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THE DEVELOPMENT OF THE DISPLACED RIGHT TURN JUNCTION

by

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Abstract
The concept of the Displaced Right Turn (DRT) is not new and has been considered as an alternative junction design to traditional at-grade and grade separated junctions since the 1950s. It enables one or more conflicting movements to take place away from the main intersection at a new "crossover junction", reducing the number of conflicts at the central node. Tests have shown junction capacity can increase with a footprint similar to a large roundabout with only a small increase in costs. The DRT concept is an innovative traffic signal junction being developed for the UK highway network by the Highways Agency. This paper summarises the research undertaken on behalf of the Highways Agency.

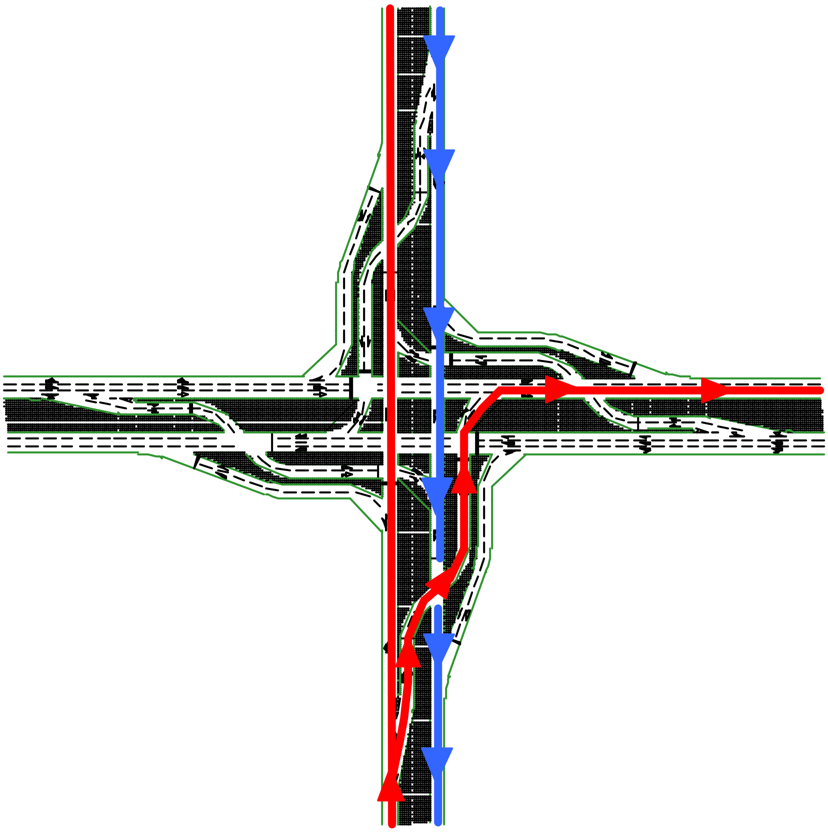

Figure 1: 4 Arm Displaced Right Turn Junction
(all right turn movements displaced)

Introduction

The concept of the DRT junction is to relocate one or more movements from the centre of the junction. This reduces the number of conflicts at the central node, which in turn can increase junction capacity. The "displaced" conflicts upstream from the central node create a new two stage junction. The right turning vehicles leave the main traffic stream some distance in advance of the main junction making their right turn across the incoming traffic at the crossover node. These vehicles are then positioned to complete their manoeuvre in parallel with their parent stream when that stream gains right of way at the central node, see figure 1. The concept reduces a conventional T-junction from 3 stages to 2 or a conventional crossroads from 3 or 4 stages to 2, significantly improving junction capacity without necessarily increasing the footprint or making an appreciable increase in cost..

In October 1998, Parsons Brinckerhoff Ltd and JCT Consultancy Ltd were commissioned by the Highways Agency to develop the DRT junction concept for application on the UK highway network. This innovative design for a signalised intersection first appeared in the Agency's Toolkit as an adaptation of the Continuous Flow Intersection design that is already established in Mexico and is being introduced, gradually, in some areas of the USA.

History

The concepts behind the DRT junction are not new. The founding principles of the DRT junction can be traced back through the literature to Lam (1967, 1968) as the Storage Island Method and there are reports that the Road Research Laboratory developed similar schemes in the 1950s (Hutchinson, 1995). Following the papers by Lam, the concept re-emerged in more detail in 1974 in a paper published by Al –Salman and Salter. Subsequently, the concept remained dormant until a paper was published on the Continuous Flow Intersection by Goldblatt et al (1994) applying the idea to the USA. Since 1994 the concept has been progressed to being constructed in several major cities in the US and Mexico.

Operation of the Displaced Right Turn Junction

Concept

The DRT concept can be applied to both crossroad and T-junctions. A crossroad requires two or four displacements (paired on the same road) to have any effect unless there are banned right turn movements. A T-junction will have one displaced movement located on either the main road or side road, see figure 2. This layout may be considered as being the optimum design in terms of the junction footprint, capacity and safety implications. Various permutations are available and could be adopted to suit certain conditions, such local geometry. For example, the left turn movement (designated B in Figure 2) does impact significantly on the junction footprint and could be removed by incorporating the left turn as part of the node 1 junction control (see Figure 3). The additional movement does make node 1 more complex and the design has to drivers do not turn left onto the wrong carriageway.

Alternatively, the junction footprint could be extended by simplifying node 1 into a single crossover and relocating movement C to a new node 3 (see Figure 4). This has effectively split the conventional single T-junction into three nodes, each operating as a two stage junction (almost the same principal as a signalled roundabout). Again, this could be further extended by allowing movement B to take place at node 1 thereby reducing the footprint without the same safety implications (see Figure 5). This solution may have capacity implications, particularly if movements B and C are relatively heavy because these movements conflict twice at node 1 and node 2 whereas on a conventional junction the does not occur.

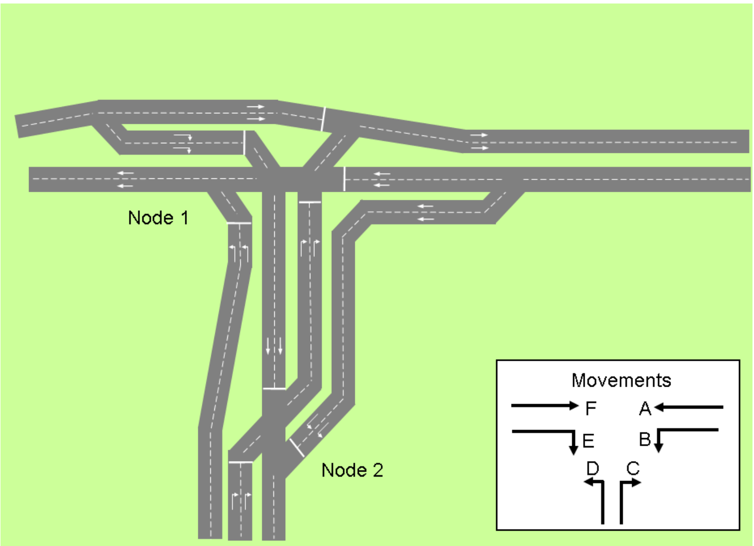

Figure 2: Generic 3 Arm Displaced Right Turn Junction
(with displacement on side road arm)

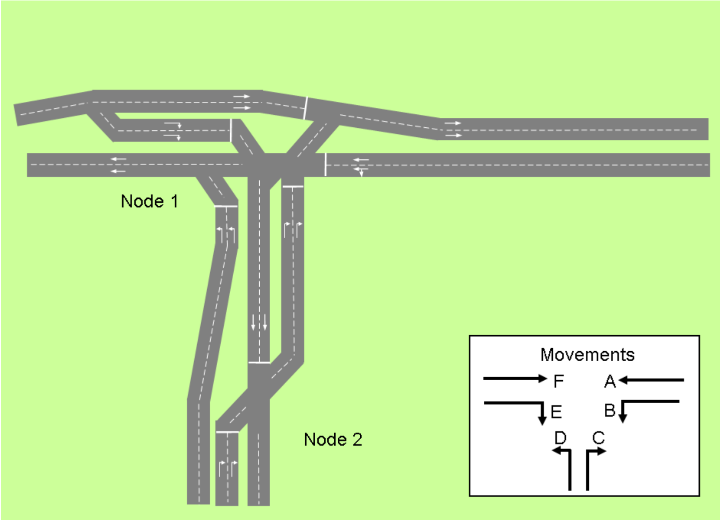

Figure 3: Generic 3 Arm Displaced Right Turn Junction
(with left turn within junction)

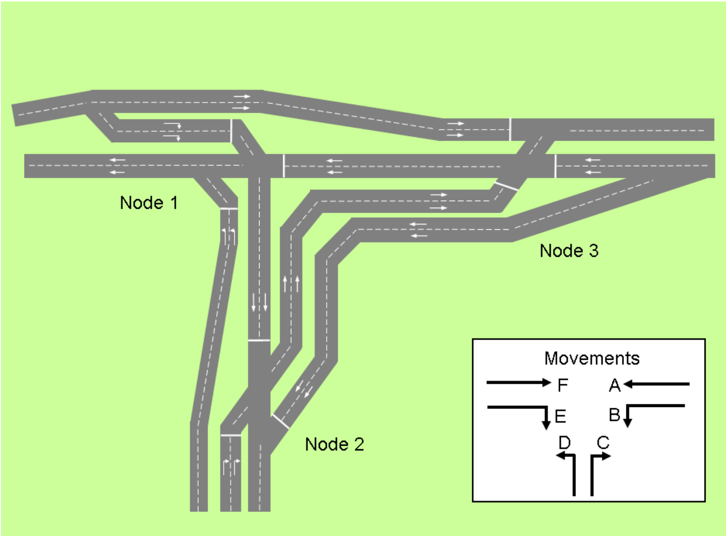

Figure 4: Generic 3 Arm Displaced Right Turn Junction
(with displacement on main road and side road arms)

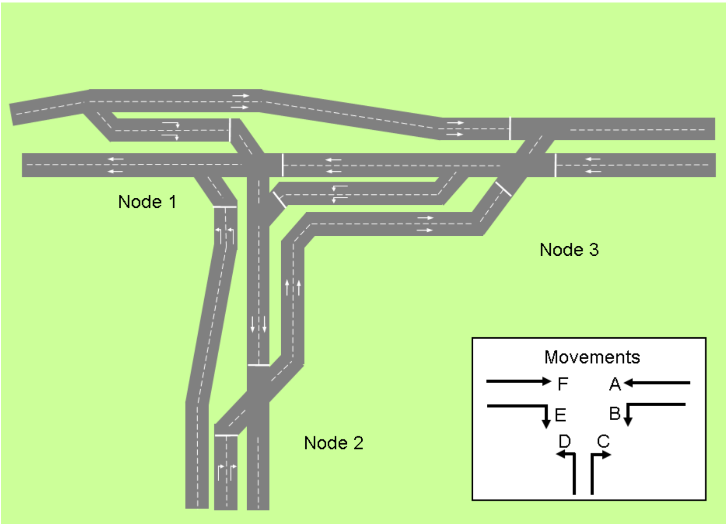

Figure 5: Generic 3 Arm Displaced Right Turn Junction
(with displacement on main road and side road arms)

Comparison to other Large Signalised Junctions

A simple desktop study was undertaken comparing the DRT concept with the a signalised T-junction and a 3 arm signalised roundabout. Generic layouts were developed for each junction type and were tested using a series of flow groups developed from three hourly flow bands. The flow bands ranged from 50 – 250 (low), 251 – 750 (medium) and 751 – 1000 (high). Each turn within a flow group was assigned a flow band and a flow was randomly assigned to that turn from that band.

The assessment was undertaken using LINSG and the results were recorded in terms of Practical Reserve Capacity and Total Junction Delay. The results summarised in Table 1 shows the DRT to outperform the signalised crossroads and roundabout by an average of 11% in capacity and 5% in delay.

	Signalised Crossroads	**Signalised Roundabout**	**DRT**
Average PRC *(%)*	43%	145%	156%
Average Delay *(pcu-h)*	15.02	11.27	10.69

Table 1: Large Signalised Junction Comparison

Co-ordination

One of the fundamental principles of the design of a DRT junction is the co-ordination between the central signal node and the adjacent crossover node(s). From a capacity point of view there is no need to co-ordinate these nodes. However, co-ordination allows for minimisation of reservoir sections which is to ensure the efficient use of road space and hence the overall footprint of the junction. The co-ordination between nodes is unique to each junction layout and as a result the co-ordination is fixed once the geometry has been decided. The co-ordination should ensure that vehicles progress through the junction without having to stop at any of the internal stop lines. In order to achieve good co-ordination, most practitioners would use platoon dispersion over a relatively long distance. Since, the distances between stop lines on a DRT may be relatively short which may negate the platoon dispersion effects and could result in platoon compression. This is an effect where the downstream signals can be given a shorter green whilst still clearing the traffic (often used in practise on signalled roundabouts).

Safety

The concept of having two or more junctions in close proximity is not new particularly if the junctions are co-ordinated, a signalised roundabout is a prime example of this. The geometric design of the central node and the crossover junction are critical in ensuring that vehicles take the correct route through the junction. At any crossover point, there will be a possibility that vehicles could turn onto the wrong carriageway. This needs to be carefully addressed in the geometric design and with the use of appropriate signing and roadmarkings. The roadmarkings and signing should be designed to steer drivers through the junction, but also must be kept to a minimum to reduce clutter and maintain the perception of a simple junction layout.

Pedestrian and Cyclist Facilities

“Walk with traffic” pedestrian facilities can easily be provided across the junction. If some traffic movements are in three or more lanes, then the effect of phase minimums and intergreen constraints may start to affect the performance of the junction. To ensure fixed co-ordination, pedestrian phases which involve variable intergreens, such as puffin and toucan crossings, should only be provided if they do not have a variable effect on the cycle time.

Public Transport

The incorporation of traditional bus priority measures, such as green time extension and demand responsive signals is difficult, as it is essential to maintain a fixed co-ordination between the signals once the junction geometry has been decided. If required the additional capacity can be re-allocated to other modes, for example, a public transport corridor (for either buses or trams) by the use of dedicated phases in the centre of the junction.

Case Studies

At the start of the project an exhaustive search was conducted throughout the UK trunk road network for potential pilot sites. The Agency's Area Managers identified a total of 20 sites that met a set of criteria deemed necessary for a pilot site. The criteria were:

- A major intersection, probably with demand flows in excess of 5,000 vehicles during the peak hour;
- The junction should consist of no more than 4 arms;
- The junction must be at grade. Even a partially grade separated junction would not be suitable; and
- The junction should be congested at certain times of the day.

The majority of suggested sites were discounted at an early stage, primarily due to insufficient numbers of right turning vehicles and/or spatial constraints. Two sites were progressed further and a detailed feasibility study was carried out, where preliminary layouts were developed and the performance assessed in terms of capacity and economics against more traditional junction solutions.

Case Study 1: M57/M58 Switch Island Junction, Sefton

M57/M58 Switch Island Junction is currently a four arm roundabout connecting the M57 and M58 at Sefton, near Liverpool. The junction is heavily congested and at the time of the feasibility study had recently undergone Phase 1 of a major junction improvement. As an alternative to the proposed dual T-junction approach a DRT junction was designed and compared against the existing plans for the junction.

The junction carried between 5500 and 7200 vehicles during the 1994 peak hours with the proportion of right turning vehicles ranging from 25 – 95%. Prior to the Phase 1 improvements there were on average 26 personal injury accidents at the junction per year, higher than the national average for a roundabout with similar flow levels.

The two proposed layouts for the junction were a dual T-junction and a dual Displaced Right Turn. Using a combination of TRANSYT and LINSIG, these layouts were assessed as a series of co-ordinated signal nodes. The results summarised in Table 2 showed that the DRT reduced the total time spent in the network by 91 pcu-h in the AM peak hour and increased average vehicle speeds by 11.3 km/h in comparison to the proposed dual T-junction. The improvement is also reflected in the PM peak where the time spent at the junction decreases by 47 pcu-h and average vehicle speeds increase by 6.0 km/h.

	AM Peak		**PM Peak**	
Scheme	**Total Time Spent** *(pcu-h/h)*	**Average Speed** *(km/h)*	**Total Time Spent** *(pcu-h/h)*	**Average Speed** *(km/h)*
Existing	343	11.4	748	4.8
Dual T-junction	206	13.0	130	18.3
DRT	115	24.3	97	24.3

Table 2: Performance of Proposed Improvements to M57/M58 Switch Island Junction

The greater capacity benefits provided by the DRT were further illustrated by the outcome of the economic assessment see Table 3, where the higher costs of the DRT (£3.0m compared to £2.8m) failed to impact on the economic benefits. The BCR for the DRT was 2.5 and the BCR of the Dual T-junction was 1.9.

		1994 Prices			
Option	**Costs** *(1999 Prices)*	**PVC**	**PVB**	**NPV**	**BCR**
Dual T-junction	£2.8m	£2.5m	£4.8m	£2.3m	1.9
DRT	£3.0m	£2.6m	£7.4m	£4.8m	2.5

Table 3: M57/M58 Switch Island Junction Economic Assessment

Case Study 2: M27 Paulsgrove Roundabout, Portsmouth

The M27 Paulsgrove Roundabout is sited to the north of Portsmouth. The junction is in a predominantly urban location and there are proposals for further development in the vicinity. The current junction configuration is a large standard roundabout with dual carriageway approaches on three of the four arms.

Traffic flows at the junction ranged are approximately 5000 in the 1996 peak periods and the volume of right turning traffic averaged at approximately 35%. The accident rate at the junction is very high. There were 80 personal injury accidents at the junction in 41 months and when compared to equivalent national statistics this was found to be 440% higher than what could be expected.

There were two options proposed to improve the roundabout, a High Capacity Signal junction as suggested by Portsmouth City Council and the DRT. The footprint of the existing layout and proposed options were similar and at that time the costs of the two schemes was estimated at £2.0m and £2.5m respectively.

Both options provided significant capacity benefits over the existing roundabout layout under the 2015 assessment, see Table 4. The performance of the DRT option was better than the High Capacity Signal junction, as average speed through the junction increased to 15.0 km/h instead of 8.0 km/h during the AM peak hour. The DRT provided further benefit over the High Capacity Signal junction during the PM peak hour where predicted vehicle speeds increased from 8.0 km/h to 17.0 km/h.

	AM Peak		**PM Peak**	
Scheme	**Total Time Spent** *(pcu-h/h)*	**Average Speed** *(km/h)*	**Total Time Spent** *(pcu-h/h)*	**Average Speed** *(km/h)*
Existing	447	n/a	317	n/a
High Capacity Signals	148	8.0	167	8.0
DRT	118	15.0	111	17.0

Table 4: Performance of Proposed Improvements to M27 Paulsgrove Roundabout

The economic assessment, in Table 5, shows the two schemes to be very similar. The BCR for the High Capacity Signal option is slightly better than the DRT. However, the NPV for the DRT is higher than the High Capacity Signal option.

		1994 Prices			
Option	**Costs** *(1999 Prices)*	**PVC**	**PVB**	**NPV**	**BCR**
High Capacity Signals	£2.0m	£1.5m	£17.8m	£16.3m	11.9
DRT	£2.5m	£1.9m	£22.0m	£20.1m	11.6

Table 5: M27 Paulsgrove Roundabout Junction Economic Assessment

A closer inspection of the junction analysis shows that the DRT has significant spare capacity beyond the design, whilst the High Capacity Signal junction is nearly at operational limits. Therefore, even though the difference, economically, is marginal the solution to solve long term capacity issues would be the DRT. Furthermore, the DRT has the advantage of providing good at-grade facilities for pedestrians and cyclists through the junction.

Monitoring Study: A4311 Motorola Junction, Swindon

The A4311 Motorola junction is a signalised intersection in the north east corner of Swindon. The junction is the first of a series of traffic signal junctions on the new northern distributor road constructed in preparation for the major development proposals to the north of the town. The junction, designed by WSP, JCT and Swindon Borough Council, opened in August 2002, the Motorola junction is the first operational DRT junction in the UK. Traffic volumes at he junction are currently low, as it is designed to accommodate the planned development in the north of Swindon.

Photo of DRT junction – Swindon (Source Nuttall, 2002)

The 3 month monitoring study included a review of speeds through the junction and a conflict study. The conflict study was undertaken as an alternative to the traditional accident investigation study that would have required a minimum of three years of accident data to enable an assessment to take place . A brief investigation showed that since the introduction of the junction in August 2002 there have been no reported personal injury accidents.

Speed surveys were conducted in September and November 2002 to investigate whether there would be any change in speed through the junction, as drivers grew more familiar with the junction layout. The review showed that vehicle speed did not change over the three months and that speeds for the crossover sections remained lower (approximately 32 km/h) than vehicle speeds for more traditional movements, such as the straight ahead and left turns (up to 60 km/h).

Conflict studies were undertaken at the DRT and a new convention 3-arm signalised junction on the same corridor. The control junction was used for comparison purposes as it was similar geometrically and in terms of turning volumes. The conflict study observed 4 conflicts at the control junction and 14 conflicts at the Motorola junction over the 12 hour survey period. Upon further inspection it was found that over 65% of the conflicts at the Motorola junction were caused by lane discipline issues at the upstream junction and minor design issues that could easily be mitigated through a review of the signing and roadmarkings at and on the approaches to the Motorola junction.

Once these conflicts are mitigated the number of incidents at the junction should be equivalent to a traditional highly trafficked traffic signal junction.

Conclusions

The lineage of the Displaced Right Turn concept can be traced to the late 1960s when Lam in his papers published in 1967 and 1968 discussed the Storage Island method of traffic signal control. The early designs failed to consider the complete signalisation of the intersection and caused concern over large volumes of traffic needing to give way at the initial crossover. This raised issue over the safety and footprint of the junction especially when traffic flows are high.

The more recent studies incorporated a fully signalised layout and illustrated that the DRT could be expected to have a footprint similar to that of a conventional roundabout.

There are several forms of the DRT concept depending on the number of arms at the junction and the number and location of crossovers incorporated into the design. There is little difference in the performance of the possible layouts and the optimum layout will depend on the physical surroundings at each location. The fundamental principle of the DRT design is the co-ordination between the signal nodes. Good co-ordination is essential to control the geometric layout of the junction given that the footprint of the junction will be a major design factor.

The pilot sites developed as a part of this study showed that the DRT concept could be designed within the footprint of a large roundabout. The feasibility studies also showed 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 reducing congestion in comparison to traditional junction layouts.

Furthermore, the desktop analysis showed that provision for pedestrians and cyclists could easily be provided at a DRT junction without compromising the capacity of the intersection using "Walk with Traffic" facilities. The pedestrian and cyclists provision also have the advantage over a traditional signal junction because the short cycle times necessary ensure pedestrian/cyclist delays are kept to a minimum.

The construction of the Swindon DRT junction has shown that the concept can be successfully incorporated onto the UK highway network. The subsequent assessment of vehicle conflicts at the junction showed there to be more conflicts at the junction. However, these could be removed with further modifications to the geometric layout of the junction and a review of the signing strategy at the upstream junction. With these conflicts mitigated, the number of conflicts at the DRT junction would be of the same magnitude as a traditional traffic signal junction.

The conclusions of this work would suggest that the Displaced Right Turn concept is an appropriate junction type for use on the UK highway network. The junction can provide:

- Operational benefits, in terms of capacity, at junctions where there are heavy right turns;
- Designs which are similar in footprint and cost to other high capacity layouts;
- Full non-motorised users provision throughout the junction;
- Additional capacity available for re-allocation to public transport corridors; and
- An accident record that is unlikely to different from any other large signalised junction.

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References

Al-Salman, H.S.T. and Salter, R.J. (1974) The control of right turning vehicles at signal controlled intersections, Traffic engineering and Control, 15, pp 683-686

Goldblatt, R.F., Mier, F. and Friedman, J. (1994) Continuous Flow Intersection, Institute of Transportation Engineers Journal, 64 (7), pp 34-42

Lam, H-K. (1967) Design of signal-controlled traffic junctions allowing right turning movement, Journal of the Institution of Highway Engineers, 14 (8), pp 23 - 27

Lam, H-K. (1968) The Storage Island Method and its Application to Crossroads Junctions, Journal of the Institution of Highway Engineers, 15 (10), pp 35 - 39