

PEDESTRIAN AND CYCLIST PROTECTION ON ROAD VEHICLES WITH HIGH OR FLAT FRONTS
IAN D. NEILSON
PARLIAMENTARY ADVISORY COUNCIL FOR TRANSPORT SAFETY
UNITED KINGDOM
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ABSTRACT

Many pedestrians and cyclists are killed and injured worldwide by being struck by the fronts of large vehicles. The EU countries are preparing to introduce car fronts which offer protection to pedestrians struck by them. Protection for pedestrians struck by vehicles larger than cars as well as by cars is needed worldwide but particularly in less developed countries. This paper (1) suggests how such protection can be introduced into the design of all vehicles larger than cars, and discusses the design problems to be solved and the way in which the existing test procedures might be used. Air bags might be used as an alternative to provide frontal protection, either wholly or just locally where flexible cushioning cannot readily be fitted. Another alternative is the provision of an electronic warning system to enable the vehicle to be braked in time to avoid, or reduce, the severity of impacts into vulnerable road users. The pros and cons of the various safety measures are discussed.

INTRODUCTION

It is not commonly realised that the majority of road accident fatalities worldwide are vulnerable road users, who are pedestrians and pedal and motor cyclists, rather than vehicle occupants. Indeed, it is estimated that 60 to 80% of the total are in the vulnerable category. Mohan (2) gives details about this and distinguishes between the situations in Highly Motorised Countries (HMCs) and Lowly Motorised Countries (LMCs). For example, while about 5,000 pedestrians are killed each year in USA, there are about 19,000 a year in China but the proportions of types of vehicles involved and the road conditions and circumstances are very different.

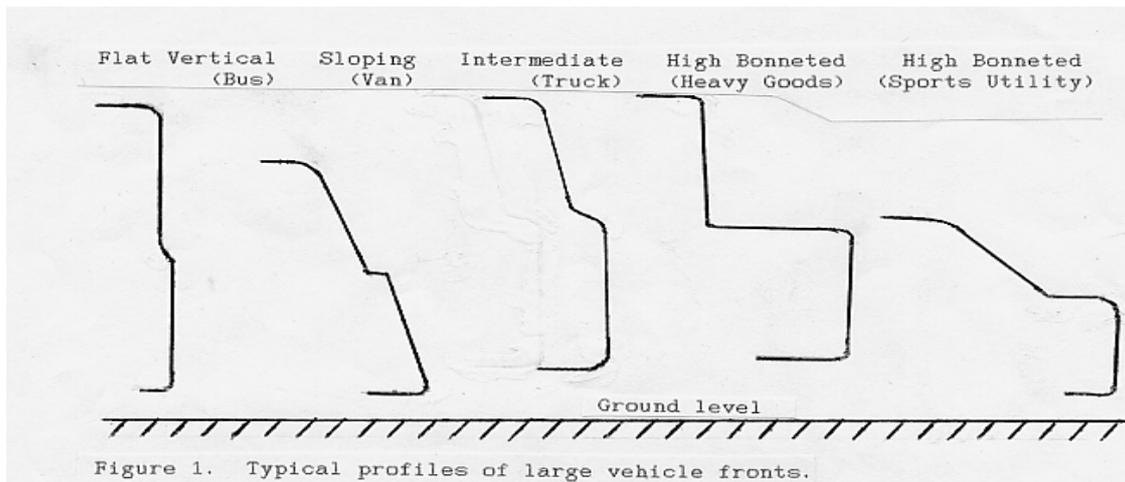
In the developed countries (HMCs) cars form the majority of the traffic and are most frequently involved with their occupants forming the majority of casualties. The pedestrian and other vulnerable road users are mostly involved in accidents in urban areas. Countermeasures are well developed and these

include highway design for safety and training in safe road behaviour with Highway codes backed up by legal sanctions and penalties. Vehicles have to meet Type Approval requirements, and these are backed up by NCAP (New Car Assessment Programme) (3) schemes and inspection systems to check vehicle condition as regards safety during their service life.

In less motorised countries (LMCs), many areas have more truck and bus involvements in accidents than do cars. This means that there is a very great need worldwide for developing means of ameliorating impacts of trucks and buses into pedestrians and cyclists as well as for reducing the numbers of such impacts. In LMCs road design measures for safety are unlikely to be introduced widely and greatly improved road user behaviour will probably not be realised in practice.

Considering all these factors, it is clear that vehicle safety features are the only means by which vulnerable road user casualties are likely to be reduced worldwide. This paper primarily stresses the need for designing cushioned fronts on all large vehicles as well as on cars. Such car frontal improvements are extensively being developed in Europe and requirements or equivalent measures are actively being agreed. The distinctive feature of large vehicles is that they have high vertical, nearly vertical or sloping fronts or have high front compartments ahead of their drivers (Figure 1), each of which give rise to slightly different design problems for pedestrian protection.

A possible additional or alternative safety device has recently been investigated by Mazda (4). This is an electronic system which uses sensors to measure the relative positions of objects ahead of the vehicle and computes whether they are on a collision course. If this is estimated to be the case they immediately apply the vehicle's brakes or give the driver instant warning of the need to do so. The pros and cons of both systems are briefly discussed.



It has been realised for 30 to 40 years that reduced speeds of road vehicles would have a disproportionately large effect in reducing both the rate at which accidents occur and the severity of those injuries which do occur. It will soon be technically possible for HMCs to start adopting ISA (Intelligent Speed Adaptation), the system in which speed limiters on road vehicles are set by satellite from ground stations. These set the maximum safe speed along any local length of road to suit local hazards, current weather, traffic and other driving problems. Such an advance will take many more years to introduce in LMCs. In any case ISA may not be as effective for reducing casualties among vulnerable road users as for other occupants.

DATA REQUIREMENTS FOR THE SELECTION AND DESIGN OF SAFETY MEASURES

Conditions relating to accidents involving vulnerable road users vary greatly between European countries, let alone between other countries around the world. However, a few details are given (5) for Great Britain in Table 1. These data are not quite complete because a few cyclists are killed in multi-vehicle collisions. Also, there are some vehicles such as multi-purpose people carriers (MPVs) and off-the-road four-wheel-drive cars which are included in the car category, but which really come in to the large vehicle category for pedestrian impact conditions. The numbers of accidents involving such vehicles are not readily available. It is shown in Table 2 that between about 55 and 70% of the pedestrian fatalities from Table 1 occur in impacts with the fronts of these vehicles. Data show that the situation for pedal cyclists is similar. A smaller proportion of motorcyclist fatalities

Table 1.

Vulnerable road users killed in road collisions in Great Britain in 1998

Vehicles involved	Pedestrians (in single/ multi-vehicle collisions)	Pedal cyclists (in collisions with one other vehicle)	Motor cyclists (in collisions with one other vehicle)
Buses or Coaches	59/3	4	4
Light goods vehicles	49/10	6	20
Heavy goods vehicles	62/11	29	36
Other large vehicles	9/1	3	12
Totals (for large vehicles)	179/25	42	72
Totals (for cars for comparison)	578/95	84	202

Table 2.
Pedestrian fatalities in single vehicle/pedestrian collisions in 1998

Vehicles involved	Pedestrians killed when front of vehicle first point of contact	Percentage of total pedestrians killed	Total pedestrians killed
Buses and coaches	41	69	59
Light goods vehicles	30	61	49
Heavy goods vehicles	36	58	62
Cars	480	83	578

occur into the fronts of vehicles and their impact speeds are usually higher, but despite this a small advantage would be gained for them by improving large vehicle fronts.

The total number of pedestrians and cyclist killed each year in Great Britain by striking the fronts of large vehicles is about 150 besides the unknown number killed by MPVs. The probable reason that this group of casualties has not received any great attention previously is that the total is made up from small numbers of impacts into the different categories of large vehicle. As already mentioned, the situation varies from country to country so that worldwide the total of vulnerable road user fatalities into vehicles of all types is very high, being from 60 to 80% of all road user fatalities.

A little further work in Great Britain would be of some help. For example, the risk to vulnerable road users of MPVs and four-wheel-drive vehicles would be of interest. There could be a study of the mode of injury and the resulting severities of injury when pedestrians and cyclists are struck by the fronts of existing designs of large vehicle. This would provide background data to help in the redesign of fronts. A detailed accident and injury study would be needed to do this.

DESIGN OF SOFT FRONTS

Purpose of Soft Fronts. There are two protective functions of soft fronts. First the area of contact is increased as the skin or shell of the front moulds around the part of the human body in contact. This spreads the loadings and so reduces the initial peak loads and thus reduces the likelihood of bones fracturing or softer tissues being penetrated by small hard spots or sharp edges of the

structure. At higher speeds of impact, the soft front needs to yield locally to prevent excessive loadings building up as the relative speed between the pedestrian and the vehicle front reduces to zero. Laminated glass breaking up and yielding under head impact is one illustration of these two processes occurring. The crazed area around the initial point of contact is larger for greater speeds of impact.

Typical Padded Frontal Structures. The skin of front panels can be of either sheet metal or suitable plastic materials. Some large vehicle fronts are currently made of one piece plastic mouldings which are relatively inexpensive and are fairly thin so that they yield when struck by human legs, body or head. They have a great advantage in that they have no edges between one panel and the next, because joints and seams inevitably are much stiffer than are the middles of the panels. Behind the outer skins there must be sufficient space for the 'dishing' of the skin to take place without hard structures or components being reached. In most cases this space is filled with fairly low density foam which enables the frontal crush to be tuned to the mass and relative impact speed of the human body component likely to strike it.

Frontal Shape or Contour. Most frontal shapes should not pose great problems to the designer seeking to provide protection to vulnerable road users, especially on fronts which are flat or only gently curving whether they be more or less vertical or sloping. Some difficulty is presented when fronts are proposed with distinct bonnets whether they be high or fairly low. The human body then must fold over the top bonnet front edge which is likely to cause injury locally unless the edge is extremely soft and yielding. Buses, trucks and coaches should present few really difficult

problems although the fronts may need radical redesigns in their details. However sports utility and cross-country four-wheel-drive vehicles may need radically different frontal profiles and shapes. MPVs or people carriers and vans should not be difficult to redesign.

Frontal Components. External rear view mirrors are a hazard to pedestrians although recent yielding designs reduce injuries and one design is almost flush with the side of the car. Larger vehicles can have their mirrors more than 2m above ground level and this removes the problem. Front lights may need to be recessed. The scuttle area between the frontal structure and the windscreen lower edge needs detailed design especially in relation to windscreen wiper motors and linkages. Currently no A post designs have managed to present sufficiently soft external edges for pedestrians and cyclists while meeting all their other design requirements. A posts of cars with long bonnets and those of trucks, buses and coaches are much less likely to be struck by vulnerable road users than are those on cars with short bonnets or on most types of vans, smaller trucks and buses.

Air Bags. Attempts have been made to cover the whole area of the fronts of large vehicles with air bags to provide protection for pedestrians. Very careful external design of the bags dividing them into separate small pockets with appropriate venting is essential if the air bags are not to bottom out when struck locally by human beings. It may be much more practicable to provide padded front structures generally but to fit small air bags locally where protective requirements cannot otherwise be met. For example those sections of A posts around windscreens which need frontal protection may have to have air bags. These might be extended in front of external mirrors. Such air bags must be easily and cheaply replaceable because they may be fired several times during the life of each road vehicle – not necessarily when a vulnerable road user is involved but just because vehicles often pass each other too closely.

Hazards to Vulnerable Road Users. Some trucks have parts of their bodies protruding out sideways beyond the width of the driver's compartment at the front. These are great hazards for vulnerable road users and such designs should not be permitted or at least the protrusions should be covered by extensive padding ahead of them.

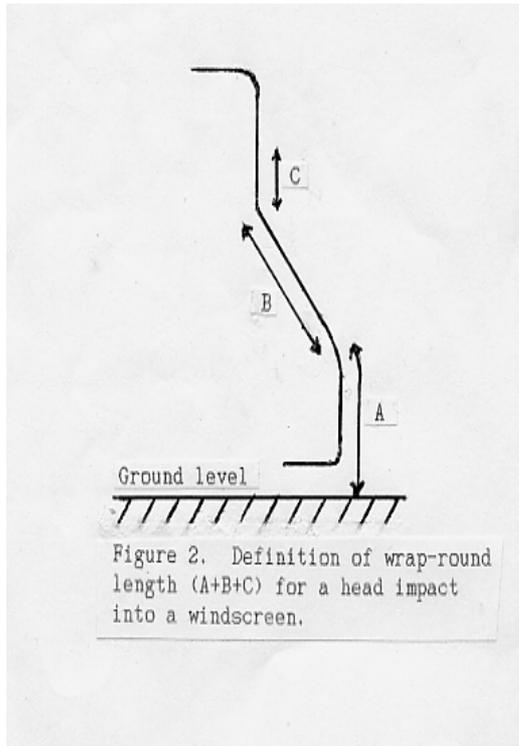
Ground Impact after Striking Vehicle Fronts. Quite a number of drivers do not notice pedestrian or cyclists until they have struck them. This means that impact speeds are then much higher and these vehicles may travel a long way forward before they are stopped. Although the victims may survive the impacts with the vehicles they may then fall to the ground and be further injured, particularly when vehicles roll over them. When the driver is braking hard at the instant of impact, he may continue to do so and then the victim may be thrown off and land well ahead of the vehicle. It may be that a vehicle with a yielding frontal face may hold on to the person struck until it has almost stopped. A design study is needed to check this matter and to propose any design solutions which may prevent those struck falling to the ground.

Performance of Vehicle Fronts. Currently most large vehicles have many areas and structures at their fronts which are effectively rigid to people struck by them. The least that should be done is that all critical areas of front should mould to the parts of the human body striking them. The protective performance increases considerably as the areas struck compress backwards without striking rigid components until relative motion has ceased. So there is a trade off between crush depth and the cost of providing it. Further investigations will show how much protection can reasonably be provided. It is only after this has been done that casualty savings may be predicted.

TEST PROCEDURE

Tests to check compliance with whatever protective measures are agreed for large vehicles must match up with, and correspond to, those being agreed for cars (6). In other words there must be a similarity of requirements at some intermediate size of front which is larger than for an ordinary car but smaller than for most buses or vans.

It would seem sensible for large vehicle fronts to be divided into sections by the simple 'wrap round' procedure (Figure 2) with the lowest level being from 200mm to say 700mm above ground level. This is the bumper height range where the impact is usually into the lower limbs of pedestrians.



It is suggested that the car pedestrian protection test for bumpers applies in this region. For 'wrap round' heights of from 1400mm to 2100mm the appropriate test is that using the adult head tests finally agreed for cars. It is important that for 'wrap round' heights of from 700mm to 1400mm a test should show that there is appropriate protection for child heads. However, the torso of the adult is much more massive than is the head of a child and so there is a need for a torso test which causes much greater indentations than the child head would make and this would be suitable for 'wrap rounds' of from 700mm to 1800mm.

Where there is a significant bonnet profile, the pedestrian impact would be significantly increased at its front edge. A third type of test corresponding to the equivalent EEVC test (6) for car fronts would be needed to check this part of the front. However, it is to be expected that in practice it would be almost impossible to meet the requirements of this test and so in reality such a test might not be used much because it might well become recognised that high bonneted profiles would never give acceptable protection to pedestrians and cyclists and therefore in future, frontal profiles would not include high bonnet shapes with sharply contoured front edges.

While the exact form of the tests for the fronts of cars has not finally been agreed in Europe it

is not possible to say in detail how the fronts of large vehicles should be tested. It would seem likely that there would be a test for the lower front to check impacts into children's lower limbs or for adult knees or lower legs. The adult and child head form tests might possibly be merged into one test, but with different impact levels to correspond to positions for child and adult head impacts. In between these leg and adult head positions the heavy vehicle bumpers would need to be buried behind softer impact structures to suit pedestrian impacts and a slightly different test shape might be needed.

There is an immediate need for test development investigations to be carried out to clarify the matters discussed. Effective ways must be found for checking the whole width of vehicle fronts at each height because the frontal stiffnesses of current vehicles tend to vary greatly across the width. However, many areas are currently much too stiff.

COMPARISON BETWEEN METHODS OF PROTECTION AND AVOIDANCE

The main aspects of the issues at stake when making comparisons between the methods of protection and avoidance are as follows:

Preliminary R & D. No great R & D would be needed for protective measures because of the work already done for protection on cars. One problem arises if tests show that pedestrians and cyclists are liable to fall to the ground and then sometimes be swept under the vehicle before it stops. Some structural development of flexible front faces is needed to find the least expensive and most durable designs. Air bag systems have already been developed for various car interior systems but air bags across the whole front of large vehicles would need to have multi-pocketed designs developed so that the air bags would not bottom out locally where they are struck. Although it would be possible to develop avoidance systems there would be much to perfect including the sensors and sophisticated computer programmes. These interpret the data so that the risks are accurately assessed and warnings to brake or to automatically control the braking are given correctly.

Costs. The development costs of protective systems would not be great because of development work already done. The avoidance braking system might well need much more development than initially

expected. Production costs for flexible protective fronts should be relatively low. Air bags would be large and fairly costly unless used only for small areas such as A post pillars. Costs while in service should be low for protective systems if localised patching procedures were developed to cope with minor damage to the fronts of large vehicles in service. Air bags need careful servicing and the risk might be that it would not be carried out. Unnecessary firings for reasons other than impending pedestrian and cyclist impacts might be expensive because of the costs of replacing air bags. Similar comments would apply to avoidance braking systems but unnecessary or false braking incidents might lead to traffic problems.

Overall Effectiveness. It is not possible to predict this at the present stage. The performance of protective fronts depends critically on the depth of crushable material provided. Air bags can more easily be designed to be effective in more extreme impacts and might well prevent more fatalities. Avoidance braking systems efficiency depends on their performance under limiting conditions and on their serviceability. They may not be satisfactory on buses because heavy braking often leads to bus passenger injuries. However, avoidance braking generally would avoid the impact completely or would greatly reduce its severity on most other occasions. As mentioned above, unnecessary firings of air bags and braking avoidance systems add negative contributions to efficiency estimates.

Effects on Driving. These should not be great unless air bags and avoidance braking systems were found to fire when not needed in the opinion of the driver. This could lead to irritation when driving in heavy traffic or on roads crowded with pedestrians and cyclists. Drivers might then be inclined to disable the automatic systems which would reduce their effectiveness to zero.

Vandalism. This could be troublesome in two ways. Young pedestrians and others might cut or damage the flexible fronts which might reduce their effectiveness locally. On the other hand, bystanders might find means of getting air bags or avoidance braking systems to fire unnecessarily. This would not matter greatly for braking systems which warned drivers to brake but did not apply the brakes automatically. A 'game' might become popular by which people rolled objects in the

road to simulate children or other objects getting in the paths of vehicles and on occasion these might trigger the air bags or the braking system and bring the traffic to a halt.

CONCLUSIONS AND RECOMMENDATIONS

1. It is concluded that priority should be given to developing the flexible energy absorbing front that not only moulds to the shape of the parts of the human body being struck by it, but also crushes back to reduce peak loadings. A total crush of 200mm might be practicable. The stiffnesses of the various parts of the front must match up with the appropriate parts of the human body. In particular it might be best to design all areas likely to be struck by children's heads to match up with them to a depth of say 100mm and then to design further crush to match up with adult torso loadings. This is the preferred design solution for reducing casualties because of its greater practicality in whole life operating conditions in LMCs as well as in HMCs and because of lower costs overall. The work needed for further development comes under three heads:

- (a) Limited collection and analysis of accident data relating to large vehicles striking pedestrians, pedal and motor cyclists with some checks on how the various injuries are sustained.
- (b) The development of flexible energy absorbing fronts.
- (c) The modification of existing car test procedures to suit impacts into the fronts of large vehicles rather than for cars.

2. Air bags should be developed to cover A post pillars liable to be struck by human heads. They might also be used to protect the front faces of rear view mirrors. Replacements might prove to be expensive.

3. It may be worthwhile to continue development of air bags for the whole of large vehicle fronts, but mainly for possible use in Highly Developed Countries.

4. It would be interesting to continue development of avoidance braking systems to avoid impacts into vulnerable road users in many conditions. Development would be needed to improve their effectiveness in marginal conditions when they either set off the braking when it is not needed, or fail to do so when it is or start the braking rather late.

REFERENCES

1. Neilson, I.D., Pedestrian and cyclist protection on road vehicles with high or flat fronts. PACTS (www.pacts.org.uk) London 2001.
2. Mohan, D. & Tiwari, G., Road safety in less motorised countries - relevance of international vehicle and highway safety standards. Vehicle Safety 2000. I Mech E C567/008/2000, London.
3. Hobbs, C.A., Gloyns, P.F. & Rattenbury, S.J., European New Car Assessment Protocol and biomechanical limits, Version 2, May 1999.
4. On the lookout for trouble, Automotive Engineer, Vol 25, Number 11, p19, December 2000.
5. Department of the Environment, Transport and the Regions, Stats 19, Police road accident data, Great Britain, 1998.
6. EEVC Working Group 17 Report. Improved test methods to evaluate pedestrian protection afforded by passenger cars. December 1998.