The Safety of Cyclists at Various Road Features

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Abstract

In the UK, as across much of Europe, current policy is to promote the use of sustainable forms of transport including cycling. The opening of the national cycle network across Britain was seen as an important step in promoting the use of the bicycle. However, a history of designing roads for use mainly by motorised vehicles has left a road network which is unable to deal with the conflicting needs of various road users. For example, many roundabouts have been designed to take account of high flows of motor vehicles with negative implications for cyclists. Similarly, the presence of pedestrian refuges, introduced in order to assist pedestrians crossing roads with relatively high flows, often results in cyclists getting 'squeezed out' by motor vehicles.

This paper reflects on various case studies in which modifications to the designs of various road features such as roundabouts and road narrowings were made, all with the aim of improving safety and accessibility for cyclists. Some lessons from Europe were incorporated in the modifications, for example, in the changes made to the roundabouts. A number of 'before' and 'after' studies were carried out to evaluate the effect of the modifications on road users' behaviour.

Although the findings on each strand of the work were limited, due simply to the low numbers of cyclists using the roads that were monitored, it is suggested that a common pattern in the effects of various designs emerged: When minor changes are made to a typical British road layout to mitigate the negative effects that cyclists associate with the design, for example using perceptual measures, drivers' behaviour seems to be modified. With more severe modifications, such as advisory separations between cyclists and drivers, the effect appears to be that both cyclists and drivers modify their behaviour. When the changes are more dramatic again, such as complete physical separation between cyclists and drivers, it seems that the effect is that only cyclists modify their behaviour, an effect which suggests that cyclists are actually worse off as a result of such changes.

Context

High Motor Vehicle Flows

The U.K. has one of the largest population densities in Europe. Politically, there is a huge pressure not to build on our 'green' areas, but to manage any developments within so-called brown-field sites. Partly as a result of this, our planning processes are extremely slow. However, with homes, work-places, shops and leisure facilities restricted to a relatively limited area despite our large population density, demand for the road space that does exist is high. Management of our large traffic flows is a challenge for our local authorities, who manage local roads, and for Government, who indirectly manage our trunk road network. As you will probably be aware, earlier this

year London introduced a congestion charge with the aim of reducing the amount of traffic entering the centre of the city. Durham is another town in England with a charge for entering specific areas, and only last week Britain opened its first toll motorway, alongside, and 'competing' with an existing non-toll motorway. The country is amongst the first to be considering the introduction of a nationwide congestion charge.

Promotion of Sustainable Transport

The same pressures also result in political support for the promotion of the 'slow' modes of transport - walking and cycling - and other environmentally friendly modes. But with limited space and high flows of motorised traffic, a joined-up strategy has yet to be achieved. The opening of the national cycle network across Britain, a couple of years ago, was seen as an important step in promoting the use of the bicycle. However, much of this is alongside existing roads, rather than segregated, and the vast majority of town centres still require cyclists to cycle amongst the motorised traffic.

Cyclists and Road Features

In this paper, the effect of various road features on cyclists is considered. This is partly based on literature that is available on the subject, and partly on studies conducted at TRL in recent years. The issue is one of safety. TRL's work in this area has considered roundabouts and pedestrian refuges, or road islands, advanced stop lines, cycle lanes, bus lanes and so on, but the main focus here is on the first two of these. In the case of roundabouts, a number of studies were completed to ascertain the effect on safety of different designs. With pedestrian refuges, some virtual reality testing and attitudinal questionnaires were carried out in addition to site surveys. The conclusions and discussion herein are based on the overview we gained from our work, whether specifically from our studies, or from work elsewhere. Limitations in the size of our studies meant that definitive conclusions could not be based on our work alone.

Roundabouts

History and Motivation

William Plelps Enos in 1903, and then, three years later, Eugene Henard, architect for Paris, first conceived of the roundabout. The first roundabouts were introduced in the Place d'Etoile in Paris, and at Columbus Circle in New York. At the time these were the world's two most motorised cities. The aim of the roundabout was to keep traffic flowing, albeit in a circle, rather than to halt traffic at traffic lights.

Of course, the issue of who would have priority soon had to be resolved, and in France priority was given to the right. This had the advantage that traffic entering the roundabout could plough straight into the junction, but the downside was that traffic on the roundabout had to give way, and hence the roundabout could easily get clogged up, with high flows, as more and more vehicles entered the roundabout, and few were able to leave. In the early days, there were also a number of high speed accidents as vehicles entered the roundabout without first slowing down.

By the 1950's, the United States had abandoned roundabouts, replacing them with traffic lights. Even today, there are few roundabouts in the U.S.A., and with a lack of familiarity with these rare junctions, accident statistics at these intersections are really quite high.

Although the first roundabout in the U.K. had been introduced in Letchworth in 1910, it was only at around the same time that British traffic engineers started to seriously toy with the concept. In 1966, the 'give-way' rule was introduced at circular intersections. As in France, this meant giving way to the right, but with traffic on the left, this actually meant that traffic entering the junction would give way to traffic already on the roundabout. The circles were also, at least in the early days, smaller than those of the French counter-part, meaning that all traffic had to be slower in order to negotiate the junction. Studies have shown that introducing a roundabout at an intersection reduces the number of accidents by a half, and the number of injured victims by up to 75 per cent. Work by TRL showed that the introduction of this give way rule at an existing roundabout increased capacity by 10 per cent, reduced delays by 50 per cent and also reduced injuries by 40 per cent.

The Effect on Cyclists

Whilst roundabouts are clearly beneficial for flows of motorised traffic, cyclists in the United Kingdom, at least, are not keen on them, often trying to avoid them altogether, citing safety as the issue. Indeed, 10% of all accidents involving cyclists occur at roundabouts, with 11% of these resulting in serious or fatal injury to the cyclist. In fact, accident rates at roundabouts are 14 times higher for pedal cyclists as they are for cars. Rear end shunts involving cyclists are common. A circulating cyclist can easily be 'cut up' by a vehicle exiting the roundabout.

Drivers are less likely to be concerned about a cyclist when on a roundabout since they are concentrating on their own use of the roundabout, which requires more concentration than on a straight road. This is purely a reflection of the fact that drivers tend to concentrate on detecting the more frequent and major dangers at the expense of smaller, less common dangers. This may explain the inverse relationship between cycle flows and accident rates: As the number of cyclists at roundabouts increases, the number of accidents involving a cyclist decreases. Equally, though, these two effects may be the result of design issues, and one may not actually cause the other.

As roundabouts in the U.K. have had to cater for higher and higher flows, there has been an increasing issue of drivers entering the roundabout conflicting with circulating cyclists. Entry arms have become increasingly tangential to the roundabout so as to avoid slowing traffic down unnecessarily, with the result that drivers increasingly have to look over their shoulder rather than to their right, to check for circulating traffic. With a reduction in the length of the glance, higher vehicle speeds, and pressure from vehicles behind not to stop, cyclists have become increasingly unlikely to be spotted and reacted to. Indeed, more than a half of cyclist' accidents at roundabouts are of this type.

With more arms on a roundabout, cyclists are also more likely to be involved in an accident. Three arm roundabouts have one quarter of the accident rates for cyclists of those for five and six arm roundabouts. Since vehicle flows and population densities are higher in the U.K., roundabouts are more common in the first place, and the number of arms on roundabouts is frequently higher. On the other hand, mini-roundabouts are more popular amongst cyclists, with lower accident rates, partly because, in the main, these are introduced where two arms directly opposite each other carry the main bulk of the flow, the reason for introduction being to enable better access for traffic entering from the minor arm(s).

We have not yet been forward thinking enough in the U.K. to introduce 'give way to cyclists' rules as the Netherlands and Switzerland have done, for instance, because of the effect on vehicle flows. Where this rule applies, cyclists are allowed to obstruct motor vehicles. To give an idea of the number of vehicles able to use a roundabout, the following table is presented for roundabouts without this rule found from some work carried out in the Netherlands:

Lanes on the Roundabout	Approach Roads	Maximum Capacity (24 hours)
One	Single carriageway	25,000
Two	Single carriageway	30,000
Two	Dual carriageway	40,000

However, when the 'give way to cyclists' rule is introduced, the capacities fall, as follows:

Lanes on the Roundabout	Approach Roads	Maximum Capacity (24 hours)
One	Single carriageway	20,000
Two	Single carriageway	22,000
Two	Dual carriageway	35,000

A Trial Approach

The choices for improving the safety of cyclists at roundabouts fall into three main categories. The first is to provide them with facilities that mean they can avoid the roundabout. However, subways bring their own safety issues, and use of pavements, alongside pedestrians, is illegal for cyclists except where shared use has been introduced. Where such use is introduced, not all cyclists are keen to travel round the roundabout, negotiating each arm in turn, in order to get through the junction. The third choice for the transport planner is to design the roundabout itself so that cyclists can use it with more comfort.

We at TRL have recently carried out some studies on four roundabouts where the geometry and design of them was modified, partly to improve conditions for cyclists. The new designs incorporated features of roundabouts of mainland Europe since the designs of roundabouts here have also evolved over the years. In recent years in Europe roundabouts have been introduced primarily on roads with lower flows, for traffic calming purposes, and to improve conditions for the higher number of cyclists.

The focus of many of the measures we studied was to reduce the speed of motorised traffic on entering and using the roundabout, and to increase the visibility of cyclists. The reasoning behind the desire for a reduction in speed was, initially, almost exclusively so that the severity of any accident that did occur was reduced. However, it was also thought that the reduction in speed would reduce the number of accidents occurring as well as their severity.

These so-called 'continental' roundabouts, needless to say, have lower capacities than those with typical UK geometric designs, and are considered to cater for flows of up to 2,500 vehicles per hour. The fact that this is still far more than the capacities presented above shows how limited the introduction of 'continental' features really was.

Some of the features that were termed 'continental' were as follows:

- A reduction in approach widths and entry widths – single lane entries and exits
  Whilst these do lead to an increase in approach arm accidents, single vehicle and entry-circulating accidents do fall.
- An increase in the size of the central island relative to the roundabout – a narrower circulatory carriageway
  This leads to a fall in entry-circulating accidents. The optimum width of the carriageway as regards cyclists is somewhere between 7m and 9m.
- An increase in the entry path curvature – arms that are perpendicular rather than tangential to the roundabout, with minimal flare on entry
  Again, entry-circulating accidents fall, but single vehicle accidents and approach arm accidents rise.

Figure 1. Gloucester 'Before' Roundabout Modifications

Figure 2. Gloucester 'After' Roundabout Modifications

Figure 3. Nottingham 'After' Demonstrating Larger Central Island

Figure 4. Gloucester 'After' Cycle Strips

Results

It should be said that, from our work alone, it was difficult to conclude that there was a benefit in safety terms to cyclists, though questionnaires we carried out indicated that cyclists felt safer.

However, when we studied our results together with other experiences, we were able to conclude that all of the features had a beneficial effect, in one way or another: a tighter geometry on approaches, a reduction in the number of entry and exit lanes and an enlarged central island did appear to have the results our theory predicted.

At the two roundabouts in Nottingham that we studied, the expansion of the central island meant that only one lane was available on the roundabout itself. When cyclists then chose to cycle down the middle of the carriageway, stopping drivers over-taking them and cutting them up, this was quite successful. This behaviour means that cyclists have to be treated like any other vehicle, with equal rights, rather than as something entirely different that needs negotiating. This reflects Swiss experience that cyclists accept single-lane roundabouts as the best option. However, it was frequently the case that cyclists would cycle at the edge of the carriageway, and this actually increased the danger posed to cyclists since drivers would then try to overtake in a more confined area.

We also found that Toucan crossings were beneficial, due to the assistance they give less experienced cyclists in crossing arms, and that there was an effect by introducing cycle strips in front of each entry arm. Although not used frequently by cyclists, these did reduce the number of occurrences of drivers over-shooting the give way line.

Pedestrian Refuges and Road Narrowings

Motivation and Effect

The promotion of walking has been referred to earlier in this paper, and this, combined with the high vehicle flows we experience, is the reasoning behind the existence of many of our traffic islands in the middle of the road. By allowing pedestrians to stop mid-way across the road, it enables them to tackle one side of the road at a time.

However, these islands inevitably make it more difficult for drivers to overtake cyclists on the road since they cannot make use of the other side of the road, even if there is a gap in the on-coming traffic. This can result in drivers rushing to overtake a cyclist before an island, cutting up the cyclist, overtaking in the narrow section alongside the island, or waiting until after the island to overtake, possibly putting undue pressure on the cyclist to get past the island quickly.

Virtual Reality Trials

At TRL, we have recently carried out some work to better understand the types of road design that cater best for cyclists. We carried out some virtual reality testing on a simulator to see how drivers reacted to cyclists when encountering them on a straight road. This we did with various designs, some including a cycle lane, and others not; some incorporating a pedestrian refuge, and others not. Different cyclist' behaviours were also controlled for. We also carried out questionnaires to gain an understanding of drivers' attitude.

Figure 5. Virtual Reality Drivers' View

Figure 6. Virtual Reality Drivers' View with Cycle Lane and Central Island

Results

The introduction of a cycle lane at a road narrowing was to improve driver confidence and ease of passing. However, the introduction of a traffic island, unsurprisingly, had a negative effect on both of these. Interestingly, despite the cyclists' behaviour being the same in all the situations, drivers assessed the cyclists as inconsiderate with the existence of an island, but as considerate when there was a cycle lane.

Where, perhaps, the findings were opposite to those mentioned so far, was with speeds. The presence of a cycle lane resulted in drivers slowing down far less, even when the cyclist was not using the cycle lane, and the presence of a pedestrian refuge had the opposite effect, as well as increasing the amount of hesitant behaviour. Neither of these, the greater speed, or the greater unpredictability, is desirable for cyclists.

In terms of positioning, the presence of a cycle lane appeared to encourage cyclists to position themselves nearer to the kerb when being overtaken near a road narrowing. The presence of a cycle lane appeared to encourage drivers to position their vehicles nearer cyclists than if there were no cycle lane. The introduction of warning signs at one of our survey sites appeared to encourage drivers to overtake the cyclist before the island and to leave less space when overtaking, though when the surface of the cycle lane was changed to green (from grey), drivers became more likely to wait until after the island before overtaking.

When we investigated the colour of the cycle lane more generally, we found that a colour different to that of the road was helpful in reducing speeds, and in delaying the overtaking manoeuvre until after the island. The reason for this is one of perception – the road looks narrower when the edge of it is coloured and this has the desired effect on the speed drivers choose to go at.

From our site surveys, we discovered that in built-up areas where traffic is heavier and vehicles sometimes park on the edge of the road, cyclists travel further from the kerb, and drivers are less likely to overtake. However, our surveys in our tests showed that a wobbling, unpredictable cyclist was viewed as more considerate than one taking a central position in the lane, perhaps because this behaviour was perceived as less actively obstructive. This, perhaps, has implications for the roundabout designs considered earlier in this paper.

Our work also showed that cyclists consider that the vast majority of drivers are hostile, perhaps even actively aggressive, towards them, when, in fact, it is only a minority of drivers for whom this is the case. However, as rare occurrences and vulnerable users, driver stress is an inevitable consequence of an encounter with a cyclist, at least to some degree. Drivers do also blame cyclists when they behave incorrectly, rather than making allowances, as they appear to do for mistakes in the driving of other motor vehicles. In fact, other drivers' behaviour is generally thought of as being more considerate than that of cyclists.

Conclusions

One key conclusion which became apparent in our work was that the ideal road is one that does not force cyclists and motor vehicles into close proximity as at roundabouts and road narrowings. The next best option is to slow motor vehicles down, which is

unpopular, in order to reduce the speed differential. There are problems in attitude from drivers towards cyclists. In the U.K. we find ourselves in a vicious circle whereby there are not enough cyclists to enable dramatic changes to take place without it being politically unpopular, and this has the result that our roads are not designed with cyclists in mind, further discouraging cyclists.

In broad terms, we found that measures that might be defined as perceptual, such as signing and tightened geometry affect driver behaviour almost exclusively. When the intention is to promote separation within a particular space, the effect appears to be that either group will modify their behaviour. When the changes are designed to completely separate cyclists and drivers, cyclists alone modify their behaviour. It is, however, felt by more experienced cyclists that integration is more desirable than segregation, and that a broad indicator of success is the level to which cyclists can behave as if there were no other traffic around. Indeed, one might say that achieving this equally for cyclists as for drivers, is key if cyclists are not to be treated as second class citizens.

On a more general scale, familiarity is key. Where there are numerous variations in the design of a junction, road users are, unsurprisingly, more likely to navigate them incorrectly. This fits in with the earlier point about the relatively high accident rates on roundabouts in the United States, where the number of roundabouts is low. Similarly, good signing and road markings are important factors in all road features, including for cyclists at roundabouts. Indeed, it is only with good signing that the introduction of radial entries to roundabouts will not increase the frequency of rear end shunts, as vehicle speed may be reduced unexpectedly without sufficient warning. Education on how new and unfamiliar road features should be negotiated by the various users is also vital to ensure that the benefits of a design are not lost.