REVIEW ARTICLE

Engineering safety on the road

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Reasons underlying the occurrence of accidents on the road are complex and involve interactions between road users and their environment. This paper examines how changes in the infrastructure and road use can provide a safer environment for all road users, whatever their age or mode of travel. Priorities for future action are identified.

Background

Engineering safety on the road has been a major concern of highway authorities for decades. The first recorded activity in the 1930s was the improvement of skidding resistance of wet roads. However it was not until after the second world war that a systematic approach was adopted to establish safety principles of engineering and traffic management, and identify problems to which engineering based solutions could be found.

A major impetus to developing safety engineering practice occurred some 20 years ago, when the statutory responsibility for safety was placed on local authorities. This required local highway authorities to *reduce* accidents and casualties through education and engineering means, and to institute accident *prevention* measures. What subsequently developed was the formation of a road safety group in each authority comprising two strands: road safety officers responsible for education and training and road safety engineers responsible for improving the environment.

It is the work of the latter to which this paper is addressed, although it is important to recognise that the integration of education and engineering practice, together with enforcement is an essential element of the success of these groups. The role of the three Es (Education, Enforcement, and Engineering) is embodied in the Local Authority Associations publication, *Road Safety Code of Good Practice*, published in 1989.¹

This paper examines the current accident situation in terms of who is injured, under what circumstances, and what factors contribute to accident occurrence. It then outlines engineering approaches to improving safety, and summarises benefits that have accrued from different types of remedial treatment, illustrated by some case studies. It ends with an indication of the potential benefits for the future and priority needs.

Current accident situation on the roads

In 1993, 3814 people were killed and 45 009 seriously injured out of a total of 306 020 casualties reported by the police. Allowing for

under-reporting of injuries to the police the true total is more likely to be 65 000 seriously injured and 500 000 casualties in total. Including non-injury accidents, the total road accident toll was of the order of £10 800 million; the average cost of an injury accident being estimated to be £44 000.

Simple analysis of the national police statistics gives a perspective of the accident situation in terms of *who* is involved (the type of road user), *where* (urban or rural area, road layout), *when* (day or night), and under *what* circumstances (dry or wet, type of collision). Detailed tabulations of information are published annually in *Road Accidents Great Britain*.² Table 1 gives some of the more frequently occurring features.

More than half of the deaths occurred on rural roads where speeds are higher than in urban areas, but serious injuries were twice as numerous on the urban roads where traffic faces more conflicts, especially at junctions.

Pedestrians and vehicle occupants make up the largest numbers of reported casualties. However allowance for the known under-reporting suggests that more cyclists are injured than pedestrians, though far fewer are killed. Children aged up to 15 years (inclusive) are mainly at risk for fatal or serious injury as pedestrians, accounting for one half and two fifths respectively of all child casualties.

Not surprisingly, cars dominate in accidents: overall, three quarters of the vehicles involved

Table 1 Features of road accidents

Road user casualties

Of those killed:

Nearly half are *car occupants*One third are *pedestrians*One sixth are *children or adolescents*

Of those injured:

Three fifths are *car occupants*One sixth are *pedestrians*One quarter are *children or adolescents*In urban areas, 57% of killed are *pedestrians*In rural areas, 72% of killed are *car occupants**Vehicles involved*

Of vehicles involved in all accidents:

Three quarters are *cars*

(involved in nearly 9/10 accidents)

Of vehicles involved in fatal accidents:

Two thirds are *cars*One tenth are *heavy goods**Accident circumstances*Three quarters of all accidents occur in *urban* areasJust over half of *fatal* accidents occur in *rural* areasOne quarter of all accidents occur in the *dark*Two fifths of *fatal* accidents occur in the *dark*One third of all accidents occur on *wet* roadsIn *urban* areas:Two thirds occur at *junctions*Two fifths on *major* roadsIn *rural* areas:Two fifths occur at *junctions*Two thirds on *major* roads**Road Safety Consultant**

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are cars, but on rural roads heavy goods vehicles make up a substantial proportion.

These statistics illustrate the differences in risk for different road users under different circumstances. An essential part of engineering for safety, therefore, is that practice is based on detailed accident analyses to identify the main problems in terms of who is involved, when, where, and why.

Factors contributing to accidents

Understanding why accidents occur has been explored in depth in studies worldwide. Many factors may contribute to accident occurrence, and most accidents involve more than one factor. Human factors contribute to 95%, road factors to 25%, and vehicle factors to less than 5%. The main human errors are: going too fast for the situation, failing to give way at junctions, following too close, overtaking improperly, misperceiving or misjudging the road situation ahead, and impairment as a consequence of drinking alcohol. Road deficiencies that are main contributory factors are: poor design of layout or control at junctions, inadequate signing, road markings and lighting, slippery roads, and obstructions on the road such as parked vehicles. Main vehicle factors are: defects in tyres, brakes and lights, arising from poor maintenance of the vehicle.

The interaction between human error and the road environment has important implica-

tions for the choice of appropriate interventions to reduce accidents. Although human error contributes to the majority of accidents, engineering and traffic management can aid and influence road users to change their behaviour, and can make their environment safer through reducing conflicts. This is particularly relevant where excess speed, lack of perception, and poor judgment are concerned.

Engineering approaches

At the basis of safety engineering is a structured system of accident investigation. *Guidelines for Accident Reduction and Prevention* have been promulgated by the Institution of Highways and Transportation (IHT) since 1980.³ Reduction and preventing are considered as separate issues, requiring different approaches.

Accident *reduction* is achieved through the application of cost effective measures on existing roads: the investigative procedure is detailed in RoSPA's *Road Safety Engineering Manual*,⁴ which covers techniques for identification of hazardous road location, diagnosis of problems, selection of treatment, and evaluation.

Accident *prevention* is achieved through the application of safety principles in the provision, improvement, and maintenance of roads: procedures are outlined in IHT Guidelines for Safety Audit, which summarises safety principles for geometric design, road surfaces, road markings, road furniture and signs, and traffic management.

The techniques, the appropriateness and effectiveness of treatments, and the safety principles are based on studies and controlled trials from worldwide experience.

Treatments (interventions) and benefits

Hazardous road locations extend far beyond the common concept of 'blackspots' to include a wide range of locations and situations. The four investigatory techniques that have been adopted take account of this range.

- (1) *Single sites*: specific sites or short lengths of roads at which accidents cluster ('blackspots').
- (2) *Mass action*: locations having common accident factors.
- (3) *Route action*: lengths of road having above average accident rate for the type of road.
- (4) *Area action*: areas requiring a global approach; a technique particularly aimed at dealing with scattered accidents, usually in urban areas.

The process of investigation in all cases is:
 Identification of problem locations
 Diagnosis of the problem
 Selection of remedial measures
 Implementation
 Evaluation of treatment

To aid this process, experience from past investigations and trials has been collated to advise on appropriate treatments according to the dominant accident types occurring. Table 2 summarises the options for remedial treatment according to the accident situation and dominant feature. Where figures are given for

Table 2 Accident types and remedial options

	Remedial options	Potential savings in accidents
<i>Urban or rural roads</i>		
<i>Wet road</i>		
Skidding or loss of control	Anti-skid treatment	30–60% (80% wet)
In darkness	Improving surface texture	
<i>Darkness</i>		
Lit road	Improve quality	30–50% dark
Unlit road	Delineate with lane and reflectorised edge markings (or) instal lighting	50–70% dark 30–50% dark
<i>Running off road</i>		
Cross carriageway or down slopes	Safety barriers	15% fatal or serious
Hitting rigid object	Safety barriers or crash cushions	15–65% severity
<i>Junctions</i>		
Overshoot from minor road at crossroads	Traffic islands in minor road	50–80%
Overshoot on main road at roundabout	Yellow bar markings	50%
Turning traffic	Traffic signals	30–50%
Restriction of sight	Waiting lanes, 'ghost' islands Realign or relocate junction, remove obstruction	20–30%
<i>Cyclists</i>		
Conflicts with vehicles	Cycle lanes or tracks	20%
<i>Urban roads</i>		
<i>Pedestrians</i>		
In road	Controlled crossing	20% (30% pedestrians)
Stepping out	Guard rails	10%
<i>Traffic lights</i>		
Running red lights	Camera detection	20–60%
<i>Speed</i>		
Too fast for conditions	Camera detection Traffic calming (specific roads)	30–40% Up to 70%
<i>Rural roads</i>		
<i>Non-junction</i>		
Overtaking	Central hatching	30–50%
Bends	Realign Chevron and warning signs	60–80% 70–80%
<i>Speed</i>		
Approaches to villages	'Gateways' and traffic calming	
Interurban	Enforcement

Figure 1 A perceptual trap for drivers: the major road is straight for two miles before it bends to the right at a junction, where a minor road continues straight on with the same width and tree line as the major road. (A) Original layout and (B) after remedy.

the potential accident savings they are based on statistically significant findings from soundly designed before and after studies. These options are relevant to single sites, mass problems, and routes. The approach for dealing with areas is somewhat different, and will be illustrated later by an example.

Overall, these measures can produce substantial savings in accidents and injury. Most of the remedial treatments involved are low cost. With the average cost to the community of an injury accident being estimated at £44 000, detailed assessments of benefit to cost have indicated a favourable first year rate of return (FYRR) of at least 50% for single sites (and often several hundred per cent); and at least 40% for mass action and route action treatments.

Examples of treatments

EXAMPLE 1 — SINGLE SITES

In a diagnosis of the accident problem at a site, it is important that engineers understand the part that human factors play. Perceptual and visual problems experienced by road users may give a lead to engineering measures to improve road user behaviour. The following is an example of perceptual 'traps', which are quite com-

mon. At the junction illustrated in figure 1, frequent accidents were reported, most occurring when vehicles travelling in the direction shown failed to negotiate the bend on the road. The junction presents a misleading visual situation, which nevertheless would cause no difficulty to the alert driver. The main road bends to the right, while the road going straight on is the minor road.

Interviews with the accident involved drivers indicated that their eyes were focused on the distant view ahead, and they did not notice either the information or warning signs. This suggested a simple engineering remedy — to realign the kerb line at the junction and to erect black and white chevrons on the projecting area of the verge on the nearside. As a result, the 'straight-through' appearance of the road ahead is now broken up and gives a guideline to the driver well in advance of the junction.

For a few hundred pounds the frequency of accidents was reduced from 10 in three years before treatment to one in three years after; a FYRR of several hundred per cent.

EXAMPLE 2 — MASS ACTION

Perceptual problems are widespread, even though they do not necessarily lead to cluster of accidents at any one site. The second example illustrates how the mass action approach can be used to overcome one such problem (figure 2). This concerns a study of crossroads of similar layout — where straight minor roads crossed major roads. Although not one of the group of sites could be classed as a blackspot, an analysis of the accidents in total indicated a dominant factor: drivers unintentionally overran from the minor road, again associated with the very straight unbroken alignment of the minor road ahead. In a controlled trial, offset traffic islands with upstanding Give Way signs were installed in the line of sight of the minor road driver at 13 such junctions.

The 'before' accident frequency at individual sites, averaging 2.8 injury accidents/year, was halved after treatment. The cost of treatment at all sites totalled £25 000: the economic saving from accident reduction over four years was 10 times this figure.

EXAMPLE 3 — ROUTE ACTION

Route action may be simply an aggregation of single site treatments (usually in urban areas) or an application along a length, such as road marking to deter overtaking, or improving skidding resistance. The example is a trial on a 3 km length of road, a through route in an urban area. For several years about 50 injury accidents had occurred annually, nearly one half of these being associated with a right turn manoeuvre and one quarter involving pedestrians. The treatment was to improve the control of traffic (by installing roundabouts) at key junctions providing access to the adjacent residential neighbourhoods, imposing right turn bans at other junctions, and adding three new light controlled crossings.

The outcome was a 12% reduction in injury accidents, with a FYRR of 55%.

Figure 2 Perspective view of 'straight-through' crossroads. (A) Original layout and (B) after remedy.

EXAMPLE 4 — AREA ACTION
A major five town trial undertaken by the Transport Research Laboratory (TRL) in the 1980s demonstrated how overall savings in accidents can be achieved over a whole area by strategic application of low cost measures, even when accidents are scattered about the network.⁵ The principle is illustrated for one of the five towns, Sheffield. The trial area of approximately 9 sq km, with a population of around 50 000, covered a network of roads bounded by clearly defined traffic routes, but within that boundary local roads all had equal status.

The management of safety in such an urban area outside the centre hinges on first defining a hierarchy of roads according to their function. Figure 3 illustrates how this hierarchy was defined: for through traffic, for local distribution of traffic, and for local access to residential areas. The figure also indicates the safety objectives for the area. From diagnosis of accidents appropriate safety measures are applied to match the needs of the new hierarchy: on the through routes and local distributors, reducing conflicts and easing flow, controlling speed and parking, and providing pedestrian and cyclist facilities; in residential areas, designating slow zones, 20 mile/hour zones, play areas, etc, the status of which is reinforced by environmental improvements and traffic calming measures.

The outcome was a 30% reduction in accidents compared with a similar control area of the town. Overall, for the five towns the reduction was 13%, with rather greater reductions in child casualties and cyclists. The FYRR was of the order of 40%.

Figure 3 Urban safety management in an area showing safety objectives.

Future priorities

In 1987, the government set a target for reducing road casualties by one third by the year 2000 (relative to a baseline average for 1981–5). Systematic accident investigation procedures and subsequent treatments have played a major part in realising this target. It is not easy to quantify this contribution, but from the known successful interventions by highway engineers it is not unreasonable to estimate that safety engineering applications have already contributed one quarter of the target savings, with the potential for further benefits.

Experience of past decades shows *what works* in safety engineering, and *what can work*. For the future it is important to maintain the impetus by extending present practice. To make further progress, more effort needs to be applied to safety management in urban areas, where the more vulnerable road users (pedestrians and cyclists, children and the elderly) will be the greatest beneficiaries. In rural areas, the

highest priority is to deal with A class roads (both single and dual carriageway) where ways of reducing speed will have greatest effect on vehicle occupants.

The way forward to greater safety on the roads demands greater cooperation between all concerned. The engineers are only one part of a broader alliance of educationalists, enforcers of the law, and health carers.

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- 1 Local Authority Associations. *Road safety code of good practice*. London: Association of County Councils, 1989.
- 2 Department of Transport. *Road accidents Great Britain*. London: HMSO, 1994.
- 3 Institution of Highways and Transportation. *Guidelines for accident reduction and prevention (international edition)*. London: IHT, 1990.
- 4 Royal Society for the Prevention of Accidents. *Road safety engineering manual*. Birmingham: RoSPA, 1992.
- 5 Mackie AM, et al. *Urban safety project 3: overall evaluation of area wide schemes*. Crowthorne, Berks: Transport and Road Research Laboratory, 1990.