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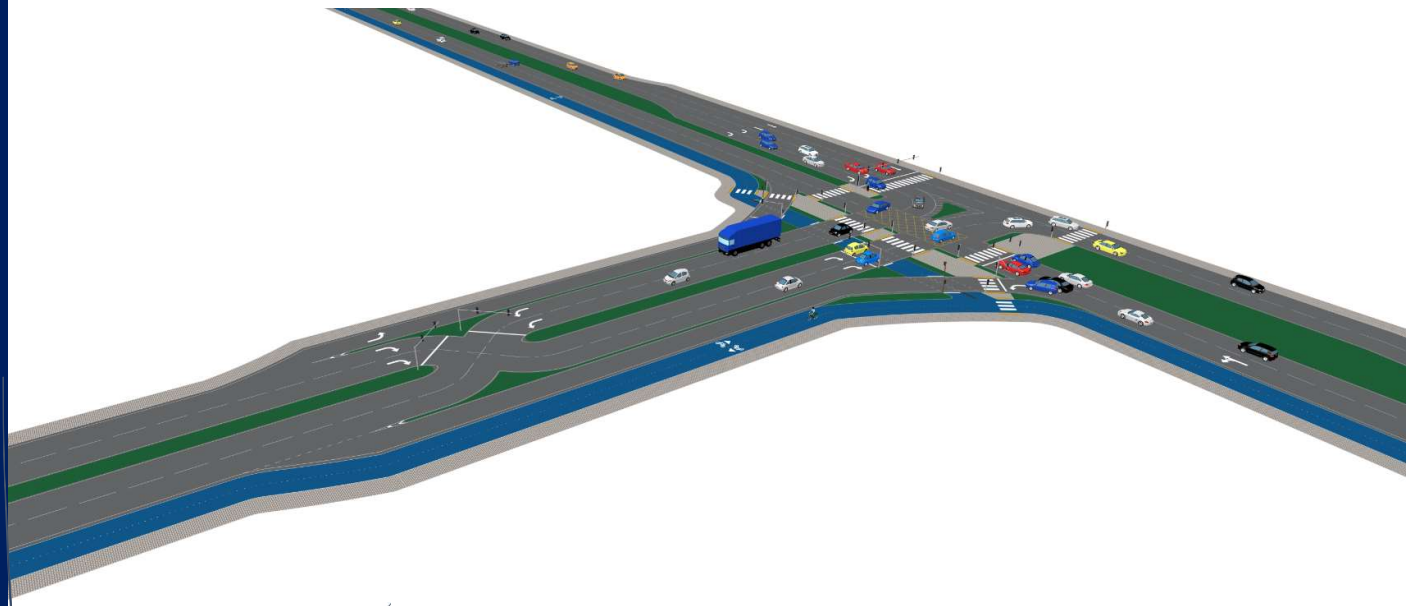
Future Transport Visions Group

Rees Jeffreys Road Fund



T Junction

The next junction on the road to net zero?

Acknowledgment

We would like to express our sincere gratitude to the Future Transport Vision Group and the Rees Jeffreys Road Fund for their generous support and funding of our project. Their contributions have been invaluable in helping us achieve our goals and we are deeply grateful for their assistance.

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Executive summary

From drivers and passengers to pedestrians and cyclists, no one enjoys waiting at traffic junctions. As well as being a frustrating experience, it can create wider adverse environmental and economic impacts and can contribute towards greater severance and social exclusion.

Taking inspiration from a range of alternative junction designs commonly used in the United States, there have only been a few tentative steps of introducing 'alternative design' junctions to resolve congestion problems at T junctions in the UK. Among these, two 'Displaced Right Turn' (DRT) T junctions have been built – one near Swindon in Wiltshire and one to the east of Torquay in Devon. Alternatively called a 'Continuous Flow Intersection' (CFI), they work on the principle of 'swapping over' the opposing streams of traffic on the minor road arm to enable unopposed right turns to be made at the main junction. This enables a simplification of the traffic signals staging, delivering improvements in capacity and reducing delays.

The re-focussing of transportation policy over the last 20 years towards a more sustainable 'decide and provide' approach offers an opportunity to revisit the DRT junction to establish whether a re-purposing of the concept can help in meeting some of the more holistic objectives of the modern transport agenda. And, by implication, whether the design should be adopted more widely across the UK and be regarded as another solution in the highway or traffic engineer's toolkit for improving the performance of T junctions across a wider, more inclusive range of metrics.

The 'XT junction' variant of the DRT developed by our team builds upon the core principles and aspirations of the engineers and designers of the original DRT junctions, in not only seeking to deliver capacity improvements and reductions in delays to general traffic, but also in lessening environmental impacts, better serving active travel modes, improving social outcomes, and conferring potential cost savings in comparison to some of the more expensive solutions currently available for congested T junction locations.

In undertaking this study, a range of hypothetical XT junction layouts varying in size and configuration have been developed and modelled. The results of the modelling exercise suggest that depending on the layout tested and the degree of active travel facilities provided, the adoption of an XT junction is likely to result in additional spare capacity in the range of 13% to 33% in comparison to an equivalent standard T junction. This spare capacity could either be used to directly benefit traffic capacity, congestion, and delays at the junction, or conversely, could be used to improve crossing time and clearance allowance for active travel modes – all without a detrimental effect on traffic and potentially at a lower cost than some of the more significant engineering solutions available. Probably the most significant benefit is the scope to reduce the operational carbon footprint, potentially by up to 35%.

The capacity savings inherent in the XT concept provides excellent opportunities for improving provision for active travel modes at three arm intersections. However, with only two known similar intersections in the UK, and each with limited active travel provision, additional work and/or testing and practical trials are required to definitively establish the safety credentials of the design. Nonetheless, the outcomes from this study suggest that the XT junction is likely to be highly effective in delivering a range of holistic improvements and improving social outcomes at congested T junctions, and (depending on uptake), could make a viable contribution towards meeting the objectives of the modern transport agenda and the UK target of net zero carbon emissions by 2050.

1 Introduction

Junction delays and congestion are issues that engineers have been trying to solve ever since the motor vehicle became the dominant mode of transport. A priority T-junction - where a minor road joins a major road and the dominant flow arms (usually the straight-ahead top part of the 'T') have priority, is the most common way of accommodating the intersection of two roads and is the most basic type of road traffic intersection. They tend to work well in low and medium volumes of traffic, but when levels increase beyond what a priority T junction can handle, alternative means of control or alternative infrastructure solutions must be considered.

For T junctions in busy areas, a particular factor impacting delays and congestion is the requirement for vehicles coming from, or to, the minor road to join the major road. Even at busy junctions, the scope for accommodating left-turning vehicles from the minor road without significant disruption to the main traffic flow is greater than that for accommodating right-turning vehicles, as the 'with-flow' nature of the left-turning movement can often be accommodated simply via priority 'give way' rules. However, right-turning movements at busy junctions often require the main traffic flow to stop for a given amount of time to let the right-turning traffic clear the junction safely. Of course, a deterioration in overall junction performance (in terms of vehicle delays) can be further compounded when, by necessity, active travel modes need to be accommodated. The result of this can be delays, long backups, congestion, negative environmental and health impacts, and increased severance of communities. And this is true for any three-arm junction, whether it be a roundabout, priority junction, or traffic light-controlled junction.

The starting point for improving any delays and congestion at traffic junctions is by firstly changing road markings or priority rules, and if that proves ineffective, optimising the traffic flows using traffic signals to apportion time more equitably between the arms. When none of these are successful, highway authorities often need to invest in significant physical upgrades to the junction. For example, building a flyover, bridge, grade-separated junction, multi-lane interchanges, etc. All these can help improve traffic flows, but they can be very costly, require a lot of space, take a long time to construct, and can be very harmful to the environment. Besides, in many cases, options are limited by cost, space constraints or environmental factors.

Several different alternative junction types have been invented to try and deal with rising traffic levels without resorting to more expensive infrastructure and civil works. The United States has been at the forefront of such innovations. The Diverging Diamond Interchange (DDI) is probably the most well-known of the established vehicle crossover-type junctions, in which the two directions of traffic on the minor road cross to the opposite side of the road for a short section before being transferred back to the correct sides of the carriageway either side of the junction. The arrangement permits access to the major road on and off-ramps under partial free-flow conditions and results in a reduced number of conflict points. The DDI has been shown to improve traffic flow and reduce congestion, as well as increasing safety by reducing the number of conflict points between vehicles. As of July 2022, it is estimated that more than 135 DDIs are operational worldwide.

The Displaced Right Turn (DRT) concept works on the principle of 'swapping over' the opposing streams of traffic on the minor road arm to enable unopposed right turns to be made at the main junction. This enables a simplification of the traffic signals staging, delivering improvements in capacity

and reducing delays. Alternatively called the Continuous Flow Interchange (CFI), the DRT is discussed in more detail in Chapter 2.1.

The re-focussing of transportation policy in the last 20 years towards a more sustainable 'decide and provide' approach, creates an opportunity to explore whether a re-purposed, and re-branded DRT junction, can make a viable contribution towards meeting the objectives of the modern transport agenda and UK target of net zero carbon emissions by 2050. Our research team have therefore developed the 'XT junction', a DRT variant which aims to not only deliver junction capacity improvements and reduced delays for motor vehicles, but also better conditions for active travel modes, reduced environmental impacts and improved social outcomes. And all at a cost which is likely to be cheaper than many conventional solutions.

In the following chapters, the 'XT Junction' is presented and evaluated as a new holistic approach for improving the performance of three arm traffic intersections. Chapter 2 presents a literature review of published work relating to existing DDIs and DRT intersections. Chapter 3 sets out an overview of the XT junction concept. Chapter 4 presents the modelling results of the theoretical case study junctions, while the social value implications of the XT junction are presented in Chapter 5.

This study is not a design manual for XT junction or any other type of continuous flow/displaced right turn junction, as many of these matters have been comprehensively covered in other publications. Other than discussing the general design principles, the purpose of this paper is to focus on the operational characteristics of the concept XT junction to determine whether it has the potential for offering a more sustainable, holistic, and equitable solution to resolving traffic congestion at other T junction locations in the UK and elsewhere. And consequently, whether the XT junction should be another established option in the highway or traffic engineer's toolbox for resolving issues at congested T junctions.

This document does not constitute a standard, specification, or regulation. It has been prepared adopting the United Kingdom Road standard of driving on the left-hand side (left-hand traffic). However, all other nomenclature and terminology in this document relating to international road junction layouts that follow right-hand traffic driving rules (such as the Diverging Diamond Interchange in the United States) is retained.

2 Literature review

This chapter will explore the body of literature and published works relating to the design, development, and implementation of crossover traffic junctions such as the DRT (or CFI) and DDI.

The efficacy of the crossover feature was first established with the construction of the first DDI in France in the 1970s, Chlewicki (2003). [4] However, some studies claim that the crossover design principle may go back as far as the 1950s, Simmon and Chick (2003). [5]

The first DDI built in the US was in 2009 in Springfield, Missouri, the concept being put forward by Chlewicki (2003). [4,8] The reconfigured intersection has been widely regarded as a relatively low-cost solution that improves traffic operations and safety (Christopher et al., 2021). [26]

The concept was further explored by the Federal Highway Administration report (Hughes et al., 2010) [10], dedicating a chapter to the DDI design, as one of four alternative intersections and two interchange designs, that offered "substantial advantages over conventional at-grade intersections and grade-separated diamond interchanges".

In 2016, the New Mexico Department of Transportation implemented the first DDI in New Mexico. [14] In November 2016, the Delaware Department of Transportation completed the conversion of an overpass at DE-1 and DE-72 (Wrangle Hill Road) west of Delaware City into a DDI. [15]

The DDI design gained popularity in the United States and was adopted by other countries as well. In Canada, the first DDI opened in August 2017 at Macleod Trail and 162 Avenue South in Calgary, Alberta, followed by another one in Regina, Saskatchewan. [18] In Australia, the Department of Transport and Main Roads of Queensland was the first to implement a DDI in 2019 at Caloundra, which connects Caloundra Road to the Bruce Highway. [23]

Nowadays, the DDI design has become a popular and effective solution for improving traffic flow and safety at intersections and interchanges around the world. As of July 2022, it is estimated that there are more than 135 operational DDIs in various countries, with many more under construction or planned. The DDI design has proven to be beneficial for reducing congestion, delay, fuel consumption, emissions, and accidents when compared to conventional designs.

2.1 The Displaced Right/Left Turn (DRT/DLT)

A DRT/DLT is an intersection design that uses dedicated turning lanes and signal phases to keep through-traffic moving while allowing right-turning vehicles to turn safely. it allows for simultaneous conflict-free right/left turns from the major arm into the minor arm and from the minor arm into the major arm. They have been shown to reduce congestion and improve safety. The term Displaced Right Turn (right-hand drive countries) or Displaced Left Turn (left-hand drive countries) is interchangeable with the term 'Continuous Flow Intersection'.

The first DRT was built in the U.S. 1995 at a T-junction on the William Floyd Parkway in the town of Shirley, Long Island, New York. Other examples can be found in Maryland, Louisiana, Utah, and New Mexico. [10]

Goldblatt et al., (1994), [1] reported that a Continuous Flow Interchange configuration (CFI) reduces delays, fuel consumption and CO_2 emissions compared to conventional intersections and that a CFI can

handle up to 50% more traffic than conventional intersections with similar geometry and signal timings. They also acknowledged some limitations and challenges of CFI adoption, such as relatively higher construction costs, increased right-of-way (ROW) requirements, potential driver confusion and safety concerns due to possible wrong-way manoeuvres.

Chick and Simmonite (2003) [5] proposed that although there is a slight increase in cost associated with the DRT concept, these additional costs are generally more than offset by the benefits in terms of increased capacity, reduced travel times and reduced congestion in comparison to traditional junction layouts. They also concluded through studies and tests, that the DRT footprint is likely to be similar to that of an equivalent conventional roundabout footprint.

According to Chick and Simmonite (2003) [5] pedestrians and cyclists could easily be accommodated at a DRT junction without compromising the capacity of the intersection using "Walk with Traffic" facilities. The pedestrian and cycle provision also benefits from the short cycle times inherent in a DRT arrangement in comparison to a standard T junction layout, keeping pedestrian/cyclist delays to a minimum.

Pitaksringkarn (2005) [6] established through VISSIM microsimulation modelling of the proposed Gude Drive/Frederick Road intersection in Maryland, United States, that the overall delay and queue lengths measured during the peak PM hour decreased from those of a conventional intersection significantly by 64% and 61%, respectively.

The United States Department of Transportation (DOT) confirmed in their report, Alternative Intersections/Interchanges (2010), [10] that a DLT intersection can improve traffic operations and safety by reducing delay, queue length, number of conflict points, and number of signal phases at the main intersection. It stated also that A DLT intersection can be implemented as a partial or a full DLT depending on whether the left-turn movements are relocated on all four approaches or only on two opposing approaches on the major road. The report also emphasizes the import of careful consideration of geometric design features such as crossover location and length, lane configuration, median width treatment, sight distance, turning radii, signing, and marking that play an important part in determining the efficiency of the design. These factors are discussed in more detail in Chapter 3.

As of the time of writing this report, in the UK, only two prototype DRT junctions are known to have been built – one completed in 2002 at the junction of A4198 Thamesdown Drive/A4311 Cricklade Road (The Motorola Junction) near Swindon in Wiltshire (as shown in Figure 1), and the other completed in 2015 at the A380 Hamelin Way/A380 South Devon Expressway to the east of Torquay in Devon (see Figure 2). Other than these two examples, there has been no other known uptake of the CFI as a solution to congested T junctions in the UK.

The Swindon junction was introduced in an area of mixed residential, light industrial and retail land use and was provided with a degree of pedestrian crossing facilities, but no cycling facilities. The Torquay junction in comparison, was in a semi-rural location with no discernible pedestrian desire-lines and no pedestrian or cycle facilities were therefore provided.

August 2002, The Wiltshire Gazette and Herald greeted the opening of the Swindon Motorola Junction with a healthy dose of scepticism. Under the headline of 'It's simply baffling'. [3] The article proceeded to question the logic and reasoning behind its introduction with suggestions that it was too confusing for most users. However, the negative tones were slightly at odds with the views of members of the

general public who were interviewed for the article, one of whom, after being involved in a minor ‘shunt’ incident shortly after the junction opened, was quoted as saying "It's quite a complicated junction for people who haven't used it before, but this incident definitely hasn't put me off”.

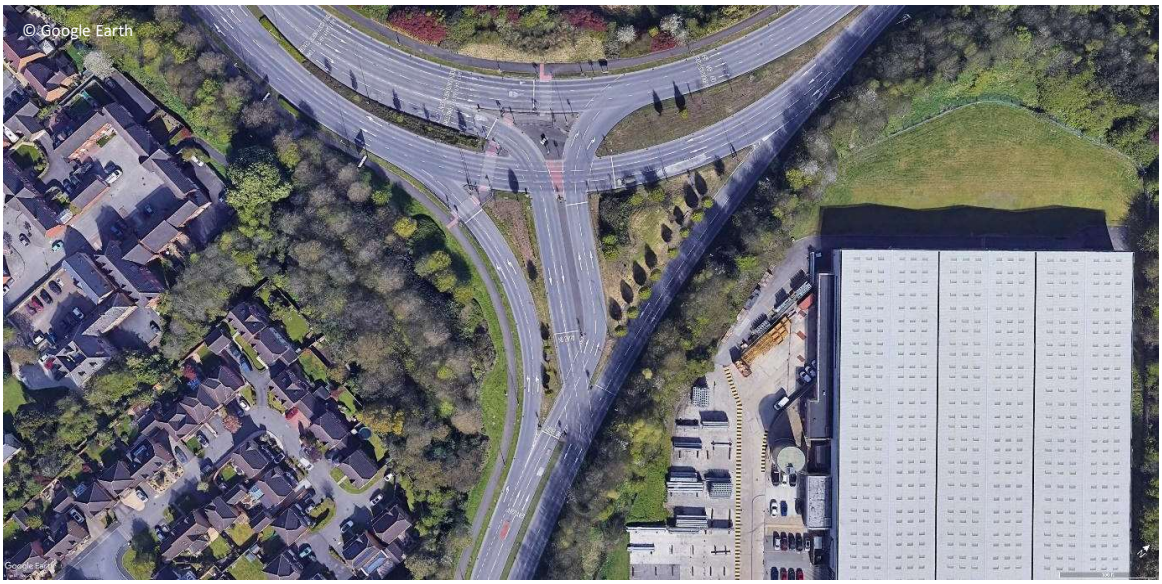


Figure 1: DRT junction at Thamesdown Drive, Swindon, UK.

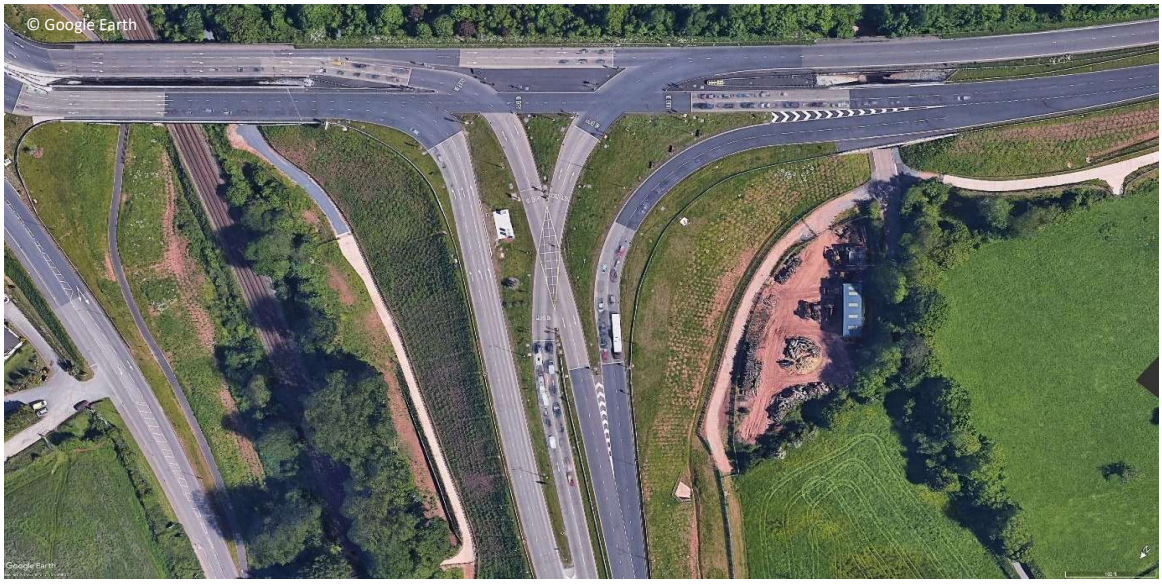


Figure 2: DRT junction at A380 Hamelin Way/ South Devon Expressway, Newton Abbot, UK.

2.2 Swindon DRT performance

A speed monitoring exercise was undertaken at the Swindon DRT junction immediately post-implementation in September and November 2002, Chick and Simmonite (2003). [5] The observation showed that vehicle speed did not change over the study period and that speeds for the crossover sections were relatively low at approximately 32 km/h when compared to the vehicle speeds related to the more traditional movements such as the straight ahead and left turns, which were recorded up

to 60 km/h. Chick and Simmonite undertook a comparison study between the DRT and a new conventional 3-arm signalised junction on the same corridor. In the conventional junction chosen for comparison purposes the geometry and turning volumes were similar to that of the DRT junction. The conflict study observed four conflicts at the control junction and 14 at the DRT junction over the same 12-hour survey period. However, further, inspection determined that more than 65% of the conflicts at the DRT junction were caused by lane discipline issues at the upstream junction and other minor design issues that could easily be mitigated through a review of the signing and road markings on the approaches to the DRT junction. They concluded that once mitigation measures to minimise the risks of these conflicts have been implemented, the conflicts should be equivalent to a similar traditional highly trafficked traffic signal junction.

2.3 UK CFI Safety records

In undertaking this study, an analysis of pre-and post-implementation accident statistics for the Swindon and Torquay junctions has been undertaken using UK CrashMap.

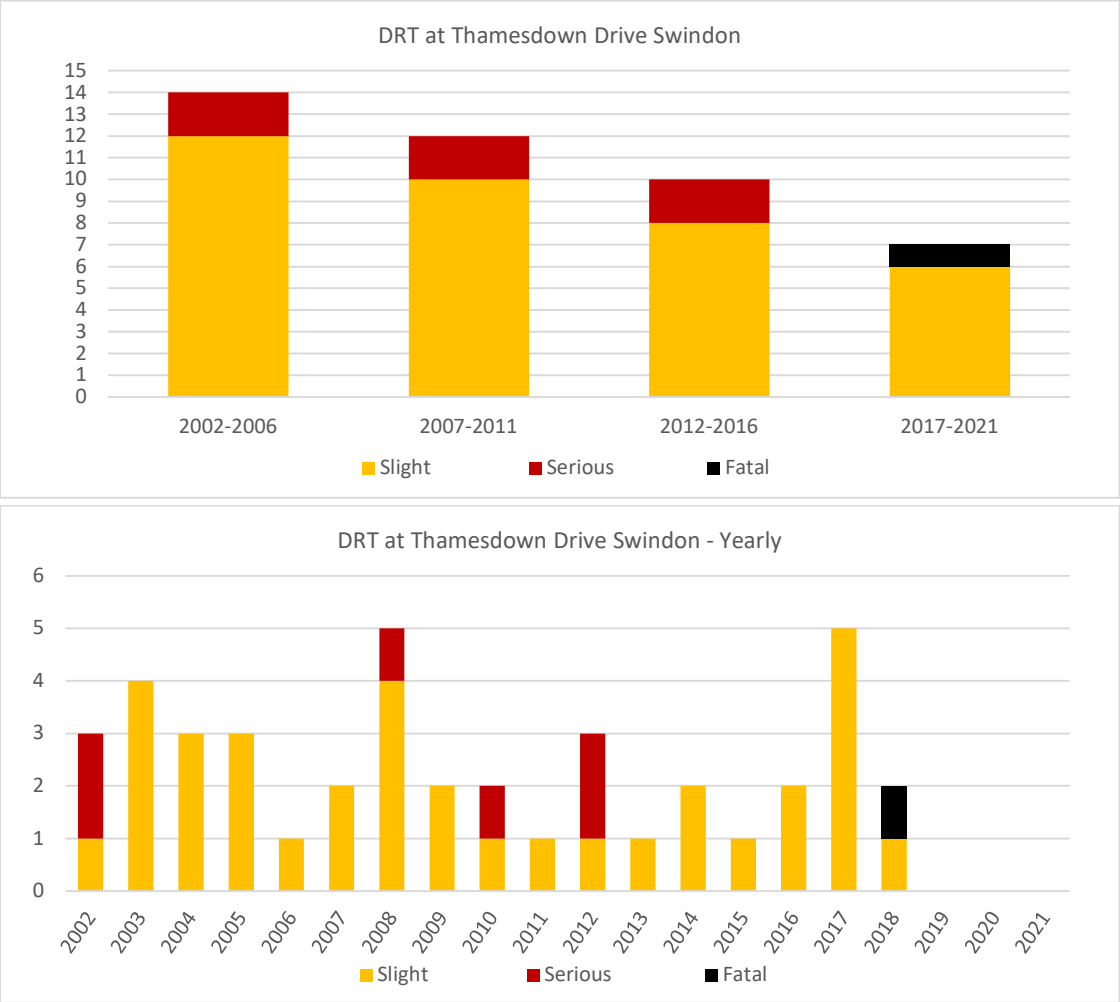


Figure 3: Accident statistics for DRT at Thamesdown Drive Swindon, from 2002 to 2021.

For the CFI at Swindon, Figure 3 shows a steady decline in total accidents across the four, five-year sample periods from 2002-2021 (top image). During the period of its operation, the Swindon CFI has seen a reduction in accidents of almost 55% from 14 incidents the four years from opening in 2002-

2006, to seven incidents in the period from 2017 to 2021. It is acknowledged that the figures presented in Figure 3 represent a 'blending' of pre- and post-opening records for the years 2002-2006 and the higher rate of accidents in this period would need to be investigated further outside of this study to establish which accidents occurred before the opening of the DRT and which occurred after. It is noted that one accident in 2018 was recorded as fatal. Further analysis shows that the fatal accident involved a collision between a vehicle and mobility scooter on the pedestrian crossing to the minor arm left turn. The incident occurred in the daytime and conditions were fine and dry, without high winds. The records indicate that both vehicle and mobility scooter were proceeding normally along the carriageway. While it is unclear whether either driver was at fault, the location of the incident on the left turn slip suggests that the incident cannot specifically be linked with the operation or functioning methodology of the DRT as a left-turn slip lane at a T junction is also an established method of traffic control and channelisation at larger, conventional T junctions.

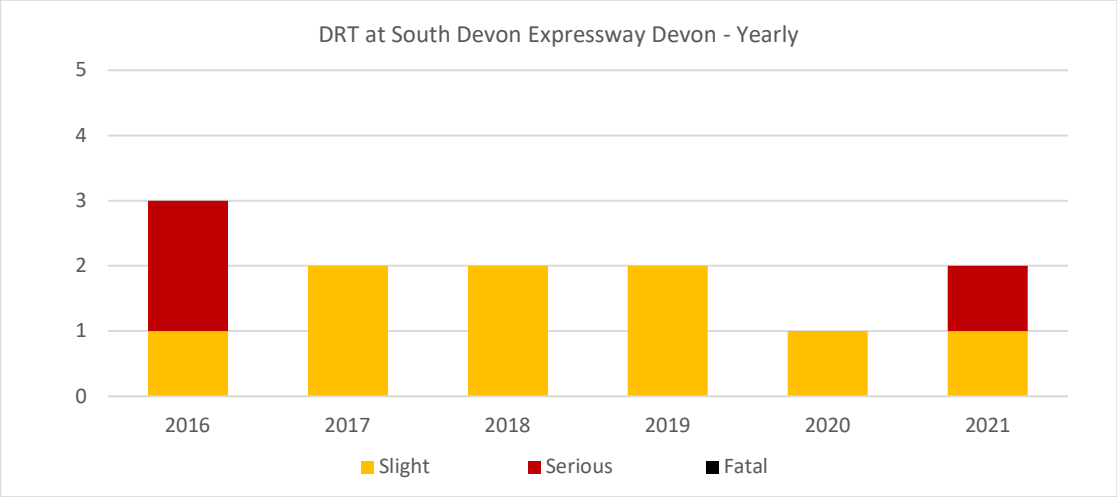


Figure 4: accident statistics for the DRT at South Devon Expressway, from 2016 to 2021.

It can be seen from Figure 4, that in the six years post-implementation, the accident rate at the South Devon Expressway junction declined from a high of three accidents in 2016 (the immediate year post-implementation), to a relatively constant rate of a two accidents in all but one of the subsequent five years, with 2020 having only one recorded accident.

In summary, the CrashMap analysis for both DRT sites in the UK does suggest that accidents have generally declined across the years that the DRTs have been operational and for which data is available. This does correlate with some limited studies conducted on DRT/CFI junctions in the United States, such as those analysed in the Federal Highway Administration, AIIR (2010) report. Indeed, when the accident rates at similar sized signalised T junctions in the vicinity of the two UK DRT junctions are viewed on CrashMap, the DRT sites do not appear to stand out in terms of suggesting any specific safety issue or accident blackspot.

The XT junction benefits from a reduction in conflict points which should translate into a reduction in accidents. It is acknowledged however, that the scarcity of available UK study sites does not point to any trend or pattern for establishing a definitive link between the adoption of a DRT junction and an improvement in road safety, and further work will need to be done in this area.

3 The XT Junction

While earlier DRT intersections have been introduced predominantly with the aim of mitigating any vehicular traffic congestion and delay, the goal of the XT junction is to deliver a more holistic and equitable range of improvements across all road user groups. To this end, an XT junction is likely to be more suited to urban, or semi urban locations – like the Motorola Junction, rather than rural or semi-rural locations, such as the Torquay example.

Like the Continuous Flow Interchange, the XT concept uses the principle of switching minor road traffic to the opposite sides of the carriageway prior to the main junction – see Figure 5. This gives the advantage of combining both movements to and from the minor road into a single phase. As a result, the junction requires only two traffic signal phases instead of three for a standard signalised T junction. The most notable feature is the right-turn crossover (the 'X' part of the junction). This allows drivers to position themselves for making an unobstructed right turn, while still on the minor road, and in advance of the intersection.

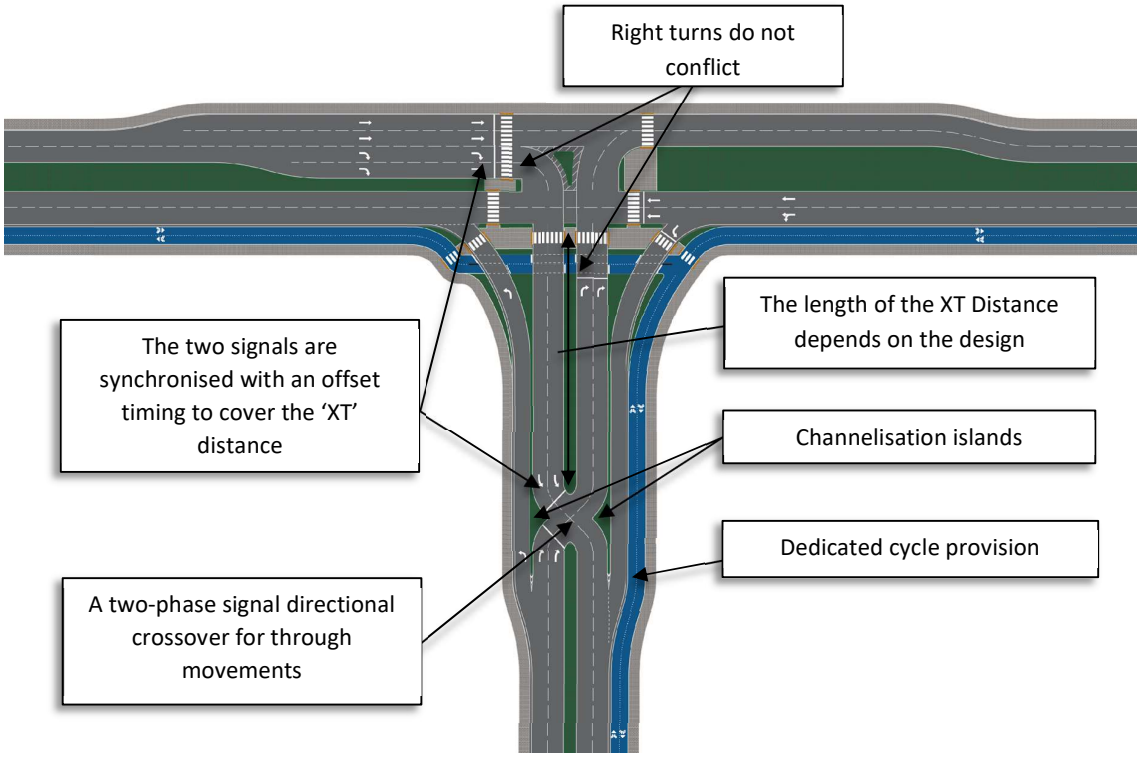


Figure 5: Key characteristics of an XT junction

3.1 Motor vehicles

The movements required to traverse an XT junction as a motor vehicle driver are as follows:

- **Right turn from major arm to minor arm** – Drivers will take up their right turning lane positions by following signs and road markings as they would for a standard T junction. At the main T junction signals, the signalised right turn is made into the minor arm side of the carriageway which normally carries opposing traffic, rather than turning into the usual lane that takes 'with-flow' traffic away from the junction. This requires sufficient space in which to

safely undertake what is in effect a tighter turn than would be the case with an equivalent right turn at a standard T junction. However, unlike a standard T junction, the 'opposing' lane between the 'X' and the 'T' parts of the junction is clear of opposing traffic and is instead dedicated to carrying the 'with-flow' traffic from the major arm into the minor arm, transitioning back to the correct side of the road at the X part further into the minor arm.

- **Right turn from minor arm to major arm** - On the approach to the main junction, vehicles turning right will position themselves in the appropriately signed traffic lane just like a normal junction, only it's a little further back – at the X part of the junction. When the X signal turns green, drivers transition across the front of the opposing traffic stream under signal control to take up a position on the approach to the main traffic signals which is on the 'opposite' side of the road. The right turn at the main junction is then made, turning into the 'correct' side of the main arm. The XT arrangement provides for a seamless transition through the crossover and main junction, meaning that in general, most right-turning drivers who wait at the crossover signals would not need to stop at the second signal at the main junction because both sets of traffic lights are synchronised. However, if more green is given to the through movements, then this will leave redundant time at the crossover. The redundant time could result in the last couple of vehicles occasionally being required to wait at the second set of signals.

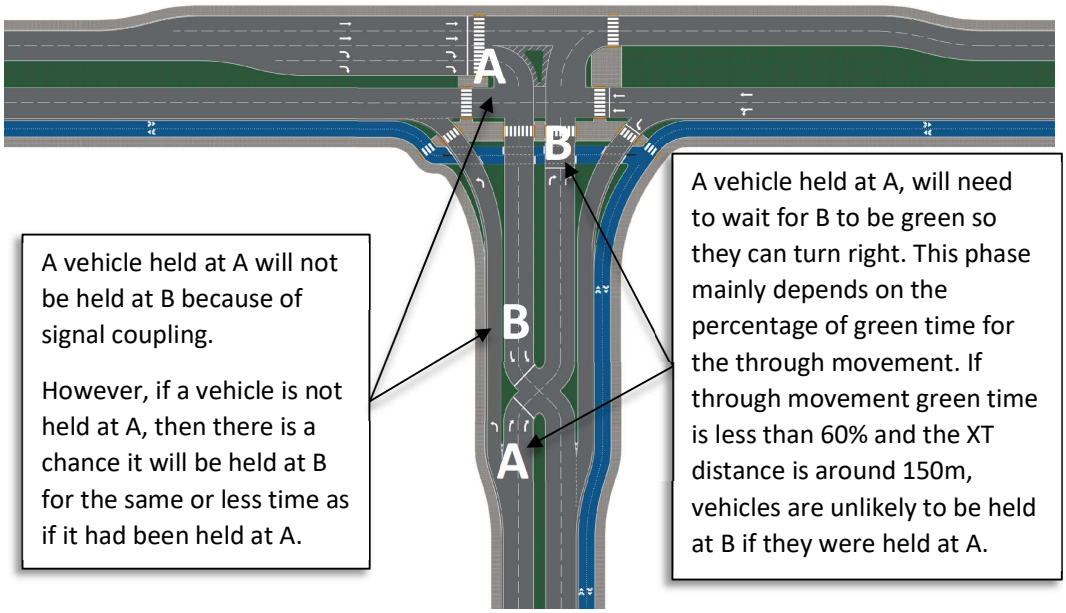


Figure 6: How the XT right turns traffic flow function.

Left turns into and out of the minor arm at the XT junction are made in the same way as filtered left turns at a conventional T junction.

Depending on site constraints, the relatively small area required to install the 'X' crossover means that the conversion from T to XT could be accommodated within the current footprint in most circumstances, reducing construction time and inconvenience. These are only small changes, but they have the potential for making a significant difference in terms of junction performance and user experience for all users.

3.2 Active travel

The XT junction is intended to cater for pedestrians and cycle users in a safe manner. This is achieved through a combination of having adequate physical space for the facilities required and using the spare capacity provided by the continuous right-turn arrangement to allow sufficient crossing and/or junction clearance time for active travel modes. Using the spare capacity released by an XT arrangement means it should be possible to accommodate additional active travel provision effectively without any detriment to vehicular traffic.

Depending on the space available, provision can either be segregated or shared between cycle and pedestrian users.

3.2.1 Pedestrians

Pedestrians are provided with signal-controlled crossing points and full crossing is achieved in a three-stage operation, as opposed to a four-stage operation in an equivalent conventional T junction arrangement.

To ensure accessibility, pedestrians will cross the junction via lowered kerbs as per a standard T junction. In circumstances where pedestrian and cycle paths are segregated, pedestrians will also be provided with uncontrolled crossing points across the cycle paths, via lowered kerbs.

Since the XT crossover is an unconventional design, extra attention is needed on human factors throughout the design process.

With a centrally-located crossing design, as per the DRT at Thamesdown Drive in Swindon for example, (shown in Figure 7), the pedestrian crossing to the centre of the junction on the major arm is unusual compared to a typical T junction design where separate crossings are usually located on the approach and exit arms. Depending on the design vehicle and XT speed, the pedestrian refuge island separating the right turn movements can be quite large and pedestrians need clear guidance and information on where to walk and where to cross. Coloured and tactile surfacing treatments can assist in this regard.

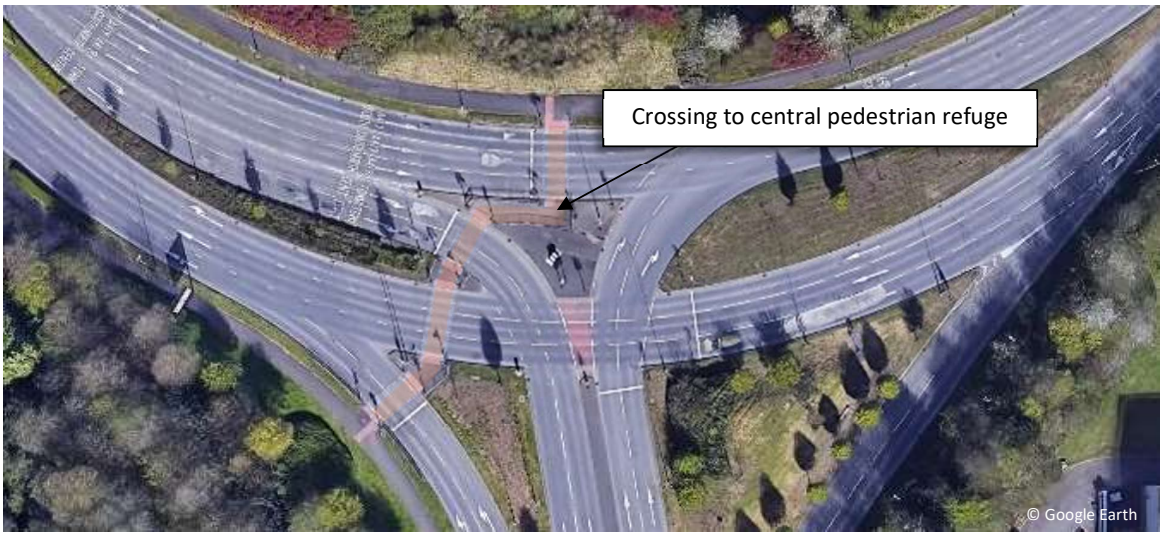


Figure 7: Pedestrian facilities at a DRT in Swindon, Wiltshire, UK.

Another consideration for the XT design is that pedestrians may not be aware of which direction the traffic is coming from as they traverse the splitter and refuge islands. In Swindon for example, the highway authority has provided pedestrian directional road markings to guide the pedestrian which way to look, as shown in Figure 8. In the Swindon example, it can also be seen that the local authority has provided tracts of guard railing to channel pedestrians in the desired direction. While there is a general move away from guard railing in recent years in pursuit of an uncluttered urban environment, the decision to include or exclude of pedestrian should always be guided by the findings and recommendations of a Road Safety Audit.

Figure 8: Pedestrian provision at the CFI in Thamesdown Drive, Swindon.

The type of information shown in Figure 8, should also ideally be provided in audio form to ensure equal access for visually impaired pedestrians. A record of a verbal message, such as "Traffic is coming from the left" should be added for both signalised and unsignalised crossings.

Extra attention should be given to the needs of pedestrians with disabilities, including those with mobility or visual impairments. Since the XT design is unconventional, there is no detailed guidance available yet. However, general principles of accessibility can also be borrowed from other types of intersections and applied here.

3.2.2 Cyclists

Cycle-friendly design should aim to minimise cycle-vehicle conflicts, provide appropriate lateral clearance between vehicles, cycles and pedestrians, minimise speed differentials between different travel modes, and manage potential conflicts.

The XT junction must therefore consider the following elements to ensure the safety and comfort of cyclists:

- **Lane markings and signage:** Clear and visible lane markings and signage are important for guiding cyclists through the XT junction. Coloured surfacing on segregated facilities can also help to delineate the facility.
- **Separation from motor vehicles:** An XT junction should provide for fully segregated cycling facilities wherever possible. Physical separation between cyclists and motor vehicles, such as protected cycle lanes or separated cycle paths, can provide an additional level of protection.

- **User comfort:** The XT design should consider the comfort of cyclists, such as providing a smooth riding surface, avoiding steep gradients, and minimising conflicts with turning vehicles.

There are a few basic design options to accommodate cycling. These options include the provision of:

- **Segregated cycle paths on each side of the carriageway:** Subject to availability space, this could be a two-way or a one-way cycle network as shown in Figure 9. While the former is preferable, the latter design can be used when there is not enough space to accommodate two-way operation.

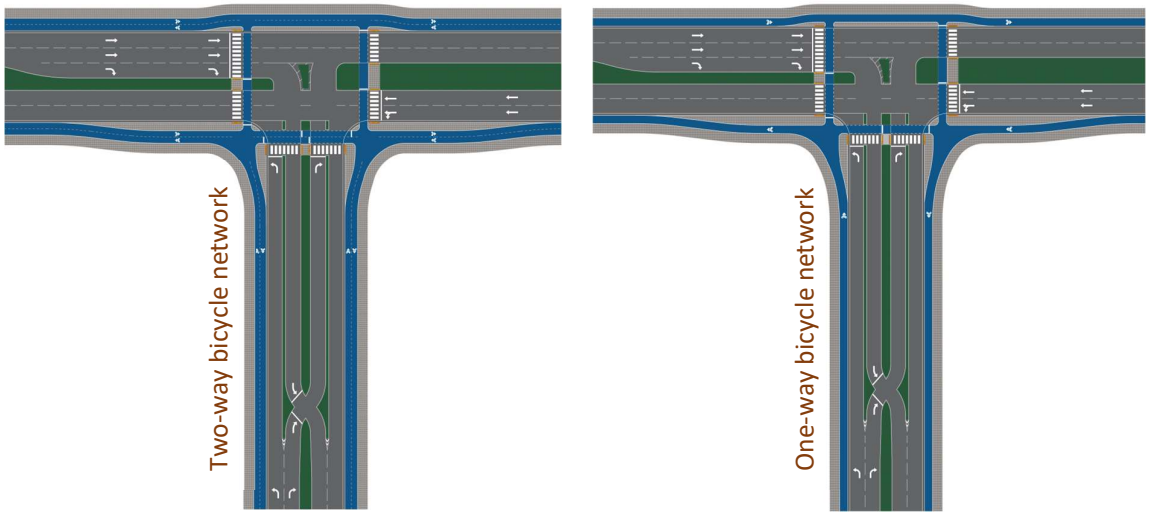


Figure 9: Dedicated cycle lanes on the outside of the roads (one way and two-way network).

- **Segregated cycle path on one side of the carriageway:** This design is suitable when available space is limited or where there is a uni-directional nature of local cycling destinations and desire-lines. To permit as smooth and seamless cycle turning movements as possible to and from the major and minor roads, cycle lanes on the major road should preferably be located on the same side as the minor road junction connection. However, on the minor road, the design is more flexible, and the cycle lanes can be positioned on either, or both sides.

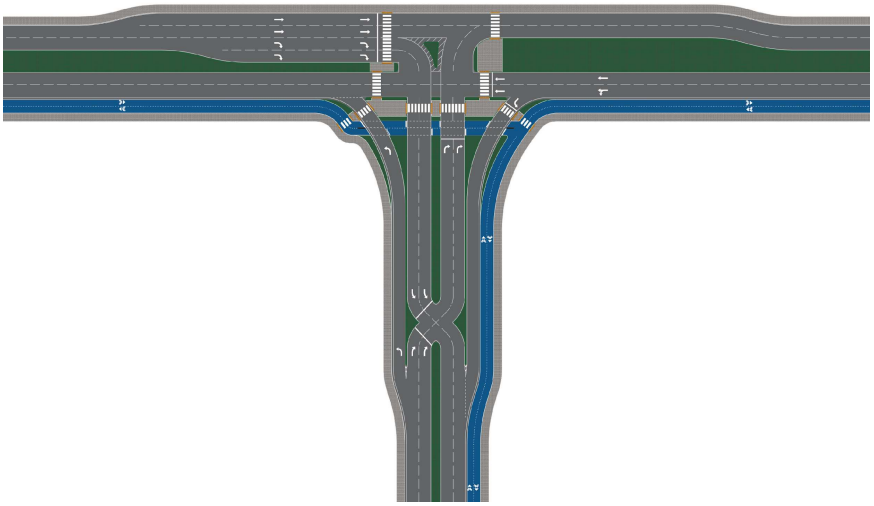


Figure 10: Dedicated cycle lanes on one side of the carriageway.

- **On-carriageway cycle lanes:** This design is suitable when the traffic volumes and vehicle speeds are low. Cyclists would follow the vehicular signals at the crossover and the main junction. The introduction of advanced stop lines to improve conditions for cyclists can also be considered. However, this option is not recommended for both typical T junctions and the XT junction if traffic volumes are high.

3.3 XT junction safety

While the accident statistics for the two existing DRT junctions presented in Chapter 2 suggest broadly that neither location is a particular accident blackspot and accident rates have improved at these locations since their implementation, it is clear that UK currently has insufficient real-life examples from which to deduce any reliable safety correlations in terms of having a robust statistical sample size. Chick and Simmonite's 12 hours post-opening observations of conflict points at the Swindon DRT and a nearby standard T junction concluded that the greater incidence of conflicts observed at the DRT were likely to be a result of insufficient road markings and signage, which, once mitigated, should mean that number of conflict incidents at the DRT should be equivalent to that of a traditional highly trafficked intersection. Indeed, it should be expected that the reduction in conflict points inherent in the XT design is likely to result in a safety improvement correlation. However, to achieve optimal performance in terms of both operation and safety, there will always be factors related to aspects such as sight lines and visibility splays, topography, design speed, speed limits, numbers of active travel users, signing and lining, and signals layouts and timings that may need adjustments to be made to the design from the concept stage right through to post-implementation.

When considering issues of overall safety in the context of proposals to introduce an XT junction solution, a particular emphasis will be placed on how the two 'unconventional' features of the traffic crossover ('X') and the unopposed right turns at the main junction will operate, and how these features will be 'read' by vehicle drivers and those using active travel modes.

The existing UK DRT examples do not incorporate active travel provision to the same extent as would be the case for an XT junction and it is therefore acknowledged that the 'contra-flow' nature of vehicular movements into and out of the minor arm may raise additional concerns with regards to operational safety, particularly when it comes to the additional provision for active travel users proposed within the XT design.

Crossing an XT junction minor arm as a pedestrian or cyclist is in fact, not dissimilar to crossing two discrete conventional roads (left-hand drive) - one after the other, where a pedestrian or cyclist would first look right, then left and then right and then left again. However, it is also acknowledged that in the context of crossing an XT junction, the crossings are located within a large junction where a person could reasonably expect to be looking right twice, then looking left twice – as would be the case for an equivalent conventional T junction with left-turn filter lanes. In this regard, there is further work to do, and it is hoped that a programme of testing and trailing can be instigated as part of a future follow-up study to derive a conclusive view on the XTs safety credentials with respect to active travel modes.

Clear signage, traffic signals and road markings will play an important part in ensuring that the approach and transit through the junction is a safe and seamless experience for all users. However, to the extent that attendant signs and road markings are required for the XT junction, the aim should be for these to supplement the priorities and rights of way to users who have already been safely and seamlessly guided through the junction by virtue of a self-reading geometrical design and a well-designed traffic signals layout.

3.4 XT crossover

The XT crossover design is similar to a DRT/CFI and DDI crossover. In the United States, the Department of Transport recommend a DDI's crossover angle should be no less than 45 degrees between opposing approaches. Research shows a higher correlation between lower crossing angles and the likelihood of more frequent wrong-way manoeuvres in oncoming lanes. (U.S. Department of transport, 2014) [13] However, the Utah DOT suggests crossover angles should be 30 degrees or greater, while the Louisiana Department of Transportation and Development recommends an angle of 10 to 15 degrees. (LADOTD, 2007) [7] As a general rule, it is more desirable to have as great a crossover angle as is possible, subject to local site conditions and land availability.

Factors influencing crossover angles:

- **Wrong way manoeuvres:** Minimising the likelihood of a wrong way manoeuvring into the opposite side of the road is a key consideration in the XT design. The larger the crossover angle, the less the junction will appear different from a conventional junction.
- **User discomfort:** One of the factors that contributes to a traffic calming effect on approaching the junction is the design of the reverse curves. Smaller curve radii promote slower speeds.
- **Exposure:** As with any skewed junction, larger crossover angles reduce the duration of potential conflict to which a vehicle is exposed, and in doing so, reducing the risk of collision when cornering.
- **Bus and Heavy Goods Vehicle turning radii:** The likelihood of overturning increases with greater crossover angles. This could be mitigated by minimizing the speed between successive geometric elements. A horizontal alignment offering smooth and consistent speed transitions, through and out of the XT junction, will best serve all motorised vehicles.
- **Alignment:** Lane alignment at the XT crossover must direct vehicles clearly to the receiving lanes. To ensure direct alignment, reverse curves must include enough tangent length between curves. A lack of indirect lane alignments or tangents between reverse curves could result in overlapped vehicle paths, or worse, drivers accidentally veering into oncoming traffic. This particularly applies to the first vehicles that are waiting for a green light behind the 'X' junction stop line.

Supplementary treatments can be used at the XT crossover angle to discourage vehicles from wrong-way movement. These include the use of road markings, signing, physical guide barriers, and signal heads with arrows. These treatments could help to emphasise the desired movement path through the crossover.

The Utah DoT recommends a vertical barrier to intercept the line of the opposing sight movement at the crossover zone. However, there is no documentation on the effectiveness of this treatment in reducing the likelihood of wrong-way movements, it should therefore be considered as an additional treatment if it were felt that additional guidance was required in addition to the traditional methods.

3.5 XT distance

The location of the XT crossover is highly dependent upon the spacing and location of the adjacent junction. Queue storage demand must also be addressed in determining the XT distance – the distance between the crossover and main junction. There is flexibility in placing crossovers when there is sufficient space available. However, the XT distance is primarily influenced by queue storage requirements, crossover curve design, skew angle – and then any other relevant constraints.

The distance between the crossover and the main junction is crucial and plays an important part in the coordination between the signal nodes, Despite the attempt by Chick and Simmonite to develop an

equation to show the flexibility of in-cycle time and displacement of the crossover node, there are no equations or guidelines to calculate the minimum/maximum design distance between the crossover and the main junction and further research is required to explore this area in depth.

The US Federal Highway Administration, AIIR report (2010) [10] recommended that the upstream crossover distance to the main intersection for a CFI/DLT should be between 300 and 400 feet (91m-122m).

Pitaksringkarn et al. (2011) [11], studied the CFI by using traffic microsimulation to determine the optimum distance for a four-arm intersection. They stated that an increase in traffic volume entering the intersection resulted in longer delays. To mitigate this, they recommended that the CFI right-turn crossover position be located further from the main intersection. In addition, they suggested a minimum distance of 60m for a volume of 2,500 PCU/h and 150m for a volume of 3,500 PCU/h when there is no length limitation.

Qi et al. (2017) [17], conducted an assessment to evaluate the operational impacts of DLT crossover distance in their study concerning the use of innovative intersection designs to improve mobility and reduce congestion. Their simulation results showed that as the crossover distance increased, the average delay at the intersection decreased. Furthermore, when the left turn crossover distance was increased to 400ft (122m) or more, there was only a slight decrease in delay as the distance continued to increase i.e., delay stabilises over 400ft. Qi et al. recommended a crossover distance of around 400ft subject to construction cost and available space. Both Pitaksringkarn et al. and Yi Qi et al. emphasised the importance of the crossover position and its influence on the capacity and efficiency of the CFI traffic operation and acknowledged the lack of comprehensive design guidelines and that more research is needed to support the existing materials.

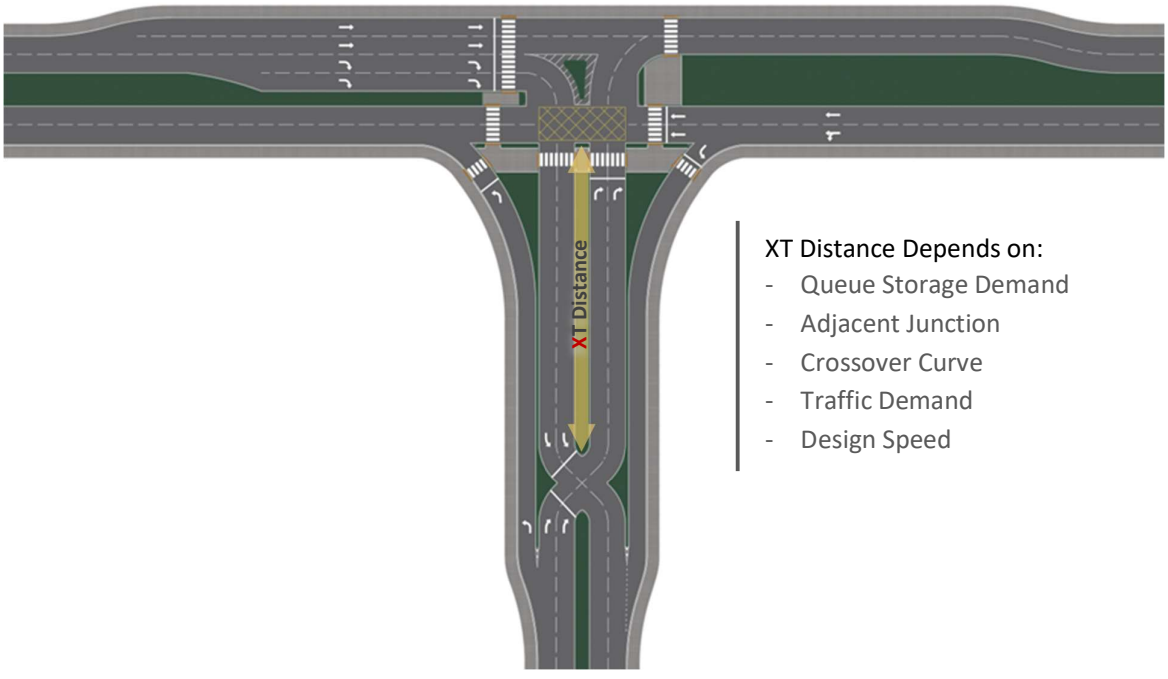
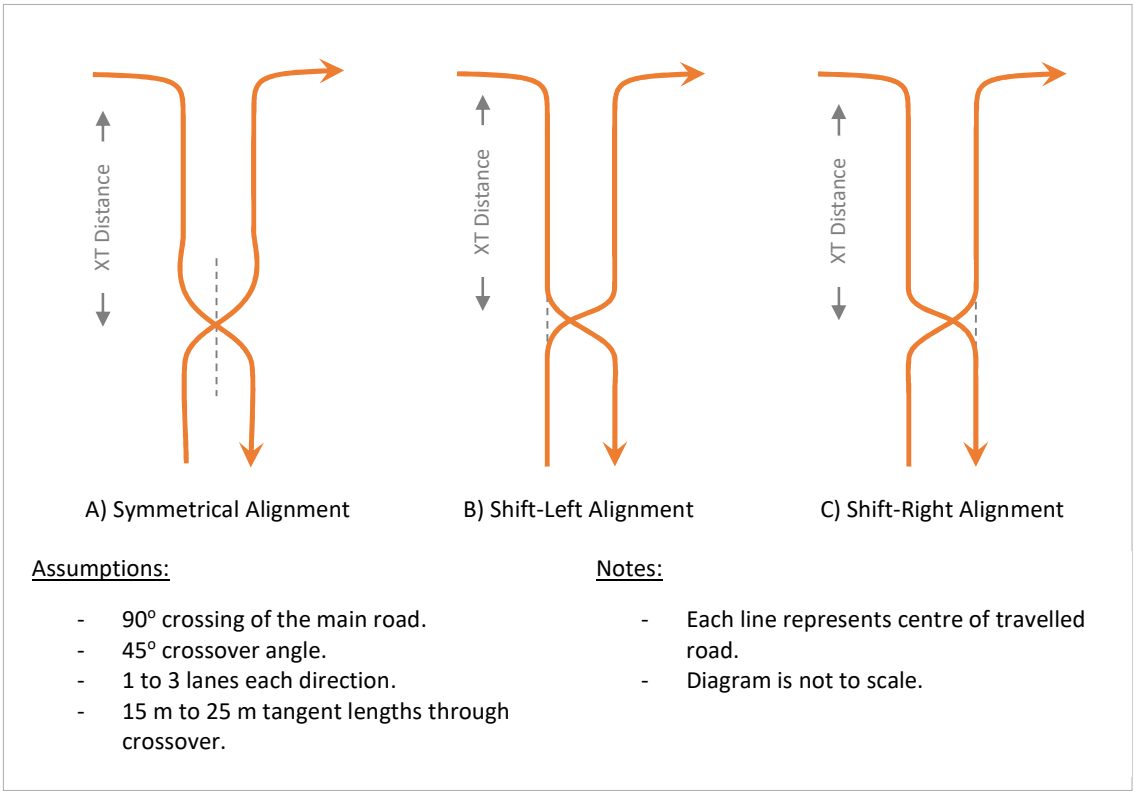


Figure 11: XT distance.

3.6 XT crossover alignment

There are two basic alignment options for the XT crossover: design, symmetrical alignment as shown in Figure 12.

- **Symmetrical alignment:** A symmetrical alignment where the carriageway is deviated to achieve a 45-degree crossover and then returned to the minimum cross-section. This design can be applied to existing T junctions. Reducing the cross-section requires curvature combinations to narrow the crossroad.
- **Asymmetrical alignment, (shift left or right):** This design approach changes the orientation of one of the asymmetrical crossroad carriageway segments to achieve a 45-degree angle for the crossover. This can be achieved by changing the projected axis of the crossover. These alternatives may be used to meet space or site constraints.



A) Symmetrical Alignment B) Shift-Left Alignment C) Shift-Right Alignment

Assumptions:

- 90° crossing of the main road.
- 45° crossover angle.
- 1 to 3 lanes each direction.
- 15 m to 25 m tangent lengths through crossover.

Notes:

- Each line represents centre of travelled road.
- Diagram is not to scale.

Figure 12: Alignment options for XT crossover.

3.7 XT Right of Way (ROW)

The acquisition of additional right-of-way land may create conflicts with existing utilities, footways, or drainage systems. In this regard, the implications of proposals to introduce an XT junction may not much different to that of proposals to increase capacity at a traditional T junction. However, much depends on the existing left-turn treatment and the size of the junction. Aspects relating to ROW which are pertinent to an XT junction solution may be as follows:

- **Auxiliary lanes:** A large T junction often has left turn auxiliary slip lanes which makes the reconfiguration of the junction to accommodate XT design easier to fit within the existing junction footprint. In the absence of these auxiliary lanes, it may be necessary to acquire the relevant land to provide these, or alternatively, in situations of existing two-lane running in each direction, it may be possible to convert one lane from each direction to be used as an auxiliary lane. **Error! Reference source not found.** presents a diagrammatic representation of XT junction left turn auxiliary lanes.
- **Medians to separate traffic:** Having some type of separation between the opposing traffic is essential for safety reasons. Depending on the type of separation and safety regulation, these medians could potentially fit within the ROW by narrowing all the existing lanes. However, this would result in a slower travel speed and slightly a reduction in road capacity.
- **Channelisation islands for the XT crossover:** The purpose of the channelisation islands is to help achieve a 45-degree angle for the crossover and help drivers to navigate to the receiving lanes. As a result, an area might be needed to accommodate these.
- **Channelisation for left-turn from and to the minor road:** Left-turn lanes from and to the minor road may require additional land to provide for auxiliary left turn provision separate from the contra-flow crossover lanes.
- **Right-turn curve radii from and to the minor road:** Vehicles turning right from and to the minor road have a sharper turning angle to negotiate when compared to a traditional T junction. This requires an additional area to accommodate the design radii for turning vehicles. As this area is within the junction, it may be possible to accommodate without the acquisition of additional land.

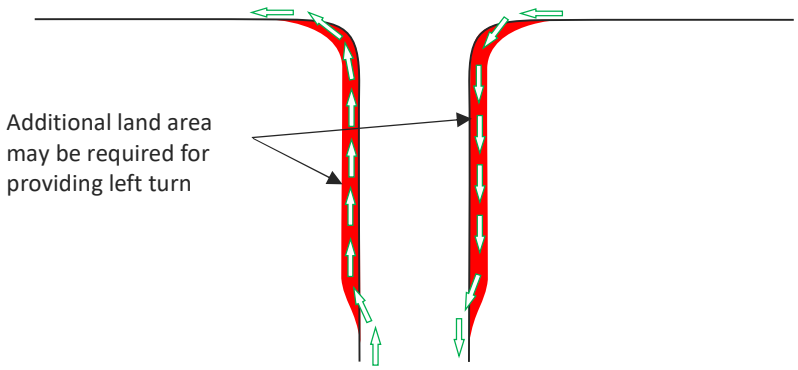


Figure 13: Example of auxiliary lanes which can be added or excluded for the XT design.

3.8 XT auxiliary lanes

The defining concept of an XT design is the removal of the right turn vehicle turning conflicts from and to the minor road. Achieving this requires right-turning vehicles to travel temporarily in the opposite direction between the left-turn lanes from and to the minor road. Therefore, the left turn requires its own lane on the minor road, and an auxiliary feeder lane from the major to the minor road for the left turn movement in the other direction (as shown in Figure 14). These auxiliary lanes also enable more capacity to be provided at XT junctions.

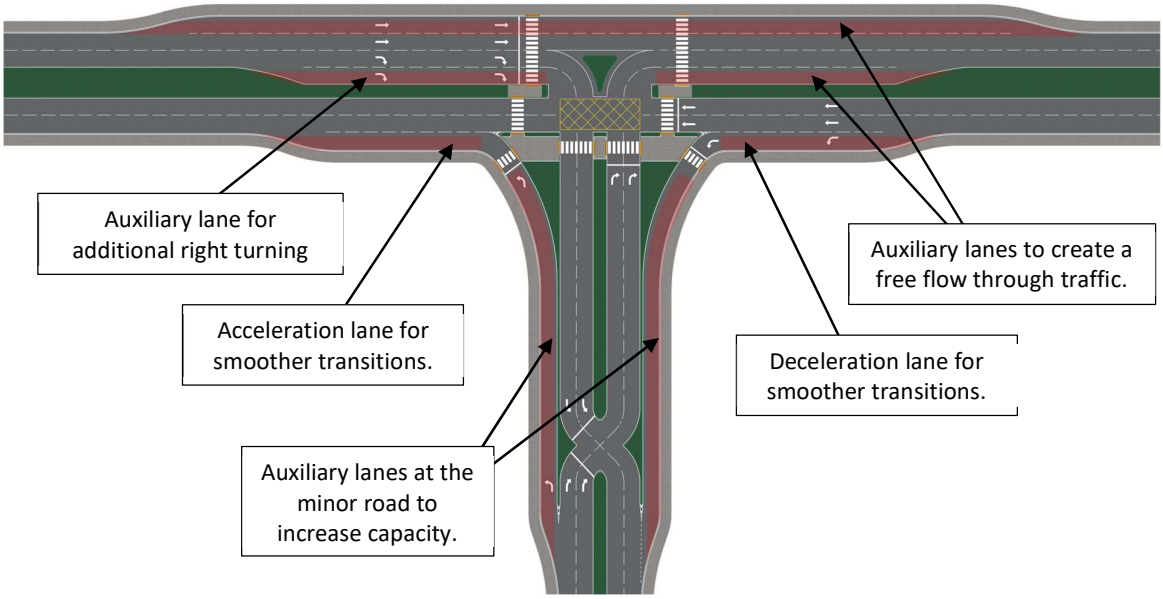


Figure 14: XT junction auxiliary lanes.

Segregated left-turns serve to improve safety, increase capacity, and improve traffic flow by allowing drivers to filter off before entering the main junction and avoid the main conflict areas and traffic signals. Auxiliary lanes are essential on the minor road if there is currently only a single lane in each direction. Benefits of auxiliary lanes at XT junction are:

- **Free flow for the major arm traffic:** Adding auxiliary lanes on the major arm for through traffic and right turns creates sufficient space for through traffic to pass through the junction unhindered as shown in Figure 14. However, this would be subject to a safety review/audit to ensure enough space is provided for vehicles to merge safely. Physical measures and road markings can be adopted to help achieve this. Nevertheless, creating a free flow for the major arm traffic is not unique to the XT design. Utilising auxiliary lanes to create free flow is a common treatment to improve junction capacity for three arm junctions, including roundabout designs, and the same principles can be applied to the XT design.
- **Smoother transitions:** Auxiliary lanes can provide a smoother transition for left-turning vehicles entering or exiting the minor road. By providing a dedicated lane for merging, drivers can better adjust their speed and position to fit into the flow of traffic.
- **Increased capacity:** Adding auxiliary lanes can also help to increase the capacity of junctions, allowing more vehicles to pass through and help reduce queues and delays.

3.9 Challenges in planning for an XT junction

There are several planning challenges that can arise when designing for, and implementing, an alternative intersection such as an XT junction. It can be complex and challenging, but with proper planning and consideration of the needs of all users and stakeholders, it should be possible to deliver in a safe and efficient manner. Some of these challenges are:

- **Public acceptance:** An XT design is likely to be a new concept to the public and so has the potential for meeting with resistance, particularly in urban or semi-urban areas. The concerns and needs of residents, business owners, and other stakeholders will therefore need to be addressed through an effective consultation, education and publicity campaign.
- **Design configuration:** An XT junction can present a number of design and engineering challenges, such as ensuring proper sight lines for drivers and optimum crossover position and alignment.
- **Right-of-way and land acquisition:** In some cases, an XT junction may require the acquisition of additional land or property, which can be a complex and time-consuming process. This can include negotiations with property owners and working with government agencies to acquire the necessary rights-of-way.
- **Coordination with agencies and organisations:** Design and implementation of an XT design will require coordination with other agencies and organisations, such as utilities, local highway authorities, and local government. This can include obtaining permits and approvals and addressing any concerns they might have.
- **Multimodal design:** As with any other road components or junctions, integrating all transport modes can be challenging due to space, operational efficiency, and other limitations. Nevertheless, an XT design usually offers an excellent opportunity to integrate multimodal facilities into a more efficient and compact junction layout than some of the costlier alternatives.
- **Proximity intersections:** The ability of an XT junction to process traffic efficiently can be affected by queue tailbacks from nearby intersections. This could require a relocation and/or redesign of the adjacent intersection, or alternatively abandonment of any intentions to implement an XT junction if suitable mitigation cannot be identified.
- **Funding:** Securing funding for a project can be a major challenge. This can include obtaining grants or other funding from government agencies or working with private sector partners to secure funding.

3.10 Summary

Like all traffic engineering solutions, the viability of a fully configured XT junction that caters for all modes will be highly dependent upon location specifics such as available land, local priorities and policies, pedestrian and cycling demand, safety record and economic evaluation/business case. The extent as to how much this will be achieved is also highly dependent upon the land available. The land requirement can be even greater when there is a need for active travel infrastructure such as pedestrian crossings and cycle lanes/paths. However, an XT/CFI – type junction solution can often only require about as much land as that required for a large roundabout. In this respect, there are likely to be numerous additional locations in the UK where it could be considered as a practical option.

4 Theoretical case studies

This chapter note sets out the junction modelling for the theoretical case study of the XT junction design. This note outlines the capacity and cycle time savings for XT junctions when compared to a comparable standard T Junction.

4.1 Junction typologies

To evaluate the capacity and cycle time benefits of the XT junction, two different layouts namely "large" and "small" junction configurations have been tested.

Figure 15 below shows the layout of a larger standard T junction and the equivalently sized XT junction design used for modelling purposes.

Figure 15: Large junction design.

Figure 16 below shows the layout of a smaller standard T junction and the equivalently sized XT junction design used for modelling purposes.

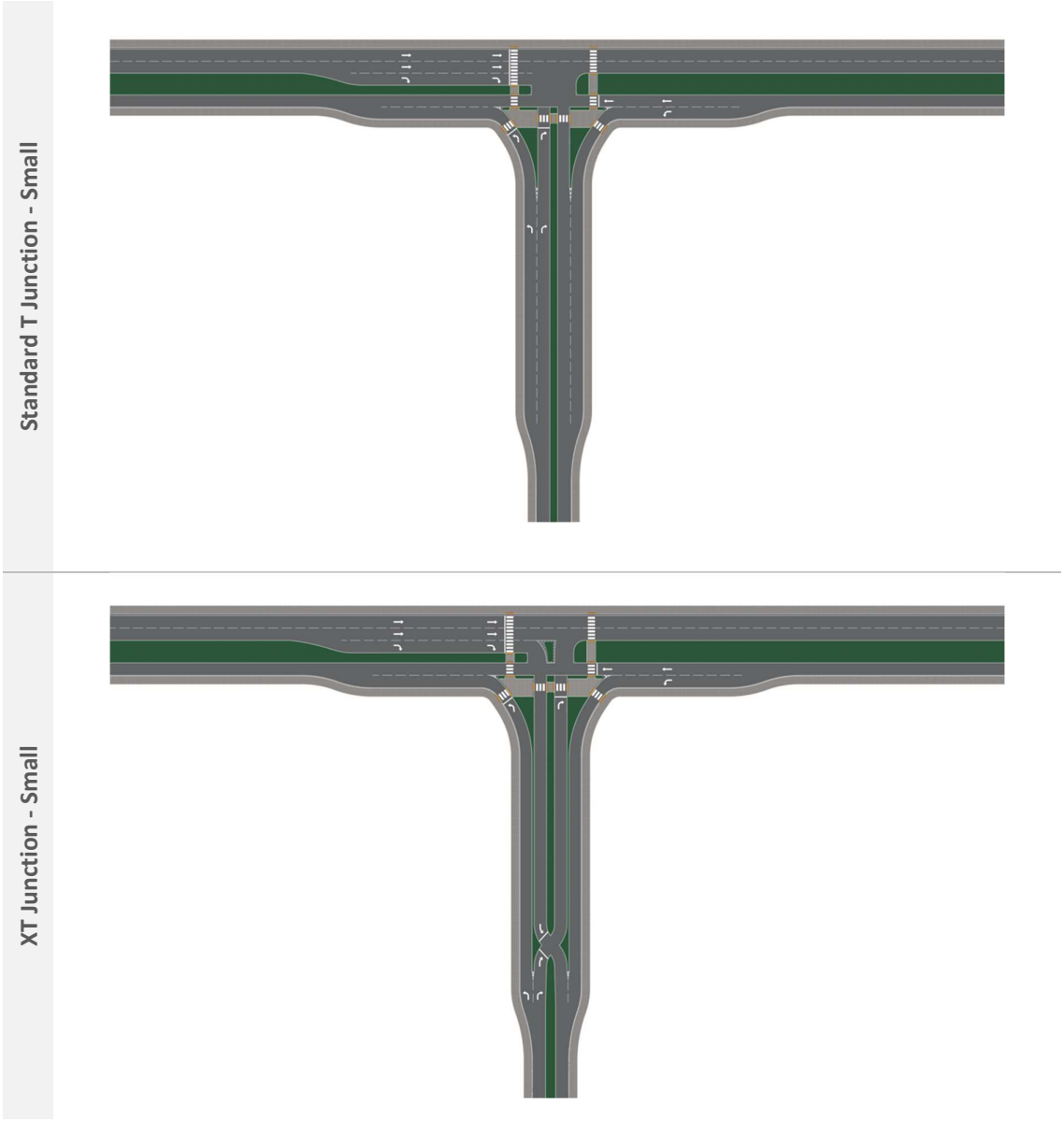


Figure 16: Smaller junction design.

4.2 Modelling scenarios and methodology

To benchmark the capacity savings and signal cycle time optimisation, it was proposed to test multiple scenarios as outlined in Table 1. Four options with varying degrees of active travel provision on a standard T Junction and XT Junction were tested for a like-to-like comparison. An additional test with a straight pedestrian crossing option on the small layout was also carried out.

Table 1: XT junction tested design features.

	Large Junction Layout	Small Junction Layout
Option 1	Advance cycle stop line (ASL) + Toucan crossing	ASL + Toucan crossing
Option 2	Toucan crossing only	Toucan crossing only
Option 3	Partial crossing (one side of a major road)	Partial crossing (one side of a major road)
Option 4	No crossings	No crossings
Option 5		Straight crossings

LinSig models for the standard T junction and XT junction were developed for each of the scenarios listed in Table 1. Signal time optimisation for Practical Reserve Capacity (PRC) was carried out at 144 sec cycle time for both the standard T junction and XT junction to realise the delay and PRC savings. Further cycle time optimisation was carried out on the XT junction to realise the cycle time savings.

4.3 Traffic input

A targeted traffic flow of 3,900 PCU/hrs for the large junction layout and 2,800 PCU/hrs for the small junction layouts were used for the analysis. These volumes typically represent the situation where the Standard T Junction would start to operate at full capacity. Table 2 and Table 3 show the traffic flows used for the analysis of the large and small junction layouts respectively.

Table 2: Larger junction flows (PCU).

	Major Road East	Major Road West	Minor Road	Total
Major Road East	0	1200	300	1500
Major Road West	1200	0	300	1500
Minor Road	300	600	0	900
Total	1500	1800	600	3900

Table 3: Smaller junction flows (PCU).

	Major Road East	Major Road West	Minor Road	Total
Major Road East	0	800	300	1100
Major Road West	600	0	400	1000
Minor Road	300	400	0	700
Total	900	1200	700	2800

4.4 Signal data

The staging and phasing of the standard T junction and the XT junction were replicated as close as possible to enable a like for like comparison. The XT junction has an additional signal stream with two phases to switch the traffic over on the minor arm.

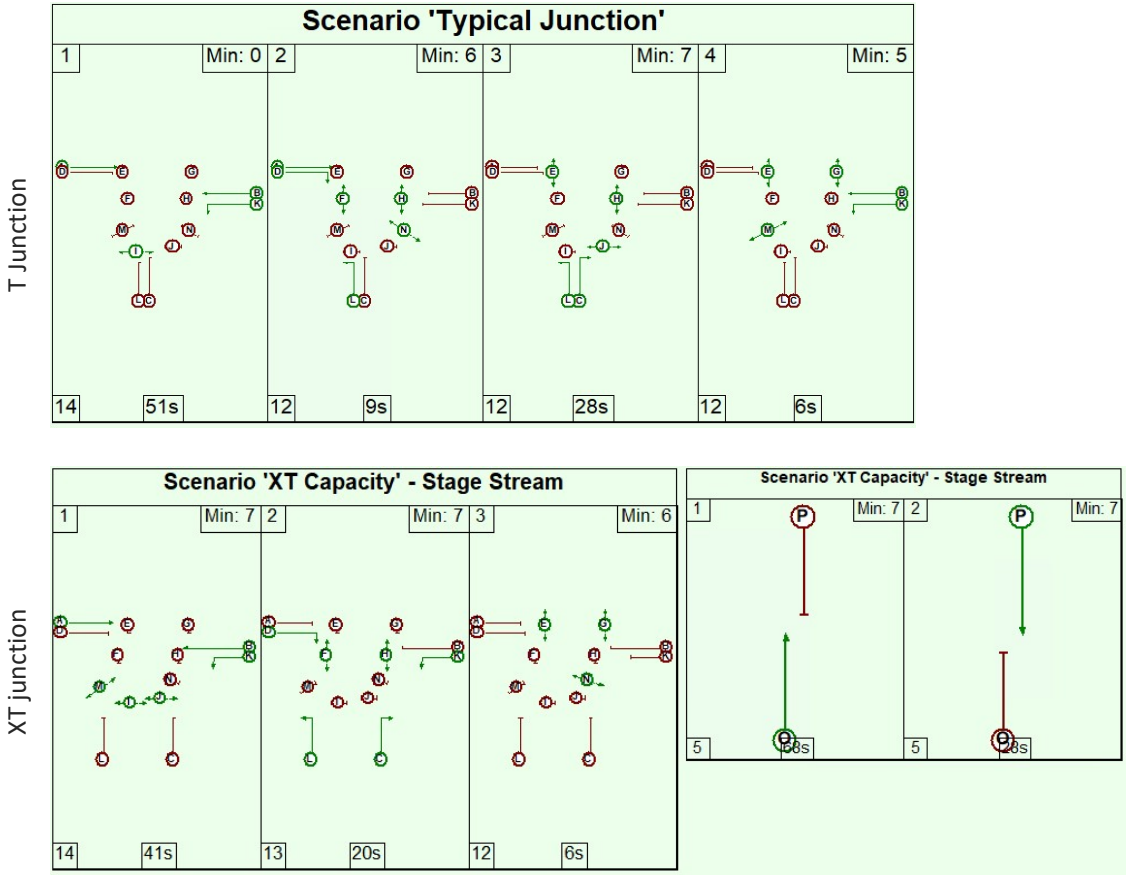


Figure 17: Traffic light signal staging for both T junction and XT junction.

4.5 Model results summary

The key performance metrics from the LinSig models are as follows:

- **Practical Reserve Capacity (PRC) (%)** – a measure of the overall junction capacity, and specifically a measure of how much additional traffic could pass through the junction whilst maintaining a maximum degree of saturation of 90% on all lanes (eg, a PRC of 0% means that the maximum degree of saturation is at 90%, while a PRC of 10% means that if 10% more traffic passed through the junction the maximum degree of saturation would reach 90%. A negative PRC means that the maximum degree of saturation is already above 90%).
- **Delay** – average delay, in seconds, per arriving vehicle across the modelled period. Again, LinSig provides this information for each lane at the junction, but the maximum value on each lane is presented in this report.

Table 4: Delay and PRC results of the junction models at 144s cycle time.

	Option	Traditional T Junction		XT Junction		Spare Capacity
		PRC	Delay (sec)	PRC	Delay (sec)	
Large Junction	Op1	-2%	57	11%	42	13%
	Op2	-1%	50	17%	39	18%
	Op3	-1%	49	24%	36	25%
	Op4	3%	41	37%	32	33%
Small Junction	Op1	-3%	43	23%	31	26%
	Op2	-1%	40	24%	29	26%
	Op3	-1%	39	27%	27	28%
	Op4	2%	34	32%	24	30%
	Op5	-3%	42	20%	31	23%

Table 4 suggests the modelled XT junction results in a spare capacity of between 13% to 33% in comparison to a standard T junction, depending on the layout tested and the degree of active travel facilities provided at the junction. This spare capacity could either directly benefit capacity, congestion, and delays at the junction, but conversely could be used to improve crossing time and clearance allowance for active travel modes, or, depending on local site characteristics and priorities, a combination of the two.

Further signal cycle time optimisation has been carried out on the XT junction to understand the cycle time savings. Table 5 below shows the cycle time savings on the XT junction. It can be observed that the XT junction results show a minimum of just under 20% cycle time saving and a maximum of 100% cycle time saving based on the active travel provision provided at the junction. This study, hence, estimates that this cycle time savings would directly result in reducing the operational carbon emissions at the junction.

Table 5: Cycle time saving for XT junction.

	Option	T-junction cycle time (sec)	Improved cycle time (sec)	Cycle Time Savings
Large Junction	Op1	144	106	36%
	Op2	144	109	32%
	Op3	144	74	95%
	Op4	144	77	87%
Small Junction	Op1	144	102	41%
	Op2	144	123	17%
	Op3	144	120	20%
	Op4	144	72	100%
	Op5	144	112	28%

* Detailed results of each junction are available upon request.

It should be noted that the theoretical case study modelling has limitations. The geometry used in the model is generalised and does not represent any location in the UK or globally. The saturation flow calculations are based on the geometry and may have practical limitations (eg. reduced saturation flow due to drivers' behaviour). In any application to a specific location, the model parameters such as saturation flow and geometry should be adjusted based on on-site surveys and observed results.

5 XT junction social outcomes

5.1 Introduction

The purpose of this Social Impact (SI) Analysis is to present the findings of the assessment of possible social impacts of implementing the XT Junction design in place of more traditional three-arm T junctions. It is important to note that the XT junction is a relatively rare design for three-arm intersections, having been implemented in only two known locations in the UK to date. This SI analysis has been carried out proportionate to the availability of data, and the stage of the design. All data is based on the findings of theoretical case studies. The social impacts that will be considered as the basis to this analysis are:

- Accidents
- Physical Activity
- Severance
- Journey quality
- Accessibility

5.2 Accidents

5.2.1 Accidents overview

Transport interventions can affect the number of injuries, casualties and fatalities that result from accidents. Accidents can occur across all modes of transport and can impact non-users as well as users. Assessing the difference between the numbers of casualties and accidents both with, and without the scheme forms the key quantitative measure for the analysis of transport interventions.

Accidents can result in no casualties (resulting in damage only) or one or more casualties (such as Personal Injury Accidents) of varying severity. Three groups are used to differentiate between casualty severity: fatal (death occurs within 30 days); serious (casualties require hospital treatment and have lasting injuries); and slight (casualties have injuries that do not require hospital treatment or if they do, effects subside quickly).

5.2.2 Qualitative appraisal

The XT junction design would increase capacity on the road when compared with a traditional T junction, while this will increase the number of cars on the road, studies have shown that despite an increase in cars in the UK, the likelihood of being in a serious car accident has decreased. (Yurday, 2021) [28]

Nevertheless, the highway features of the junction itself may reduce accidents through reducing the number of points at which two vehicles are likely to pass in opposite directions, relative to a traditional T junction. The signals at the crossover (X) part of the junction would force traffic to stop and create less room for human error by eliminating right-turning conflicts between the minor road and oncoming traffic from the main road. The channelisation of movements may also decrease the likelihood of wrong-way manoeuvres.

The Department of Transport (DfT) suggests that cyclists must be physically separated and protected from high volume motor traffic, both at junctions and on the stretches of road between them by creating physically separated cycle infrastructure. This can also reduce the risk of accidents. (DoT, 2018) [29] The possibility of, and recommendation to, add cycling and pedestrian paths in design implementation will help to create segregation between cyclists, pedestrians, and vehicular traffic. Signalised crossings will also help to reduce road accidents between active travellers and vehicles due to reduced instances of collision whilst crossing the road.

The X (crossover) point of the new junction design should help to reduce speed through the naturally speed-controlling curvature of crossover movements. A University of Wisconsin study found that reducing speed to slightly (up to 5%) below the recommended limit could reduce accidents by up to 50%. (McCahill, 2018) [21] Therefore, the XT junction design could reduce accidents and improve safety for users when compared with a traditional T junction design.

5.3 Physical activity

5.3.1 Physical activity overview

There is a recognised relationship between transport, the environment, and health impacts; with transport affecting the level of physical activity that people engage in. (Road Transport and Health, 1997) [2] Physical activity levels can be improved through the promotion of active travel modes over motorised transport, and through the provision of infrastructure and facilities that support active travel modes, such as cycle storage facilities and segregated cycle lanes.

5.3.2 Qualitative appraisal

Physical inactivity is a primary contributor to a broad range of non-communicable diseases such as coronary heart disease, stroke, diabetes, and some cancers. Physical activity also has an important role to play in preventing weight gain and obesity as well as improving mental health. (TAG, 2022) [31]

The XT junction design reduces the amount of carriageway required from the original T design, releasing space for active travel modes by providing opportunity to integrate additional pedestrian and cycling measures in the area. Physical activity may also increase due to perceptions of increased safety because of reduced accidents around the XT junction. If junctions are built with segregated cycle lanes and accessible pedestrian infrastructure, there may be a minor improvement to health outcomes because of increased active travel opportunities.

Exposure to air pollution is a significant risk factor for non-communicable diseases, (GOV.uk, 2018) [22] and emissions produced by motor vehicles are known to have a detrimental effect on human health. There are three main conditions associated with air pollution, which are respiratory conditions (such as asthma), cardiovascular disease (CVD), and lung cancer. According to the WHO, one third of deaths from stroke, lung cancer and heart disease are due to air pollution, with nine out of ten people across the globe now breathing polluted air, which kills seven million people every year globally. (WHO, 2018) [27] There is also emerging evidence of associations between poor air quality, and poor mental health and mental disorders including bipolar and depression and Alzheimer's, with studies hypothesizing that pollutants affect the human brain via neuroinflammatory pathways. (Khan et, al. 2019) [25]

Figure 18 shows the results of modelling using traffic analysis software which compares the average CO_2 levels resulting from traditional T-junctions compared with the predicted average CO_2 emissions

from the XT junction design. The graph shows that CO_2 levels are predicted to be lower with the new design. Further modelling forecasts that the XT junction would reduce the CO_2 emission by 10% for non-congested existing T junctions and by more than 35% for congested T junctions.

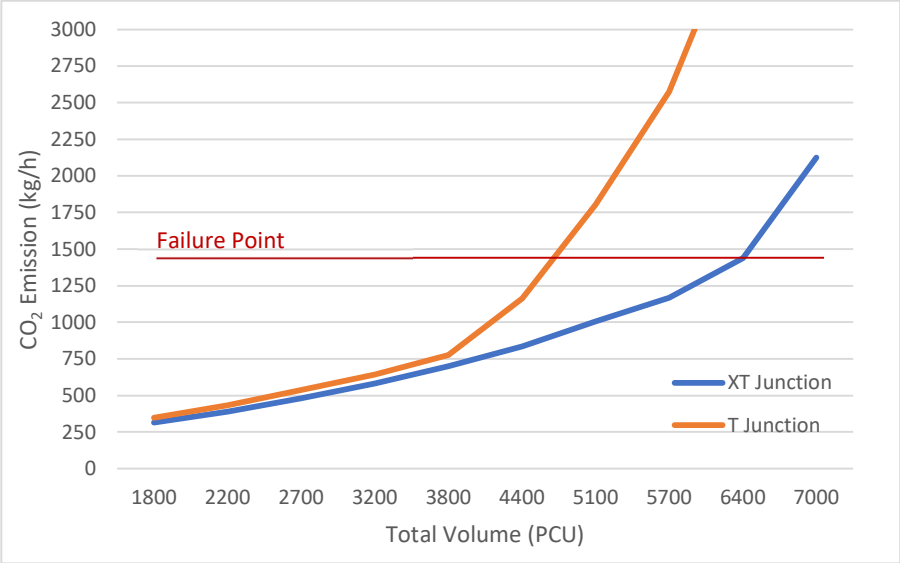


Figure 18: CO_2 comparison graph.

As such, a reduction in CO_2 emissions may have a slight beneficial impact on both respiratory and mental health in the community where XT junction is implemented. These positive impacts are likely to be more beneficial to human health the more that XT junctions are rolled out throughout the UK to replace standard T junctions to create a cumulative effect.

5.4 Severance

5.4.1 Severance overview

Severance is defined as the separation of residents from facilities that they use within their community that is caused by a substantial change in transport infrastructure or change in traffic flows. (TAG, 2022) [31] Severance will only be an issue where either vehicle flows are significant enough to substantially impede pedestrian movement or where infrastructure presents a physical barrier to movements. Severance primarily concerns pedestrians, as cyclists generally move around the transport network differently.

5.4.2 Qualitative appraisal

Implementation of the XT junction in place of a traditional T-junction has the potential to improve vehicle flow because of the increased junction capacity and reduced congestion. Therefore, it may be slightly easier for users to access community facilities because of its implementation due to improvements in pedestrian's ability to navigate the junction more efficiently. However, this is heavily reliant on the location of implementation of the design and relative local transport and roads.

Introducing pedestrian footways at the junction, with signalised pedestrian crossing facilities on each arm would improve pedestrian movements. This could mitigate the issues of severance for active travel users created by busier and more unsafe T-junctions, encouraging active travel and likely enable people to choose more sustainable modes.

5.5 Journey quality

5.5.1 Journey quality overview

Journey quality is a measure of the real and perceived physical and social environment experienced while travelling. This section will only consider route uncertainty as part of this impact in accordance with the function of the intervention. Journey quality factors can influence travel choices, with poor journey quality potentially dissuading individuals from making journeys on certain modes of transport, while good journey quality often goes unnoticed and becomes something that is expected. (TAG, 2022) [31]

5.5.2 Qualitative appraisal

Initially, and due to the scarcity of this type of junction in the UK, the XT junction may cause some confusion and anxiety for its users. Studies have shown that first impressions of a new junction design plan usually include users expressing their concern for the seeming complexity of attempting to drive through the new road layout. Nevertheless, when drivers have been interviewed after using new junction designs, this concern is often lifted. (U.S. DoT, 2014) [13] This may be due to lack of experience and education on the new junction design, so is likely to be an initial perceived concern, rather than a long-term impact. Therefore, this anxiety should reduce as junction implementation and use becomes more prevalent.

The XT junction provides an opportunity to increase the capacity of the junction by around 30% depending on location, traffic distribution and the presence of other types of travel modes. This should reduce user stress by easing congestion and delay (as shown in Figure 19) and decreasing journey time, improving journey quality. Decreased congestion should in turn decrease route uncertainty for users.

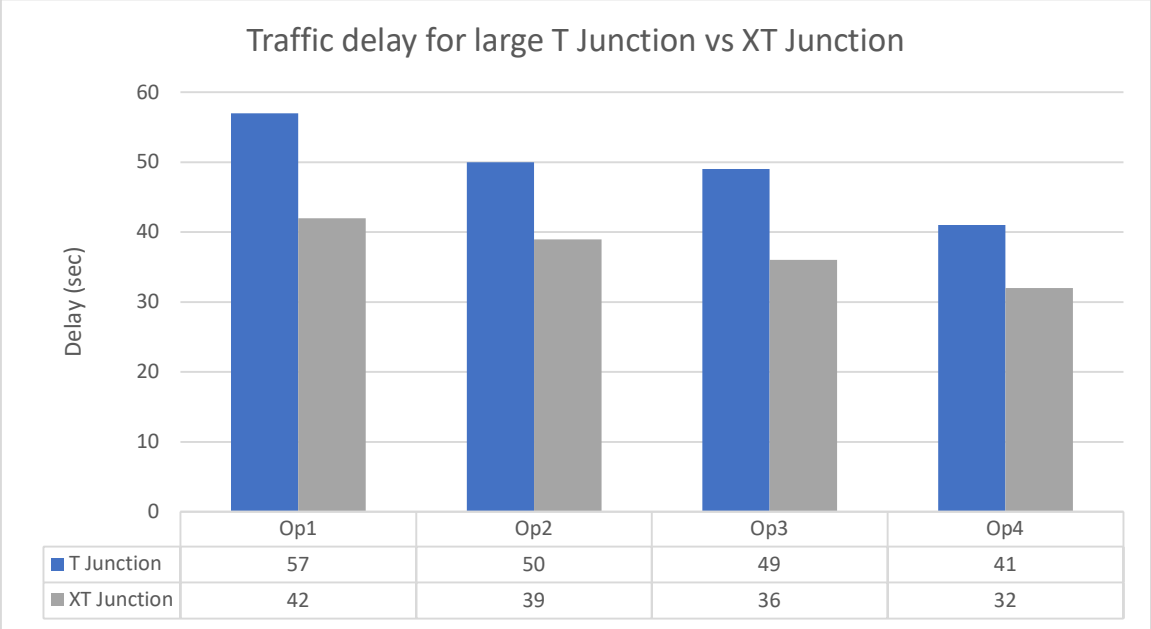


Figure 19: Comparison in traffic delay times between a classic large T Junction and XT Junction.

5.6 Accessibility

5.6.1 Accessibility overview

Accessibility impacts can be experienced by more vulnerable residents, such as those with disabilities and older residents. Residents without access to a private car, disabled people and the elderly can become more reliant on public transport, walking and cycling, or lifts from friends and family; these networks can often lead to social exclusion. Accessibility covers availability and physical accessibility, cost, services, safety, and travel horizons.

5.6.2 Qualitative appraisal

The XT junction has the potential to make it easier for people to travel by bicycle and walking as well as for those in motor vehicles if active travel routes and accessible pedestrian infrastructure is included. If active travel facilities are not included in the implementation of the design, accessibility for non-motorised users could become more difficult than a traditional T junction due to the additional complexity of the road. More complex road environments create a greater cognitive load, and such changes may impact groups particularly sensitive to the changes in visual stimuli including older people and disabled people, particularly those with autism.

XT junctions would decrease congestion. Research shows that traffic can present a barrier for disabled people accessing community resources. National Travel Survey data shows disabled people are generally more likely to experience travel difficulties in the daily trips that they make. (DoT, 2019) [24] Disabled people who travel by car are more likely to report difficulties due to congestion and roadworks. (DoT, 2017) [19] A reduction in congestion could slightly reduce these difficulties, helping to tackle feelings of loneliness and social isolation. (Equality and Human Rights Commission, 2017) [20] It is important to note that these positive accessibility benefits may only be experienced as a cumulative impact of XT junction being implemented throughout the locality and would also be dependent on other transport facilities in the local area.

Table 6: Barriers to accessibility.

Barrier to accessibility	Assessment
Availability and physical accessibility of transport	There is the potential for a slight beneficial impact on the availability and physical accessibility of active travel options should walking and cycling infrastructure be included in the junction design. This could also help more vulnerable people with accessing nearby public transport dependant on the location of the junction. This will only be the case if the cycling and pedestrian infrastructure is provided alongside the XT junction.
Cost of transport	There are no expected changes to the cost of transport.
Services and activities located in inaccessible areas	The XT junction design would improve connectivity by reducing congestion and delays. This could make education, employment, and community facilities slightly more accessible from a wider range of transport mode options.
Safety and security	There is expected to be a beneficial impact on safety because of the XT junction design due to traffic and reduced stop-start traffic. Vehicle speed should also be reduced due to the crossover movement of the junction. If

	pedestrian and cycle infrastructure is included as part of the junction, safety may also increase for these user groups.
Travel horizons	There are no expected changes to the travel horizons of those using the junction.

5.7 Conclusion

To conclude, it is expected that the XT Junction design is likely to have beneficial social outcomes overall, when compared with a traditional T junction. This is due to the crossover (X) feature leading to reduced conflict points and potentially increasing road safety and reducing accidents, whilst reducing CO_2 levels, and creating potential for cumulative health benefits within local communities. An estimated average capacity increase of 30% should also improve journey quality by slightly decreasing congestion and journey times. In addition to this, a reduction in congestion could slightly reduce accessibility difficulties, helping to tackle feelings of loneliness and social isolation in the community.

It must be reiterated, however, that all the above benefits would only be slight, if not at all, based upon the use of only one XT junction in a locality due its triviality relative to the wider highway network. XT junctions would have to be rolled out on a larger scale to replace T junctions throughout a locality or geography for a tangible beneficial social impact to be realised.

Furthermore, additional benefits listed in the main chapters above are in part or wholly reliant on the inclusion of active travel and pedestrian infrastructure. Therefore, if these features are not included in the implementation of an XT junction, social impacts would be greatly reduced.

5.8 Recommendations

This chapter is a very high-level appraisal of the anticipated social outcomes of the XT junction design. As the XT junction is currently in the early stages of research and development, and the existing UK continuous flow intersections are mainly predicated on the principle of improving vehicular traffic flows, it would be appropriate to re-assess the social outcomes if it were to progress to implementation within a project or scheme. With a location-based study area for the XT junction, a more extensive assessment could look further into the equality and distributional impacts on different characteristic groups within the locality that are protected under the Equality Act.

6 Conclusions

This report has investigated the potential benefits and disbenefits of The XT junction concept - a new Displaced Right Turn design, reimagined and re-engineered to meet a modern transport agenda and in support of the UK's target of net zero carbon emissions by 2050.

The two existing UK junctions most like the XT concept are predominantly intended to deliver improvements in traffic flow and prevent congestion. However, this study has determined that it may be possible to better use the capacity benefits inherent in the DRT concept to deliver benefits to both active travel users and vehicular drivers in a more equitable and holistic way.

This study has demonstrated that an XT junction has the following advantages over an equivalently sized conventional T junction:

- Reduced congestion and delay – up to 33% capacity improvement.
- Up to 100% traffic signal cycle time savings.
- Reduced conflict points – which should lead to improved safety.
- Improved conditions for active travel modes.
- Reduced severance due to improvements to pedestrian crossing facilities.
- CO_2 emissions cut by 10% for non-congested T junctions and 30% for congested T junctions.
- Also delivers similar congestion relief benefits as bridges/flyovers or tunnels for much less cost.

Some potential disadvantages:

- Confusion – especially among vulnerable user groups.
- Potential for greater land requirement.
- May be more costly than conventional means of improving standard T junctions.
- Limited UK evidence around safety available.
- Greater uptake required for delivering tangible social outcomes.

As there is limited safety data available for the two existing UK CFI junctions, additional work and/or testing and practical trials are required to definitively establish the safety credentials of the design – particularly when considering the extended active travel features and facilities proposed by the XT solution.

It has been shown that the physical area required to implement an XT solution can be greater than that for a conventional T junction – particularly when factoring in the need to provide auxiliary bypass or filter lanes, and effective segregation for active modes. However, in many cases, the land required can be around the same as that required for a large roundabout. In this respect, there are likely to be numerous additional locations in the UK which currently suffer congestion, severance, poor active travel provision, and safety issues that could benefit from the introduction of an XT junction solution. Indeed, the presence of two similar intersections currently operating successfully in the UK demonstrates that these challenges are not entirely insurmountable. But like all traffic engineering solutions, the viability of a fully configured XT junction is highly dependent upon location specifics such as available land, local priorities and policies, pedestrian and cycling demand, safety records and justification via a robust economic evaluation/business case.

The potential for a positive social impact with the introduction of an XT junction over that of a conventional T junction has also been established. However, to realise any tangible benefits in social value, the XT junction would need to be rolled out on a much larger scale such that a positive cumulative effect can be obtained.

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