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Effect of side road junction design enhancements and flows on priority for crossing pedestrians and cyclists

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ABSTRACT

Enhancements to designs or carriageway markings are increasingly used by engineers to reinforce pedestrians' and cyclists' priority when crossing side roads at their junctions with main roads. Yielding behaviour in 13,402 interactions was collected at enhanced and control junctions. Enhanced junctions created high proportions of interactions demonstrating priority for pedestrians and cyclists (by design: 90%, markings with zebra: 88%) and eliminated voluntary yields by them. A negative binomial model with log-link accounting for junction type and flows indicates 1.4 times more yields forced by drivers onto pedestrians and cyclists with enhanced design, and 1.1 times more with enhanced marking with zebra. There is no effect of the crossing set-back distance from the main road, cyclists experience fewer forced yields than pedestrians, and cycling towards main road traffic is not problematic. The research confirms the efficacy of enhancements, supported inclusion of enhanced designs in Scottish guidance, and is influencing guidance interpretation.

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Pedestrian; cyclist; side road junction; yielding; junction design

1. Introduction

The most common junction type in urban street networks is where a side road joins a main road. Many people make daily movements through these types of junctions either as pedestrians or cyclists crossing the side road, or as drivers and riders making turning movements. While they are perhaps the most mundane type of junction, their ubiquity means that any deficiencies in their operation are widely experienced by the travelling public.

Pedestrians and cyclists crossing the side road have priority over drivers and riders who are turning in and out at the junction. An issue of concern amongst transport planners and engineers is whether their design assists in reinforcing this priority. There has been considerable enthusiasm within the design community to develop enhanced designs to improve their effectiveness in recent years.

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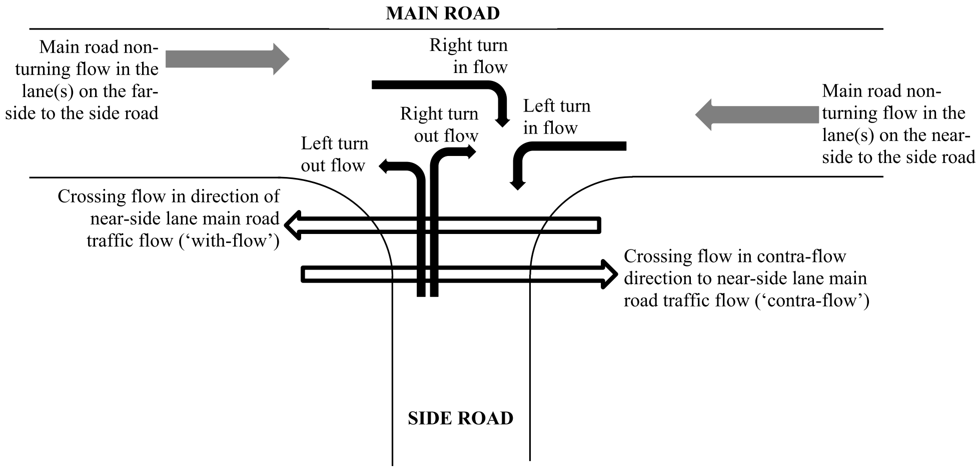

Figure 1. Turning flows and crossing flows at a side road priority junction.

The different possible movements at priority junctions create many interactions between the streams of traffic. Figure 1 illustrates the turning and crossing flows based on the UK left-hand rule of the road. Motorised vehicles and cycles (which are classed as vehicles) in the carriageway make turning movements that create turning flows. Pedestrian traffic and cycle traffic on the footway or on a cycle track adjacent to the carriageway create crossing flows across the side road. These crossing flows are in two directions: one in the same direction as the main road traffic flow in the lane on the side nearest the side road ('with-flow'), and a second flow in the contra-direction ('contra-flow'). In the UK, pedestrians and cyclists crossing the side road (which we summarise as 'people crossing' when we are talking about both) have priority over drivers and riders (of motorcycles and cycles) turning in and out of the side road.

In addition to being required to give way (yield) to the pedestrian and cycle traffic crossing the side road, turning traffic is required to give way to other streams of traffic on the carriageway. The traffic turning left out of the side road gives way to main road traffic in the near-side lane that is travelling straight on. The traffic turning right out of the side road in addition gives way to main road traffic in the far-side lane. Traffic turning right into the side road gives way to approaching main road traffic.

Drivers and riders in the carriageway making turning movements at side road junctions often do not cede priority to people crossing the side road. Recently there have been developments in design and markings to enhance side road junctions to reinforce this priority. This study investigates enhanced junctions to understand whether they reinforce priority for people crossing. The rest of the introduction summarises junction enhancements, the relation between design and regulations, what is known from previous findings, and finally states the aim of this study.

1.1. Junction enhancements

At conventional junctions the side road carriageway creates a break in the footway and cycle track. The kerb at the crossing point may be dropped to carriageway level to avoid a step down from the footway to the carriageway. Sometimes, a raised crossing may be provided with no other enhancement, and this is called ‘Side Road Entry Treatment’.

These conventional layouts create a break in the continuity for pedestrians and cyclists, despite their having priority over turning drivers and riders. Priority for people crossing may be enhanced with additional Give Way lines on the carriageway both sides of the footway and cycle track crossing. Such ‘Marked Priority’ crossings may also include a zebra crossing for pedestrians, which would then create, with a cycle track, what is called a ‘Parallel Crossing’. Figure 2 shows an example of Marked Priority.

An issue with the crossing movements is that they can be in one of two directions: either in the same direction as the flow on the main road on the side nearest the side road, or in the opposite direction. UK guidance (Local Transport Note 1/20, Department for Transport 2020) suggests that, for safety reasons, the preference is for one-way cycle tracks in the same direction of the main road near-side flow.

The crossing may be either adjacent to the kerb line of the main road, or be set back from the main road kerb line. ‘Full set-back’ is at least a car length (5 m) from the kerb line, and partial set-back is less than full set back but not adjacent to the kerb. Local Transport Note 1/20 (LTN 1/20) suggests full set-back is suitable for side road traffic flows up to 2000 passenger car units (PCU) per day, partial set-back where flows are less than 2000 PCU/day and speeds are low and with frequent gaps in the main road traffic stream. This stipulation is to prevent drivers waiting to turn out of the side road from blocking the crossing. Other design guidance suggestions include that the crossing is raised to footway level, the surface should contrast with the carriageway, and that small (4 to 6 m) radii are used where the kerb line turns the corner.

The guidance suggests that busier side roads may benefit from a zebra. A zebra crossing, according to regulation, needs at least two white painted zig-zag markings on the approach to the crossing on both sides of the road and both sides of the crossing.

Figure 2. A junction with Marked Priority.

Hence a zebra cannot be used without set-back, otherwise the markings would extend into the main road.

In order to simplify the process and reduce the cost of introducing zebras at side roads, there have been trials of so-called 'simple zebras' across side roads which omit not only the zig-zag markings, but also the required illuminated yellow globes (historically known as 'Belisha Beacons'), and additional lighting (see the 'Previous findings' section below for evaluation studies). Figure 2 shows illuminated yellow globes. Visible in the picture are also zig-zag markings for a zebra crossing across the main road to the right-hand side of the picture. Visible in the image are also zig-zag markings both sides of the zebra across the side road.

As an alternative to Marked Priority, the priority for people crossing may be enhanced with a raised continuous footway and cycle track creating a break in the side road carriageway. Figure 3 shows an example of Design Priority.

Features of Design Priority crossings are the continuity of surfacing of the footway and cycle track, the absence of kerb lines around the junction corners, and ramps up from the carriageway for turning traffic. Cycling by Design (Transport Scotland 2021) suggests that Design Priority should encourage lower driver speed by conveying a strong visual indication of priority for people crossing. It suggests they are suited to low motor traffic volumes and speeds. Cycle by Design suggests the kerbs should be eliminated, yet Active Travel Act Guidance (Welsh Government 2021) offers options with and without kerb corner radii.

The issue of the use of tactile paving at Design Priority has been contentious. Tactile paving is paving in the footway with 5 mm high, 25 mm diameter flat-topped upstands (blisters) that are set 64–67 mm apart. The paving guides visually impaired pedestrians to the crossing point and is laid in the footway over the full width of the crossing point. The purpose is to indicate that crossing the tactile involves entering a carriageway. It is required in Marked Priority layouts where the pedestrian leaves the footway to cross

Figure 3. A junction with Design Priority.

the carriageway, but not in Design Priority layouts because a Design Priority layout has a footway that is continuous.

So far as a choice between Marked Priority and Design Priority enhancements is concerned, LTN 1/20 suggests it depends on context and budget. Design Priority has typically been deployed with no set-back, and marked priority with set-back.

1.2. Relation between design and regulation

Road-user behaviour is influenced by both street design and regulation (Flower 2022). Sometimes only one factor, either design, or regulation, is changed. For example, regulations in Finland changed in 1997 and removed the need for turning drivers to give way to cycles crossing on a cycle track, other than where it is enforced by signs. Räsänen, Koivisto, and Summala (1999) found that driver speed and yielding behaviour remained unchanged because the change reinforced pre-existing behaviour. By contrast in Sweden, Leden et al. (2006) found that the re-design of crossings combined with a stricter code to improve safety and mobility for pedestrians significantly increased driver yielding to people crossing.

Regulation enhancement has taken place in the UK. Highway Code Rule 170 has always stated that drivers should give way to pedestrians crossing a side road that they are turning into or out of (Department for Transport 2022). The code was revised on 29th January 2022 to add in the need to give way to pedestrians waiting to cross. Rule 180 requires right-turning drivers to 'watch out for cyclists, motorcyclists, pedestrians and other road users'. Rule 183 states that, when turning left into a side road, drivers should give way to any vehicles using a bus lane, cycle lane or cycle track from either direction. Finally, a new rule, Rule H3, adds that drivers turning into or out of a junction should not cut across cyclists.

The following section summarises relevant literature, approximately from oldest to most recent, that considers junction enhancements and their impacts on user behaviour.

1.3. Previous findings

In early work in the Swedish context, Gårder, Leden, and Pulkkinen (1998) found that cycle track priority crossings increased cycle flows and speeds, reduced drivers turning speeds, and reduced risk. Key informants thought the colour contrast of the crossings was important, and this is supported by evidence in the Japanese context by Iasmin, Kojima, and Kubota (2016).

Pedler and Davies (2000) studied UK junctions with various levels of priority for pedestrians and cycle traffic, and levels of set-back. They noted pedestrians benefitted from raised crossings and give way lines positioned in advanced of their crossing location. Wood et al. (2006) found little difference in the proportion of occasions drivers yielded at Side Road Entry Treatment sites in London (56%) compared with control sites (59%), suggesting such (minimal) treatments have little effect on behaviour. Steer Davies Gleave (2018) found drivers yielded at Design Priority crossings on 79% of occasions to people crossing, but they had no control site data.

Jones, Matyas, and Jenkins (2021) evaluated a trial at two sites with 'simple zebra' crossings, which are zebra crossings, but without the usually required yellow globes, zig-zag markings or additional lighting. They are cheaper to install because there is no need to provide power to the junction, and they can be installed near to the kerb line, i.e. on the crossing desire line, without the minimum required number of two zig-zag markings. The study showed that drivers give way on a higher proportion of occasions with such 'simple zebras' (57–71%) compared to locations without (26–43%). Even though drivers appear to respond well to zebras without the required yellow globes, zig-zags and additional lighting, a change to the traffic regulations would be required to make them legally enforceable without this additional paraphernalia. The unintended consequence of introducing them at some side roads, but not all, should also be considered (Browne and Flower 2023), as there may be a tendency for some drivers only to give way to people crossing the side road if a zebra is present.

In summary, re-designs can influence driver speed, reduce risk and 'benefit' pedestrians. Minimal design changes in schemes such as side road entry treatment have no effect, and studies of design priority have to date been without controls.

1.4. The aim

Much UK design development has taken place even since previous studies. Some of the detailed current guidance, such as flow levels for different treatments noted above are, to varying extents, ambiguous and, have little to no basis in evidence. There is no literature relating to Marked Priority junctions. The previous UK study of design priority did not have controls.

Now that more of these enhanced junctions are in evidence on UK streets, it is timely to study Design Priority and Marked Priority junctions in comparison with conventional junctions used as controls.

Junctions may be evaluated against a range of variables including whether they work as intended in relation to priority rules, capacity for all road users, queueing and delay, speed management and, related to that, risk. Junction designs may also be developed specifically to enhance the streetscape to assist with placemaking.

This paper focuses on the first of these variables, and this is because the design enhancements are being put in place specifically as a way of reinforcing the priority rules that exist in the regulations, and as a result of drivers generally not adhering well to these rules. The two wider studies considered safety in more detail than is reported here. It is referred to in the methods and results section to the extent appropriate.

The point of view taken for defining yields is that of the road user who has the priority, i.e. the pedestrians and cyclists crossing the side road. This is not the standpoint we normally take as traffic engineers, which is more often than not that of the driver. We have made this choice amongst the two options possible simply because it appears logical to investigate the problem from the point of view of the user who has priority, even though this is often denied to them. Hence, from the perspective of people in the crossing flow, we define three types of yield that the person crossing the side road may be involved with: (i) contrary to the rules, the person crossing was forced to yield by a turning driver or rider, or (ii) the person crossing voluntarily yielded to turning drivers or riders, and (iii) in accordance with the rules, the person crossing did not yield. We surmise that forced yields may have the greater propensity to influence the level of risk at the junction.

Most side road junctions have a level of flow that means that the usual traffic engineering performance measures of delay and queuing are of little or at least less concern. There were no queueing or delay issues at any of the junctions studied.

Hence, the aim of the research is to understand yielding behaviour adopted by people crossing the side road at conventional side road junctions compared with Design Priority and Marked Priority junctions.

From video observations of interactions, we present descriptive analysis of the proportions of different yield types, and a negative binomial model with log-link with the dependent variable being the number of forced yields of people crossing in a 15-minute period and the independent variables being dichotomous variables for junction type and continuous variables for flows in the 15 min period. In addition, but not fully reported in this paper, focus groups were undertaken with a range of road users to help interpret the results, and an analysis of the collision record. Key informant interviews provided knowledge and understanding from the point of view of practicing traffic engineers. Evidence created will assist in the application of existing design guidance and inform further design development. Section 2 defines the methodology, Section 3 presents the results, and Section 4 discusses the results.

2. Methodology

In this section the following aspects of the methodology are addressed in turn: sample selection; observational data collection method, including video as means of data collection, timing of data collection, and detail on the time stamping; focus groups method; for completeness, reference to risk assessment that is not reported in this paper is also mentioned.

2.1. Sample selection

There are five possible Marked Priority layouts and three possible Design Priority layouts according to LTN 1/20 (Department for Transport 2020). Table 1 and Figure 4 show these eight possible types of junction. As noted above, Marked Priority crossings with a zebra crossing with no set-back are not currently possible because of the requirement for a minimum of two-zig-zags each side of the crossing.

Sites were selected from across the UK as follows:

- Three Marked Priority junctions with zebras (two T1's and one T2, according to the nomenclature in Table 1)
- Nine Marked Priority junctions without zebras (four T3's, two T4's and three T5's)
- Ten Design Priority junctions (three T7's and seven T8's)
- Three control junctions

Table 1. Types of Marked Priority and Design Priority layout and set-back.

	Full set-back	Partial set-back	No set-back
Marked priority with cycle track and zebra (parallel) crossing	T1	T2	
Marked Priority with cycle track crossing and no zebra	T3	T4	T5
Design Priority crossing	T6	T7	T8

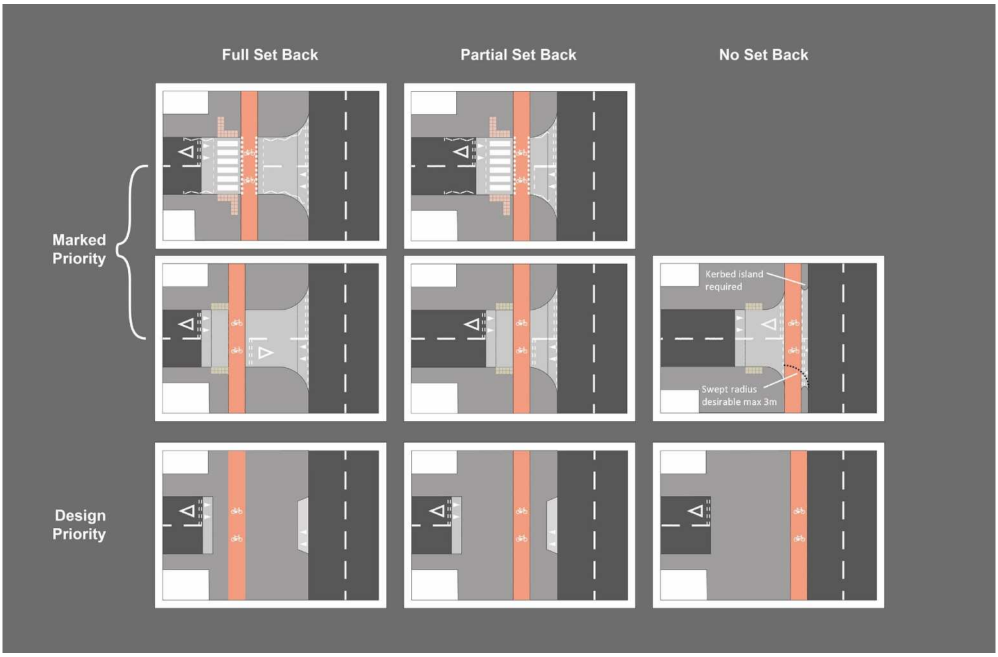

Figure 4. Types of Marked Priority and Design Priority layout and set-back. Source: Department for Transport, 2020.

In addition to our own good knowledge of the UK network, selection was supported by knowledge and assistance from experts in the traffic engineering community, some of whom were part of our steering group. There are no sites which perfectly match the idealised layouts shown in design guidance, rather selection was based on attempting to meet the standard layouts as closely as possible. No sites with Design Priority and full set-back (T6) were found. Two sites did not provide Marked Priority for crossing pedestrians over vehicles turning out of the side road (one T4 and one T5). At one T3 site it was possible only to turn in left or to turn out left of the side road. At one T5 site and two T7 sites it was only possible to turn in, but not out. At one T8 site it was possible to turn out left only, at another it was possible to turn out, but not in and at a third it was not possible to turn out right.

2.2. Observational data collection

Observational studies were carried out using video footage using one to three cameras (depending on site requirements) positioned on street lighting columns adjacent to the side road junction. Twenty-four hours of video footage was collected at the twelve sites with Marked Priority (between 18th May and 1st July 2021 in Bedford, Birmingham, Bradford, Cheltenham, Leeds, and London), the ten sites with Design Priority (21st and 28th January 2020 in Edinburgh, Leeds, London, Nottingham and Southampton) and the three control sites (18th May and 9th June 2021 in Liverpool, London and York).

Weekdays were chosen when local schools and universities were in session and after it had been verified that walking, cycling and driving activity had returned following the various Covid-19 pandemic restrictions during 2020 and into 2021.

Time stamps were recorded by the survey contractor for every interaction. In addition to the internal quality assurance procedures of the survey contractor, a sample of video footage was checked by the researchers to confirm the validity of their manual coding. Each observed interaction was then studied on the video by the researchers and more detailed manual coding was carried out as follows: (i) person crossing was forced to yield by a turning driver, or (ii) voluntarily yielded, or (iii) did not yield. Other coding included the following: the driver turning movement (left in, left out etc.); direction of travel of the person crossing (with or contra-flow relative to nearside of main road); and the type of person crossing (pedestrian, cyclist, and 'other' users of wheeled vehicles such as wheelchairs, mobility scooters, prams, and pushchairs). The data was input into a spreadsheet with a single entry per interaction with fields including site number, date, time, turning vehicle type, crossing person type and type of yield. For the modelling, these data were aggregated to fifteen-minute periods with a row per fifteen-minute period. The fields included site number, set back, presence of zebra, crossing flows by type and turning flows, and numbers of yields by type.

2.3. Focus groups

Focus groups were conducted on-line because of the Covid-19 pandemic. Despite restrictions being relaxed by the time some of them were taking place, there was still a need to avoid unnecessary travel. Five groups with twenty-six people took place in May 2020 focused on Design Priority junctions and eight groups with forty-seven took place in March 2022 focused on Marked Priority junctions. We were particularly careful to ensure input from disabled people with different types of impairments to provide a wide range of experiences. Twenty-seven participants reported having an impairment. Scheduling included weekend days and different times of the day. The results are discussed below in the light of knowledge from the focus groups. Key informant interviews were undertaken with eight participants, and the study was further supported by an advisory group. For full reporting of the focus groups, the reader is referred to Ricci and Parkin (2023).

2.4. Risk assessment

Though not fully reported here, the assessment of safety was undertaken in the two studies (Flower, Ricci, and Parkin 2021; Flower, Bolado Saenz, and Parkin 2023) by using data from the UK collision record for a period of typically five years before the enhancements were put in place and using as many years of data in the after period as were available. It should be stressed that the enhancements to the junctions were being put in place for reasons of enhancing the junction to reinforce priority, and not because of a collision issue at these junctions.

3. Results

3.1. Descriptive data

Table 2 summarises the data on yielding. Of the 1192 interactions at the three control junctions, 43.3% did not require the person crossing to yield. Sometimes the person

Table 2. Number of yields by the person crossing by type of junction.

					Number of yields by type				Percentages		
Type and site	No. of sites	No. of 15-minute observation periods	Set-back	Zebra	None	Voluntary	Forced	Total	None	Voluntary	Forced
Control sites	3	221			516	546	130	1192	43.3%	45.8%	10.9%
T1 Marked Priority	2	117	F	Y	777	1	166	944	82.3%	0.1%	17.6%
T2 Marked Priority	1	90	*P*	Y	1575	0	142	1717	91.7%	0.0%	8.3%
T3 Marked Priority	4	341	F		1585	253	744	2582	61.4%	9.8%	28.8%
T4 Marked Priority	2	157	*P*		627	0	141	768	81.6%	0.0%	18.4%
T5 Marked Priority	3	257	N		1020	1	595	1616	63.1%	0.1%	36.8%
T7 Design Priority	3	72	*P*		305	15	75	395	77.2%	3.8%	19.0%
T8 Design Priority	7	168	N		3808	58	322	4188	90.9%	1.4%	7.7%
Totals	25	1423			10,213	874	2315	13,402			

crossing could have taken priority but did not, and they indicated to the driver that the driver could proceed. There was nearly an equal proportion (45.8%) of these voluntary yields as no yields. 10.9% of people crossing were forced to yield by turning drivers' behaviours.

At Marked Priority junctions with a marked cycle crossing and an adjacent zebra crossing (i.e. a parallel crossing) the proportion of occasions when the person crossing did not yield was much greater than at the control junctions: 82% with full set-back and 92% with partial set-back. There were very few voluntary yields, but there was a difference in relation to forced yields with full-set-back demonstrating a higher proportion of forced yields (18%) than partial set-back (8%). Note there are no examples of Marked Priority with a zebra with no set-back because of the requirement for a minimum of two zig-zag markings on the zebra approach.

At Marked Priority junctions with Give Way lines on the carriageway both sides of the footway and cycle track crossing (i.e. with no zebra crossing), the proportion of occasions the person crossing does not yield varies from 61% (full set-back) to 82% (partial set-back), with high proportions of forced yields (18% for partial set-back and 37% without set-back).

Design priority with no set-back has a high proportion of occasions when the person crossing does not yield (91%), but this is lower with partial set-back (77%). Forced yields are low with no set-back (8%) but higher with partial set-back (19%). There are slightly more voluntary yields at Design Priority than at Marked Priority (between 1.4% and 3.8% at Design Priority) but these proportions are much lower than at the control junctions. Note there are no examples of Design Priority with full set-back because, with a continuous footway, it would typically be adjacent to or near to, the main road kerb line.

In summary, providing either Marked Priority or Design Priority has the effect of substantially reducing the proportion of voluntary yields by people crossing. Voluntary yields represent occasions when people crossing are demonstrating they know they have priority, but they are deferring to a driver. The effect of enhancing priority therefore assists in enforcing priority for people crossing because voluntary yields are, in broad terms, converted to 'no yields'. There is also evidence of a small increase in forced yields. A Marked Priority junction without a zebra assists in reinforcing priority for people crossing, but not to the extent demonstrated with a zebra. There is relatively little difference in performance between Marked Priority with a zebra and Design Priority.

Overall, it appears that junction enhancements have a beneficial effect on reinforcing priority. These changes in proportions of yielding have happened because behaviour of both the people crossing and drivers has changed as a result of the physical nature of the Marked Priority and Design Priority. The changes assist in confirming the rule of the road that turning drivers should give way to people crossing a side road.

3.2. Modelling forced yields

The proportions discussed above do not account for turning flows of vehicles in the carriageway and crossing flows of pedestrians and cyclists over the side road, and Table 3 summarises flow data for 15-minute periods. Mean crossing flows of pedestrians and cyclists (i.e. number of people crossing) across the side road vary from 15.5 to 53.4

Table 3. Mean 15-minute crossing flows and turning flows by junction type.

	Control	Marked Priority	Design Priority	Overall mean
Crossing flow in direction of nearside main road flow	15.5	20.8	53.4	25.5
Crossing flow contra-flow to nearside main road flow	16.2	15.9	29.3	18.2
Turns left out	8.9	16.0	9.6	13.8
Turns right out	6.5	11.6	2.7	9.3
Turns left in	6.3	15.6	3.9	12.2
Turns right in	8.6	15.2	6.8	12.8

Note: crossing flows are counts of people walking and cycles, turning flows are counts of vehicles (including cycles).

per 15-minute period. Generally, the Design Priority junctions had higher crossing flows than the other junction types. Mean turning flows of vehicles in the carriageway varied from 2.7 to 16.0 per 15-minute period, and hence the flows are of a similar scale, but generally lower than, the crossing flows. Generally, the Marked Priority junctions had higher turning flows than other types of junction.

Sixteen exploratory models were created with the distribution of the number of yields following a negative binomial regression model with log link. The dependent variable was the total number of forced yields in a 15-minute period, and for some models the total number of forced and voluntary yields combined. Explanatory variables included junction design features and the crossing and turning flows. Crossing flows were disaggregated into the classifications of pedestrian, cyclist and 'other', and some models aggregated these flows. Six models had categorical variables for junction type (Design Priority or Marked Priority relative to the base of the control junctions) and they tested for distance of set-back and presence of a zebra. Some models tested the product or ratio of the aggregate turning and crossing flows, and interactions of the junction type with disaggregated flows. No relationships were found, and hence no modelling was undertaken, of the effect on forced yields of corner turning radii, near-side bus lanes (three of the twenty-five sites) and the presence of a ghost island in the main road where vehicles wait to turn right into the side road (eight sites). All the models had similar explanatory power, but many models had many non-significant terms, especially the models with interactions terms.

As a result of the considerations above, one model emerged as the most informative model, and its parameters are shown in Table 4. Marked Priority and Design Priority are categorical variables representing the presence of that type of junction relative to the control junctions. The flows are divided into pedestrian and cyclist flows, and the flows of the other types of people crossing. 'With-flow' indicates the person crossing is travelling in the same direction as traffic in the main road lane nearest the side road. 'Contra-flow' indicates they are travelling in the opposite direction. The elasticities have been estimated for the mean value of the variables.

There are 3.487 times more forced yields at Marked Priority without a zebra than the control junctions. With a zebra, this reduces to 1.087 times (=3.487 × 0.312). At Design Priority there are 1.423 times as many forced yields. It should be noted that the proportion of forced yields are in the range 7.7% and 19.0% at Marked Priority with a zebra and Design Priority junctions, which are the two designs emerging as potentially preferred solutions. Hence, they represent relatively low numbers, and so percentage changes will be relatively high. Notwithstanding, it is interesting that there is a larger proportion of forced yields for enhanced junctions. We think this could be linked with the

Table 4. Number of forced yields regressed against the junction type and turning and crossing flows.

Variables	Coefficient (β)	Wald Chi-Square	*P* value	Mean value	Elasticity
Dependent: number forced yields				1.56	
Intercept	−2.927	151.235	<.001		
Base: control site					
Marked Priority, base	1.249	77.212	0		3.487
Design Priority	0.353	3.779	0.052		1.423
Marked Priority base: no zebra					
Marked Priority: with zebra	−1.165	51.654	<.001		0.312
Pedestrian with-flow	0.017	26.569	<.001	14.08	0.239
Cycle with-flow	−0.001	0.182	0.669	10.86	−0.011
Other users with-flow	0.164	15.622	<.001	0.56	0.092
Pedestrian contra-flow	0.022	35.636	<.001	13.22	0.291
Cycle contra-flow	0.009	6.816	0.009	4.50	0.041
Other users contra-flow	0.023	0.269	0.604	0.46	0.011
Left turn out flow	−0.001	0.142	0.706	13.79	−0.014
Right turn out flow	−0.001	0.044	0.833	9.28	−0.009
Left turn in flow	−0.009	3.83	0.05	12.18	−0.110
Right turn in flow	0.048	109.865	<.001	12.76	0.612
Log likelihood	−2143				
Akaike's Information Criterion	4380				
Negative binomial factor	1.25				

person crossing having greater confidence in taking priority, as is their right, coupled with some drivers thinking they are still entitled to take priority, despite the enhanced designs (and of course the rules). It should also be noted that the control sites may not have been typical: were they to have had an unusually low number of forced yields the effect revealed in this analysis may be exaggerated.

Non-significant variables include: the cycle flow in the direction of the near-side main road flow; the flow of 'other' users in the contra-flow direction; and vehicle flows turning out of the side road both to the left and to the right.

The elasticity for the right turn into the side road is 0.612. This implies that for an increase in mean flow of one vehicle per 15-minute period (from 12.76 to 13.78, equivalent to an 8% increase) there is an increase of just under 5% in the natural logarithm of the number of forced yields. This is the largest elasticity in the model. The elasticity for the left turn into the side road (−0.110) implies that an increase in the flow of traffic has the effect of reducing the number of forced yields.

Of the crossing flows, the flow of pedestrians crossing in the contra-flow direction to the main road nearside flow of traffic creates the greatest increases in the number of forced yields (0.291), but this is only modestly greater than for pedestrians travelling with nearside main road flow direction (0.239). The elasticity for the contra-flow cyclist flow (0.041) is much less than for the pedestrian flow.

4. Discussion

In the first section of the discussion, we consider the effect of junction enhancements on reinforcing crossing priority and compare our findings with the literature. In the second section, we consider the determinants of forced yields in relation to UK design guidance. We then consider limitations of the study and suggestions for further research. Finally, we outline the impacts to date of the research.

4.1. Effect of junction enhancements on reinforcing crossing priority

People crossing were able to cross the side road with priority on a higher proportion of occasions at Marked Priority junctions with zebras (82% to 92%) and Design Priority junctions (77% to 91% of occasions) compared with the control junctions (43%). The effect of enhancement appears to be to reduce the proportion of occasions when people crossing yield voluntarily at the control junctions (46%) to negligible levels. Our findings are therefore in line with Leden et al. (2006), who found significantly increased driver yielding to people crossing with the combination of stricter rules and junction re-design.

We found that on 91% of occasions people crossing did not yield at Design Priority layouts with no set-back. Where there was partial set-back, the proportion was 77%. This contrasts with Steer Davies Gleave (2018), who found drivers yielded at Design Priority crossings on only 79% of occasions to people crossing. However, design Priority appears to create better priority for people crossing than Side Road Entry Treatment: Wood et al. (2006) found drivers yielded in London on 56% of occasions.

At Marked Priority crossings without a zebra people crossed with priority on 61% to 82% of occasions, depending on the level of set-back. With a zebra, people crossed with priority on 82% to 92% of occasions. The presence of the zebra appears, therefore to have a large effect. Zebra road markings were perceived by focus group participants to be well-recognised and well-respected, hence perceptions of junctions which featured this type of pedestrian crossing tended to be more positive. Marked priority junctions that did not have a zebra crossing were perceived as creating ambiguity.

Our findings suggest that all Marked Priority crossings should have parallel crossings, i.e. crossings with a zebra. This contradicts the guidance which suggests that zebras should be considered only at busier locations.

Jones, Matyas, and Jenkins (2021) found that at conventional junctions provided with simple zebras (i.e. zebras without yellow globes, zig-zag markings or additional lighting) there were a higher proportion of occasions when drivers yielded priority. Coupling their finding with ours, we suggest that there is further scope for design development of simple zebra crossings at enhanced side road junctions. Such simple zebras would require a change to traffic regulations.

4.2. Determinants of forced yields

The inverse of someone taking priority when crossing a side road is the occasion when they are forced to yield by the behaviour of the turning driver. These forced yields may create the greatest risk.

In the safety analysis, the numbers of collisions were so low in both the before and after cases that individual junction analysis was of no value because of lack of statistical power. We found that, in aggregate, there were statistically significantly fewer collisions for Marked Priority in the after period compared with the before period ($\chi(1) = 10.1$, $p = 0.01$), and for Design Priority the change was on the cusp of being statistically significant at the 95% level of confidence ($\chi(1) = 3.84$, $p = 0.05$). We do not place weight on these estimates because of possible variability in effect between junctions, and the absence of knowledge about the way turning and crossing flows may have changed over the years. We think that prospective studies would be required to understand risk related issues at junction enhancements of these types.

The modelling of forced yields was undertaken to understand the potential for the generation of risk. This sub-section discusses the effects on forced yields of different factors in the following order: turning then crossing flows, type of junction enhancement, set-back, and finally detailed design issues.

So far as the effect of turning flows are concerned, the most common reason for a forced yield is linked to the right turn into the side road and the modelling found a large effect size with an elasticity of 0.612. Focus group participants confirmed that traffic turning off the main road creates most concern.

Compared with other types of turning, drivers turning right into the side road have a relatively high cognitive load in relation to the number of different crossing and turning flows that need to be considered. It appears that drivers turning right in are less aware of, and responsive to giving priority to, people crossing. They are much less responsive to offering the priority that is due to people crossing than drivers turning right out of the side road. This could be because they feel a greater need to move off the main road when they are waiting to turn. In addition, it could have something to do with the relatively wide angle of view required for identifying on-coming traffic and people crossing the side road (although this angle of view is less wide than for drivers turning right out of the side road).

This finding about the propensity of drivers turning right into the side road to cause proportionally more forced yields suggests that driver awareness training in relation to side road junctions needs to focus most on this manoeuvre. Ghost islands, or right turn pockets, may sometimes be provided on main roads to provide a space for right turning vehicles to wait while allowing through traffic to pass on their near-side (i.e. far-side from the side road). There is increasingly a move away from providing ghost islands on many streets. Their absence can assist in slowing main road traffic as a result of vehicles turning right. However, there could be value in considering the use of ghost islands specifically where there is evidence of inappropriate driver behaviours turning right into a side road at enhanced junctions, or banning some turning movements.

So far as the effect of crossing flows is concerned, pedestrians crossing the side road in the contra-flow direction to the nearside main road lane flow have a modestly higher number of forced yields than pedestrians crossing with flow. Interestingly, cyclists have many fewer forced yields than pedestrians. It appears that the concern placed on cycle traffic moving in the contra-flow direction as expressed in the design guidance is mis-placed.

It was expected that one of the models with (at least some) interaction terms for junction type and flow may have provided deeper insight. No interaction terms were consistently significant and often had the effect of making the main effect of a variable weaker. We therefore found no joint relationship between the type of design and the flows. In other words, the flows have the same scale of effect on every type of junction. Again, this contradicts the design guidance which suggests Design Priority is better where there are lower flows.

So far as types of junction enhancement are concerned, we found that there are around 9% more forced yields at Marked Priority junctions with a zebra crossing than at the control junctions, and 42% more at Design Priority junctions. This points to the value of zebras as noted in the discussion above, and suggests it may be appropriate to consider a hybrid of Marked Priority and Design Priority that in some way incorporates a simple zebra. However, the inclusion of a zebra implies a carriageway crossing which undermines the notion of a continuous footway or cycle crossing.

So far as set-back of the crossing from the main road kerb line is concerned, the descriptive data suggests that there may be an effect of set-back with lower proportions of forced yields for Marked Priority with a zebra with partial set-back (8.3%), and Design Priority with no set-back (7.7%) compared with the control junctions (10.9%). The modelling, however, revealed that the level of set-back had no effect on forced yields.

The focus group participants thought any deviation caused by set-back needs to be clearly and unambiguously indicated in some way for blind or partially sighted people. They also noted that cyclists may continue to use the carriageway rather than deviate on a route that is set-back from the kerb line. Some participants noted that the design of a set-back may bring people cycling and walking into too close a proximity. Blocking of the crossing by drivers was not a major issued mentioned in the focus groups.

Taking together the considerations about set-back of the focus group participants, and the possible effect of set-back on forced yields, considerations about set-back should extend beyond the simple idea in the guidance that set-back is implemented to control for drivers blocking the crossing point.

So far as detailed design issues are concerned, the focus group participants confirmed that detail is important. Wheelchair and mobility scooter users prefer there to be no slopes and cambers, dropped kerbs at both sides of a crossing point, or raised crossings. They also confirmed that the use of tactile paving would be counterintuitive at Design Priority (i.e. continuous footways) and should not be used. This road user suggestion, interestingly, contradicts key informants' understanding of the apparent obligation to use tactile paving even at Design Priority.

Focus group participants recognised a need for more consistency in design between junctions in the same urban area. They suggested that the consistent use of road markings, treatments, and street furniture across the country to minimise ambiguity and confusion. We also think that enhancements at some junctions but not others may lead drivers to reduced driver compliance at conventional junctions, something supported by Browne and Flower (2023) in their study of simple zebras at some side roads in Victoria, Australia. This requires further research.

4.3. Limitations

Ideally, research would create experimental conditions where variables are adjusted individually to assess effects. It would be costly to do that for data collection of the type needed for this sort of study. Hence, we rely on collecting data from the real world, in the manner of a natural experiment. This approach brings with it limitations.

Firstly, while generally complying with the guidance, every junction in the study had unique characteristics of their own. We were limited by the types of junctions available, and had to accept the variability we encountered, including in kerb radii, and presence or otherwise of bus lanes and ghost islands. In addition, there is variability in designer compliance with the guidance (and some of these departures in design detail are noted at the beginning of the methodology section).

We made attempts to study as much variability in design detail as possible, but the variability was of course limited by the junction sample size of 25. We therefore concentrated on factors for which we did have sufficient variability, i.e. flows and types of yield.

Safety is a prime concern of our profession. The nature of our retrospective study, the level of detail and known limitations of the historic collision record, and the absence of knowledge of historic flows limits the ability to draw conclusions in relation to safety. Further research might adopt a prospective approach to study risk at enhanced junctions.

4.4. Impact of the research

The research has directly supported the decision to include Design Priority (continuous crossings) in the updated version of Cycling by Design (Transport Scotland 2021). The authors have provided advice based on the research about the interpretation and further development of guidance to Transport for London, Active Travel England, Welsh Government and, as part of the development for the third edition of Manual for Streets, the Department for Transport. The authors presented findings in a webinar on 12th January 2024 to over 800 traffic engineers, which demonstrates the high level of interest in side road design enhancements.

5. Conclusion

The UK Highway Code states that people crossing a side road have priority over drivers turning in or out of the side road. This study has explored the types of yield that are taking place at twenty-five junctions: three conventional junctions, twelve junctions with priority reinforced with road markings and sometimes a zebra (Marked Priority), and ten junctions with a continuous footway and cycle track (Design Priority).

We conclude that Marked Priority with a zebra crossing and Design Priority crossings are preferred solutions because they support the rules for priority. We also conclude that there is scope for the further use of 'simple zebras' without zig-zags and illuminated yellow beacons, and they may have a part to play in creating a hybrid of Marked and Design Priority junctions.

We found that less set-back is beneficial because it creates a higher proportion of occasions when people crossing do not yield, as it is their right not to do. Focus groups supported less set-back and did not identify issues with blocking of the crossing with no set-back. We conclude that the default approach should be for crossings not to have set-back, and that guidance should be revised to move away from a presumption for set-back to avoid blocking.

Drivers turning right into the side road create most forced yields. Focus group participants expressed much concern about this turn movement. We tentatively suggest that driver training and possibly ghost islands in the main road may assist.

Despite the guidance being wary about bi-directional cycle tracks, we conclude that they may be used without concern because drivers create fewer forced yields for cyclists than they do for pedestrians, and contra-flow crossing movements (where people crossing face on-coming drivers) do not create additional forced yields by people crossing.

An unintended consequence of wider application of enhanced junctions could be that driver behaviour at non-enhanced junctions becomes worse. On the other hand, better behaviour at enhanced junctions may positively influence behaviour at non-enhanced junctions. Further research is required to understand this potential phenomenon. In addition, we recommend prospective studies to better understand safety issues at junction enhancements such as the ones we discuss.

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