Intersection and Interchange Design Alternatives:

A primer for the US 64 corridor study stakeholders workshop participants

Introduction

An **intersection** is a junction between two roads without a bridge. For many junctions with major roads in North Carolina, such as US 64 in Wake County, a traffic signal is often used at the crossing of the two roads to let different directions of travel go at different times. Since both roads are at the same vertical "grade", these junctions are sometimes called "at-grade" intersections. The different possible travel "movements" at the intersection include left turns, (straight) through, etc. from the various directions approaching the intersection.

An **interchange** is a junction between two roads with a bridge carrying one of the roads over the other and ramps connecting the roadways to provide access. Since the crossing roads are at different vertical "grades", these junctions are sometimes called "grade-separated" interchanges. Sections of divided highways that have zero signalized intersections – with all major crossings using interchanges – are called "freeways" (i.e., "free flow" travel without traffic signals) or "expressways" (i.e., "express" travel without traffic signals).

The goal of any intersection or interchange design is to provide the best possible user experience within the context of the natural and built environment, and amidst financial, time, and other limitations.

The users of an intersection or interchange might include any of the following "modes" of travel:

- Pedestrians
- Motor vehicles
- Trucks
- Bicyclists
- Transit vehicles
- Emergency vehicles

The purposes of travel for those traveling through a junction could be:

- Commuting to work
- School
- Shopping
- Out-of-town travel
- Visiting neighbors
- Leisure
- Responding to emergencies

The directions of travel for users at a location could be:

- Major roadway, straight through
- Minor roadway, straight through
- Turning right or left from major roadway to minor roadway
- Turning right or left from minor roadway onto major roadway

Users at an intersection or interchange can be neighbors, other local users, other users from within the same county or region, and visitors from other parts of the state, region of the country, nation, or beyond.

Of course, different intersection and interchange options at any location will optimize the travel experience of various user "modes", trip purposes, travel directions, and travel origins. In addition, there are other tradeoffs to consider beyond user experience, including cost and context sensitivity. However, while there is no single "right" answer, some designs will be better than others at meeting various goals.

For intersections along major roadways – such as US 64 in western Wake County – a primary design goal is to streamline travel flow for users in the main direction of travel, while minimizing adverse impacts to other travel directions, within the context of the natural and built environment and amidst financial, time, and other limitations. From a purely "traffic operations" standpoint, this goal requires the consideration of various intersection design alternatives that will allow users along US 64 to see green lights more often at traffic signals. Each of the intersection options on pages 1 through 8 of this primer are "innovative intersection designs" that reroute left turns to or from US 64, and/or reroute travel for those crossing US 64. Doing so eliminates the need for the traffic signal to allow for one or more turning or crossing travel movements, and the time thus saved by reducing one or more of those signal "phases" can be given back to US 64 in the form of longer or more frequent green time. Of course, the "best" design may or may not be the one that retains the most green time for US 64, since there are other tradeoffs to consider, including financial, neighborhood context, impacts to travel in other travel directions, etc.

For interchanges along major roadways, the primary goal of eliminating travel conflicts with the major roadway has been achieved by definition – by the bridge. In addition, the use of a bridge may (or may not) also improve the user experience for other directions of travel as well. As with intersection design, the goal of interchange design is to improve travel in all directions within the context of the natural and built environment and amidst financial, time, and other limitations. Each of the interchange options on pages 9 through 15 of this primer are interchange designs that optimize different characteristics at the expense of others, such as land costs, construction costs, pedestrian and vehicle travel along the side street, left turning travel, etc.

The decision of whether to use an intersection or interchange at a given location, as well as the specific intersection or interchange design selection, is always based on an analysis of tradeoffs: financial, available land, construction cost, environmental impact, neighborhood impact, benefits and challenges for users along the major roadway, benefits and tradeoffs for travel along the minor roadway, etc. In general, the worst interchange will still "operate better" than the best intersection – because the bridge allows two conflicting directions of traffic to go at the same time, one on top of the other. And in general, any interchange will cost far more than any intersection, because bridges cost more than pavement on gravel and earth.

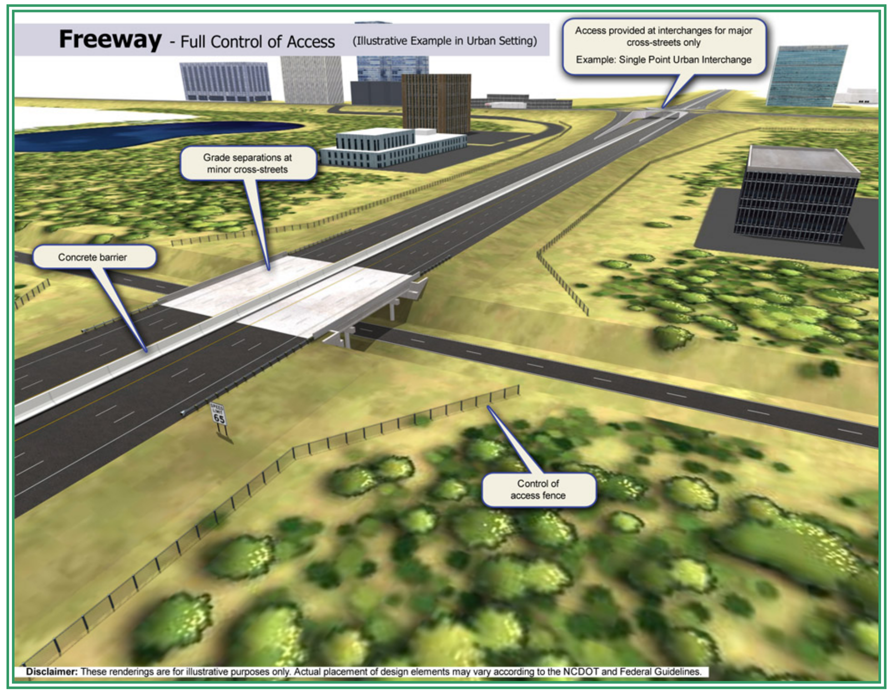
While there is no single "right" answer, there are better and worse designs for both interchanges and intersections at a given location, based on a particular set of goals for the location as well as the characteristics that pertain to that junction, including context and specific design constraints. It may be that an interchange provides a better set of tradeoffs than an intersection, but funding does not allow for bridge construction, at least in the near term, so that both a short-term preferred intersection design and a long-term preferred interchange design are developed for a location.

Innovative intersection design alternatives are found on pages 1-7 of this primer, with a summary on page 8.

Interchange design options are found on pages 9-14 of this primer, with a summary on page 15.

CORRIDOR CLASSIFICATIONS

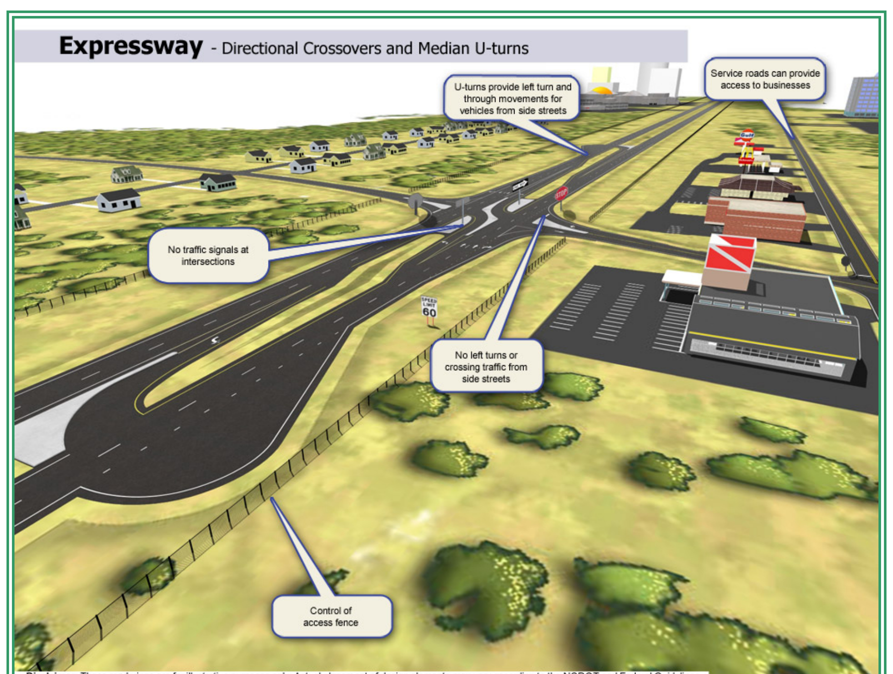
Freeway Alternative Concept



Freeways are the highest classification of roadways and are characterized by a divided roadway with full control of access and include grade separations or interchanges at cross streets. Freeways provide a high level of mobility with a low level of access and have a speed limit of 55 mph or greater and only allow access at interchanges. The most common application of freeways is on the Interstate system, although numerous freeways exist along routes not designated as Interstate highways. To provide access to properties along freeways service roads that connect to cross streets with interchanges are typically constructed. Examples of freeways in the Triangle Region include I-40, I-540, US 64/264 Knightdale Bypass and US 70 Clayton Bypass.

Based on the evaluation of a freeway alternative in previous studies and by the Corridor Study Team it was determined that a freeway alternative would meet the goals of the study and be most appropriate for the portion of the corridor between the US 64 Pittsboro Bypass and NC 540 with the exception of the portion across Jordan Lake.

Expressway Alternative Concept



Expressways are the next highest classification of roadways, below freeways, and are characterized by a divided roadway with limited or partial control of access with access provided only at interchanges for major cross streets and at-grade intersections for minor cross streets. Expressways provide high mobility with low-to-moderate access and have speed limits of 45 mph to 60 mph. Expressways do not allow traffic signals and strongly discourage direct driveway connections. At-grade median crossovers are allowed for traffic crossing the expressway and for traffic making u-turns. In urban areas with higher traffic volumes, median crossovers may not be provided if adequate safe gaps in traffic can not be provided. The portion of US 64 from Green Level Church Road to Laura Duncan Road is an example of an urban expressway while the section from Mt. Gillead Church Road to Farrington Road, across Jordan Lake is an example of a rural expressway.

Based on the evaluation of an expressway alternative in previous studies and by the Corridor Study Team it was determined that an expressway alternative would best meet the goals of the study and be most appropriate for the portion of the corridor across Jordan Lake and from NC 540 to US 1.

Signalized Intersection Alternative Concept

Signalized Intersections are the next classification below expressways and are characterized as facilities with traffic signals. A corridor of signalized intersections is commonly referred to as an arterial or boulevard and is the existing classification for a majority of the US 64 Corridor within the study area.

Based on the evaluation of a Signalized Intersection alternative by the Corridor Study Team it was determined that a Signalized Intersection alternative was not likely to meet most of the goals of the study; however, based on the potential impacts associated with freeway and expressway facilities it was decided that signalized intersection alternatives could be considered, where appropriate, as a means to minimize the effects on the local communities. The Corridor Study Team determined that the only location where a signalized intersection alternative may be appropriate is the section of US 64 from east of Lake Pine Drive to the US 1 interchange.

SIGNALIZED INTERSECTION, EXPRESSWAY AND FREEWAY CONCEPTS

Based on the results of the preliminary alternative evaluation three facility types were chosen as potential solutions for portions of the corridor. The following section will present potential applications of each of the facility types and discuss the potential benefits and liabilities of each concept.

SIGNALIZED INTERSECTION CONCEPTS

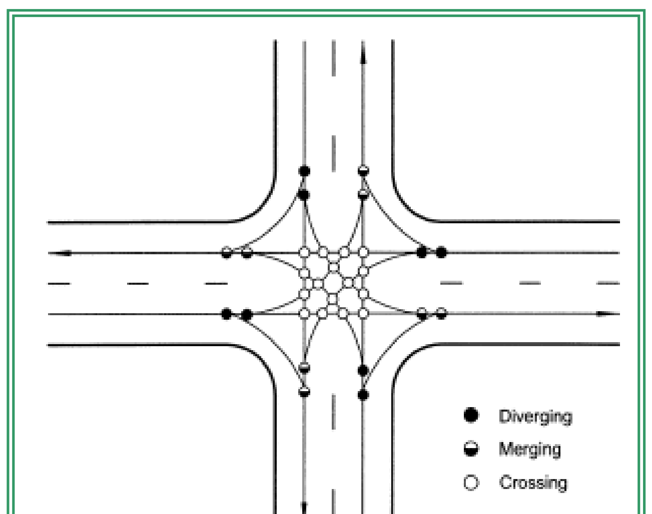
The range of solutions for improving existing signalized intersection facilities is accomplished through either expanding the facility by adding additional through and/or turn lanes or by improving the efficiency of the intersections themselves. For many years the preferred method of improving signalized corridors has been to provide additional capacity by adding additional lanes to the facility. Studies have shown that this method can be very costly and have diminishing returns. This issue has caused a new line of thinking to emerge with alternative methods being considered to improve the operations of intersections without adding additional through lanes. This section will present the concepts for improving signalized intersection facilities and is based largely on the information presented in the Federal Highway Administration's Publication *Signalized Intersections: Informational Guide*.

Traditional Intersection Treatments

Traditional intersection treatments include allowing traffic movements from all directions at each intersection. Signalized intersections typically include providing lanes for turning vehicles and may include providing exclusive green arrows at signals for turning vehicles. Many of the intersections along US 64, including the intersection of US 64 and Mackenan Drive/Chalon Drive (shown at right) would be categorized as traditional intersections.

The benefits of the traditional intersection are that it provides for direct access for all directions of travel and provide for pedestrians crossing the roadways. The fundamental liabilities for traditional intersections are that they are limited in the volume of traffic that can pass through them in a given time period. At traditional intersections the amount of green time is proportioned based on the traffic volumes for each movement. As volumes increase the green time is forced to be divided among more movements, for example, as the volume of left turn vehicles increases, eventually an exclusive green turn arrow is added to the signal for the left-turn traffic. By adding this additional movement it takes time away from another movement. As more movements are added as exclusive movements the signal becomes more inefficient as it requires time to transition from one movement to another movement.

Eventually the amount of traffic that can be processed by a given intersection is exceeded and the signal begins to fail. When a conventional intersection is no longer able to process the volume approaching the intersection the typical method of improvements is to add additional turn lanes and/or additional through lanes. As stated above, this method of expansion can be cost prohibitive, include impacts to the natural and human environments and provide diminishing returns because the larger footprint requires increased time for vehicles and pedestrians to travel through the intersection.



Source: FHWA Signalized Intersections: Informational Guide

Additionally, the safety of traditional intersections is problematic due to the large number of conflict points. The diagram, shown at left, displays the conflict point for a traditional intersection, with each conflict point representing a location for a potential crash. A traditional intersection includes 32 conflict points.

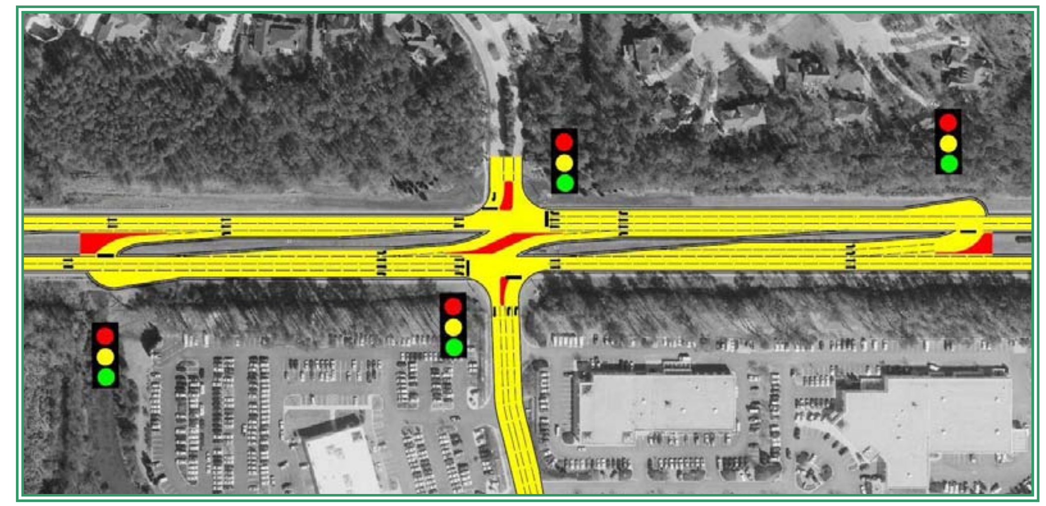
The primary method for improving upon the traditional intersection is to reduce the number of conflict points at the intersection. This provides safety and traffic operations benefits by reducing the number of movements who share the green time and by reducing the number of conflicting volumes at a single location. The goal of many of the unconventional intersections types is to spread out the movements into more than one location to allow for fewer conflict points and more green time for each of the movements. The signalized intersection concepts discussed in the following sections have emerged as the preferred method for improving the safety and efficiency of a corridor without greatly increasing the footprint of the intersections along the corridor.

Superstreet

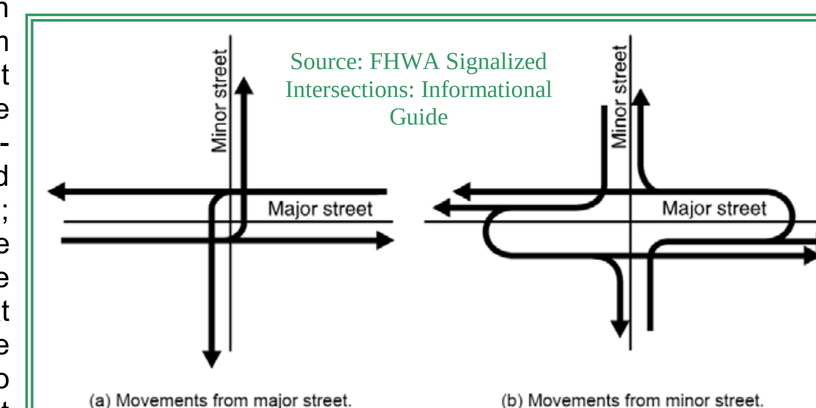
The Superstreet concept refers to a reconfiguration of a traditional intersection by redirecting some or all of the left turn movements away from the main intersection. The left turn movements are re-routed to median U-turn locations approximately 600 feet downstream. There are two primary applications of Superstreets and a third related application that is often considered to be part of the Superstreet concept. The two primary applications are the Superstreet with Direct Major Street Left-turns and the Superstreet with Indirect Major Street Left-turns. The third related type is a Superstreet with Direct Minor Street Left-turns. Each of the three types will be described in detail in the following sections.

Superstreet with Direct Major Street Left-turns

The application of the Superstreet with Direct Major Street Left-turns is the most common in urban locations and is the standard application unless there is an overwhelming factor that would result in considering one of the other Superstreet configurations. The Superstreet with Direct Major Street Left-turns requires the through and left turning vehicles from the minor street approach to turn right, proceed to the downstream U-turn and then return in the opposite direction. The movements from the major street are unaffected as the main intersection still allows for all movements from the major street. The illustration below shows the Superstreet with direct major street left-turns.

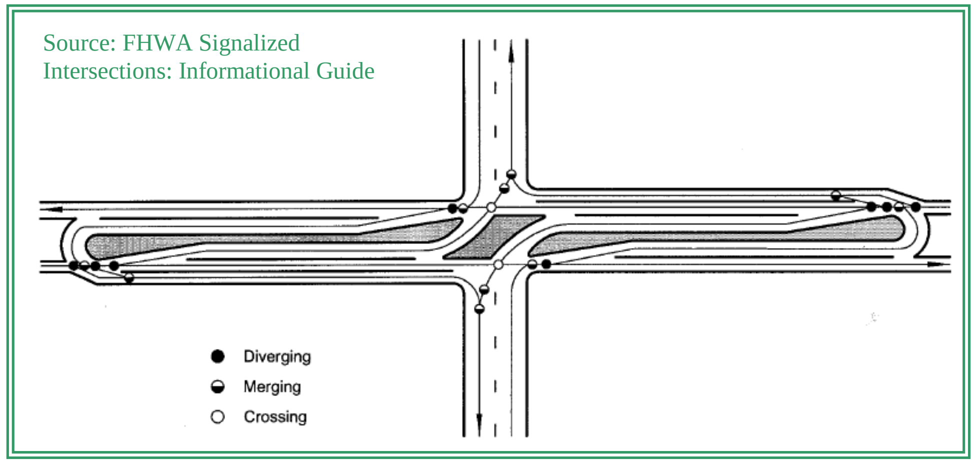


The primary benefit of this configuration is that redirecting the through and left turn movements to the median U-turn location reduces the number of conflicting movements that need separate signal phases at the main intersection to only two. The two signal phases would first give a green light to the major street through traffic, followed by the second phase which would give the green light to the left turns from the major street at the same time as the right turns from the minor street, because the movements do not conflict. The two median U-turn locations would also be signalized and would operate similarly with only two phases; the first again being the through traffic and the second allowing the U-turn movement. The reduction in the number of movements that occur at each intersection allows the intersection to operate more efficiently and to give more of the green time (typically about 70% of the total cycle length) to the heavy through movements. An additional benefit of the Superstreet concept is that because no traffic is crossing the median from the minor street, each direction of the major street can operate independent of the other direction allowing the signals to be coordinated to progress as though each direction were a one-way street. Due to this increased ability to coordinate the signals along the corridor, it is likely that as long as the motorist follows the



Source: FHWA Signalized Intersections: Informational Guide

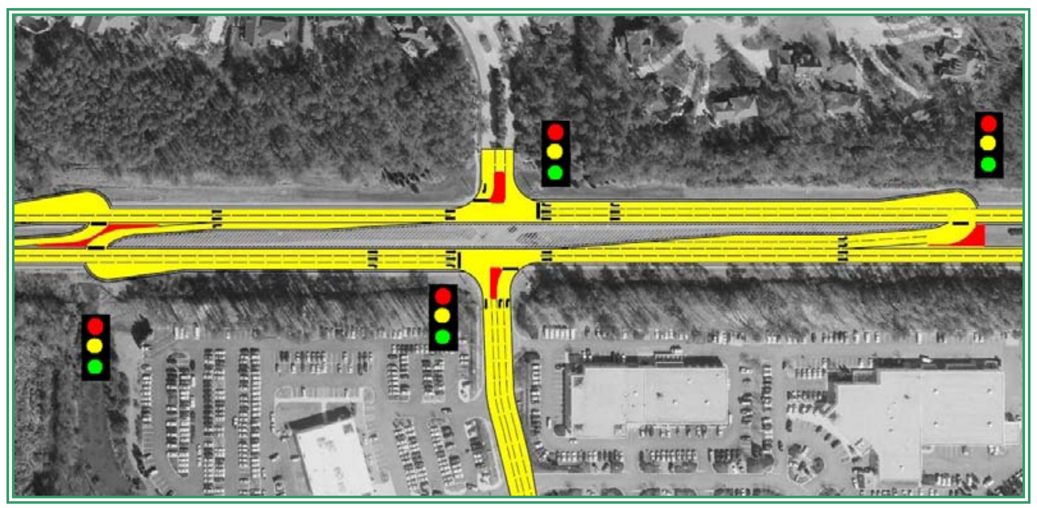
speed limit, they will only need to stop once along the length of the Superstreet corridor. A comparison of the safety of the Superstreet configuration to a conventional intersection shows that the number of conflict points is reduced from 32 to 20 with the most dangerous crossing maneuvers reduced from 16 to 2 as shown in the following illustration.



The Superstreet does have a potential liability for pedestrians because it utilizes a two-stage diagonal crossing that also requires some pedestrians to first cross the minor street before crossing the major roadway. The pedestrian crossing maneuvers occur at the same time as the major street traffic is turning left and the minor street traffic is turning right, thus allowing for pedestrians to cross without a conflicting traffic movements as typically occurs at traditional intersections.

<u>Superstreet with Indirect Major Street Left-turns</u>

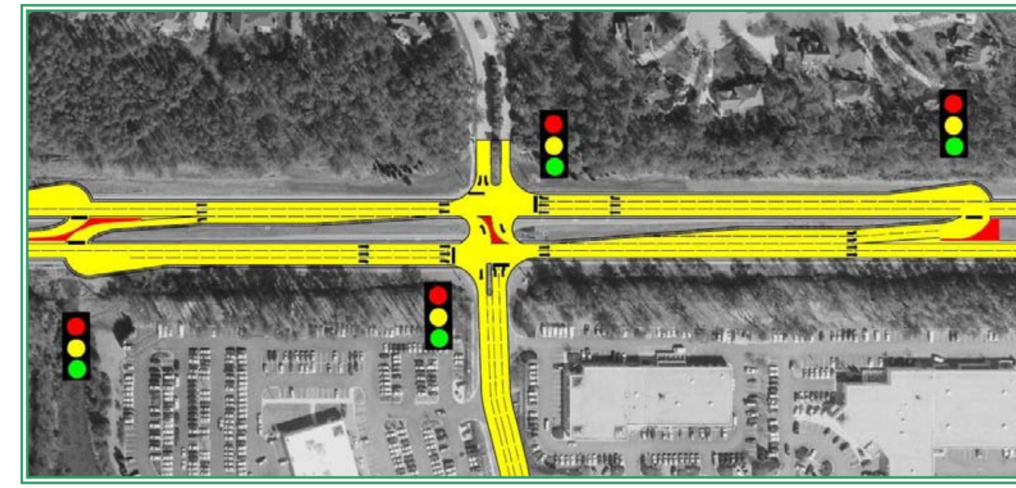
The Superstreet with indirect major street left-turns is very similar to the configuration with the direct major street left-turns with the exception that the left-turn movements from the major street are redirected to the downstream U-turn location as shown in the following illustration.



The benefits of this configuration over the previous configuration are that it provides for a more aesthetic environment, provides additional refuge for pedestrians and further reduces the number of conflict points to 12 including the elimination of all crossing conflicts. The redirection of the major street left-turn movement can result in additional stress on the u-turn signals and have the potential to reduce the efficiency of the traffic operations slightly.

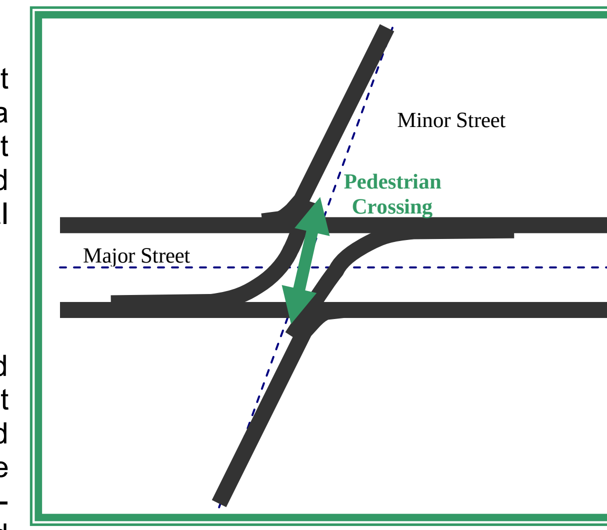
<u>Superstreet with Direct Minor Street Left-turns</u>

The third variation of the Superstreet concept is the Superstreet with Direct Minor Street Left-turns, which allows left-turns from the minor street directly onto the major street roadway. The left turns from the major street roadway to the minor street are directed to a downstream u-turn location, identical to the movement in the Superstreet with Indirect Major Street Left-turns. The minor street through movements are accommodated in the same manner is with all of the other Superstreet concepts requiring vehicles to turn right and make a u-turn at a downstream location. The Superstreet with Direct Minor Street Left-turns is shown in the following illustration.



The benefits of this configuration over the other Superstreet concepts are that it can accommodate high left-turn volumes from a minor street which may overwhelm the U-turn signal. The liabilities associated with this configuration are that it does not allow for both sides of the major street to operate independently due to the left-turn movements requiring the major street traffic signals be combined as a single signal. There are also concerns with how pedestrians would navigate this configuration as the crossing pattern is a two-stage crossing that has more conflicts with turning traffic due to the left-turn movements and would likely require a longer wait time in the median to make the second stage of the crossing.

<u>Superstreet Concept at Skewed Intersections</u>



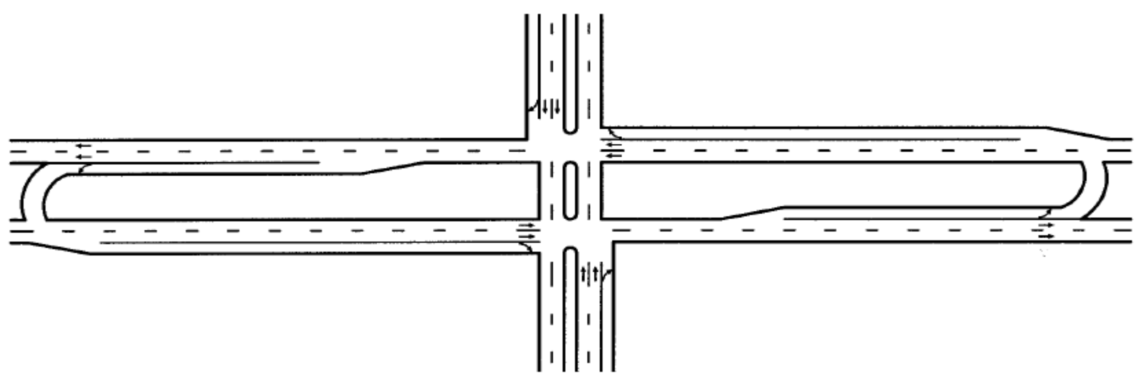
The Superstreet with Direct Major Street Left-turns concept can be modified slightly at skewed intersections to allow for a nearly perpendicular pedestrian crossing of the major street roadway. This configuration creates a larger central island increasing the pedestrian refuge and allowing for additional safety for pedestrians waiting in the median.

<u>Summary of Superstreet Concept</u>

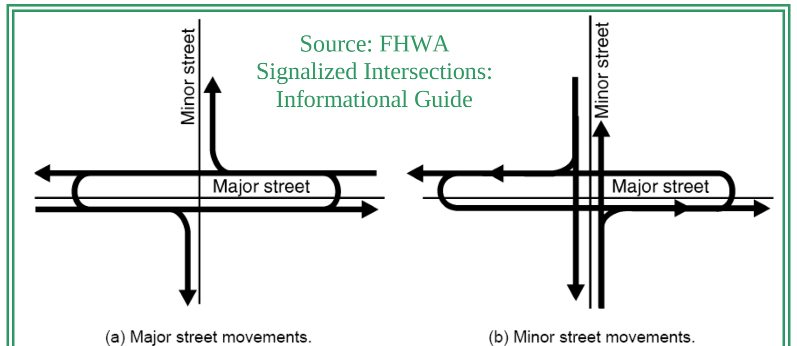
The Superstreet concept provides for substantially improved traffic operations by reducing the number of movements that occur at a single location and by allowing for improved coordination along the facility. The Superstreet does generate several concerns related to safety for pedestrians with a two-stage crossing, concerns with navigation for bicyclists and access to adjacent properties. The Superstreet concept also has several concerns related to bicyclists crossing the intersection, where the bicyclist is forced to avoid the intersection, act as a pedestrian or act as a vehicle. There is not a significant issue if a bicyclist acts as a pedestrian; however if they act as a vehicle there are concerns with safety for bicyclists as they must travel a longer distance and mix with weaving vehicular traffic. The potential benefits and liabilities for the Superstreet are shown in Table 1 at the end of this section.

Median U-turn Crossover

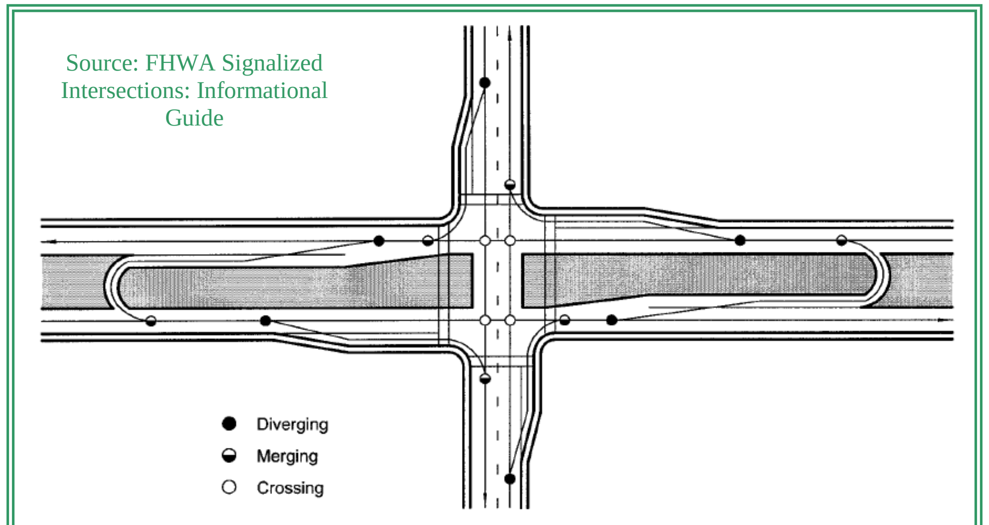
The Median U-turn Crossover is another unconventional intersection type that improves traffic operations by reducing the number of movements that occur at a single intersection. The Median U-turn Crossover is also commonly referred to as the Michigan U-turn due to the widespread use of this intersection type throughout the state. The Median U-turn Crossover concept eliminates all left-turn movements at the main intersection and moves them to median crossovers beyond the intersection. To turn left from the major street the driver crosses through the main intersection, makes a U-turn at the median crossover, returning in the opposite direction, turning right onto the minor street. To turn left from the minor street onto the major street, the movement would be the same as with the Superstreet, where the driver would turn right onto the major street and make a U-turn at the median crossover and continue back through the main intersection. The difference between the Median U-turn Crossover and the Superstreet is that the Median U-turn Crossover allows through traffic from the minor street to pass through the main intersection instead of turning right and using the median U-turn as is required for the Superstreet. The illustration below shows the Median U-turn Crossover.


Source: FHWA Signalized Intersections: Informational Guide

The median U-turns could also be placed on the minor street and would operate with the same traffic pattern or the median U-turns could be placed on both the minor street and the major street to further improve efficiency. The Median U-turn Crossover requires a wide median with a recommended width of 60 feet; otherwise additional pavement should be added to the outside travel lane to safely complete the U-turn maneuver. The ability to coordinate the signals along a corridor is less efficient than with a superstreet because the signals along the corridor must be coordinated in both directions. To improve the efficiency of the signal coordination the Median U-turn Crossover concept is best for corridors with uniform block widths, such as the grid pattern that makes the systems in Michigan very efficient. The Median U-turn Crossover is most suitable for locations that have relatively high major street and minor street through volumes and relatively low left-turn volumes.



Source: FHWA Signalized Intersections: Informational Guide



Source: FHWA Signalized Intersections: Informational Guide

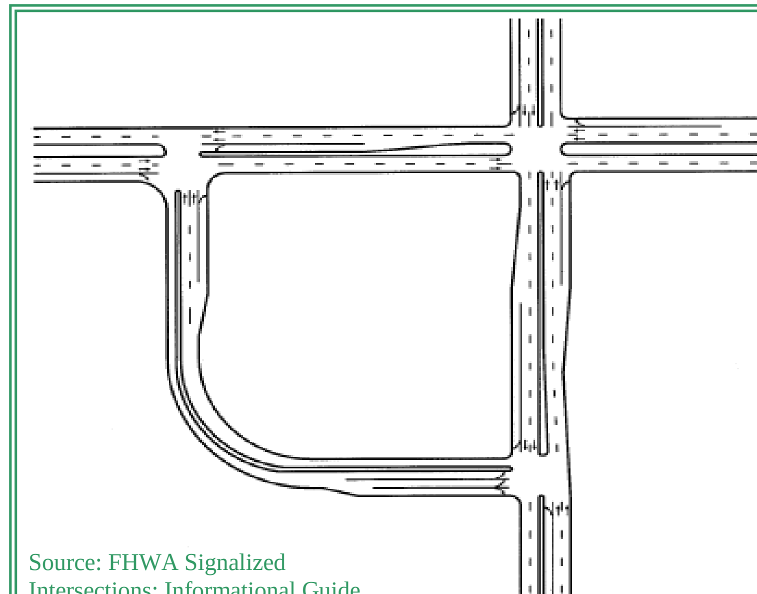
The safety of the Median U-turn Crossover has been evaluated extensively due to the widespread use in Michigan and based on a research study it was determined that the crash rate for facilities with median u-turns was 49 to52 percent less than for roadways with traditional intersection configurations along corridors with more than one signal per mile. A comparison of the number of conflict points for a Median U-turn Crossover, shown at left, and a traditional intersection show that the number of conflict points is reduced from 32 to 16 with the Median U-turn Crossover with all 12 of the left-turn crossing maneuvers are eliminated.

The Median U-turn Crossover allows for traditional pedestrian crossings at the main intersection and due to the elimination of the left-turn movements reduces the number of conflicts to pedestrians. The increased median widths required for the Median U-turn results in longer crossing distances for pedestrians and increased delay to vehicular traffic due to long pedestrian crossing time for the signal. Due to this additional length some locations require the use of a two-stage crossing for pedestrians. The Median U-turn Crossover provides for bicycle movements more efficiently than a Superstreet intersection; however for unsignalized Median U-turns the turning paths for u-turn vehicles should be evaluated to ensure that they do not encroach on bike lanes.

<u>Summary of Median U-turn Crossover Concept</u>

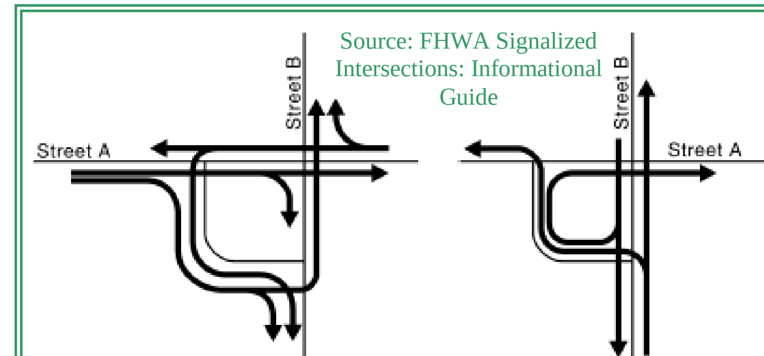
The Median U-turn Crossover concept provides for substantially improved traffic operations by reducing the number of movements that occur at a single location and by allowing for improved coordination along the facility. The Median U-turn Crossover does generate some concerns related to enforcement and education to prevent illegal left turns at the main intersection. There is also the potential for impacts to the access for parcels with direct driveway access to the major street because the access may need to be restricted within the influence area of the median U-turn locations. The potential benefits and liabilities for the Median U-turn Crossover are shown in Table 1 at the end of this section.

Quadrant Roadway


Source: FHWA Signalized Intersections: Informational Guide

The Quadrant Roadway concept includes providing an additional roadway between two legs of the intersection that accommodates the left-turn movement traffic. Drivers who wish to turn left from either the major street or minor street will be required to drive further, but the efficiency of the main intersection is greatly improved by eliminating the left-turn movements. The Quadrant Roadway creates two additional intersections, approximately 500 feet from the main intersection, to accommodate the left-turn traffic. The illustration at left shows the Quadrant Roadway configuration.

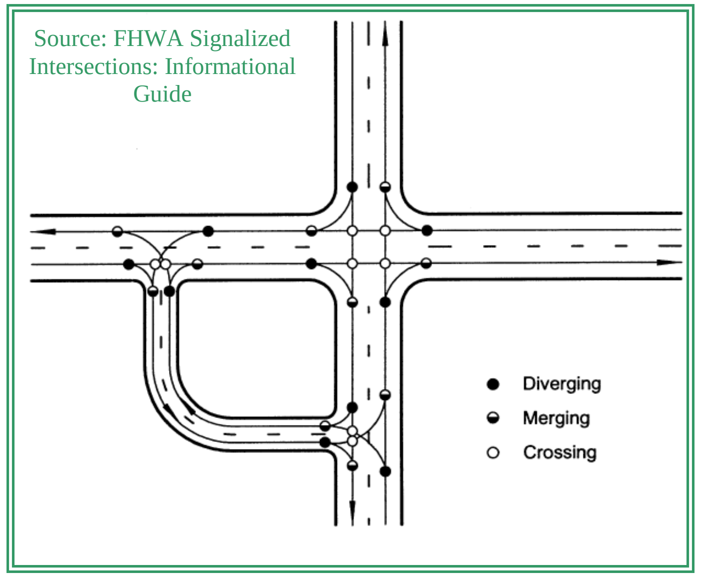
The Quadrant Roadway concept is most applicable for locations that have both high through volumes and high left turn volumes. The concept is also a very good option when the quadrant roadway and intersections already exist as part of the existing development pattern. By eliminating the left-turn movements at the main intersection more green time can be given to the through traffic. The two offset intersections also operate efficiently because they create three-leg intersections. The three leg-intersections are efficient because they allow time for each of the movements; the through movements, the left turn movements to the quadrant roadway and



Source: FHWA Signalized Intersections: Informational Guide

the left turn movements from the quadrant roadway to the major street. The three-leg configuration only includes one of the through movements making it more efficient from a traffic operations standpoint.

The Quadrant Roadway is also an effective way to set up an intersection that will eventually be upgraded to an interchange or become a grade separation as it provides for movements that are similar to a ramp and loop at an interchange. For this reason, Quadrant Roadways are often referred to as Square Loop intersections. The Quadrant Roadway concept allows for traditional pedestrian crossings at the main intersection and due to the elimination of the left-turn movements reduces the number of conflicts to pedestrians. The elimination of left-turn lanes also decreases the median width resulting in shorter crossing distances for pedestrians and reduced delay to vehicular traffic due to the shorter pedestrian crossing time for the signal. The pedestrian, however would have to make an additional crossing due to the new intersection included by creating the Quadrant Roadway segment.



Source: FHWA Signalized Intersections: Informational Guide

A comparison of the safety of the Quadrant Roadway concept to conventional intersections shows that the number of conflict points is reduced from 32 to 28 with the number of merging/diverging conflicts increasing from 16 to 20 and the number of crossing conflicts being reduced from 16 to 8. The results of the safety evaluation show that the Quadrant Roadway offers the potential for a minor increase in rear-end collisions and a major decrease in left-turn collisions. The illustration at left shows the conflict point diagram for the Quadrant Roadway concept.

Summary of Quadrant Roadway Concept

The Quadrant Roadway concept provides for substantially improved traffic operations by reducing the number of movements that occur at a single location. The Quadrant Roadway does generate some concerns related to enforcement and education to prevent illegal left turns at the main intersection. There is also the potential for impacts to access to parcels with direct driveway access to the major street because the access may need to be restricted within the influence area of the Quadrant roadway locations. The potential benefits and liabilities for the Quadrant Roadway are shown in Table 1 at the end of this section.

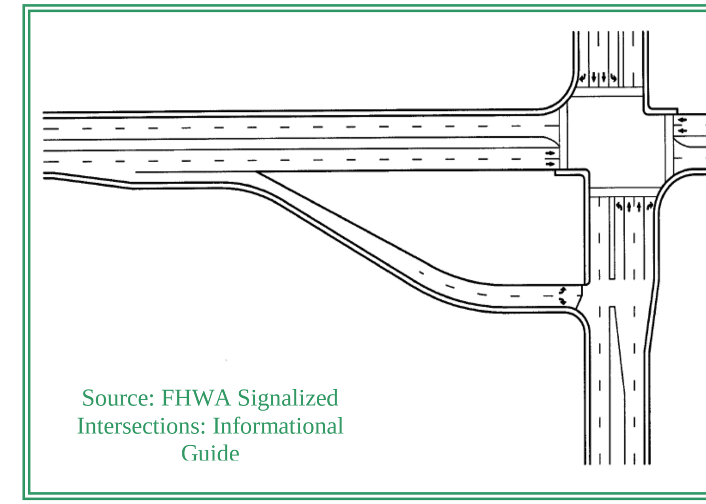
Quadrant Roadway with Grade Separation

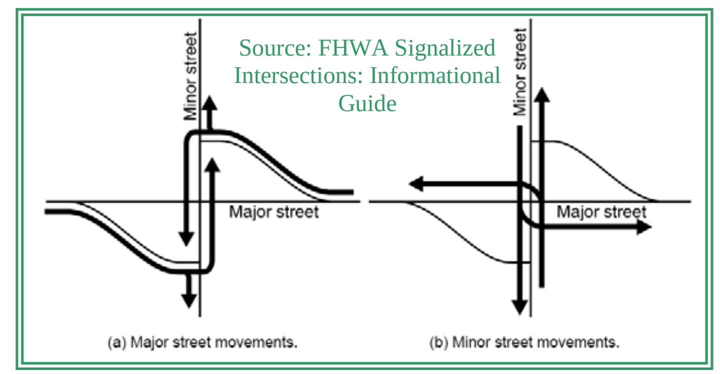
The Quadrant Roadway with grade separation is a variation on the Quadrant Roadway discussed above. The Quadrant Roadway with Grade Separation adds an overpass at the main intersection improving the operations of the intersection substantially. This configuration can also be developed with Quadrant Roadways in two quadrants and is known as a Quadrant Interchange (discussed in Expressway Concepts section) that eliminate the left-turn movements at one of the roadway and make the intersection operate similar to a scaled down interchange. An example of a single quadrant (left turns allowed on both roadways) is shown at right.

The safety of the Quadrant Roadway with grade separation further improves safety by removing an additional 12 conflict points, reducing the total number of conflict points to 16 as compared to the 32 for a traditional intersection. The safety for pedestrians is greatly improved with the grade separated crossing as it allows for free movement through the intersection due to the overpass structure. One potential liability of the Quadrant Roadway with Grade Separation is that it may require the acquisition of additional property to allow for the increased elevation of the overpass and may restrict access near the overpass due to the grades on the roadway. Additionally, construction of the overpass at existing intersections may require substantial detour routes or relocation of the roadway in order to keep the existing roadways operational during construction. The potential benefits and liabilities for the Quadrant Roadway with Grade Separations are shown in Table 1 at the end of this section.

Jughandle

The Jughandle is an unconventional intersection concept that redirects left-turn movements from the major street by creating a one-way ramp that connects to the minor street to allow left-turn movements. The Jughandle concept includes placing the ramps in two quadrants of the intersection in advance of the intersection in each direction. All major street turns – left, right and U-turns are made from the right side of the roadway. Drivers wishing to turn left exit the major roadway at the ramp on the right side and then turn left at the minor street and continue straight through the intersection along the minor street. The illustration at right shows the Jughandle concept.

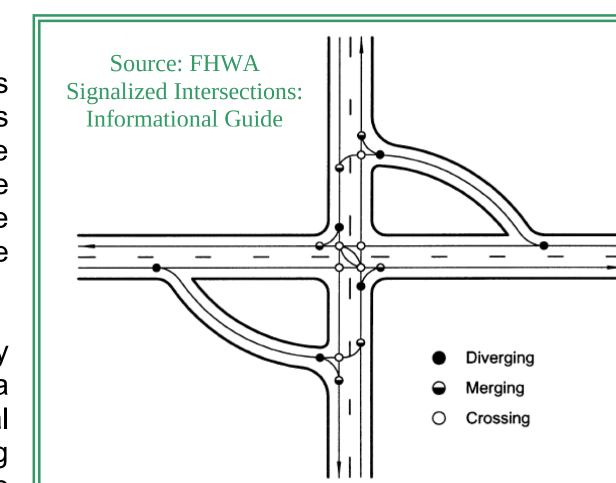

Source: FHWA Signalized Intersections: Informational Guide



Source: FHWA Signalized Intersections: Informational Guide

The Jughandle concept is most appropriate for intersections with high major street through movements, low-to-medium major street left-turn movements, low-to-medium minor street left-turn movements and any amount of minor street through volumes. The Jughandle is also a very effective solution at intersections with narrow medians that cannot accommodate a left-turn lane or cannot accommodate large vehicles making u-turns. The signing of the intersection is vital to the Jughandle concept as it is not intuitive to exit to the right to turn left and requires adequate advanced notice to the driver. The Jughandle concept increases the exposure of pedestrians to traffic due to the additional intersections required, however the pedestrian crossing at the main intersection is narrower due to the lack of left and right turn lanes.

The safety of the Jughandle concept is demonstrated by reducing the number of conflict points in comparison to a traditional intersection from 32 to 26 which offers the potential for a substantial decrease in left-turn collisions. The following illustration shows the conflict diagram for the Jughandle



Source: FHWA Signalized Intersections: Informational Guide

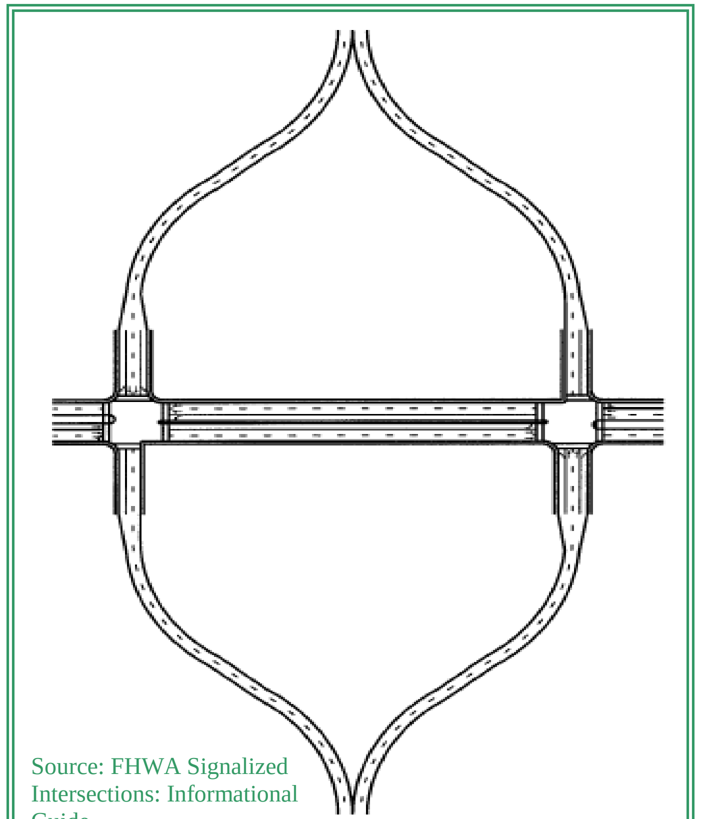
concept.

Summary of Jughandle Concept

The Jughandle concept provides for improved traffic operations by redirecting the left turns away from the main intersection, allowing more green time to be allotted to the major street through traffic. The Jughandle does have some potential liabilities due to the increased footprint to accommodate the ramps and the potential for conflicts between bicyclists and vehicles at the exit point to the ramps. There is also the potential that the location of the Jughandle ramps may require additional control of access along the minor street which may have an impact on access to adjacent properties. The potential benefits and liabilities for the Jughandle are shown in Table 1 at the end of this section.

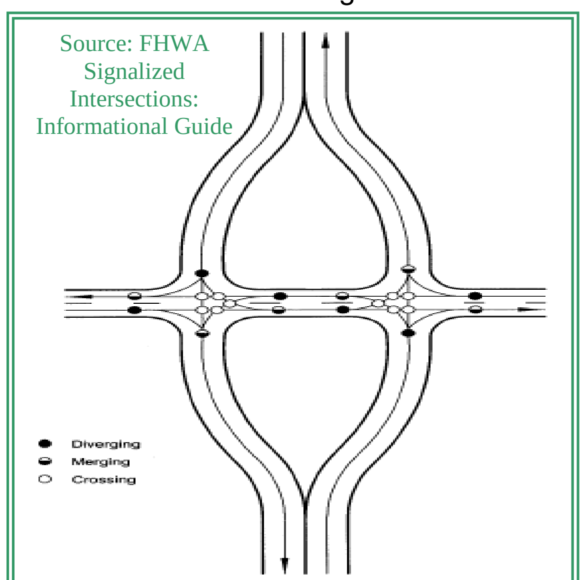
Split Intersections

The Split Intersection concept essentially creates an at-grade diamond interchange between two roadways. The Split Intersection requires that the major street roadway split into two one-way streets as it approaches the minor street. This configuration creates two intersections where the each intersection serves fewer movements than a single traditional intersection. Each of the intersections would have separate allotments of green time for the major street through, left and right traffic, the minor street left turn traffic and the minor street through traffic, resulting in improved traffic operations. The illustration to the right shows the Split Intersection concept.



Source: FHWA Signalized Intersections: Informational Guide

The Split Intersection concept is most applicable where a future interchange is likely to be constructed but either cannot yet be justified or is too expensive to construct. The benefit of the Split Intersection is that there would not need to be any additional property acquired to construct the diamond interchange in the future. This concept is best used for new roadways being planned or for those that are being retrofitted with an increased level of control of access, such as converting an arterial with signals to an expressway or freeway. The split intersection reduces the pedestrian crossing distance substantially, but because the intersections have the look and feel of an interchange, pedestrians may find them intimidating and drivers may be less aware of pedestrians' presence.



Source: FHWA Signalized Intersections: Informational Guide

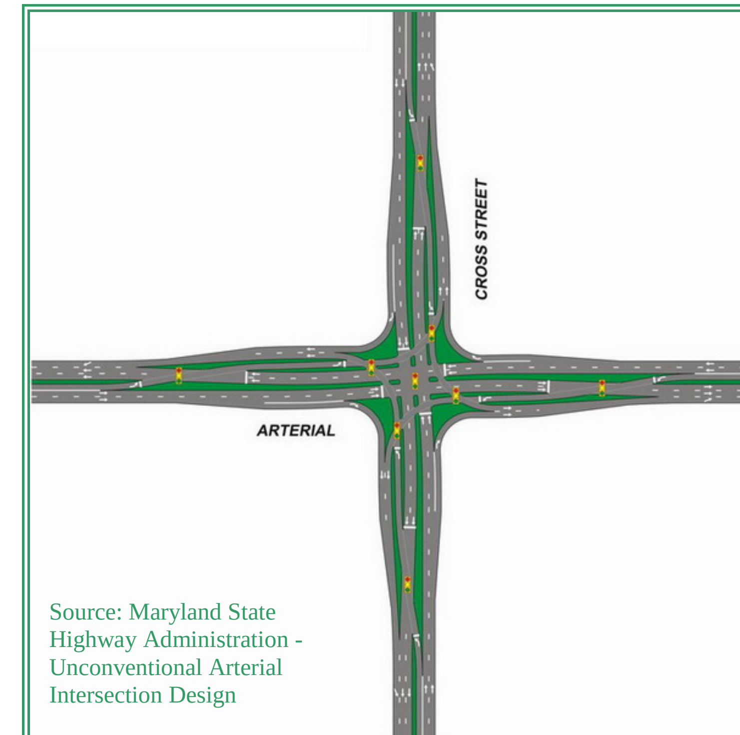
A comparison of the number of conflict points between a Split Intersection and a traditional intersection configuration shows that the number of conflicts is reduced from 32 to 22 with the potential for a significant decrease in left-turn collisions. The illustration at left shows the conflict diagram for the Split Intersection concept.

Summary of Split Intersection Concept

The Split Intersection concept provides for improved traffic operations by splitting out the movements that occur at a traditional intersection into two separate intersections. The concept allows for a substantial increase in the amount of green time that can be allotted to the major street through traffic. The concepts main liabilities are that it requires additional land to construct initially and tends to have a higher initial construction cost as compared to other unconventional intersection configurations. The potential benefits and liabilities for the Split Intersection are shown in Table 1 at the end of this section.

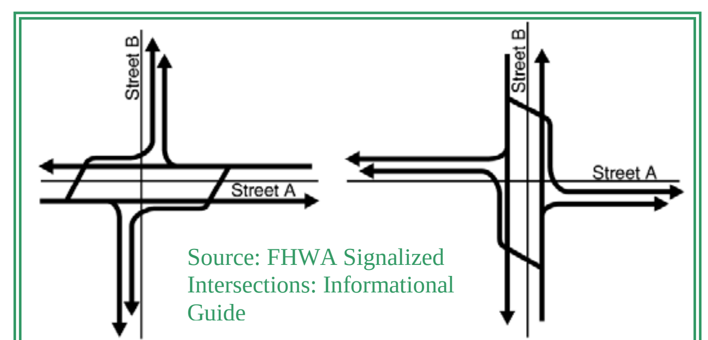
Continuous Flow Intersection

The Continuous Flow Intersections concept is another unconventional intersection concept whose goal is to reduce the number of conflicting movements at the main intersection in order to allow for more green time for the major street through traffic. The Continuous Flow Intersection removes the conflict between left-turning vehicles and through traffic in the opposite direction by crossing the left-turn traffic to the left side of the roadway. The crossing from the right side to the left side is accomplished at a midblock signalized intersection for each approach that will include the continuous flow lanes. Note that this section describes an at-grade concept; a grade-separated version of the Continuous Flow Intersection was patented, but the patent expired in 2003.



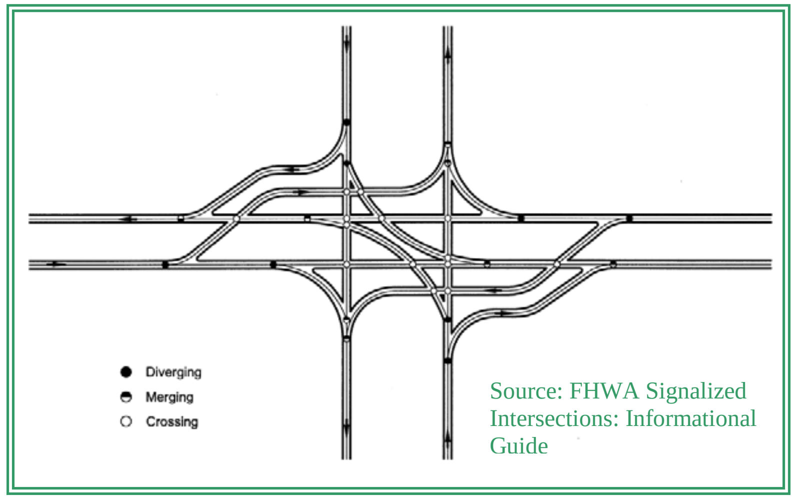
Source: Maryland State Highway Administration - Unconventional Arterial Intersection Design

The Continuous Flow Intersection Concept is most appropriate with high through and left-turn volumes and minimal u-turn volumes as the configuration restricts these movements. The left-turning vehicles are likely to experience more delay at this type of intersection; however the through traffic operations are substantially improved. The Continuous Flow Intersection concept is extremely flexible and can be implemented from only a single leg to all four legs of the intersection depending on the traffic volumes.



Source: FHWA Signalized Intersections: Informational Guide

The Continuous Flow Intersection does present some challenges for pedestrians although the concept does provide a substantial benefit to pedestrians because all crossings are completed when there is not conflicting turning vehicles. The pedestrian crossing for this concept requires a two-stage crossing and the layout and operation may not be readily apparent to pedestrians, especially visually impaired pedestrians. Due to the unconventional traffic flow the audible clues that visually impaired pedestrians utilize are disrupted and consideration should be given for specially designed pedestrian signals at Continuous Flow Intersections.



Source: FHWA Signalized Intersections: Informational Guide

The safety of the Continuous Flow Intersection as compared with a traditional intersection configuration results in the total number of conflict points being reduced from 32 to 30 (shown at left) with the potential for a major reduction in left-turn collisions and the potential for a major increase in angle collisions. The education required for drivers at Continuous Flow Intersections is a concern although limited studies have found that drivers quickly adjust to the configuration and after an initial break-in period there is little driver confusion. The maintenance of this concept is also a potential concern for snow removal and safety in the event of power outages to the signalized intersections.

<u>Summary of Continuous Flow Intersection</u>

The Continuous Flow Intersection concept provides for improved traffic operations by splitting out the left-turn movements in advance of the intersection to eliminate the conflicting movements at the main intersection. The concept allows for a substantial increase in the amount of green time that can be allotted to the major street through traffic. The concepts main liabilities are that it requires a larger footprint than traditional intersections; however it is more compact than a typical interchange. There are also concerns with access to adjacent properties due to the requirement for greater access control in the vicinity of the midblock crossing signals. The potential benefits and liabilities for the Continuous Flow Intersection are shown in Table 1 at the end of this section.

Summary of Signalized Intersection Concepts

A summary of the concepts discussed above is shown in Table 1 on the following page. Each of the nine unconventional signalized intersection concepts are compared relative to the Traditional Intersection Treatment for the following attributes:

- Safety (evaluates the vehicular safety of the intersection by comparing the number of conflicts points (potential crash locations) for the concept with the number of conflict points for a traditional intersections)
- Traffic Operations (evaluates the traffic operations of the concept based on overall intersection travel time)
- Bicyclist and Pedestrian (evaluates the ability of the concept to provide for safe and efficient mobility for bicyclist and pedestrians)
- Footprint (evaluates each concept based on the amount of land required to construct the concept)
- Access (evaluates each concept on its ability to provide for efficient access to adjacent parcels and roadways as compared to a traditional intersection)
- Education and Enforcement (evaluates each concepts ability to understood by the driver and the ability to enforce the traffic pattern included in the concept)

The table provides a description of the potential benefits and potential liabilities for each concept as well as a qualitative rating for how well it addresses each individual attribute.

The qualitative rating system includes the following measures:

★★★★★ - Favorable
★★★★ - Slightly Favorable
★★★ - Average
★★ - Slightly Unfavorable
★ - Unfavorable

It should also be noted that these qualitative evaluations are for each individual attribute and that the weight of each of the attributes is not equal. Different individuals are likely to prioritize certain attributes higher than other individuals would. For example a business owner may prioritize access to their business with much greater weight, while an avid cyclist may prioritize multi-modal considerations. The challenge in evaluating the concepts and developing a solution is that a balanced approach must be taken as no one concept is superior for all attributes. When applied to the US 64 Corridor it is important that the individual context for each location be considered when evaluating the potential options.

Table 1: Signalized Intersection Concepts Summary

Concept Type		Safety	Travel Operations	Bicycle/Pedestrian	Footprint	Access	Education and Enforcement
Traditional Intersection Treatments		★	★	★★★	★★	★★★★★	★★★★★
		32 Conflict Points	Inefficient operation due to many movements being required at a single location	Standard crossing pattern for pedestrians and bicyclists; however some conflicts with vehicles	Larger footprint to accommodate turn lanes and inefficient operation requires more lanes	Provides full access to all movement	Standard configuration, well understood by drivers, pedestrians and bicyclists
Superstreet with Direct Major Street Left-turns		★★★★	★★★★★	★★	★★★	★★★★	★★★
	Potential Benefits	20 Conflict Points	Less delay for major street movements	No conflicting vehicle movements	May reduce need for adding additional lanes	Provides same access as traditional intersection for major street traffic	None
	Potential Liabilities	None	Longer travel distance and slightly longer time for minor street movements	2-stage diagonal crossing and concerns with bicycle crossing	Needs wider median or u-turn bulb-outs	Redirects side street through and left-turns to u-turn location	Potential for driver, pedestrian and bicyclist confusion
Superstreet with Indirect Major Street Left-turns		★★★★★	★★★★	★★★	★★★★	★★★	★★★
	Potential Benefits	12 Conflict Points	Less delay for major street through movements	No conflicting vehicle movements and increase refuge in median	May reduce need for adding additional lanes, more aesthetic	Provides same access for major street through and right movements	None
	Potential Liabilities	None	Longer travel distance and time for minor street and major street left turns	2-stage diagonal crossing and concerns with bicycle crossing	Needs wider median or u-turn bulb-outs	Redirects major street left and side street through and left-turns	Potential for driver, pedestrian and bicyclist confusion
Superstreet with Direct Minor Street Left-turns		★★★★	★★★	★	★★★	★★★	★★★
	Potential Benefits	20 Conflict Points	Less delay for major street through movements	None	May reduce need for adding additional lanes	Provides for major through and right movements and minor street left-turns	None
	Potential Liabilities	None	Longer delay for minor street through and right turn movements	2-stage crossing with extended wait time and bicycle concerns	Needs wider median or u-turn bulb-outs	Redirects major street left-turns and minor street through movements	Potential for driver, pedestrian and bicyclist confusion
Median U-turn Crossover		★★★★	★★★	★★★	★★★	★★★	★★
	Potential Benefits	16 Conflict Points	Less delay for major street through movements	Standard crossing for pedestrians and bicyclists with fewer vehicle conflicts	May reduce need for adding additional lanes	Provides same access for major and minor street through movements	None
	Potential Liabilities	None	Longer travel distance and time for minor street and major street left turns	2-stage crossing is typical	Needs wider median or u-turn bulb-outs	Redirects all left-turn movements to u-turn location	Potential for illegal left-turns & driver and bicyclist confusion
Quadrant Roadways		★★	★★★	★★★	★★	★★★	★★
	Potential Benefits	28 Conflict Points – Potential major decrease in left-turn collisions	Potential reduction in delay and queuing	Decreases crossing distance at main intersection by removing left turns	Benefit if roadway already exists	None	None
	Potential Liabilities	Potential minor increase in rear-end collisions	Potential for longer travel distance for turning movements	Number of intersections to cross increases	May require additional land and have high construction cost	May reduce access to quadrant roadway and redirects some turns	Potential for illegal left-turns & driver, and bicyclist confusion
Quadrant Roadways with Grade Separation		★★★★	★★★★★	★★★★★	★	★★	★★★★
	Potential Benefits	16 Conflict Points	Reduction in delay and queuing	Removes pedestrian conflicts at main intersection	None	None	None
	Potential Liabilities		Potential for longer travel distance for turning movements	None	Requires additional land and high construction cost, aesthetic concerns	Redirects more turn movements to quadrant roadway, reduces some access	Minor potential for driver, pedestrian and bicyclist confusion
Jughandle		★★	★★	★★	★	★★★	★★
	Potential Benefits	26 Conflict Points	Reduction in overall intersection travel time	Decreases crossing distance at main intersection by removing left turns	None	None	None
	Potential Liabilities	None	Longer travel time for left-turns using Jughandle	Increased number of intersections and concerns with exit to Jughandle conflicting with bicycle lanes	Requires additional land and may have high construction cost	May reduce access to near Jughandle and redirects some turns	Potential for illegal left-turns and requires good advanced signing
Split Intersections		★★★	★★	★★★	★	★★★★★	★★★★★
	Potential Benefits	22 Conflict Points	Improves traffic flow for through movements	Shorter crossing distance	Can be step toward interchange at future interchange locations	Provides for all movements	None
	Potential Liabilities	Potential for wrong-way movements	May have problems with queuing depending on spacing distance	May not be perceived as being pedestrian friendly	High initial land and construction costs	Larger footprint may require some access restrictions	None
Continuous Flow Intersection		★★	★★★	★	★	★★★★	★★
	Potential Benefits	30 Conflict Points	Improves traffic flow for through movements	No vehicle conflicts during pedestrian crossing	None	Provides for all movements	None
	Potential Liabilities		More delay for left-turn movements	2-stage crossing and concerns with visually impaired pedestrians	Requires additional land and higher construction cost, aesthetic concerns	Larger footprint requires additional access restrictions	Potential for driver, pedestrian and bicyclist confusion

★★★★★ - Favorable ★★★★ - Slightly Favorable ★★★ - Average ★★ - Slightly Unfavorable ★ - Unfavorable SEE DESCRIPTIONS ON PAGE 7 FOR ADDITIONAL DETAILS

Expressway Concepts

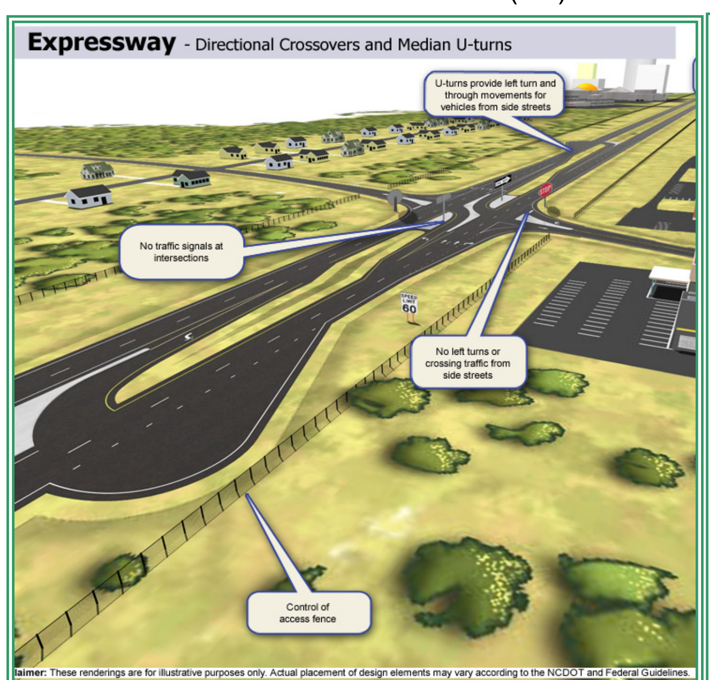
The range of solutions for upgrading an existing signalized intersection facility to an expressway is accomplished through removing the signalized intersections and improving the connections to the existing minor streets. The expressway concepts are generally separated into two categories; urban concepts and rural concepts.

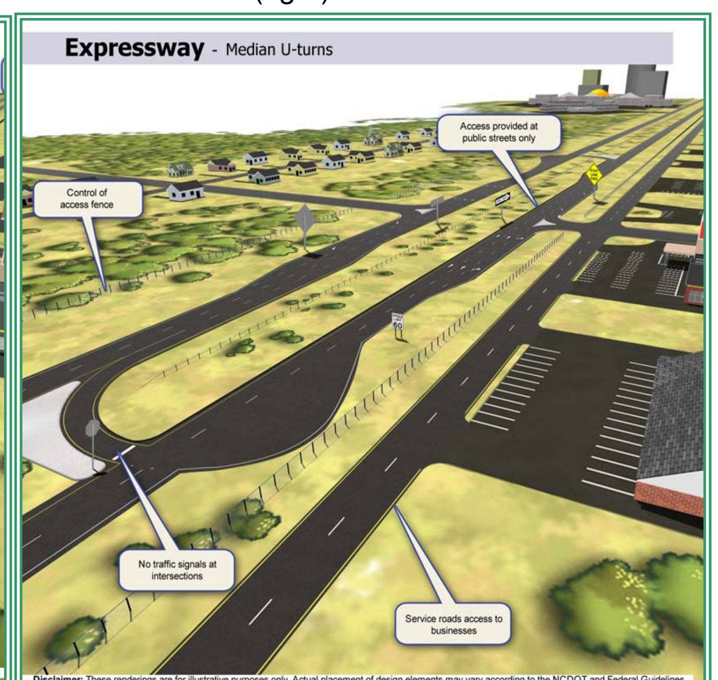
Rural Expressway Concepts

The rural concepts are typically converting the major intersections into at-grade unsignalized intersections that allow only right-turn movements to and from the minor street and limited left-turn and U-turn movements at unsignalized locations along the major street. The at-grade intersections include providing adequate acceleration and deceleration lengths to safely transition cars to and from expressway speeds. Rural expressway concepts are typically applicable for divided facilities with projected major street daily traffic volumes less than 25,000 vehicles per day and projected minor street daily volumes less than 2,500 vehicles per day.

Right-in/Right-out with Median U-turns

The preferred method of providing an expressway facility in a rural area is to utilize a configuration that converts minor street intersections to allow only right-turn movements to and from the minor street, which is typically referred to as a “right-in/right-out” configuration. Traffic from the minor street wishing to go straight or left would first turn right onto the major street and then enter a u-turn lane at a location approximately 800 feet downstream where they could make a u-turn in the opposite direction and either turn right into the minor street (completing the through movement) or continue straight through (completing the left turn movement). The left turn traffic is typically handled with either a left turn at the minor street intersection or by traveling beyond the intersection and making a u-turn to travel back to the minor street. The determination of whether or not a direct left turn will be provided is based on the projected volume of traffic on the minor street. This configuration is essentially an unsignalized version of the Superstreet configuration described in the signalized intersection concepts section. The illustrations below show the Right-in/Right-out with Median U-turns concept both with the direct left turns at the minor street (left) and with the median u-turns (right).





Urban Expressway Concepts

The urban expressway concepts typically rely on developing grade-separated (overpass) crossings for major side streets and allowing unsignalized connections to minor side streets as long as adequate acceleration and deceleration lengths can be achieved to safely transition cars to and from expressway speeds. The ability to allow unsignalized left-turn and u-turn movements along the major street, as is typical for the rural concepts, is not possible as the major street traffic volume exceeds 25,000 vehicle per day, thus meaning that the access to an from major roadways will require grade separation. In its simplest form, the only way to allow vehicles to cross the median of the major street for volumes greater than 25,000 vehicles per day is with a signalized intersection or with a grade separated crossing. Because expressway facilities do not allow signals, the only means of providing full access is through grade separating the minor street and major street from each other. The following sections detail the concepts that are typically used for expressway facilities in urban areas.

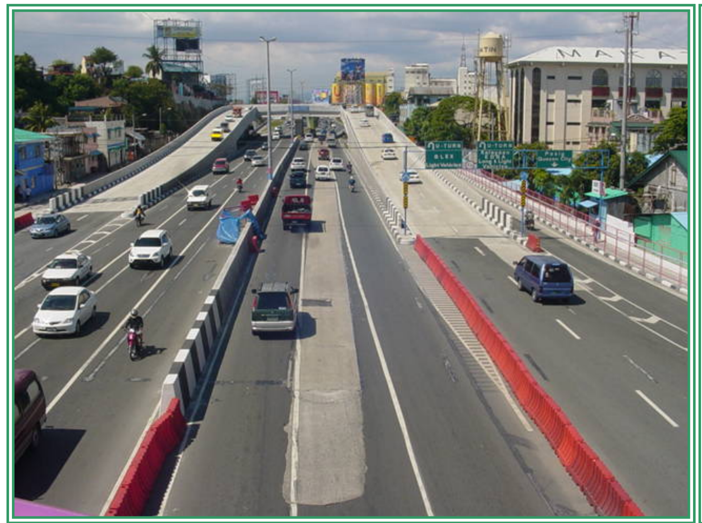
Quadrant Interchange

The quadrant interchange is very similar to the Quadrant Roadway with Grade Separations described under the signalized intersection concepts section. The Quadrant Interchanges is commonly referred to as a “Square Loop Interchange” as it emulates the functions of a loop and ramp in an interchange in a more compact form. The Quadrant Interchange includes an overpass at the main roadway intersection and quadrant roadways in two quadrants of the intersection. This configuration eliminates the left-turn movements to and from the major street roadway and makes the intersection operate similar to a scaled down interchange. The configuration can also be used with quadrant ramps in all four quadrants, thus eliminating all of the left-turn movements on both the major street and minor street. The elimination of the left-turn movements from the major street allows it to operate without any signalized intersections in accordance with the expressway definition. The following images show examples of Quadrant Interchanges.

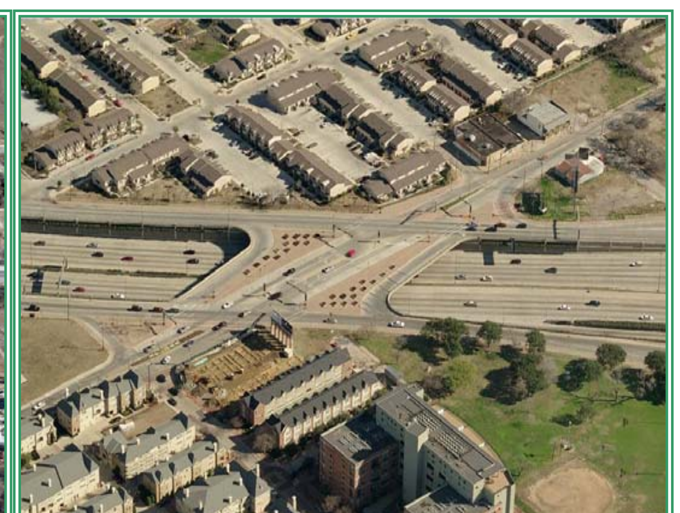
Depending on the traffic volumes on the quadrant roadways, the land inside of the quadrants can be developed with limited access to the quadrant roadways. The major street connections should be designed with adequate acceleration and deceleration lengths to safely transition cars to and from expressway speeds. The length of the quadrant roadways is typically based on the greater of the distance required to connect the grade separated roadways or to accommodate the traffic queued at the signalized intersection on the minor street.

Grade Separated U-turns

The Grade Separated U-turns is a concept that is used along an expressway corridor in conjunction with right-in/right-out intersections to collect all of the traffic that desires to cross the major street as a minor street through or left-turn and have it exit to the right onto a grade separated U-turn bridge. The concept has been utilized in several locations outside of the United States and is typically only used in highly urbanized areas where the cost of acquiring additional property is cost restrictive. The following images show the Grade Separated U-turn concept.



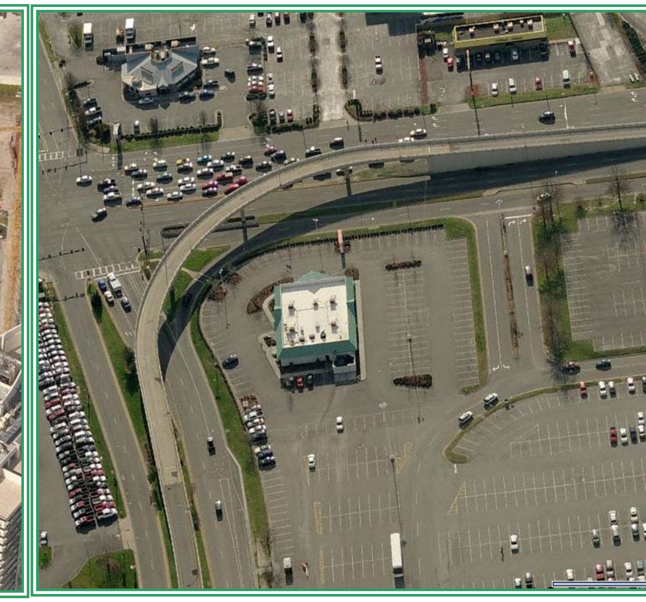
The more common application of the Grade Separated U-turn concept in the United States is in Texas where they are used extensively along with frontage roads that run parallel to the major street roadway. Access to and from local roadways is provided onto the one-way parallel frontage roads and vehicles that wish to turn left follow the frontage road to a location where u-turn movements are allowed either on a bridge over the major street or with the major street passing over the u-turn roadway. The following images show the Grade Separated U-turn concept with parallel frontage roads.



The primary concerns with the Grade Separated U-turn concept is that it takes additional land to construct the frontage roads and the aesthetics related to the grade separation are a concern in the vicinity of residential areas.

Grade Separated Median Left-turn

The Grade Separated Median Left-turn is an expressway concept that allows for left turns from the major street roadway to minor streets by means of a grade separated bridge over the opposing direction of traffic. The use of the elevated bridge eliminates the conflict between the left turning traffic from the major street roadway and the traffic traveling along the major street roadway in the opposite direction. The following images show the Grade Separated Median Left-turn concept.



The primary concerns with the Grade Separated Median Left Turn concept are similar to the Median U-turn concept with the aesthetics and noise impacts related to the grade separation are a concern in the vicinity of residential areas. Additionally, the tighter design for the turning traffic can create the potential for truck rollovers on the ramp

Parallel Frontage Road with Slip Ramps

The most common strategy for urban expressways is to utilize a system of parallel frontage roads that separate local traffic from through traffic. The parallel frontage roads connect to and from the major street through traffic lanes at appropriate locations with slip ramps that enter and exit on the right side of the major street roadway. The parallel frontage road concept is beneficial because it allows for signalized intersections on the frontage road at minor streets that provide access to adjacent property as well as uninterrupted travel along the major street through lanes. With the Parallel Frontage Road concept there are two ways to treat the minor street access points; either as three-leg intersections without major street cross access or as four-leg intersections that include a grade separated crossing of the major street through traffic. The grade separated cross streets can also be utilized for vehicles who wish to make left turns where a minor street intersects the frontage road at a three-leg intersection. To accommodate the left-turn movement, the driver would make a right turn onto the frontage road and travel to the next four-leg intersection with a grade separation, turn left onto the crossing roadway and then left again onto the frontage road traveling in the opposite direction. The driver would then merge onto the expressway at a slip ramp entrance. The locations of slip ramps are placed such that they can provide an adequate level of access to and from the frontage roadways without overloading the major street through lanes or the frontage roads. The location of the parallel frontage roads in relation to the major street through travel lanes is dependent on the constraints along the corridor. The frontage roads could be separated by barriers or retaining walls where there is little available land along the corridor or could be separated from the major street traffic even as far outward as one block away from the major street through traffic with access to property along both sides of the frontage road. The following image shows the Parallel

Frontage Road with Slip Ramps concept along the Durham Freeway.

The primary concern with the Parallel Frontage Road with Slip Ramps is the size of the footprint required to accommodate the frontage roads and slip ramps. Additionally, due to the need to grade separate the minor streets the major street through lanes are often constructed as overpasses or bridge structures over the existing minor streets which generate concerns due to noise and the aesthetics in residential areas.

Reduced Form Interchanges

The urban expressway often functions similarly to a freeway system due to the need to grade separate the crossing movements to and from minor streets. Because of this, the practice of utilizing freeway interchanges that are modified to be more compact is a common strategy for urban expressway corridors. The design speed of the urban expressway facility is typically less that that of an urban freeway and the expectation from drivers is such that it is acceptable to have lower speed connections to the expressway major street. The interchange types for freeways are discussed in Section 3.2.3 and these configurations can be modified slightly to allow for a more compact footprint that better fits into the context of an urban expressway corridor. The primary changes to the configurations are to allow for lower speed ramps and loops that have adequate acceleration and deceleration lengths to safely transition cars to and from expressway speeds. The typical design speed for ramps exiting and entering an expressway with a design speed of 55 miles per hour would be 30 miles per hour as opposed to 50 miles per hour for a typical freeway. The design speed for loops is typically reduced from 30 miles per hour to 20 miles per hour which results in a much smaller radius for the loop. In addition to standard ramps and loops, any flyover ramps could be constructed with reduced design speeds of 20-30 miles per hour as opposed to 50-60 miles per hour for a freeway facility thus substantially reducing the size of the ramp. The design of any reduced form interchange should be evaluated to determine that the design will operate safely and that it does not violate driver expectations.

FREEWAY CONCEPTS

The range of solutions for upgrading an existing signalized intersection facility to a freeway is accomplished through removing the signalized intersections and either removing the minor street connections or upgrading the connections to interchanges. This section presents the different configurations for freeway interchanges. Freeway interchanges are typically broken into two classifications; service interchanges and system interchanges, with the major distinction being the type of facility that intersects the freeway. A service interchange is an interchange between a freeway and a minor street that is not another freeway or expressway and includes unsignalized or signalized intersections along the minor street. A system interchange is an interchange between two controlled access facilities such as freeways and expressways. System interchanges are typically very complex, have numerous potential solutions based on the traffic volumes and in general are unique solutions to the given area. For this reason, this section focuses only on service interchanges. To protect the traffic operations and safety of the interchange, NCDOT policy calls for a minimum length of 1000 feet along the minor street from the location where the ramp or loop ties to the minor street have controlled access with no roadways or driveways allowed in this area. Therefore any service road needed to maintain access along the freeway once it is upgraded must tie in at a location that is a minimum of 1000 feet from the ramp intersection.

Simple Diamond Interchange

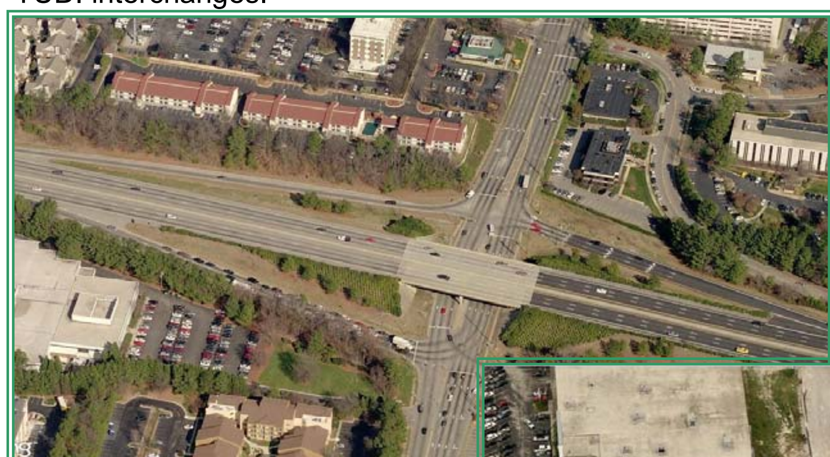
The Simple Diamond interchange is the standard configuration for NCDOT in rural areas. The configuration includes a single ramp in each of the four quadrants with the intersections along the minor street placed 800-1000 feet apart. The configuration allows for the interchange to be upgraded to include internal loops, if traffic volumes increase in the future, without having to reconstruct the interchange or purchase additional property. This interchange configuration provides low-to-medium traffic capacity, has a low construction cost and requires a medium-to-high amount of land to construct. The following images show examples of Simple Diamond interchanges.

Compressed Diamond Interchange

The Compressed Diamond interchange configuration is a variation of the Simple Diamond interchange and is characterized by reducing the distance between where the ramps to the minor street from greater than 800 feet to range of 400-800 feet. This configuration does allow for the addition of future loop ramps and is best in rural areas where future traffic volumes are not likely to increase, such as in locations in sensitive watersheds or with natural features that limit future growth. This interchange configuration provides low-to-medium traffic capacity, has a low construction cost and requires a medium amount of land to construct. The following images show examples of Compressed Diamond interchanges.

Tight Urban Diamond Interchange

The Tight Urban Diamond Interchange (TUDI) is a further variation of the Simple and Compressed Diamond configurations that is typically only used in urban areas where there is substantial constraints on the property immediately adjacent to the intersection. The TUDI further reduces the distance between the ramp intersections to less than 400 feet, which typically requires that retaining walls be constructed between the ramps and the freeway. This interchange configuration provides medium-to-high traffic capacity, has a high construction cost and requires a low amount of land to construct. The following images show examples of TUDI interchanges.



Single Point Urban Interchange

The Single Point Urban Interchange (SPUI) is a variation of a TUDI that includes a single signal that controls all of the traffic at the interchange. The signal is located in the center of the intersection and controls three sets of movements. The first set of movements are the through movements along the minor street, the second set is for the left turn movements from the ramps to the minor street and the third set of movements is for the left turns from the minor street to the ramps. The turning movements at a SPUI pass through a single intersection, similar to a traditional intersection, therefore the turning movements overlap each other and can occur at the same time. The turning movements either occur on a butterfly shaped bridge above the freeway or below the freeway overpass. The right turn movements are usually controlled by yield signs with acceleration lanes where the ramp intersects the minor street, although some SPUI's include signals for the right turn traffic, which is detrimental to the overall traffic operations of the interchange. One of the main concerns with SPUI's is that the traffic signal does not include any protected movements where pedestrians can cross perpendicular to the minor street because the traffic flow is continuously flowing. This interchange configuration provides medium-to-high traffic capacity, has a high construction cost and requires a low amount of land to construct. The following images show examples of SPUI interchanges.

Partial Cloverleaf Interchange

The Partial Cloverleaf Interchange is an interchange configuration that includes adding at least one loop a diamond interchange design. The partial cloverleaf interchange has several forms including configurations that place a pair of loop/ramp combinations in opposite quadrants of the interchange or on the same side of the minor street, which is common when there is a constraint such a river or railroad on one side of the minor street. A Partial Cloverleaf Interchange can either use a loop in place of a ramp or in addition to a ramp allowing for less conflict on the minor street by eliminating some of the left turn movements. In general the traffic operations of a Partial Clover Interchange improve as additional loops are added without the removal of the ramps, thus providing for additional flexibility to accommodate future traffic demand. To

preserve the traffic operations of a Partial Cloverleaf Interchange it is important that the design not include surface streets that connect opposite the location where the ramp and loop connect to the minor street as this configuration has a substantial negative effect on the traffic operations of the signal. This interchange configuration provides medium-to-high traffic capacity, has a medium construction cost and requires a medium amount of land to construct. The following images show examples of Partial Cloverleaf Interchanges.

Full Cloverleaf Interchange

The Full Cloverleaf Interchange is a further expansion of the Partial Cloverleaf configuration where a total of four ramps and four loops are included in the design, accommodating movements in all directions without making any left turns. The Full Cloverleaf Interchange can be very efficient and is sometimes used for freeway-to-freeway connections for lower volume freeways. The major downside to the Full Cloverleaf is that it includes a total of four weaving movements between each of the loops which can result in traffic safety and operation inefficiency. To improve the safety and operations of Full Cloverleaf interchanges a parallel roadway, called a Collector-Distributor (C-D) can be constructed that exits from the freeway in advance of the interchange, connects to all of the interchange ramps and loops, including the weaving section, and then merges back into the freeway. The C-D roadway redirects the turning movements and weaving movements away from the higher speed through traffic on the freeway, improving the safety and traffic operations of both facilities. This interchange configuration provides medium traffic capacity, has a medium construction cost and requires a high amount of land to construct. The following images show examples of Full Cloverleaf Interchanges.

Split Diamond Interchange

The Split Diamond Interchange concept builds off of the traditional diamond configurations; however instead of having ramps tie to a single minor street the Split Diamond has a pair of ramps to one minor street and a second pair of ramps on a parallel minor street with a pair of one-way roadways connecting the minor streets between the ramps. This configuration is beneficial where there are multiple major roadways crossing a freeway that are too close to each other to each have an interchange. The Split Diamond allows for access to these multiple minor street crossings and improves the overall traffic operations in the area by spreading out the traffic onto multiple minor streets instead of just one. This interchange configuration provides medium-to-high traffic capacity, has a medium construction cost and requires a medium amount of land to construct. The images at right show examples of Split Diamond Interchanges.

Roundabout Interchange

The Roundabout interchange concept has been used for many years and recently has re-emerged in several revised forms as interchange concepts that are both highly functional for traffic flow and aesthetic.

<u>Rotary Roundabout Interchange</u>

The traditional use of Roundabouts for interchanges included having a single large roundabout where the ramps tie to the minor street, typically with the freeway crossing over the roundabout. This configuration was commonly referred to as a Rotary Interchange and was found most often in Massachusetts and throughout New England. The primary concerns with the Rotary Interchange were that they required a very large footprint and extensive bridging along the freeway while only providing a low level of traffic operations due to the constraint on traffic capacity of the single-lane roundabouts. For these reasons the Rotary Interchange is typically not used in urban areas, with very few having been built in the past several decades, and many of the original interchanges being replaced by

more common forms of interchanges such as diamonds and partial cloverleaf interchanges.

Modern Roundabout Interchange

The new form of Roundabout interchanges that have become exceeding popular in the past decade utilize a pair of smaller radius roundabouts at each point where the ramp intersects the minor street. The pair of roundabouts allow for good traffic operation and allow the minor street crossing of the freeway to occur on a single bridge. The bridge crossing of the freeway is typically narrower than for a traditional diamond interchange because the Roundabout Interchanges do not include left turn lanes. For this reason, the Roundabout Interchange has been a popular low-cost retrofit for diamond interchanges that have narrow two-lane bridges over the freeway, because they can vastly improve the traffic operations without reconstructing the bridge over the freeway. For higher volume right turn movements bypass lanes can be constructed such that the traffic does not enter the roundabouts, thus increasing the traffic capacity of the configuration.

Recently a more compressed form of Roundabout Interchange has emerged that combines the best features of the Rotary Interchange with the best features of the Modern Roundabout Interchange to form an extremely compact interchange design. The design is currently being implemented for the first time in Carmel, Indiana along Keystone Avenue. The concept is essentially to create a TUDI interchange with a single roundabout that has been compressed into a figure-eight configuration. The interchange concept allows for excellent traffic operations and in some locations includes a dual lane roundabout and right-turn bypass lanes resulting in traffic operations that are comparable to many diamond interchange configurations. The primary benefit of the concept is that they are much more aesthetic and pedestrian friendly than traditional interchanges and in the Carmel application resulted in substantially fewer property relocations. The Carmel application also lowered the major street through lanes below grade to minimize the effects of noise and to improve the aesthetics along the corridor.

Summary of Freeway Concepts

A summary of the freeway concepts discussed above is shown in Table 2 on the following page. Each of the nine freeway concepts are compared for the following attributes:

- Traffic Operations (evaluates the traffic operations of the concept based on overall interchange travel time)
- Bicyclist and Pedestrian (evaluates the ability of the concept to provide for safe and efficient mobility for bicyclist and pedestrians)
- Footprint (evaluates each concept based on the amount of land required to construct the concept)
- Construction Cost (evaluates each concept based on the likely cost to construct the concept)

The table provides a description of the potential benefits and potential liabilities for each concept as well as a qualitative rating for how well it addresses each individual attribute. The qualitative rating system includes the following measures:

★★★★★ - Favorable
★★★★ - Slightly Favorable
★★★ - Average
★★ - Slightly Unfavorable
★ - Unfavorable

It should also be noted that these qualitative evaluations are for each individual attribute and that the weight of each of the attributes is not equal. Different individuals are likely to prioritize certain attributes higher than other individuals would. For example a property owner who walks to the grocery store may prioritize multi-modal with much greater weight, while a commuter may prioritize traffic operations. The challenge in evaluating the concepts and developing a solution is that a balanced approach must be taken as no one concept is superior for all attributes. When applied to the US 64 Corridor it is important that the individual context for each location be considered when evaluating the potential options.

Table 2: Freeway Concepts Summary

Interchange Type		Traffic Operations	Multi-modal	Property Required	Construction Cost
Simple Diamond		★★	★★★★★	★	★★★★
	Potential Benefits	Can be expanded with loops to improve traffic operations in the future	All pedestrian crossings can be made without conflicting with vehicles	None	Due to spread out configuration may allow for narrower bridges
	Potential Liabilities	Bridges may not be setup to accommodate future expansion	None	Requires a very large area of land	None
Compressed Diamond		★★	★★★★★	★★	★★★★
	Potential Benefits	None	All pedestrian crossings can be made without conflicting with vehicles	None	None
	Potential Liabilities	Cannot be expanded by adding loops and bridges may not accommodate future turn lanes	None	Requires a large area of land	None
Tight Urban Diamond		★★★★	★★★★★	★★★★★	★
	Potential Benefits	Traffic signals can be coordinated to allow traffic to flow more freely	All pedestrian crossings can be made without conflicting with vehicles	Can reduce impacts in areas where land process are very high or where constraints exist	None
	Potential Liabilities	Requires additional lanes outside of interchange to hold left turn traffic	None	None	Tight configuration requires wider bridges and retaining walls
Single Point Diamond		★★★★	★★	★★★★★	★
	Potential Benefits	Reduces the conflict between left turning traffic by overlapping movements	None	Can reduce impacts in areas where land process are very high or where constraints exist	None
	Potential Liabilities	If ramp traffic requires signal for right turn traffic operations can be affected	Crossing minor street cannot be done without stopping all traffic. Free flow turns may conflict with pedestrians and bicyclists	None	Tight configuration requires larger or longer bridges and retaining walls
Partial Cloverleaf		★★★★	★★★	★★★	★★★
	Potential Benefits	Adding additional loops and ramps can greatly improve traffic operations	Potential that pedestrian crossings can be made without conflicting with vehicles if loops aren't free flowing	Can convert ramps to loops and eliminate property acquisition in some quadrants of the interchange	None
	Potential Liabilities	Adding minor street intersection opposite ramp connections can greatly reduce traffic capacity	Conflicts with pedestrians and bicyclists can occur if free flowing loops are included in the design	Adding additional ramps and loops will increase the property needed	None
Full Cloverleaf		★★★	★	★	★★★★
	Potential Benefits	Eliminates all left turn movements	None	None	Due to spread out configuration may allow for narrower bridges
	Potential Liabilities	Creates four weaving sections between each set of loops that may negatively affect traffic operations	Problematic for pedestrians and bicyclists due to weaving section between loops and potential for free flowing ramps	High speed connections require larger radius ramps that increase the size of the interchange	Can be very costly if collector-distributor roadways are needed
Split Diamond		★★★★	★★★★★	★★	★★
	Potential Benefits	Allows for multiple high volume minor streets in close proximity to have access	All pedestrian crossings can be made without conflicting with vehicles	Provides improved access to more property	None
	Potential Liabilities	The overall traffic capacity of the interchange is reduced because the ramps include through traffic movements	None	Requires land to construct roadway between ramps connecting minor streets between ramps	Requires additional roadways and more bridges and can include retaining walls if there are constraints adjacent to the freeway
Roundabout - Rotary		★★	★★★★	★★	★★★
	Potential Benefits	None	Accommodates pedestrians well for low volume roundabouts with low speeds	None	None
	Potential Liabilities	The traffic operations are constrained by the roundabouts ability to handle the traffic volumes	Can increase pedestrian distance for larger radius roundabouts. Do not accommodate bicyclist as safely	Requires large footprint to accommodate larger radius roundabout	Larger radius roundabouts require either very long bridges along the freeway or multiple bridges for the roundabout
Roundabout - Modern		★★★	★★★	★★★★★	★
	Potential Benefits	Can include multilane roundabouts and bypass lanes for high right turn traffic	Accommodates pedestrians well for low volume roundabouts with low speeds	Can reduce impacts in areas where land process are very high or where constraints exist	None
	Potential Liabilities	May not be able to handle extremely high left turn volumes	Potential for conflicts with right turn bypass lanes and for visually impaired pedestrians. Do not accommodate bicyclist as safely	None	Tight configuration requires retaining walls and non standard bridge shapes

★★★★★ - Favorable ★★★★ - Slightly Favorable ★★★ - Average ★★ - Slightly Unfavorable ★ - Unfavorable

SEE DESCRIPTIONS ON PAGE 14 FOR ADDITIONAL DETAILS