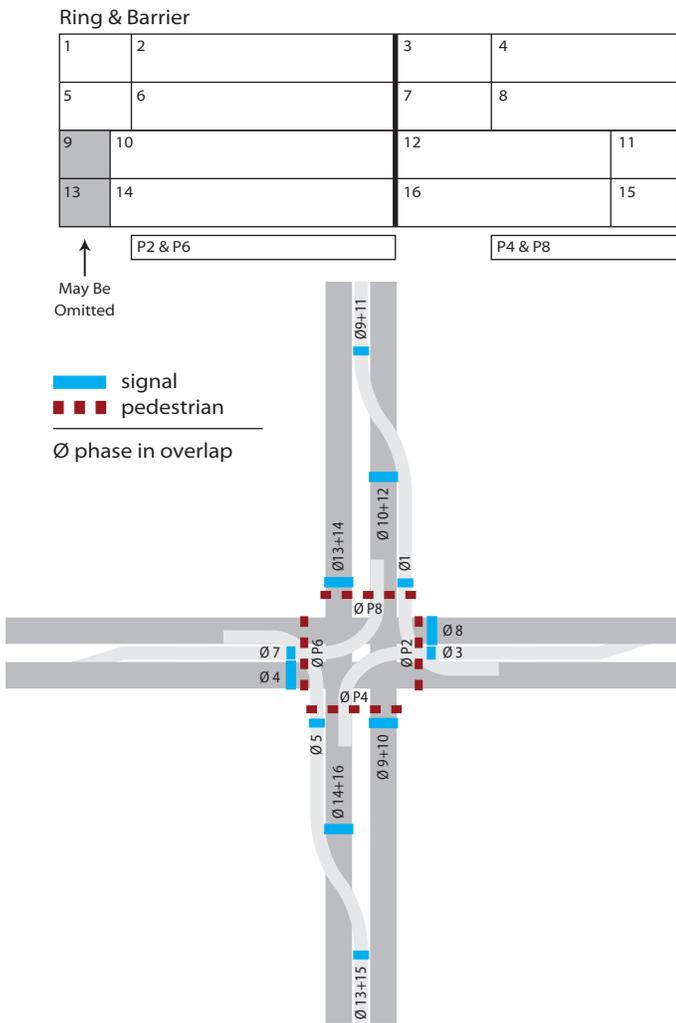
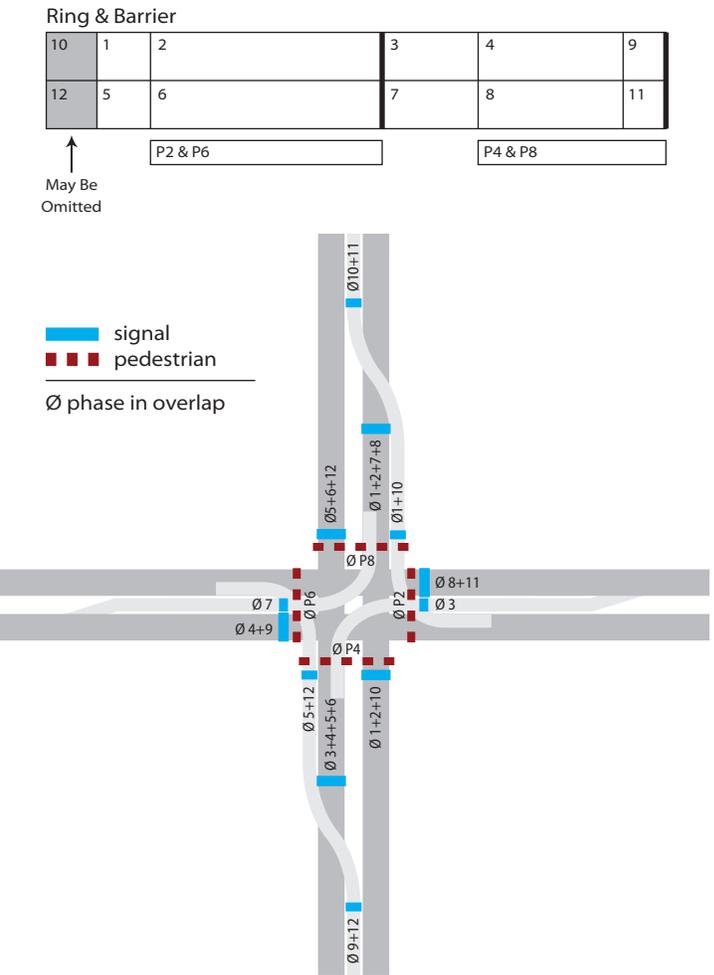


exhibit 5-6:
2-leg cfi signal timing (two ring)



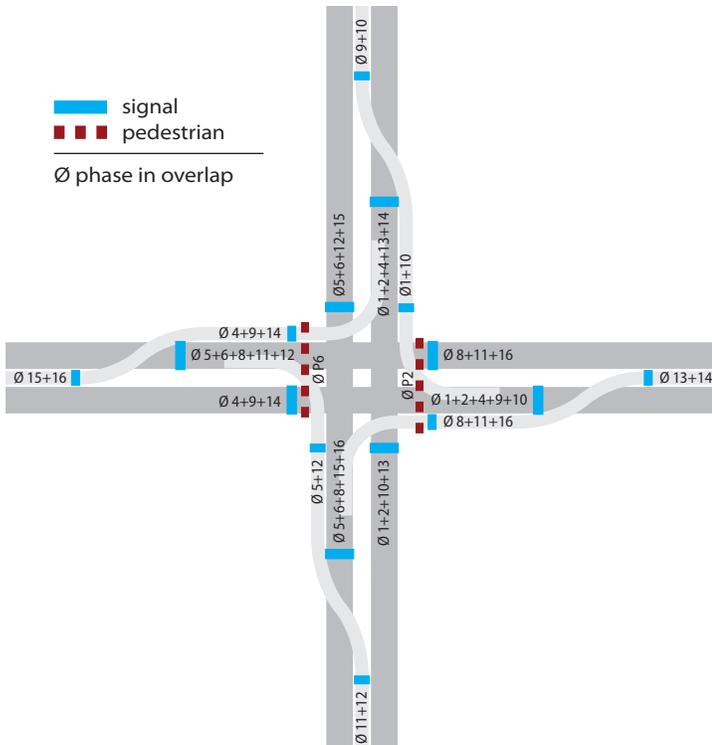
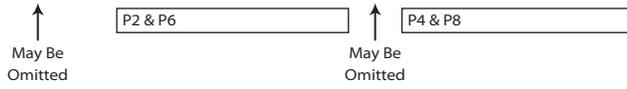
Pedestrian Timing

UDOT implemented pedestrian crossing strategies which differed from the conceptual CFI approach. UDOT intended for pedestrians to operate like they do at any typical intersection. Based on this goal, UDOT modified the signal timing plan to accommodate a pedestrian phase after clearing the displaced left turn phase (as shown in the exhibits). Simply, the left turn \emptyset and through movements proceed simultaneously at a green light. After serving the left turn traffic, the left turn light turns red (while the through movement is still green) and allows the pedestrian phase to turn green (if a call exists). This strategy has the potential to reduce efficiency at the intersection if heavy left turn traffic exists.

exhibit 5-7: 4-leg cfi signal timing

Ring & Barrier

| | | | | | | |
|----|---|---|----|----|---|----|
| 10 | 1 | 2 | 13 | 14 | 4 | 9 |
| 12 | 5 | 6 | 15 | 16 | 8 | 11 |



SECTION 4 - CFI DESIGN PARAMETERS

As introduced in previous sections, the intent of the information in this section is to identify areas requiring unique attention and is not intended to be overly prescriptive in its guidance. As with any intersection design, care should be taken to identify and address items specific or unique to each design. The CFI design guidance provided in this chapter is meant to supplement the guidance provided by the latest editions of publications such as the AASHTO's "A Policy on Geometric Design of Highways and Streets" (Green Book) and "Roadside Design Guide", FHWA's "Manual on Uniform Traffic Control Devices", and UDOT Standard Drawings.

Micro-Simulation Use in Design Iteration

The capacity of a CFI is a function of its geometric design and signal timing. Although rules of thumb can be applied in developing a CFI design, optimizing that design requires a keen understanding of how driver behaviors, such as speed and acceleration, influence ideal geometric parameters such as the crossover distance (refer to the *Unguren Equations* in Section 2). While these equations provide guidance for first iteration geometrics, the most efficient way to develop an effective CFI footprint is to use micro-simulation tools during traffic analysis to iteratively develop a preliminary CFI footprint. Micro-simulation using a well calibrated model allows evaluators to confidently develop optimal CFI capacity by simultaneously and iteratively adjusting key geometric and signal timing parameters. Once an optimal CFI footprint is established using micro-simulation, the modeled footprint can be used as the basis of a CAD design. Flexibility should be provided throughout the design process to align and fine-tune geometric design constraints with the micro-simulation models, while being conscientious of the potential effects of design changes on signal timing.

Design Speed

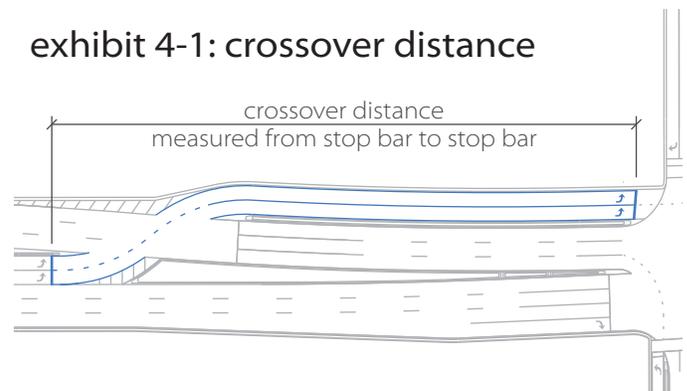
As of 2013, Utah has constructed CFIs on roadways with speed limits ranging from 35 mph to 60 mph. When designing CFIs on high speed facilities with horizontal and/or vertical curves, care should be taken to provide

adequate Stopping Sight Distance (SSD) in advance of the CFI crossover left turn storage bay as well as the main intersection. UDOT has designed crossover left turn lanes for travels speeds of approximately 25 to 30 mph.

Crossover Distance

The crossover distance, measured from the main intersection stop bar to the crossover stop bar (**Exhibit 4-1**), is one of the most important features in CFI design. For a CFI, the left turn capacity is primarily a function of the crossover distance. For example, a lower left-turn volume would permit the use of a shorter crossover distance, while a longer crossover distance provides greater flexibility to accommodate higher turn volumes. As of 2013, UDOT has designed crossover distances on CFIs ranging from about 300' to 800'. Introducing these

exhibit 4-1: crossover distance



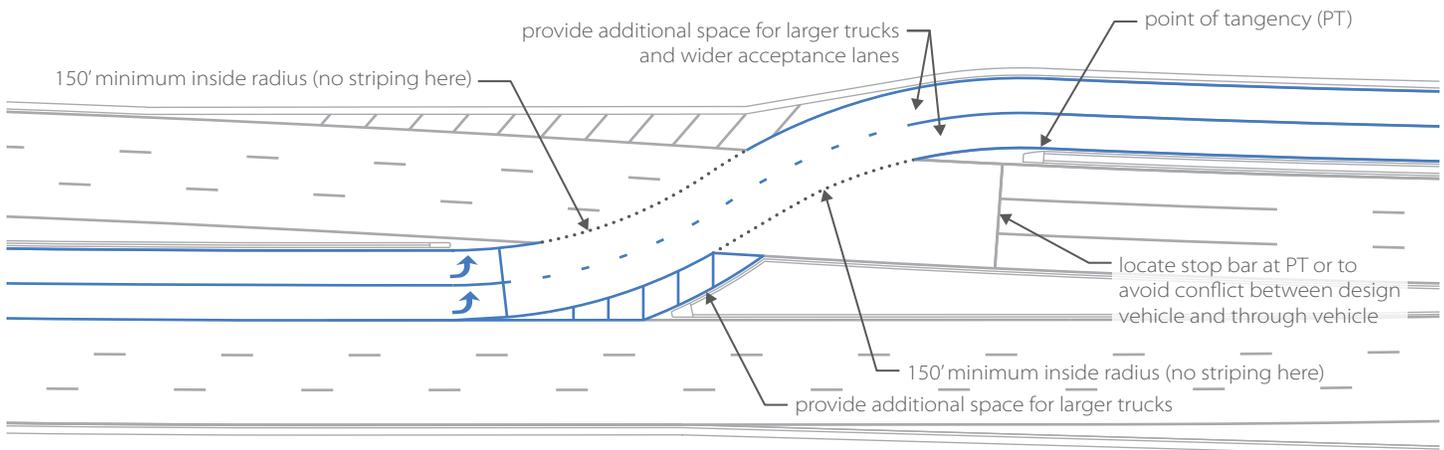
lengths is not intended to be limiting or guidance, it is only intended to show the range of distances UDOT has implemented (to date). Special consideration should be given to each case, using micro-simulation analysis, in order to maximize the capacity of the left turn without over designing.

While designing crossover lanes, designers should apply the same guideline and standards, such as those for lane widths, curves, and striping, established by UDOT for conventional intersections.

Turn Pocket Storage

The design of left turn and right turn lanes/storage, like traditional intersections, is based on the operational needs and traffic demands of the respective turn movements. Designers should consult the project Traffic Engineers evaluating the CFI for specific lane requirements and

exhibit 4-2: horizontal curves through crossover left turn



lengths. As a simple rule of thumb for estimating purposes only, an engineer can apply the one-foot-per-car rule to estimate left turn storage lengths: one foot of storage for every vehicle (e.g. a left turn with 400 vehicles would equate to 400' of single lane storage or 200' of dual lane storage).

As would be appropriate for any intersection on a high speed facility, additional deceleration distance, in addition to the required turn pocket storage, is recommended at the CFI to allow vehicles to slow sufficiently, out of travel lanes, before arriving at stopped vehicles in a queue. Most of the deceleration should occur in the taper area provided prior to the recommended storage pocket length.

The placement of left turn storage at the CFI directly affects the placement of CFI way-finding signs which will be discussed later in this section.

Turn Radii

As discussed, a key feature of the CFI is the crossover left turn lane(s). Naturally, the length of a crossover curve is a function of the radius and crossover distance. For a 25 mph design speed and cross slopes ranging from 0% to 4%, the horizontal curve radii on crossovers range between 150' to 180' (see **Exhibit 4-2**). Designers should also apply design vehicle turning templates at crossovers and other locations to verify that paths of simultaneously (if dual lane) traveling vehicles (including the design vehicle) don't overlap or run over channelization features. In addition, designers should consider the effects of radii size to help slow vehicles traveling at speed upon entering the

crossover left turn area. Designers should also consider wider (14' to 16') receiving lanes for left turn vehicles at the crossover location and the main intersection (also to be verified with turning templates).

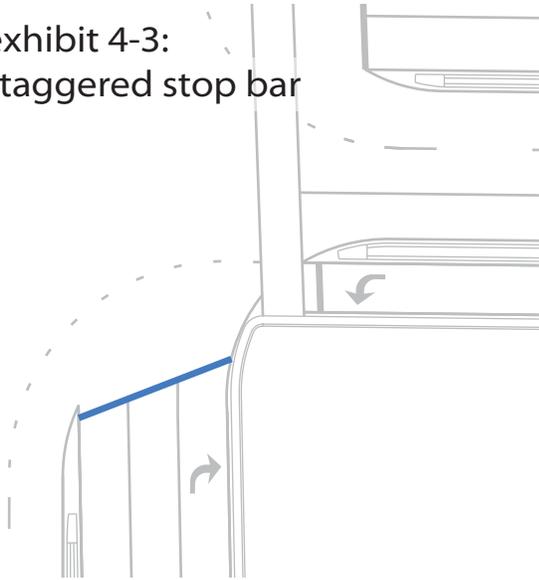
Note: The turn radii requirements of simultaneous vehicles should consider local laws and guidance for large trucks, which are required to turn left in the outside-most lane for multi-lane movements in Utah. This could potentially reduce turn radius requirements. Designers should verify, through the use of design vehicle turning templates, that adequate turning radii are provided for all turn movements at a CFI.

In the case of a CFI at a skewed approach, it may be necessary to pull back the stop bars on the adjacent approach to accommodate the left turn path of a design vehicle. In that case, an angled stop bar may help optimize the approach vehicle storage. While conventional intersections also require angled stop bars to accommodate left turning vehicles, the issue is exacerbated at a CFI due to the fact that the displaced left turn lane is located even closer to the receiving lanes. **Exhibit 4-3** illustrates how the side street stop bars need to be pulled back from the intersection with a skewed approach.

For right turn movements without a bypass right lane, the turn radius should be designed small enough (UDOT recommended a back of curb radius of 2.5') to help limit the potential for vehicles turning right into oncoming displaced left turn lanes and better "guide" vehicles into the appropriate receiving lane. To allow uninterrupted

flow of right turn vehicles in bypass right turn lanes, UDOT prefers a 25'-55'-25' compound radius. **Exhibit 4-4** provides an example of the right turn design across a displaced left turn scenario. To further reduce the chance for potential conflict, LED blankout signs, as discussed in

**exhibit 4-3:
staggered stop bar**



the Signing section below, are used at these locations.

Horizontal Curves and Roadway Alignment

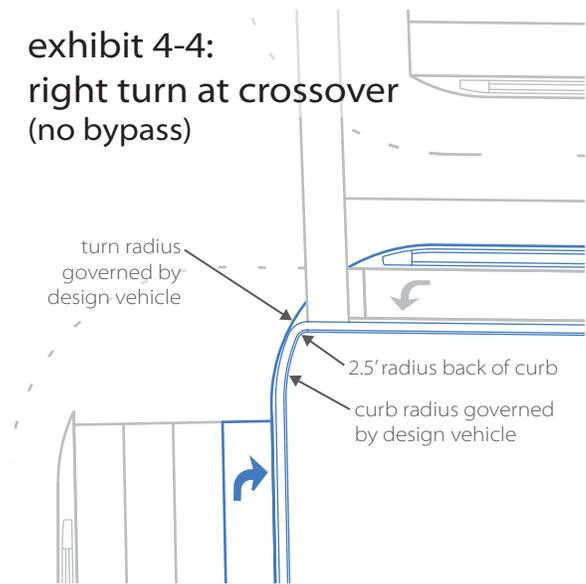
The geometry of a typical CFI intersection includes displaced left turn lanes and bypass right turn lanes that shift incoming movements to the left side of each intersection approach. Additionally, crossover left turn storage in the middle of the roadway requires wide center medians to protect and channelize the crossover movements. Consequently, it is frequently necessary to shift the horizontal alignment of the roadway in order to properly align through lanes and to minimize the horizontal width requirements of the CFI.

Typical UDOT design practice for urban roadways has tended to emphasize the use of tapers over horizontal curves in shifting roadway alignments. This is understandable given the simplicity of calculating taper lengths as opposed to designing horizontal curves. Despite the moderate increase in design complexity for curves versus tapers, it should be recognized that shifting horizontal alignments using curves provides benefits to drivers that include less abrupt shifting movements, more natural transitions, and improved driver comfort. These factors are not trivial,

especially in designing new intersections where drivers are expected to focus on unfamiliar signage and new movements instead of being distracted by abruptly shifting lane movements common to tapered shifts. Consequently, UDOT recommends using curves instead of tapers for alignment shifts wherever possible in CFI design.

At several urban limited-access expressways (e.g. Bangerter Highway in Salt Lake City), the design speeds are higher than 45 mph and the superelevation is less than 4%, which exceeds the values provided in the Urban Speed Table of the Green Book. While Green Book guidance for horizontal curve radii is more complicated than what needs to be discussed in this document, it should be noted that the values provided in these tables are common values for urban roadways, but do not represent limiting values according to the methodology. Consequently, for simplified design guidance regarding CFI alignment shifts and horizontal curves, we have

**exhibit 4-4:
right turn at crossover
(no bypass)**



provided an expanded Urban Speed Table (Exhibit 4-5) that lists minimum horizontal curve radii based on speeds of up to 65 mph and superelevation values of between -4% and 4%. This table is consistent with Green Book methodology and uses the Method 2 formula, as follows:

$$R_{min} = \frac{v^2}{15(0.01e_{max} + f_{max})}$$

exhibit 4-5: minimum radius

Green Book Provided Minimum Radii ←

→ Calculated Minimum Radii

| e (%) | 15 mph | 20 mph | 25 mph | 30 mph | 35 mph | 40 mph | 45 mph | Calculated Minimum Radii | | | |
|-------------|-----------|------------|------------|------------|------------|------------|--------------|--------------------------|------------------|------------------|------------------|
| | R (ft) | R (ft) | R (ft) | R (ft) | R (ft) | R (ft) | R (ft) | 50 mph R (ft) | 55 mph R (ft) | 60 mph R (ft) | 65 mph R (ft) |
| -4.0 | 54 | 116 | 219 | 375 | 583 | 889 | 1,227 | 1,667 | 2,241 | 3,000 | 4,024 |
| -3.0 | 52 | 111 | 208 | 353 | 544 | 821 | 1,125 | 1,515 | 2,017 | 2,667 | 3,521 |
| -2.8 | 51 | 110 | 206 | 349 | 537 | 808 | 1,107 | 1,488 | 1,977 | 2,609 | 3,435 |
| -2.6 | 51 | 109 | 204 | 345 | 530 | 796 | 1,089 | 1,462 | 1,939 | 2,553 | 3,353 |
| -2.4 | 51 | 108 | 202 | 341 | 524 | 784 | 1,071 | 1,437 | 1,903 | 2,500 | 3,275 |
| -2.2 | 50 | 108 | 200 | 337 | 517 | 773 | 1,055 | 1,412 | 1,867 | 2,449 | 3,201 |
| -2.0 | 50 | 107 | 198 | 333 | 510 | 762 | 1,038 | 1,389 | 1,833 | 2,400 | 3,130 |
| -1.5 | 49 | 105 | 194 | 324 | 495 | 736 | 1,000 | 1,333 | 1,754 | 2,286 | 2,965 |
| 0.0 | 47 | 99 | 181 | 300 | 454 | 667 | 900 | 1,190 | 1,551 | 2,000 | 2,561 |
| 1.5 | 45 | 94 | 170 | 279 | 419 | 610 | 818 | 1,075 | 1,391 | 1,778 | 2,253 |
| 2.0 | 44 | 92 | 167 | 273 | 408 | 593 | 794 | 1,042 | 1,344 | 1,714 | 2,167 |
| 2.2 | 44 | 91 | 165 | 270 | 404 | 586 | 785 | 1,029 | 1,327 | 1,690 | 2,134 |
| 2.4 | 44 | 91 | 164 | 268 | 400 | 580 | 776 | 1,016 | 1,310 | 1,667 | 2,102 |
| 2.6 | 43 | 90 | 163 | 265 | 396 | 573 | 767 | 1,004 | 1,293 | 1,644 | 2,071 |
| 2.8 | 43 | 89 | 161 | 263 | 393 | 567 | 758 | 992 | 1,276 | 1,622 | 2,041 |
| 3.0 | 43 | 89 | 160 | 261 | 389 | 561 | 750 | 980 | 1,260 | 1,600 | 2,012 |
| 3.2 | 43 | 88 | 159 | 259 | 385 | 556 | 742 | 969 | 1,245 | 1,579 | 1,984 |
| 3.4 | 42 | 88 | 158 | 256 | 382 | 550 | 734 | 958 | 1,230 | 1,558 | 1,956 |
| 3.6 | 42 | 87 | 157 | 254 | 378 | 544 | 726 | 947 | 1,215 | 1,538 | 1,929 |
| 3.8 | 42 | 87 | 155 | 252 | 375 | 539 | 718 | 936 | 1,200 | 1,519 | 1,903 |
| 4.0 | 42 | 86 | 154 | 250 | 371 | 533 | 711 | 926 | 1,186 | 1,500 | 1,878 |

notes

1. computed using superelevation distribution method 2 from the aashto 's a geometric design of highways and streets, 6th edition (green book)
2. superelevation distribution method 2 utilizes equation 3-10 and f_{max} values listed in exhibit 3-15 of the green book
3. values for speeds 15 to 45 mph match values from exhibit 3-16 of green book.

Designers should consider using the minimum radii provided in this table for urban roadways with design speeds in excess of 45 mph and superelevation rates less than 4%. An important consideration in using the minimum curve radii from the expanded Urban Speed Table is the understanding that just because a minimum radius is provided, it doesn't mean that it must be used. It should be recognized that there are many places in the design of an intersection where the use of greater than minimum radii could improve the comfort of drivers without lengthening the longitudinal construction impacts of the project as a whole. As in all design efforts, design engineers should exercise good engineering judgment in applying the radii from these tables.

Curves Verses Tangent Tapers for Alignment

As previously discussed, typical UDOT design practice for urban roadways tends to emphasize the use of tapers over horizontal curves in shifting roadway alignments. For a

lateral shift over a short distance, this approach is very sensible since the lateral shift occurs over approximately the same distance for either approach for short distances. For the larger alignment shifts associated with the CFIs (typically 20' to 40'), the use of horizontal curvature in shifting alignments can save hundreds of feet of lateral alignment impacts (e.g. ROW impacts) when compared to the tangent approach. Exhibit 4-6 demonstrates how the use of curve radii (from the Urban Speed Table, Method 2, Green Book) compares to the use of simple tapers in shifting horizontal alignments. The longitudinal impact savings demonstrated in this table should be considered along with the additional benefits that include an improved level of comfort experience by drivers as they navigate a horizontal curve as opposed to a more abrupt tapered transition.

Lane and Shoulder Widths

UDOT design standards recommend a minimum 4' wide

exhibit 4-6: tapers vs. curves

the length required to shift a lane 18 feet

| speed (mph) | length based on taper ¹ (feet) | length based on curves ² (feet) | savings by using curves (feet) |
|-------------|---|--|--------------------------------|
| 25 | 188 | 124 | 64 |
| 30 | 270 | 158 | 112 |
| 35 | 368 | 195 | 173 |
| 40 | 480 | 237 | 243 |
| 45 | 810 | 275 | 535 |
| 50 | 900 | 318 | 582 |
| 55 | 990 | 365 | 625 |
| 60 | 1,080 | 417 | 663 |
| 65 | 1,170 | 476 | 694 |

1. taper lengths calculated using equations per udot standard drawings
2. curve lengths per aashto assuming -2% superelevation and no tangent between curves

shoulder along the edge of pavement. A wider than minimum shoulder is recommended where appropriate, to better accommodate stranded vehicles and for bicycle use.

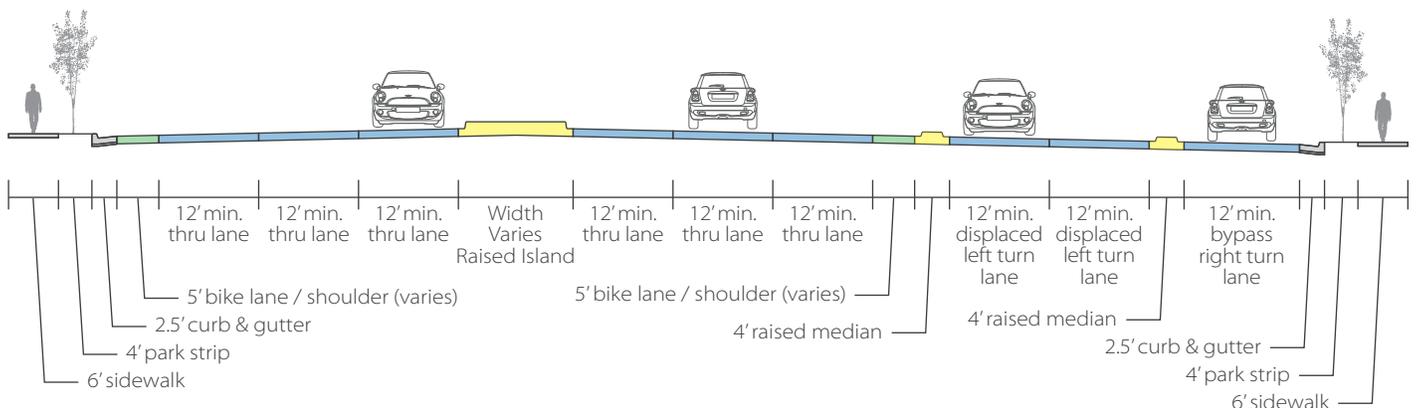
UDOT design standards recommend minimum 12' wide travel lanes, especially for receiving lanes. Under special circumstances, such as right-of-way/ utility conflicts, UDOT has approved, for CFIs, the use of 11' and 11.5' wide through lanes through the design exception process.

Through lanes, narrower than 12', are not recommended at a CFI, especially in areas that are confined by medians. UDOT also recommends left and right turn lanes be a minimum 12' wide, although narrower turn lanes have sometimes been approved through the UDOT design exception process. While some CFIs in Utah have been designed with receiving lanes as narrow as 12', this design has been recognized as undesirable for future CFI designs. Particularly in cases where right turns and crossover lefts converge simultaneously into receiving lanes, the receiving lanes should ideally be 16' wide and no narrower than 14'. Special consideration should be given to the design of turning radii and striping for receiving lanes to best keep vehicles in their correct lanes in this area. Receiving lanes at a CFI crossover are also recommended to be 16' wide and no less than 14' wide. **Exhibit 4-7** illustrates a cross-section showing various lane widths and other dimensions at a CFI.

Median Use & Mountable Curb

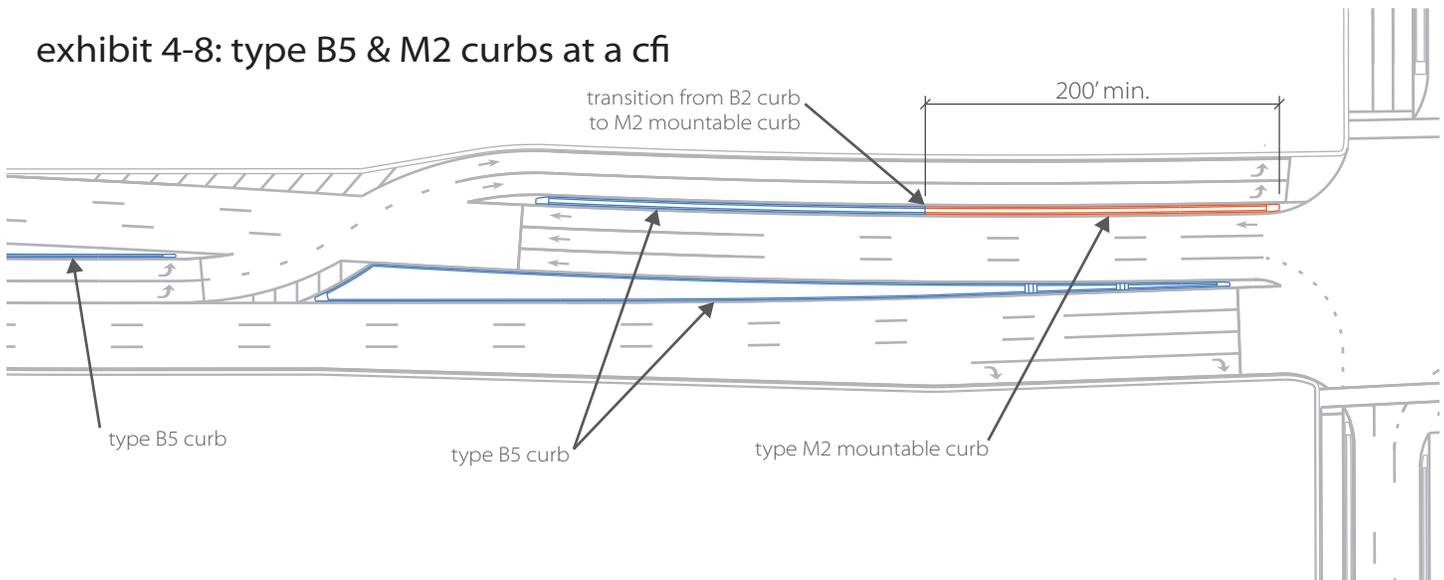
A CFI typically has three medians channelizing traffic along one approach of the intersection, one median that separates opposing through movements and two that separate crossover left turn vehicles from oncoming through traffic and oncoming bypass right turn traffic. The expensive right-of-way acquisition common to urban settings has encouraged minimizing CFI roadway width. Consequently, UDOT has used back-to-back B5 curbs for CFI medians on past projects. Since this configuration results in narrow medians with reduced visibility, all

exhibit 4-7: typical cfi cross section



note: receiving lanes for left and right turns should be 14' minimum (16' ideal)

exhibit 4-8: type B5 & M2 curbs at a cfi



medians should be equipped with reflectors (now defined in the UDOT Standard Drawings) to improve median visibility.

Though CFIs have now been operational in Utah since 2007, UDOT engineers occasionally observe errant drivers traveling in the wrong direction down the CFI displaced left turn lane. To provide errant drivers an escape route into the correct lanes, UDOT requires mountable curb to separate the displaced left lanes from the through lanes. Therefore, an M2 curb should be used instead of a B5 curb within 200' of the main intersection if the crossover length is greater than 400'. A typical UDOT median layout and recommended curb type is illustrated in **Exhibit 4-8**. An M2 curb is an inch shorter than the B5 curb and provides a gradual mountable slope over which vehicles can drive without damage.

Lane Merges

For lane merges in the CFI intersection area, adequate taper lengths should be provided as per current design standards. **Designers should bear in mind that designing to minimum standards is not always necessary.** In areas where multiple lane merges and/or complex weaving movements occur at a CFI, additional merge distance may be appropriate where not prohibited by other physical geographic or design constraints.

Striping Near Medians

Solid striping spaced at least 2' from the edge of roadway (illustrated in **Exhibit 4-9**) should be used on either side

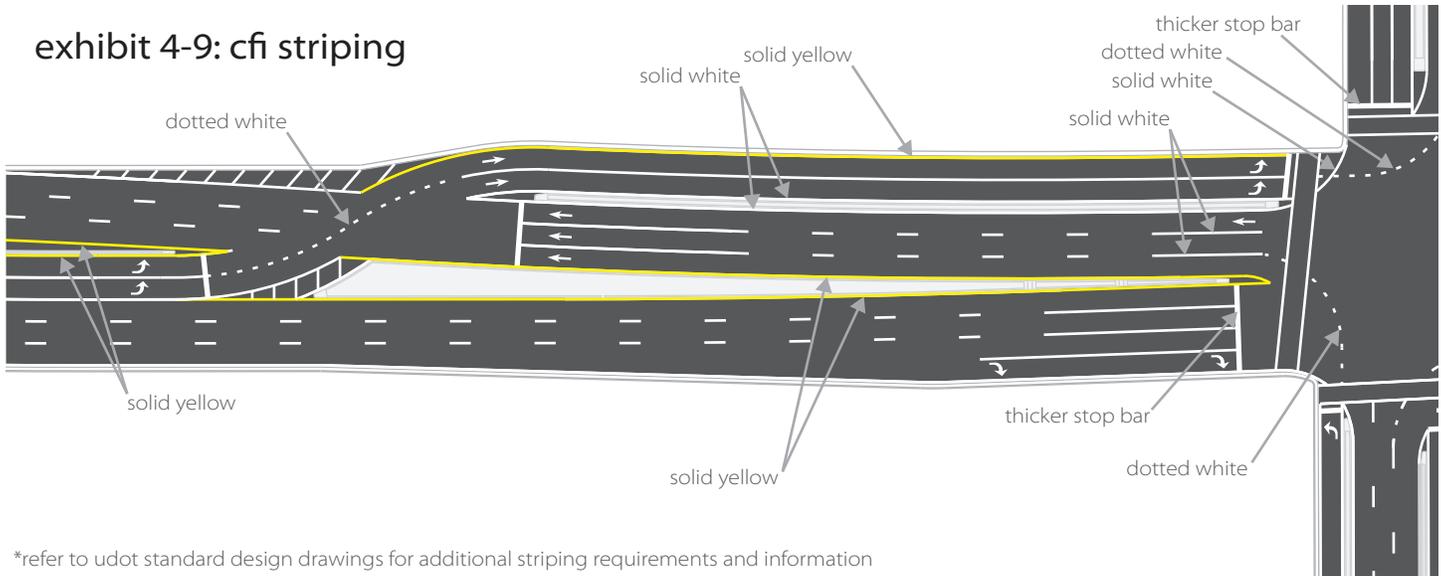
of the medians to provide buffer to traveling vehicles. Yellow striping should be used against medians on the driver's left side and white striping against medians on the driver's right side. In areas where single or multiple lanes are completely channelized while negotiating turns or curves (displaced left turn lanes for example), attempt should be made to provide more than a 2' buffer between travel lanes and the median.

Roadway Striping

Striping (illustrated in **Exhibit 4-9**) provides helpful navigation information to the traveling public using the CFI. Although the CFI is an unconventional intersection, striping consistent with the standards established by the MUTCD ensures that a consistent message is always conveyed to drivers.

One of the unconventional features of the CFI is the crossover left turn lanes or displaced left turn lanes. UDOT has typically provided a crossover location several hundred feet prior to the main intersection, where left turn lanes cross oncoming traffic and are directed to the outside of the oncoming through traffic. Dotted white lines or "turkey tracks" are typically used to delineate the path of crossover left turn movements in order to guide left turning vehicles and to discourage them from entering the conflicting through lanes in a wrong way movement. Designers should consider whether to provide these dotted lines on just one side of the crossover path, or on both sides. Pavement markings, especially

exhibit 4-9: cfi striping



*refer to udot standard design drawings for additional striping requirements and information

dotted lines, tend to fade over time and require periodic maintenance. Strategically eliminating some dotted lines at crossover locations or at intersection left turn locations saves both time and money in long-term maintenance. Alternately, designers should consider specifying grooved thermoplastic markings that would resist friction from tire paths and snow plows.

Consideration should be given to locate the crossover left turn stop bar in the departure radius of the approach instead of the turn bay tangent to better guide the vehicles entering the displaced left turn lanes. The stop bar for the through movement at the crossover may be placed at the tangent point created by the median island striping that separates the through lanes from the displaced left turn lanes. Utmost care should be taken to not place the stop bar in the travel path of the crossover vehicles (verified by a turning template). To draw drivers' attention to the stop bar at the main intersection and to discourage drivers from making a prohibited "right turn on red" movement across a displaced left turn lane or creeping too far into the intersection (typical behavior when a stop bar is placed back farther from the intersection), designers should consider wider-than-usual stop bars, up to 24 inches wide. To ensure that drivers keep clear of the turning radius of the displaced left turn travel path at the main intersection, word pavement markings with the message, "KEEP CLEAR", can be used between the stop bar and the intersection. Crosswalk designs at a CFI should meet the

standards for either school or non-school crossings.

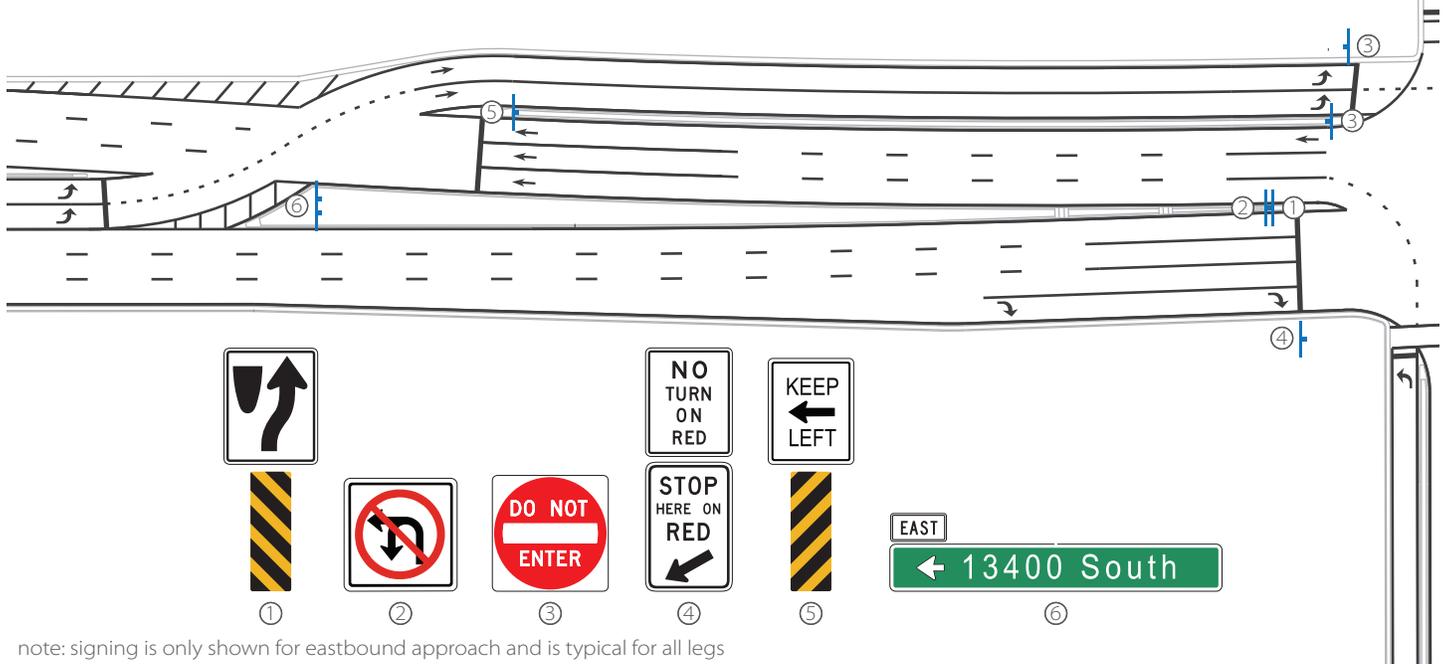
Given the previous discussions and potential conflict that can occur in the receiving lanes, especially where no bypass right turn lane is provided and left and right turn movements converge simultaneously, consideration should be given to provide solid white striping for 100' or more from the intersection (instead of white skip striping) to further delineate the travel lanes and discourage lane changes. Through arrow markings can also be provided for the CFI receiving lanes at the main intersection or at the crossover location as deemed necessary by engineering judgement. The through arrow marking provided in the receiving lane for the right turn vehicles crossing the displaced left turn lane(s) can be beneficial in providing guidance to right turns and help keep them from accidentally entering the displaced lanes.

Roadway Signing

UDOT has typically provided a crossover left turn where left turning vehicles are stopped several hundred feet in advance of the main intersection. Since this location to turn left is new, it is important to inform drivers about the upcoming crossover left turn in order to avoid missed turning opportunities. To minimize confusion, standardize placement of way finding signs, and generally improve consistency in CFI signing, UDOT has recently developed new sign placement standards for CFIs.

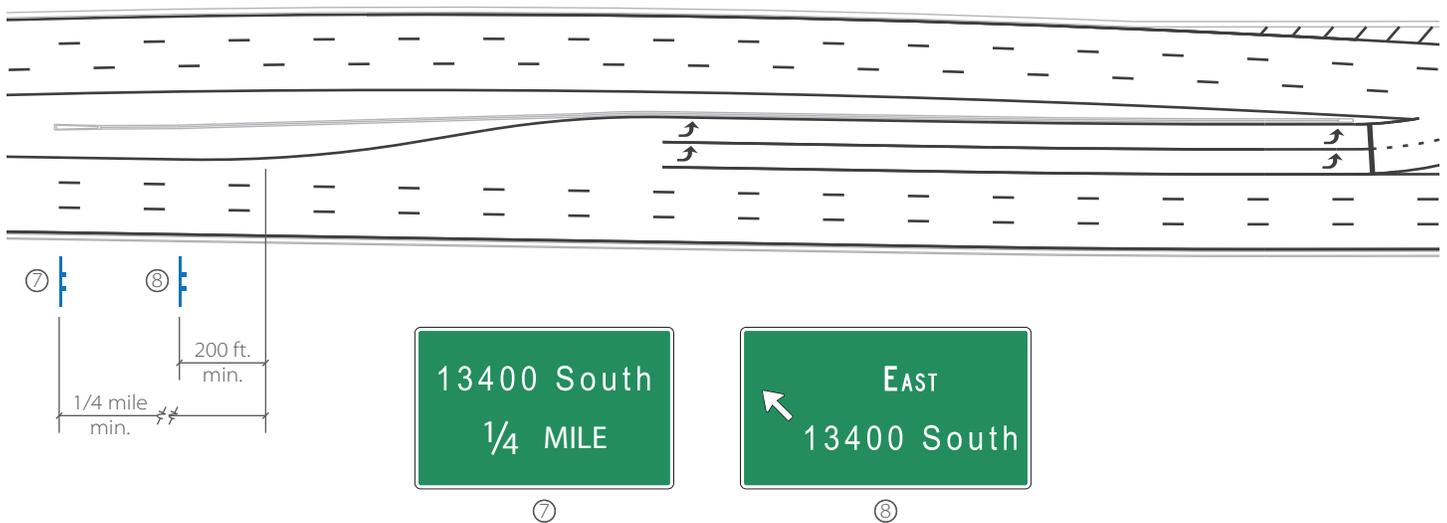
UDOT's new sign placement standard requires that left

exhibit 4-10: cfi signage



note: signing is only shown for eastbound approach and is typical for all legs

exhibit 4-11: advanced cfi signage



note: signing is only shown for eastbound approach and is typical for all legs

turn way finding signs be placed at least 200 feet in advance of the approaching crossover left turn bay taper. The standard also requires that another way finding sign be placed one quarter of a mile in advance of the crossover left turn bay taper. **Exhibit 4-10** illustrates

UDOT standard signs and placements at a typical CFI.

In addition to the advance messaging at the left turn crossovers, several additional intersection signs and placements have been identified in the sign guideline to minimize driver confusion and to aid way finding.

LED Blankout Signs

UDOT has utilized LED Blankout Signs to prohibit certain movements (typically right turns) that are normally allowed at conventional intersections. The rationale behind the use of these signs is that “no right turn on red” restrictions are one of the most frequently violated restrictions to drivers. With potentially severe results for such a violation at a CFI (a prohibited right turn t-bone collision with displaced lefts), a no right turn LED sign that illuminates during the red phase has been implemented to enhance driver awareness of the prohibited movement. In cases where the CFI intersection is particularly wide (greater than 150’ from stop bar to blankout sign mounting location), these LED signs may be appropriate on both the signal mast arm and a pole on the near side of the intersection. **Exhibit 4-12** shows one such application

exhibit 4-12: LED no right turn on red



of the LEB blankout signs at the CFI at 6200 South & Redwood Road in Taylorsville, UT.

In some cases, blankout LED signs have also been used to prohibit right turn movements when opposing left turn movements have a green signal and insufficient receiving lanes exist (e.g. dual left turn lanes and a single right

turn lane converge into only two receiving lanes). This application is usually confined to scenarios where not enough receiving lanes exist to accept both right turning movements and displaced left turn movements at the same time. The blankout LED sign helps control this conflict by holding right turns back during the green phase until the CFI lefts have completed their movement. In this case, the LED blankout sign accompanies a protected right turn signal. As described in Section 2, this conflict could also be addressed by adding receiving lanes.

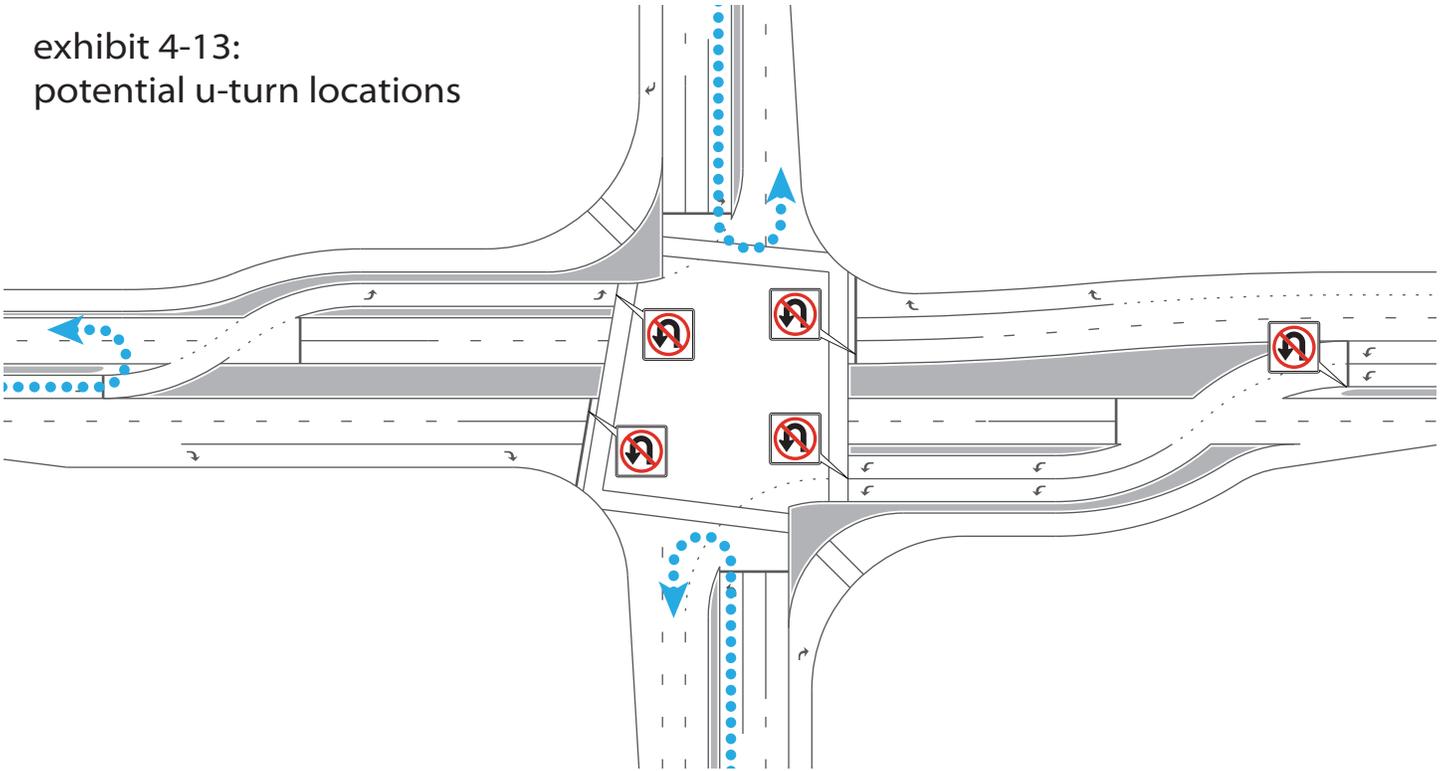
Signing U-Turns at CFIs

In the past, UDOT has sometimes prohibited U-turns at CFI crossover locations and on non-CFI intersection approaches to avoid driver confusion. While this has been a past precedent borne mostly from an abundance of caution in controlling movements at these new intersections, U-turns can safely be performed with CFI crossover movements and on non-CFI intersection approaches at CFI intersections. U-turns should generally be allowed unless specific safety hazards can be identified that conflict with proposed u-turn movements. For example, U-turns should be prohibited for through movements (vehicles traveling away from the intersection) at the crossover location.

At locations where bypass right turn lanes merge with through lanes, caution should be given to allow U-turn movements to assure no conflict would be created for U-turn and merging vehicles. To avoid this conflict while still allowing U-turns at the crossover, the bypass right turn lane should be merged with through lanes at a downstream location so as to avoid the crossover U-turn conflict.

Since U-turns are allowed in Utah at all intersections where not specifically prohibited with signs, this simply means that crossover locations could be left unsigned with regard to U-turn movements unless there are reasons to specifically designate them as allowed or prohibited movements (multiple crossover lanes for example). Where U-turns are specifically allowed or prohibited, appropriate U-turn signage should be displayed in accordance with the *MUTCD*. Potential U-turn locations at CFIs are illustrated in **Exhibit 4-13**.

exhibit 4-13: potential u-turn locations



Signals & Lighting

Signal indications at the main intersection of a CFI are similar to a conventional intersection. The displaced left turn phase at the intersection is never permissive only, and has been controlled, to date, with a protected red, yellow and green arrow head (a type III signal head). The through phase is displayed with a green ball (type I signal head), and right turns across displaced left turn lanes are prohibited with an LED Blankout “No right turn on red” sign. The LED sign may be supplemented with a protected only right turn signal head for better compliance or where necessary to avoid undesired conflicts. On the non-CFI legs at the main intersection, consideration should be given to running the traditional left turn movements as protected + permissive movements with a flashing yellow arrow when practical. At the crossover location, the through movements are controlled with a Type I signal head (many of which have been optically programmable heads to minimize visibility from the main intersection) and crossover left turns are controlled by type III signal heads with angled arrows (45 degrees up and to the left) pointing towards the displaced lane. Ongoing discussions entertain the application of protected + permissive type V head or type IV flashing yellow heads for the crossover

locations when appropriate, but none have been installed to date due to the lack of any benefit the permissive option would provide.

Signal design at a CFI should adhere to the same standards for traditional intersections, adhering to *MUTCD* and *ADA Guidelines*. All the signals at a CFI operate from one controller. Given this, appropriate planning should occur to ensure that phasing, overlaps, and channels are correctly assigned and able to operate in the cabinet and controller of choice. Also, because more signal heads and detectors are usually necessary at CFIs, ensure that sufficient hardware is provided to control the detectors and signals at the intersection. Furthermore, depending on the type of detection being used, check the design to ensure that the signal from the crossover detectors will be adequate to communicate with the cabinet. Lastly, the blankout LED no right turn signs, if necessary, are wired into the signal system to correspond the illumination with the correct signal phase.

Lighting at the CFI should be designed with considerations similar to a conventional intersection. At the main intersection, the luminaires should illuminate receiving

lanes of traffic, stop bars, and the crosswalks. Luminaires should also be provided to illuminate CFI crossovers and the area between the crossover and main intersection.

Bicyclists, Pedestrians & Disabled Persons

Because of the unconventional movements and crossing distances at CFIs, positive guidance is necessary for non-vehicular traffic to move safely through the intersection, the primary groups being bicyclists and pedestrians. The operational and safety needs of both groups should be considered in the design of a CFI.

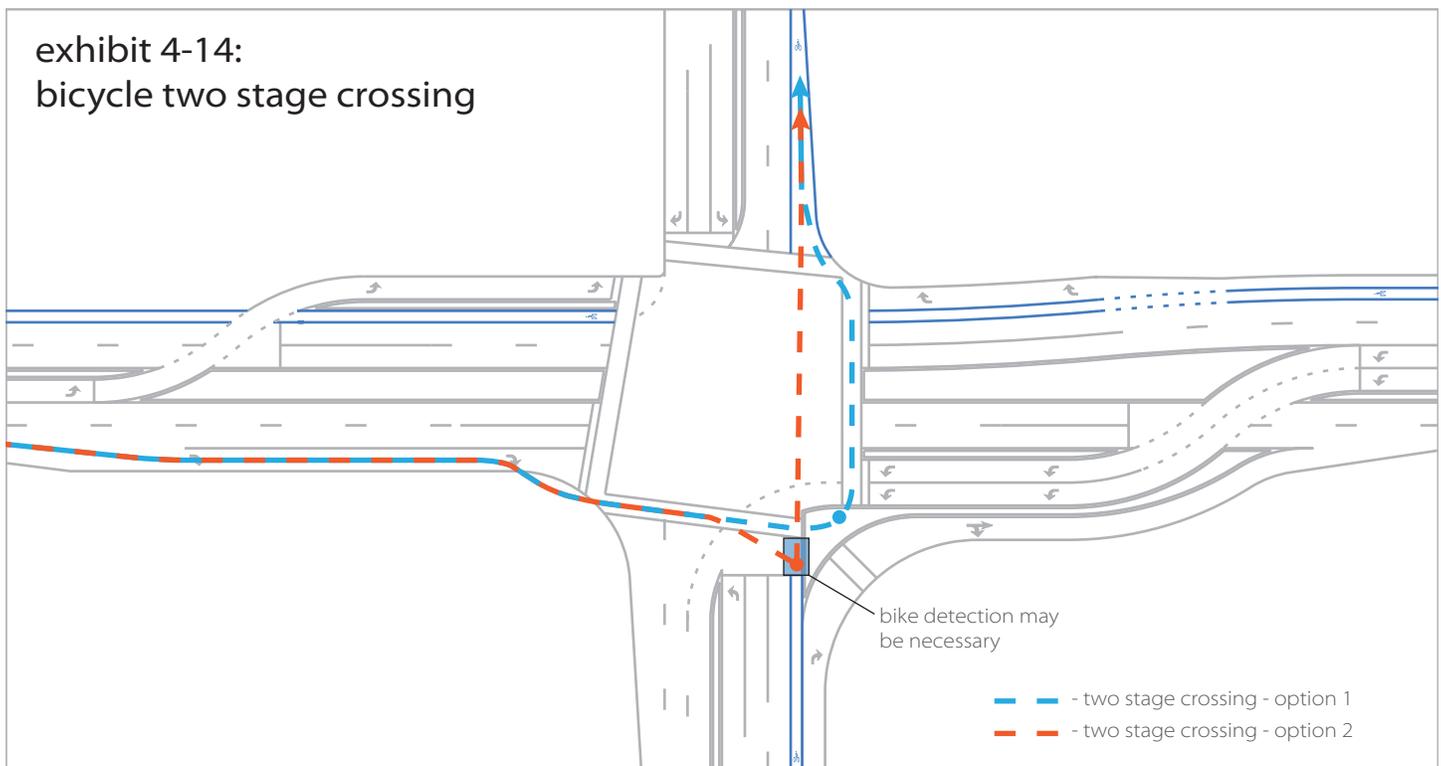
Designers should further consider that at least two types of bicyclists exist – experienced cyclists who ride on roadways with vehicular traffic (and prefer to ride there) and recreational bicyclists (which may include children) who operate on sidewalks with pedestrians. Experienced cyclists are typically comfortable riding along with vehicular traffic and performing many of the same movements and may only need wider shoulder lanes or paved shoulders to navigate a CFI. The less confident and less experienced recreational bicyclists may need designated bike routes or may likely choose to follow the sidewalks and pedestrian crossings through the intersection.

In designing a CFI, engineers should consider the bicyclist population that is likely to use the intersection. If the bicyclist population is likely to be experienced road cyclists, engineers may only need to provide wider shoulder lanes (14 feet desirable) and/or paved shoulders (4 feet wide minimum) through the CFI. For example, the experienced cyclists making a left turn could stay in traffic, merge left, and make left turns along with left turn vehicles (which is not likely to occur on multi-lane or high-volume facilities), or alternately, they could cross the intersection like pedestrians do in a two-stage crossing process (**Exhibit 4-14**). If the bicyclist population is likely to be inexperienced, engineers should either consider bike lanes (5 feet minimum width) through the intersection or provide crosswalks (which may already be part of the design for pedestrians) for them to follow.

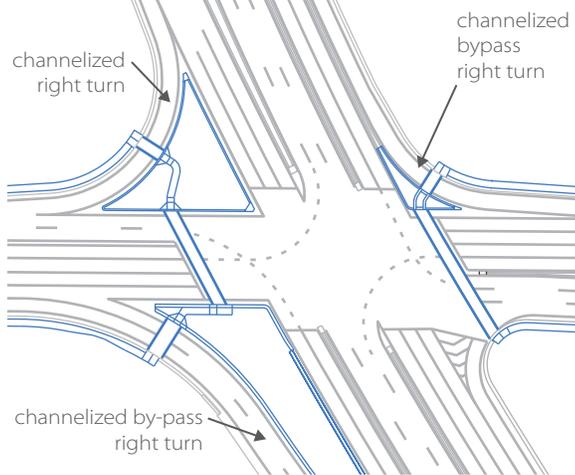
On high speed facilities, consideration should be given to provide bike paths (5 foot minimum width) that are physically separated from vehicular traffic by an open space or barrier or simply prohibit bicycle use altogether.

Refuge Islands

The CFI tends to be wider than a conventional intersection, mainly because of additional medians required to separate



**exhibit 4-15:
refuge islands at the cfi**



conflicting movements of traffic and the curvature in the roadway needed to provide directional guidance to motorists. In order to cross a wider-than-usual-intersection, pedestrians naturally need more crossing time. The early academic CFI pedestrian crossing strategy utilized a multi-stage crossing plan to minimize longer crossing times using refuge islands (which also helped improve signal timing efficiency). UDOT chose to modify this strategy to provide more conventional pedestrian crossing paths with one continuous movement. Consequently, this decision minimized the need for refuge islands other than those necessary to separate the free bypass right turns, which require larger turning radii, from the rest of the intersection. The early academic CFI strategy provides additional refuge islands between the displaced left turn lanes and the opposing through vehicles, in line with the pedestrian crossing path.

As stated, refuge islands (illustrated in **Exhibit 4-15**) are required for pedestrians crossing a CFI with a by-pass right turn lane. The pedestrian push button for the signal is located on this island and from this point, pedestrians cross the intersection like they would at a traditional intersection.

Pedestrians cross to and from this median after yielding to by-pass right turn traffic.

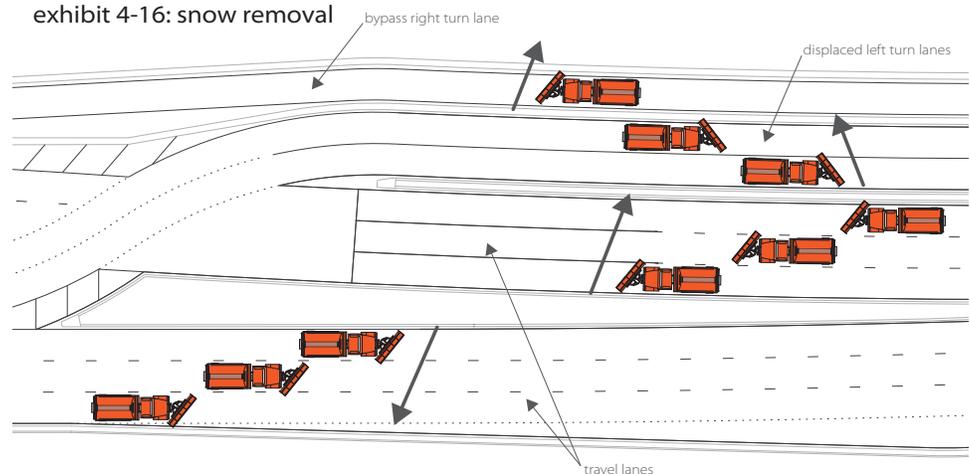
In designing the refuge island, engineers should consider the size of the island and its ability to accommodate the number of pedestrians crossing the approach per signal cycle. In addition, the island should ideally shield pedestrians, recreational bicyclists, and wheelchair bound pedestrians from vehicle traffic.

The ADA requires a minimum 48" x 48" area for wheelchair bound people to maneuver. With an M2 type curb (30" wide) required at an intersection and a 2 foot buffer on either side of it provided by striping, pedestrians unable to complete their crossing maneuver can theoretically seek refuge between the M2 medians separating opposite directions of traffic.

Snow Removal

Snow removal from the travel lanes of a CFI has been a difficult design consideration for CFIs in Utah. The multiple (and often narrow) channelizing medians, combined with additional movements outside of the normal intersection footprint, complicate operations for snow plow drivers. Plowing operations tend to push accumulated snow storage to the right shoulder on the outside of the roadway. While this works well for traditional intersections, in a CFI, this typically throws snow directly into the displaced left turn lanes. If the same procedure were to be used for plowing displaced left turn lanes, it would throw snow right back into the through travel lanes. This scenario is complicated further by bypass right turn lanes on the

exhibit 4-16: snow removal



outside of the displaced left turns. Consequently, plows moving through the displaced left turn lanes need to throw snow to the left side of their vehicles so that the snow can continue to be moved from travel lanes, to displaced left turn lanes, to bypass right turn lanes, and finally to the shoulder on the outside of the intersection. The snow removal operation at a CFI is illustrated in **Exhibit 4-16**.

Snow Storage and Median Drainage

Given the high cost of right-of-way acquisition, construction, and maintenance associated with providing median treatments wide enough to store snow, designers have typically elected to minimize median footprints within the CFI. Even with attempts to minimize median sizes, some pavement areas not utilized by medians or travel lanes could be graded, hatched, and utilized for snow storage. In such cases where medians or other paved space wide enough for snow storage are utilized, drainage should be proactively managed with grading and inlets to drain water out of the traveled way.

Drainage is extremely important at a CFI and needs to be pro-actively addressed. The various lane groups (e.g. travel lanes, displaced left turn lanes, and bypass right turn lanes) are separated by raised medians making it difficult to drain surface water appropriately. The addition of storm drains along the raised medians may be necessary to remove excess water from the roadway.

SECTION 6 – COMMUNICATIONS AND PUBLIC INVOLVEMENT

Expect Opposition

UDOT’s public involvement mission statement is “to capture the public’s vision and sense of need by establishing an ongoing dialogue that is collaborative, respectful, and timely.” In order to capture, gain, or win “the public’s vision and sense of need” on the question of innovative intersection treatments such as the CFI, extraordinary efforts are often required to establish the type of “ongoing dialogue” or communications that result in public understanding and acceptance. This is not because the operation and benefits of a CFI are difficult to understand or to prove, but rather because it is human nature to suspect and oppose new ideas until they have been sufficiently proven by time and by trial. Therefore, some level of public opposition should always be expected whenever new ideas including CFIs are introduced.

Budget Pro-actively

To make innovation seem commonplace enough to minimize public objection and to prove the merit of new or provocative ideas requires thoughtful strategy, careful execution, and persistent effort in developing and implementing a public involvement and communications plan that will address the potential concerns of the affected public. This plan should account for goals, measurable objectives, concerns and opportunities, key audiences,

messages, strategies, tactics, scheduling, and evaluation tools.

Developing and executing an effective plan requires an appropriately sized budget to “capture” or win over “the public’s vision”. What then is an appropriately sized budget? Considering the high hurdle to win public opinion on the question of an innovative concept such as the CFI, consider adjusting the public involvement budget two to three times the size of a traditional budget as needed to accommodate the challenges of communicating and solving grass roots issues. This guidance should not be construed to mean that budgets must be this high, or

that they might not need to be even higher at times given the identification of specific needs. Still, consideration should be given to the public involvement needs and budget at an early development stage to ensure that

the addressing of vital public involvement needs is not restricted. Additionally, a funding source should be identified for administrative efforts outside of the project to address on-going requests from other DOTs and municipalities who are interested in implementations of innovative concepts. Efforts to photographically document pre-construction, during construction, and post-construction conditions for education and messaging purposes could also be considered in these funding sources or within the project budget.

As an example, the budget for the 3500 South CFI was larger than usual because it introduced a first-in-Utah concept that required extra public education and outreach, including to groups far beyond the usual group of “public, businesses, and drivers directly affected” by

*New opinions are always suspected,
and usually opposed, without any other
reason, but because they are not al-
ready common.*

— John Locke

Guidelines for developing and tools for implementing an effective and appropriately scoped public involvement plan can be found on the UDOT website starting with the Public Outreach Planner (POP). The recommendations within this section may be used to enhance the recommendations of existing guidelines in accommodating the unique needs of innovative concepts like the CFI.

exhibit 6-1: Photo of Continuous Flow Intersection



the construction. Since it was a new concept, it attracted special scrutiny from city and school leaders who were concerned about school children and adults who would walk through and near the intersection, which required additional safety outreach.

Understand Your Audience(s)

Many project related public involvement and communications efforts automatically assume (in scoping or in execution) that the only audiences to be addressed are the public, the businesses, and the drivers directly affected by the project. With innovative concepts like the CFI, this is certainly not the case. Internal UDOT staff, UDOT leadership, public decision makers, industry leaders, legislators, and municipal leaders all have an interest in the development and implementation of these new ideas. We recommend that all of these parties be considered as stakeholders, and as potential audiences for project communications. In turn, while some audiences have common needs, each audience may also have distinct needs that complicate or expand public communication efforts and require individualized and unique communication strategies and tactics.

Identify and Measure Success

Planning efforts and NEPA documents identify a “needs assessment” or “purpose and need” step where project

needs and metrics of success are developed. The identification and measurement of these needs is not merely a bureaucratic requirement, but provides an opportunity to identify needs and measures that may be messaged as part of a public information campaign. Measurement of need and demonstration of success is a key part of building trust through the public accountability process. It is an opportunity to demonstrate the merit of new concepts like the CFI over time and highlighting actual operating results from application in the field.

Any potential metric that is used to measure the success of the project (traffic volume, congestion, travel time, safety, economics, etc.) should be measured both prior to implementation and post implementation (a before/after study). The differential comparison of pre- and post-implementation metrics to modeled efforts and to other project needs expectations is the essential work required to conclusively demonstrate merit and value to a potentially skeptical public and stakeholder group.

Manage Expectations

In developing value statements about project performance from a before/after study comparison, it is important to select timeframes for measurement that will match public expectations. For example, although excellent delay and travel time saving may be anticipated in a

future planning year that is 20 to 30 years away, it is important to recognize that a constructed improvement is being evaluated by the public right now. Public opinion will simply not wait 20 to 30 years to pass judgment on whether or not the public justification for the project is being met. Public opinion can develop and harden very quickly absent clear messaging about the value provided. Consequently, when developing and messaging value statements, it is important to clearly demonstrate value that meets the needs of the project. In addition, set realistic expectations for the value to be expected by using opening day measurements rather than measurements for some period 20 to 30 years down the road. This approach will allow expectations to be exceeded, which enhances the perceived value to the public.

Demonstrate Public Accountability

Without measuring the performance of the innovative concept versus the need that it is intended to serve, there is no closure of the public accountability loop to demonstrate good stewardship over public funds. This accountability to the public is critical to maintaining transparency and trust and should be included as part of every project that may come under public scrutiny, but certainly for all projects that implement new and potentially controversial ideas

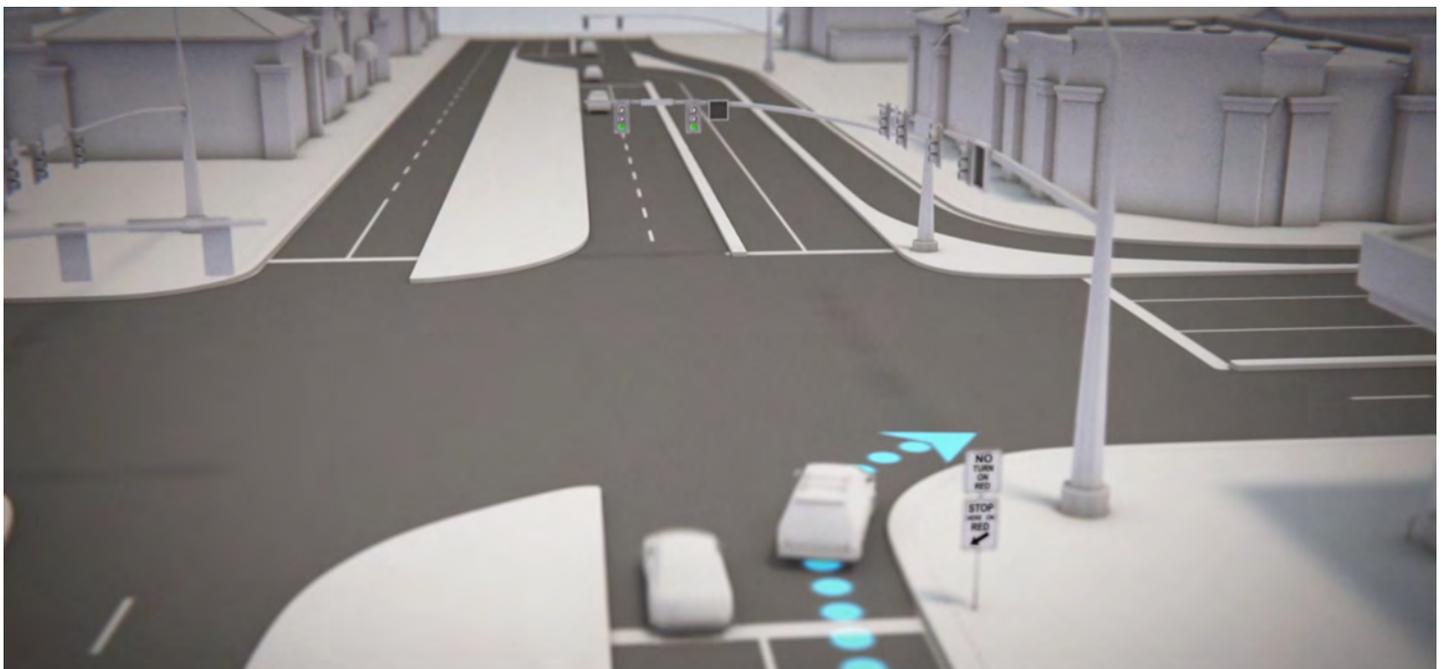
like the CFI. The positive outcome leads to the DOT's ability to secure funding for new projects and to advance the goals of transportation within the State.

Tell an Engaging Story

Distributing facts and figures alone does not engage the public in a way that allows them to grasp, retain, and accurately broadcast critical project messages. In developing effective public messaging, we recommend using the form of the story to broadcast key project messages whenever possible. The use of a story format provides a framework for understanding and resolving problems that facilitates ease of understanding, retention, and communication to others. It is a format that is particularly well suited to identify problems or project needs and to demonstrate how those problems are resolved by the proposed improvements. The story form personalizes UDOT and other key stakeholders and extends public trust.

The development of a "story" for public messaging should include elements that engage or develop interest with those who see or hear the story. The use of monotone voices, technical jargon, plodding camera movements, and unimaginative visual effects does not engage viewers nor does it enhance the story telling experience.

exhibit 6-2: Educational Video Screen Shot



Consequently, public messaging should include engaging dialogue, simplified messages, dynamic camera movements, and captivating visual effects that reinforce the messages to be communicated. The use of these and other effective storytelling elements will engage viewers in a way that encourages consumption of the entire message and provides greater potential for that message to be retained and shared with others. An example of how UDOT implemented this approach on the first CFI at 3500 South was to develop a presentation that told the story of increasing congestion at the intersection, how it

was impacting drivers, and how UDOT considered several solutions before deciding upon the CFI.

Other Communication Tools

The rise of the internet and social media has allowed simple and effective mass communication while simultaneously encouraging a proliferation of messaging that requires strategic differentiation in order to be heard. Multiple tools available for communicating important public messaging should be considered in broadcasting project related public information including commonly used tools such as project websites, YouTube, social media links, project hotlines, public meetings, and printed project communications. Print and broadcast media should be considered on a more selective basis where appropriate, as should project specific mobile applications or apps.

Public Involvement During Construction

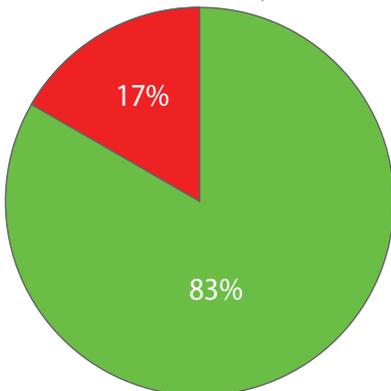
Public involvement during construction is especially critical to communicate traffic changes and timeframes associated with the inconvenience of construction. Door to door distribution and direct contact open lines of communication and build trust and confidence for impacted businesses and property owners. Ensuring that complaints are initially lodged with those empowered to resolve them allows resolution to occur at the lowest possible level. Variable message signs (VMS) and other location specific broadcast methods are critical to communicate expectations with the traveling public, including outreach for commuters who can't be reached door to door. One of the lessons learned on past CFI

exhibit 6-3: business accommodations

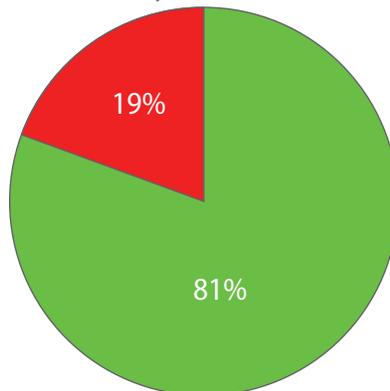


exhibit 6-4: public survey on the cfi ■ yes ■ no

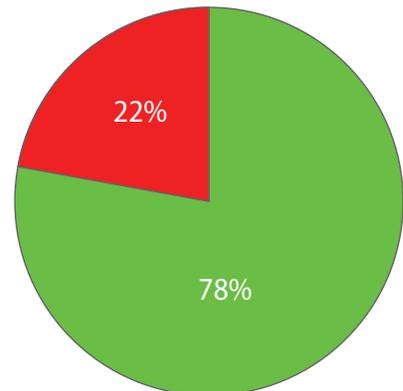
has the traffic improved?



easy to drive?



safe to drive?



survey data courtesy of ppbh

projects is that the public outreach for the commuter user group should be covered well.

Public Perception of the CFI in Utah

Overall, the limited out-of-direction travel, significant congestion reduction, and improved safety of the CFI has been well received by a vast majority of Utah's traveling public. Transportation focus groups have offered unsolicited recommendations for new CFI intersection locations, which is indicative of long-term public acceptance of the concept (public survey data provided by PPBH applies only to the 3500 South Bangerter CFI, even though this data is consistent with anecdotal feedback from other CFI projects as well).

Worth noting is the fact that most of Utah's CFIs have been constructed on access restricted corridors like Bangerter Highway. The existing access restrictions on these corridors, prior to CFI construction, have helped minimize the impacts of new medians on adjacent business access. Where CFIs have been constructed in areas with fewer existing access restrictions and a greater number of businesses, access accommodations have been an ongoing concern for businesses and the municipalities in which they reside. We expect that future implementations in highly commercialized areas would need to address and mitigate these concerns.