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Work Stream 5 - Literature Review looking at Dutch Style (fully segregated) signalised junctions

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Executive summary

This report presents the findings of a literature review carried out by TRL on behalf of TfL, investigating the topic of the 'Dutch style junction'. This style of intersection design was later defined as a fully segregated signalised junction to avoid the misunderstanding that can be caused by infrastructure design branded as being Dutch style.

Dutch style signalised junctions have a few key design attributes;

- Segregation of the approach to the junction
- Separation islands on the corners of the junction to protect cyclists movements
- Clear cyclist driver indivisibility on the exit of the junction.

Along with the junction layout design considerations, this literature review has also looked at the signal timings used on these junctions. Delay to cyclists and the chance of them having to stop are both key considerations when setting signal timings for this style of junction in Holland.

When considering how this style of junction would work on the UK highway one of the key concerns is that of the pedestrian crossing facilities. Not only do they need to cross a cycle lane uncontrolled, but the segregation between the cycle lane and the carriageway is an area that requires further design consideration.

When looking at the available evidence of this style of junction it is clear to see that there needs to be further work and research to understand exactly how this style of junction would operate will all aspects of a typical UK urban network, as well as understanding the perceptions and resultant behaviour of UK cyclists when faced with this design of facility.

1 Background

This literature review is focussed on the so-called 'Dutch Style Junction'. This is a loosely defined term for a junction design specifically suited to segregating cyclists on the approach to the junction on all arms. This style of junction continues the segregation into the junction, rather than integrating the cyclists back into the stream of motorised vehicles, so a more precise term would be 'Fully Segregated Signalised Junction'. To avoid ambiguity the latter term will be used in this report. An additional report has been produced to cover the topic of ways of turning right for cyclists at traffic signal controlled junctions. This reports reference is Crabtree, M R (2013). Ways to turn right for cyclists – a literature review.

This approach to junction design has been present in Holland in various forms for many years, however during this literature review it has become clear that there has been little published research into this specific junction layout. As a result this review has focussed on some of the design characteristics of the Fully Segregated Signalised Junction. For example, the segregation through the junction, the pedestrian and cyclist interactions and intervisibility between cyclists and drivers of motorised vehicles as a result of the displacement of the cycle route when crossing the side road. This review has also looked at the types of interactions between user groups that this junction configuration aims to mitigate.

Analysis of London cycle accident data for 2010 shows that 24% of pedal cyclist collisions took place at signal controlled junctions (TfL Fact Sheet 2011-1 Pedal cyclist collisions and casualties in Greater London). Analysis also shows that the mid junction area is the most dangerous with 61% of the collisions being recorded at this point (Bedingfeld et al, 2011). Furthermore, in over 75% of cyclist collisions, 'failed to look properly' was noted as one of the contributory factors (also referred to in other literature as 'looked but failed to see' errors: Reynolds et al, 2009; Herslund & Jørgensen, 2003). These figures are for all collisions involving cyclists, rather than specifically those collisions that took place at a signalised junction. Even so, this suggests that the intervisibility between drivers of motorised vehicles and cyclists is an important consideration when designing for safe infrastructure including intersections. Unfortunately corresponding collision figures for the Netherlands are not available.

In order to ensure safety and comfort of cyclists in The Netherlands, the CROW design manual for bicycle traffic (2007) recommends using Traffic Control Systems (TCS) at intersections where between 10,000 and 30,000 passenger car units per day (pcu/day) need to be handled. TCS have the effect of reducing the number and severity of cycle-motor vehicle collisions by reducing the difference in speed between the two modes at junctions. TCS at an intersection can include a signal, advance detection such as inductive loops or microwave detectors, and a bicycle push button. Specific bicycle signals such as advance green lights and advanced stop lines also improve safety at junctions as they can reduce conflicts with vehicles. However TCS can also significantly impede the flow of cyclists. The CROW manual recommends that "an average waiting time of less than 15 seconds is good, while one of more than 20 seconds is poor." This can be also be seen on the graph shown in figure 6 of this report. When a cyclists is forced to stop (chance of stopping is 1 on the graph) a 15 second wait time is deemed to be acceptable, whereas a wait time in excess of 20 seconds is deemed to give poor cyclist service at the traffic signals. Where the chance of stopping is decreased the length of stopped time can be increased to still fall within acceptable tolerances. Section 2.8 of this report looks at possible stage sequences for running a fully segregated junction. The Dutch guidance on acceptable stopped time and chance of stopping can play a part in deciding which stage sequences are acceptable whist maintaining a good level of service for all road users.

The Dutch Design Manual for Bicycle Traffic (the 'CROW manual', CROW 2007) states that it is important to consider priority when it comes to developing TCS policy, for example, "a basic principle that can be applied is that main cycle routes have right of way at intersections inside the built-up area."

Dutch guidance for junction design differentiates between lower speed roads (<70kph) and higher speed roads. For the former, recommended designs take cyclists through the junction with other traffic, albeit with different lanes and signal phases. For the latter, guidance recommends taking the cyclists away from the junction, with separate crossing facilities, or even grade separation to avoid potential conflicts.

The CROW manual (2007) highlights the point that traffic lights are usually installed to ensure the quick and safe flow of motorised traffic and thus on intersections where motorised traffic is dominant, traffic lights are designed primarily for this. However, as a result the time available for slow traffic is often limited at intersections with traffic lights, resulting in long waiting times for cyclists and pedestrians. Research on behalf of the Dutch Bicycle Council concluded that this was often unnecessary and there are measures that can prevent it (Ede, Fietsberaad, 2003). The research at 24 intersections in provincial capitals has proven that green light times for motorised traffic at many intersections are set too long 'as a precaution'. In many cases it proved possible to set a shorter cycle time, which not only improved the flow of bicycle traffic, but also that of other vehicle types. It identified cycle friendly control as being no longer than 90 seconds, with the generally accepted time of 120 seconds for motorised traffic therefore being too long.

It is not always possible to provide for all movements of cyclists at junctions and therefore it may be necessary to permit sub-conflicts between motor vehicles and bicycles in a situation with traffic lights. This may be to reduce waiting times or due to lack of space. Such sub-conflicts must only be permitted between cyclists continuing straight on and motor vehicles turning off from the parallel traffic flow (or vice versa). Good visibility of cyclists is of crucial in these circumstances. The CROW manual (2007) does not recommend allowing sub-conflicts between motor vehicles and bicycles if:

- The intensity of motorised traffic turning off is higher than 150 pcu/h
- A two way cycle track is involved, as some of the cyclists will then appear from an unexpected direction
- There are large volumes of lorries turning right (because of the risk of a blind spot accident).

The crow manual offers a clear separation between different road classes and the subsequent requirements for different cycle facilities to be installed in these environments. Where the road provides a distributor function, for example a district access road or main road in the UK, specific bicycle facilities should be included. The design of these facilities varies to some extent on the space available but more importantly the predicted cycle demand. The Crow manual gives the options in two different tables, one for roads in the main urban ‘built-up’ areas, and the other for roads outside of the urban centres. These tables have been reproduced in Appendix 1. Throughout all of the guidance in the crow manual on the different measures that can be applied to the highway, the emphasis is always on there being a judgement made by a qualified individual that results in a network that is safe and attractive to use for cyclist. Naturally the balance that needs to be struck in the decision is making the right choice for the network as a whole.

It is not only Holland that uses this style of junction, Denmark also have junctions that use the fully segregated design to protect cyclists. Naturally Danish design, road use etiquette and legislation is all slightly different to that of Holland, however the principle of their fully segregated junction design is similar. Danish cycling guidance (Collection of Cycle Concepts, 2012) refers to signalisation as having a highly favourable impact on safety outside the intersection as well as the intersection; specifically in urban areas the beneficial effect is approximately 1.5 times greater than the benefit at the intersection itself. Evidence from analysis of accidents before and after the introduction of segregated cycle networks alongside highways in Copenhagen suggests that there was a disproportionate increase in accidents at junctions (Jensen et al, 2007). This has driven the development of methods for improving separation (by time or space) between cyclists and other traffic through junctions. One of the types of collision that saw the biggest increase is that of right turning (left in the UK) traffic and cyclists. The report does not pin point the cause of this increase however it would be reasonable to assume that the removal of cyclists on the links between junctions goes some way to removing them from the thoughts of drivers, therefore any cyclists that are integrated within the traffic flow may be positioned in areas of the carriageway that drivers are not expecting them to be occupying. Likewise the increase in incidents could be a result of the interactions where a cycle track crosses a side road, where this crossing is uncontrolled, poor judgement of gaps in traffic could lead to the increase in collisions seen.

Research by Jensen (2009) found that converting non-signalised junctions to signalised junctions has safety benefits in that it significantly reduces right angle crashes although it does appear to contribute to an increase in rear-end crashes. They also found that at converted four armed intersections there was a decrease of nearly 30% in bicycle and moped incidents.

Fully segregated signalised junctions are just one of many approaches that can be used to make signalised junctions friendlier to cyclists. Dutch design guidance (CROW) describes other methods such as early green phases for cyclists, free right turns and multi-stage turns.

2 Design

The fully segregated signalised junction combines separate signal phasing for cyclists with a degree of physical segregation within the junction. In the example shown in Figure 1 cycle lanes are marked across each of the four arms, creating a box-shaped 'orbital' cycle lane, with various forms of physical segregation to protect waiting cyclists from turning motor vehicles during the main traffic phases in the cycle. A cyclist turning left (equivalent to right in the UK) would proceed around in an anti-clockwise direction until they reached their exit. Different approaches can be taken to phasing the cyclists, in urban areas an 'all-green' phase would be commonly used so that cyclists on all arms proceed at the same time (it would be expected that signalling arms individually for cyclists would have significant impacts on junction capacity). Furthermore, at some locations, a right-turn on red is permitted for cyclists, permitting some cycle movements outside the main cycle phase. It would not always be the case that cyclists would be expected to follow the cycle lanes- at many locations left turning cyclists would take a diagonal path directly across the junction instead.

A video showing a junction in Groningen with many of the above features is available from the Fietsberaad website www.fietsberaad.nl[1].

Potential difficulties include how pedestrians are managed, and conflict between different flows of cyclists crossing each other's paths. It is not clear from Figure 1 how pedestrians are provided for. The Groningen video appears to show 'zebra' type markings but it is not clear what priorities are in place. Observation of the video suggests that conflicts between cyclists and pedestrians, and between cyclists and other cyclists, are managed informally through negotiation between individual road users; akin a shared space situation.

Figure 1 – Image of fully segregated signalised junction taken from YouTube video http://www.youtube.com/watch?v=FlApbxLz6pA

[1] A direct short URL to the relevant page is http://tinyurl.com/dutchcycleallgreen

Although designs vary, there are a number of commonly-found features of the design of these junctions, as described by McIntyre and Murphy (2011):

- Corner Island
- Pedestrian Platform
- Stop Line Location
- Road Markings

These are discussed in greater detail below.

2.1 Corner Island

As previously mentioned, these types of junction in the Netherlands often have a ‘corner island’ (shown in Figure 2) on each corner of the intersection. The principle of these islands is that they provide a physical barrier between the cycle track/lane and the road where motor vehicles are present, making cyclists more comfortable.

The corner islands help protect cyclists turning right in the Netherlands (left in the UK) but also help to ensure safety at crossings as the slight curves they create in the cycle track improves visibility of those cyclists going straight on. The curve in the cycle track caused by the islands also acts to slow down the speed of cyclists at junctions, reducing the likelihood of a collision with motor vehicles. Considering how these corner islands might be perceived by cyclists in the UK, there is the potential that the deviation of the desire line might encourage cyclists to use the main carriageway along with motorised traffic to maintain momentum through the junction.

In terms of the interaction between cyclists travelling straight across a junction and motor vehicles turning right, the corner islands force the car to meet the cycle crossing at a right angle, dramatically increasing visibility of cyclists. The layout in Figure 2 includes marked pedestrian crossings, parallel to the cycle lane.

Figure 2 - Image highlighting the presence of a corner island

(http://wiki.coe.neu.edu/groups/nl2011transpo/wiki/ba51e/Dutch_Intersection_Design_with_Cycle_Tracks.html)

2.2 Pedestrian Platform

Figure 3 also shows a pedestrian platform adjacent to the corner islands on the traffic side of the cycle track/lane. This provides a safe place for pedestrians to queue up when crossing, avoiding the need for them to wait in the cycle lane. The shape of the pedestrian platform depends on the corner island. If the corner island is small, there will not be a wide pedestrian platform. The curve of the turn itself can also determine whether there is room to have a tapered pedestrian platform. Clearly a small pedestrian platform would not be suitable for very high pedestrian flows, which may limit applicability in central London.

Figure 3- Photograph of a pedestrian platform

(http://wiki.coe.neu.edu/groups/nl2011transpo/wiki/ba51e/Dutch_Intersection_Design_with_Cycle_Tracks.html)

2.3 Stop Line Location

Often in the UK, cyclists and motor vehicles have the same stop line or only a short distance between, putting cyclists at more of a disadvantage at junctions. However, many Dutch signalised junctions have a stop line for cyclists that is ahead of the stop line for motor vehicles (shown in Figure 4). This enables slower moving cyclists to have already passed through the junction by the time the motor vehicles enter the junction. The setback of motorised traffic behind cyclists also assists them in making turning movements. This is of benefit in terms of reducing conflicts between cyclists travelling straight on and motor vehicles turning right in the Netherlands (left in the UK). When there is a green light for both approaching motorists and cyclists, the distance between the stop lines significantly increases the visibility of the cyclist to the motorist when they are looking ahead towards the area of conflict.

Figure 4 – photograph of a junction showing separation between bicycle stop line and the motorised traffic stop line.
http://wiki.coe.neu.edu/groups/nl2011transpo/wiki/ba51e/

Figure 5 - Different stop line locations for cyclists and motor vehicles also illustrating the use of Elephant feet and Sharks teeth road markings (Source: http://wiki.coe.neu.edu/groups/nl2011transpo/wiki/ba51e/)

2.4 Road Markings

Two main types of road markings are used at fully segregated junctions: Elephant feet and Sharks teeth. The Elephant feet markings indicate the presence of a crossing approaching both to motor vehicles, alerting them to slow down and beware of cyclists, and to cyclists, alerting them to be cautious of motor vehicles approaching. The Sharks teeth markings inform the both approaching cyclists and motorists that they must give way to intersecting traffic. Figure 5 shows examples of each. Sharks teeth are not covered in The Traffic Signs Regulations and General Directions 2002, Elephants feet markings are an approved marking (diagram 1063), however require DfT approval before implementation.

2.5 Cycle lanes through junctions

Clearly defined cycle route through junctions are a key element of the fully segregated signalised junction. These are usually red in colour in the Netherlands. In Denmark these are blue. The principle behind coloured cycle lanes through junctions is that, by marking the area of conflict between motor vehicles and cyclists road, users will pay closer attention to this conflict. Cyclists are also given clearer guidance on the route through the junction area. Jensen (2008) carried out a before and after accident study of blue cycle crossings at signalised junctions in Denmark and found that the safety effect of these crossings depends on the number of them at the junction. The use of one blue cycle crossing was found to reduce the number of incidents at the junction by 10%; however the use of two and four blue cycle crossings had the effect of increasing the number of incidents by 23% and 60% respectively. These results were primarily related to rear-end collisions and collisions with right turning motor vehicles. It appears that too many blue cycle crossings result in motorists having too much focus on the pavement or cyclists and therefore pay less attention to traffic signals; the number of incidents involving red-light driving motorists increased. It was also found that the more arms there were to a junction the poorer the safety effect of the blue cycle crossings.

Hunter (2000) also investigated road user behaviour before and after the implementation of blue cycle crossings in Portland, USA. They found that significantly fewer cyclists looked out for motor vehicles or used hand signals following the use of blue crossings, potentially reducing their awareness of other vehicles in the junction. However; motorists also altered their behaviour, with more slowing or stopping on approach to a junction with the blue markings. The study reported that 76% of cyclists and 49% of motorists using junctions with blue cycle crossings felt they were safer. Similarly in Copenhagen, Jensen (2006) found that cyclists reported a lower level of perceived risk, were more comfortable and more satisfied when blue cycle crossings are present at junctions.

2.6 Angle of Turn

The normal geometry of Dutch cycle track crossings ensures that motorists and cyclists are at 90 degree angles, meaning that each can clearly see the other. Typically, Dutch junctions have a much tighter turn than those in Britain and this forces motorists to reduce their speed almost to a complete stop, giving them time to assess any pedestrian or cyclist crossings and thus reducing both the risk of a collision and the severity should one occur.

2.7 Raised Exits

Gårder et al (1998) have found in a study in Sweden that more bicycle collisions occur at locations where cycle lanes intersect with side roads than where there are no cycle facilities. However, by raising exits and crossings (either pedestrian or cyclist) at junctions, cyclist crashes were reduced by 33%. The study also found that crossing facilities at intersections had a more positive effect on the number of crashes involving pedestrians than crossing facilities on road sections.

In the Netherlands, where a cycle lane crosses a minor road, it is recommended that it is elevated in order to reduce the speed of motor vehicles turning into or out of the minor road and this reducing likelihood and severity of any collision.

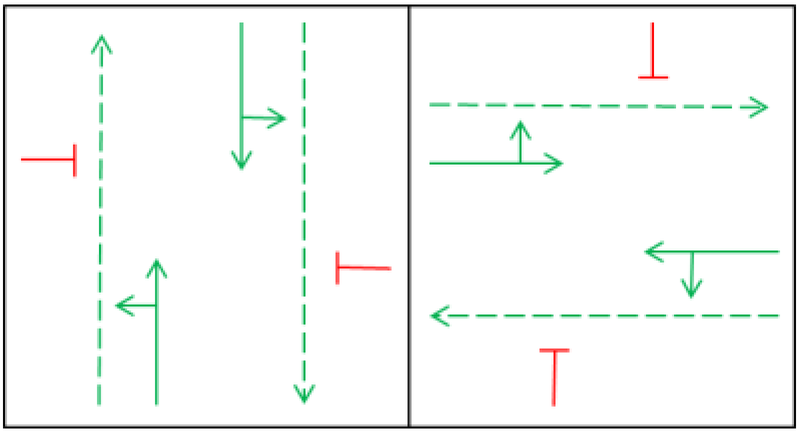
In the Netherlands, crossings are generally a continuation of footway and cycle tracks and thus are elevated compared with the road level. This means that the motorist has to reduce their speed turning into or out of the minor road and stop before then driving up on to the pavement thus reducing likelihood and severity of any collision. Comparatively, in the UK it is typically the pedestrians or cyclists who have to stop and then cross the side road. No evidence has been found to suggest that raise tables have a positive or negative impact when combined with a signal controlled crossing, however the CROW manual makes many references to the use of raised tables, or plateaux, for the purpose of speed reduction of motorised traffic within the junction.

2.8 Traffic signal control

When considering how a fully segregated signalised junction can operate from a signal timing perspective it is clear that there are a few different options. Firstly it should be noted that there are two options with regard to control of the cyclist's movements, either priority (gap acceptance) or signal controlled. Both strategies for cyclists control are widely used in Holland. The Design Manual for Bicycle Traffic (Crow 2007) does not state the preferred stage structure for running the signals at a fully segregated signalised junction, instead this appears to be determined on a junction by junction basis. The design manual does however, give various guidance to signal engineers to help them ensure that the stage structure chosen is suitable for bicycle traffic. This guidance is based around waiting time and the probability of having to stop; so that the end result is a signalised junction that is bicycle friendly.

2.8.2 Cyclists running with traffic, turning traffic giving way to cyclists on the exit

Example stage structure

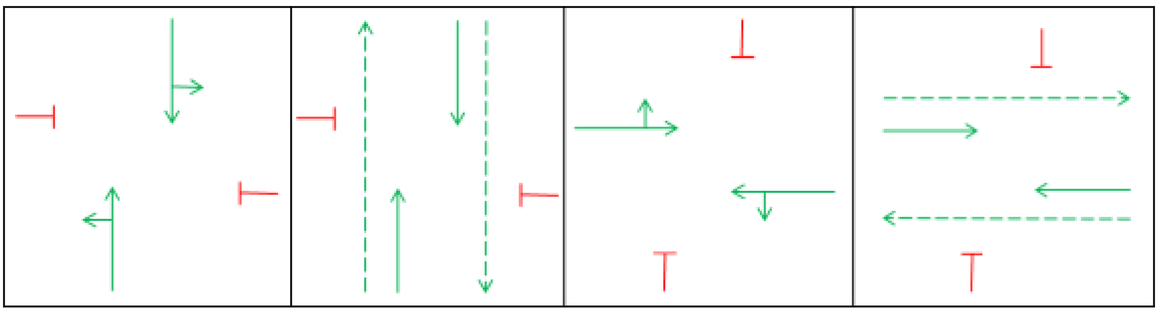


Cycle movement shown as dashed arrow

The stage structure that is used on this style of junction is not a restricted design. There are examples where cyclists will be given a green signal at the same time as a motorised traffic movement. If this signal stage sequence is used in Holland the junction staging is often run anti-clockwise around the junction. This means at a signal controlled crossroads when one stage is terminated the next stage in the sequence is the one to the right. Naturally in the UK this would run in the opposite direction due to us driving on the left hand side of the road. What this achieves is a reduced delay for cyclists turning left (right in the UK) because in two consecutive stages a cyclists should be able to make a left turn. This principle works in a similar way to the two stage right turn investigated in Work Stream 6.

2.8.3 Cyclists running with traffic, turning traffic giving way to cyclists on the exit

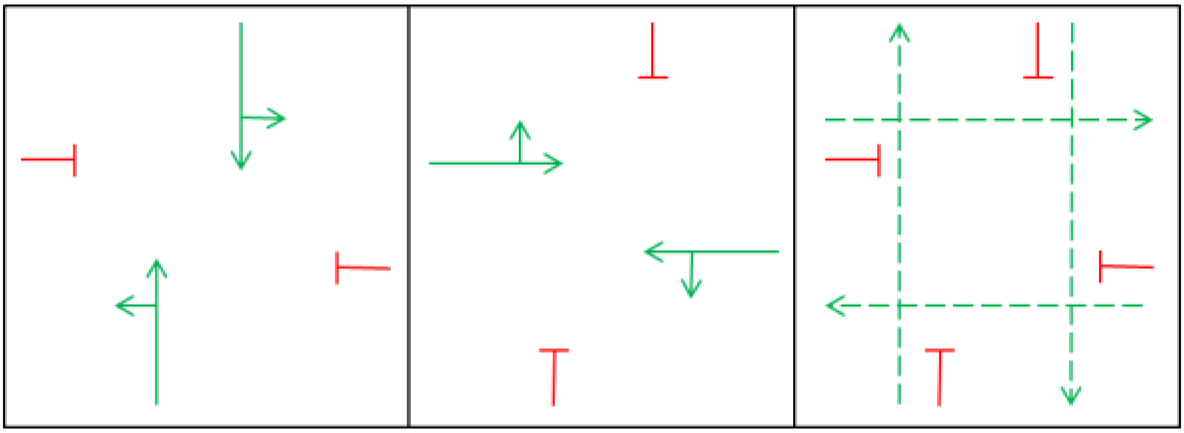
A possible variation to running cyclists in conflict with motorised traffic is to hold the left turning traffic when the cyclist movement is being run. An example stage structure of how this might work can be seen below.



Cycle movement shown as dashed arrow

2.8.4 All round cycle stage

Example stage structure



Cycle movement shown as dashed arrow

Evidence suggests, however, that cyclist traffic phases are not always run at the same time as vehicle traffic. If this is the case then design work must be undertaken to keep the delay to cyclists to a minimum and reducing the number of times they are likely to have to stop. One such method could be to run the cycle movements as designated stages, and coordinating the cycle stages at adjacent junctions to manage progression for cyclists based on their average cruise speed.

2.8.5 Stops and delay

The probability of having to stop is determined by dividing the red light time by the cycle time to determine the proportion of the cycle that an approaching cyclist will experience a red signal. Naturally the number of times a bicycle phase is run and the cycle time set will both play a huge part on this calculation. The waiting time is calculated to understand how long a typical cyclist will have to wait when the signals are on red. The average waiting time for a fixed set of signals is simply half the red light time, in non-fixed time signals is a little more complicated as this will fluctuate throughout the day. The maximum waiting time is the maximum red light time.

The relationship between the probability of a cyclist having to stop and the average wait time is presented in a table showing a clear division for 'good', 'moderate' and 'poor'. This gives engineers a means to check the impact of their signal design decisions, and provide corrective action if necessary. CROW (2007) states that maximum waiting times in built up areas should be less than 90 seconds, whereas outside built up areas this maximum wait time should be kept below 100 seconds. In certain situations this may preclude the use of an all-round cycle phase, and require the cyclists to be run with motorised traffic phases. Generally The Netherlands accepts signal cycle times of approximately 120 seconds when only considering motorised traffic; however CROW makes it very clear that this is not acceptable where cyclists are concerned. At a busy intersection where a cycle time of greater than 120 seconds is required it is clear that multiple bicycle phases per cycle are necessary, whether this be fixed or on a demand dependant basis via bicycle detection.

The interactions of cyclists with pedestrians needs to be considered here too. Where cyclists are expected to give way to pedestrians then these phases can be run together keeping the junction cycle time lower and therefore keeping the waiting time to cyclists within acceptable tolerances. In Denmark a similar design of junction works by running cyclists with pedestrians, however, in Denmark it is a culturally accepted practise to give way to pedestrians on the crossing. Adoption of a similar policy in the UK would require significant publicity and behavioural change in order to operate safely.

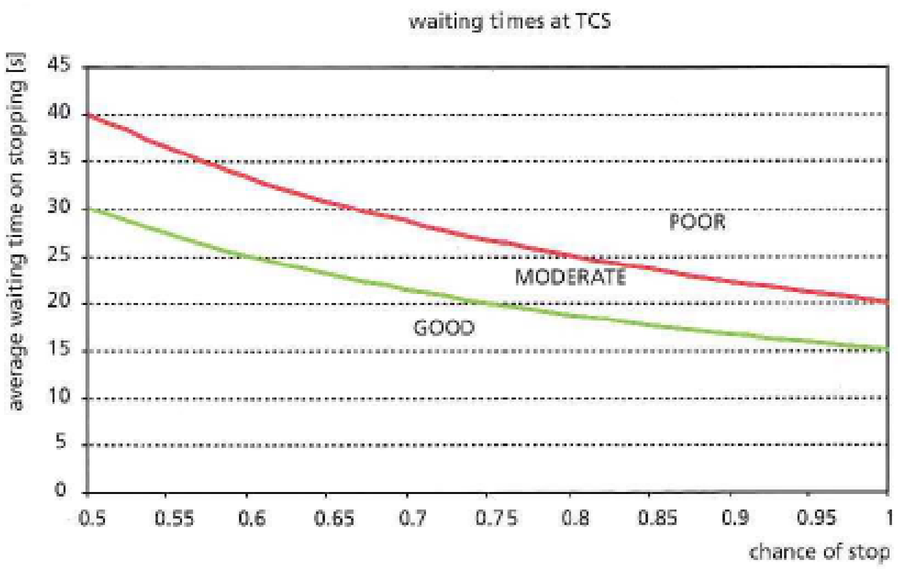


Figure 6 – Graph showing the relationship between the chance of stopping and average waiting times for cyclist at traffic signals

Source: Design Manual for Bicycle Traffic, CROW 2007

2.9 Width of cycle tracks

The Design Manual for Bicycle Traffic states minimum widths of cycle tracks on the basis of bicycle throughput and minimisation of delay due to oversaturation. These widths are:

- 1.00metres wide up to 3,300 cyclists per hour
- 1.80metres wide up to 4,700 cyclists per hour

No details are given in the Design Manual for Bicycle Traffic as to where these figures came from, however their application in London should be used with caution. London's roads are very different to those in the Netherlands, and cyclist behaviour is also likely to be different.

3 Cyclists and pedestrian interactions

The junction layout shown in Figure 7 guides cyclists away from the centre of the junction as they cross side roads. This movement locates ahead cyclists in close proximity to pedestrians, as such the interactions between cyclist and pedestrians in this layout is crucial. The Fact Sheet produced by SWOV (2010) on crossing facilities for cyclists and pedestrians reports that in Holland more than half of serious crashes (with fatalities or inpatients) in which cyclists or pedestrians are involved occur while crossing the road, an estimated 32% of these crashes occur on crossing facilities. However if the numbers of serious crashes are considered alongside the numbers of cyclists and pedestrians using these facilities it is clear that in general these crossings are relatively safe.

Figure 7 below shows a junction in Utrecht in the Netherlands. It is clear from this example that the cyclists and pedestrians each have their own crossing area as part of this design, however there is interaction between cyclists travelling in the cycle lane perpendicular to the flow of pedestrians. The fact sheet produced by SWOV (crossing facilities for cyclists and pedestrians, 2010) states that there should only be one priority rule at facilities used by both pedestrians and cyclists, the options for this rule are; both parties have priority, neither party has priority or both have traffic lights. Where either movement has priority then clear road markings should be used to communicate this message. At this junction the pedestrians have a designated pedestrian phase to give them priority to cross each arm of the junction. This priority only takes them across the traffic and tram movements not the cycle track. To cross the cycle track there appears to be no markings to highlight priority to either pedestrians or cyclists so in this instance neither have priority over one another, however both cyclists and pedestrians are given priority over traffic and trams through the use of traffic signals specific for each movement. This can be seen in Figure 8.

Figure 7 - Junction of Beneluxlaan and Van Heuven Goedhartlaan in Utrecht Netherlands

Figure 8 - Image of the cycle and pedestrian ‘interaction zone’ at Junction of Beneluxlaan and Van Heuven Goedhartlaan in Utrecht Netherlands
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4 Blind spot crashes

A particular issue at junctions is the vulnerability of cyclists to heavy vehicles. Knowles et al (2009), Kim, et al (2007) and McCarthy and Gilbert (1996) found that, while most cycle accidents involve a passenger car, a high proportion of serious injuries at junctions involve heavy goods vehicles. Most such incidents occur during manoeuvres, in particular during left turns and at roundabouts or at junctions with traffic lights where cyclists get the green light simultaneously with other traffic (SWOV Factsheet: Blind Spot Crashes, 2012). Robinson (1995) found that around half of HGV accidents resulting in cyclist injury occur when the HGV is travelling at less than 10 mph. This suggests that relative positioning and visibility of the cyclist may be a key factor in these incidents. Thus segregation at junctions would be beneficial.

One method that appears to be effective in reducing cyclist injuries at signalised junctions is to reduce the speed of traffic through junctions; with physical calming methods are a reliable means of achieving such a reduction. These have several manifestations:

- Blue crossings- increase awareness and slow motorised traffic
- Raised exits/ crossings- reduces speed increases assessment time and reduces collisions
- Angle of turn- sharper turns force a reduced motorist speed

5 Scramble alternative

The CROW manual does not specifically discuss the fully segregated signal controlled junction. Instead it makes some specific suggestions for maintaining segregations through signal controlled junction for given circumstances.

The CROW manual mentions an all-round green for cyclists as an alternative to the box turn. This is where cyclists from all directions receive green signals simultaneously. The scramble stage allows cyclists to make any movement, including right turns which can occur diagonally across the junction. This has been seen to work in Holland, but a certain amount of patience and cooperation between cyclists is necessary.

The diagonal crossing is a variation of the Dutch Style Signal Controlled junction and is presented in the CROW manual. The diagonal cycle crossings run with other non-conflicting traffic phases, the two diagonals running separately. The impact that the scramble might have on a junction's capacity could result in unacceptable performance.

6 Cyclist and driver behaviour

When considering how experience from Dutch and Danish practice might be applied to the UK it is necessary to consider the effect of cultural and legal differences that affect how people use the roads.

There is scope for cyclists to not use the segregated cycle lane through the junction as it results in a less direct route if travelling ahead. The avoidance of using this part of the facility will not only remove the possible safety benefits of keeping cyclists segregated, but may also introduce additional disbenefits. Likewise more knowledge is needed about the cyclists and pedestrian interactions with this type of facility. The pedestrian and cycle interactions on the fully segregated signalised junction likely to differ from those presently in use in the UK. For instance by continuing the segregation through the pedestrian crossing, not only is there a segregation median that now needs to be negotiated by pedestrians, but also there is the matter of priority between these two user groups. If left to operate as a priority situation then this could cause complications to vulnerable pedestrian user groups such as those with mobility issues or sensory loss. Likewise if a signal controlled option is selected to manage this interaction then an improvement would be needed in cyclist compliance of traffic signals. The trials investigating low level bicycle traffic signals under the current project could help provide an indication whether this is possible using this additional equipment.

7 Assessment of Suitability

To set the findings in context, the following assessment has been carried out to look at the suitability of the fully segregated signalised junction on the road network in London.

	Current knowledge	Suggestions for future research
Influence on cyclist traffic	It is likely that by fully segregating cyclists through a junction the potential for collisions between cyclists and left turning traffic will be reduced. It is expected that there will be an increase in the feeling of security offered by the segregation. However it also has the potential to cause frustration to cyclists if they are travelling ahead at a junction and are forced to deviate too far from their desire line. The geometry of how the segregation is implemented needs to be carefully controlled.	A greater understanding is required on the compliance of UK cyclists with this junction layout. Will the segregation be used throughout the junction, or will cyclists bypass the segregation when travelling through the junction to save themselves time and the deviation that the cycle lane requires. Likewise it is unclear at this stage whether UK cyclists wanting to turn right would do so by progressing through the junction first then making their turn, or whether they would turn across in front of the motorised traffic at the stop line and then progress to their exit lane against the flow of traffic and cyclists
Influence on pedestrians	There is some uncertainty about how the pedestrian and cyclist interactions will work in the UK. Dutch evidence suggests that it is not necessary to have a formal priority rule in place or signal control. However in the UK it is foreseen that not having a clear priority hierarchy between road users means that these two classes could see an increase in conflicts following the implementation of a fully segregated signalised junction. Of particular concern would be pedestrians with mobility impairments or sensory loss, these members of society would be at greatest risk from these junction	More research is needed on these pedestrian cyclist interactions. To a certain extent this is being trialled on the Dutch Style Roundabout in Work Stream 2, however the geometry and method of control is distinctly different on the Dutch Style Roundabout, as such any findings will not be directly applicable to the Fully Segregated Signalised Junction.

	changes.	
Influence on general motorised traffic	Depending on how the signal sequence was run depends to what extent the motorised traffic would be impacted. The cyclists could be signalised alongside traffic movements, however there would need to be a clear priority rule in place to give way to cyclists crossing the exits of the junction, without this adopted behaviour this form of junction is limited to running the cyclist movements in a separate stage to motorised traffic. This could either be independent or combined with pedestrian movements. However, where cyclists and pedestrians are to be run together, it is also required to have a priority rule in place where cyclists would give way to pedestrians on the pedestrian crossings. Where additional independent stages are used there will be a notable impact on junction capacity, and vehicular delay. Whilst at the junction there is not much additional space required to provide the corner islands, space is going to need to be provided on the links between junctions to make this style of junction an integrated installation.	Further investigation into the option of drivers of motorised traffic giving way to cyclists on the exit of junctions. Greater understanding and quantification of the delay that an all-round cycle stage would have at some key junctions. Further investigation into a few key junctions to quantify the necessary land take required from the carriageway and the pedestrian realm to make this design work.
Influence on public transport	As described above, separate cycle stages will cause additional delay to buses due to the reduction of road green time for motorised vehicles.	Quantification of the expected delay, including the investigation of any mitigation strategies for this delay.
Likely impact on safety of cyclists	It is likely that this formation of junction will reduce the likelihood of certain types of accidents, particularly those involving large vehicles turning left across the path of cyclists. However the conflict point between vehicles and cyclists have been moved to the	A greater understanding is required through a research study to show the influence of the interaction angle and whether this reduces likely collisions at this style of junction. Further understanding and trialling would be required before

	exit of the crossing. The theory here is that the interaction between the two parties will be at 90 degrees to one another. By starting the cyclists in front of the motorised traffic the cyclists should have cleared the conflict point before the motorised vehicle gets to the conflict area. If not then a priority ruling would need to apply. It is unclear at this stage whether the perceived benefits this claims to offer will be realised when used in an on-street location. The literature identified for this study provided little evidence on the likelihood of collisions between cyclists with this junction layout.	implementing a fully segregated signalised junction on a route where a two way cycle track is present.
Compatibility of junction measures with existing infrastructure	Low level traffic signals with cyclist aspects would be required the give a positive signalisation to the cyclists movements. This will also aid keeping the street furniture to a minimum. From a junction geometry perspective there would need to be further investigation into how this style of junction would be implemented without reducing the quality of the traditional style of pedestrian crossings used in the UK. Whilst this style of junction doesn't need excessive amounts of space, it is foreseen that there could be compromises needed at many London locations due to the shortage of land available, this could result in narrower than desired footways or cycle lanes, or the loss of traffic lanes that could cause a greater amount of delays to public transport routes and other motorised traffic. This style of junction would require the use of Low level signals for bicycle traffic.	A detailed design would be required to show the full impact of this layout of cycle facilities alongside a standard UK junction based pedestrian facility, to show the true impacts this would need to be based on a series of seemingly suitable sites in London. A greater understanding is required to clarify how type of facility would work with a two way cycle track as it is understood that this is a proposition for many London cycle routes.

8 Conclusion

A greater understanding of pedestrian and bicycle interactions at this style of junction is required before this junction could be implemented on the highway. Likewise more design work and a greater understanding is required before implementation of the layout to ensure compatibility with the current UK pedestrian crossing designs, predominantly this is a layout consideration.

Cyclist behaviour

It would also be important to understand the likely behaviour of cyclists and their adoption of this form of junction. There is only a limited potential for trialling this on a test track as it is often witnessed that participants involved in off street trials act in a more cautious manner than they might on the highway.

Junction layout and signal staging

A greater understanding is also needed in order to test the impact of providing traffic signal stage sequences that are bicycle friendly, and fully understanding the impact this has elsewhere on the network.

As the table in section 7 shows there is insufficient strong evidence in previous research to suggest that this style of junction is suitable to be implemented onto the London road network without prior detailed investigation. There are likely to be complications with junction layout and providing enough space for pedestrians and cyclists to safely use the junction in high volumes, this would need to be investigated on a case by case basis. It is clear that this style of junction works well in other European countries, however this style of junction is commonplace there and so will be well understood by road users. It is unclear from the research available how well this style of junction would perform when only implemented at a selection of junctions where sufficient space could be found, so that most road users rarely encounter one. There is the potential that the additional segregation through the junction might not realise the benefits seen by other countries that use this style of junction.

Legislation and publicity

Due to the information presented in this literature review, the fully segregated signalised junction should not be viewed as a junction solution that is near implementation. Alternative junction designs which have clearly documented benefits on the UK highway should be prioritised above this design. Currently there are no legislation problems with using this style of junction in the UK. The two areas where improvements might be needed to make this junction style a more useable prospect, would be to publicise the chosen strategy for traffic and cyclists interacting at 90 degrees to one another on the exit of the junction. Similarly the approval of low level bicycle traffic signals will help to make the physical installation easier to install whilst keeping levels of street clutter in mind.

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9 Appendix 1 – Tables showing option diagrams for road sections in built up areas and outside of built up areas.

Option diagram for road sections inside the built-up area

Table reproduced from Design Manual for Bicycle Traffic

<table>
<tr><th rowspan="2">Road category</th><th rowspan="2" colspan="2">Max. speed of motorised traffic (km/h)</th><th rowspan="2">Motorised traffic intensity (pcu/day)</th><th colspan="3">Cycle network category</th></tr>
<tr><th>basic network ($I_{bicycle}$ > work 750/day)</th><th>cycle route ($I_{bicycle}$ 500-2500/day)</th><th>main cycle route ($I_{bicycle}$ > 2000/day)</th></tr>
<tr><td></td><td colspan="2">n/a</td><td>0</td><td colspan="3">solitary track</td></tr>
<tr><td rowspan="3">Estate acces roead</td><td colspan="2" rowspan="3">walking pace or 30 km/h</td><td>1 - 2.500</td><td colspan="2" rowspan="2">combined traffic</td><td rowspan="3">cycle street or cycle lane (with right of way)</td></tr>
<tr><td>2.000 - 5.000</td></tr>
<tr><td>> 4.000</td><td colspan="2">cycle lane or cycle track</td></tr>
<tr><td rowspan="3">District acces road</td><td rowspan="2">50 km/h</td><td>2x1 lanes</td><td rowspan="3">irrelevant</td><td></td><td colspan="2"></td></tr>
<tr><td>2x2 lanes</td><td colspan="3">cycle track or parallel road</td></tr>
<tr><td colspan="2">70 km/h</td><td colspan="3">cycle track,moped/cycle track or parallel road</td></tr>
</table>

Option diagram for road sections outside of the built-up area

Table reproduced from Design Manual for Bicycle Traffic

Function		Speed (km/h)	Intensity (pcu/day)	Bicycle traffic road section function	
				basis network	(main)cycle route (I_{cycle}> 2,000/day)
Motorised traffic road section function	Estate access road	60	1 - 2.500	combined traffic	cycle street, if I_{pcu} < 500 pcu/day[1)]
			2.000 - 3000	cycle lane or cycle track	cycle track, or perhaps lanes
			> 3000	cycle track	
	District access road	80	irrelevant	cycle/moped track parallel road	

1 Plus any additional requirements in the area of safety