FATAL URBAN CYCLIST COLLISIONS WITH LORRIES: AN IN-DEPTH STUDY OF CAUSATION FACTORS AND COUNTERMEASURES USING A SYSTEM-BASED APPROACH

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ABSTRACT

In the UK and other countries cyclists are the only group of road users with increasing fatalities and cyclist protection has become a high priority both to reduce the risks of cycling and the perception of risks amongst cyclists. The objective of this study is to apply a systems approach to a causation analysis of fatal crashes in order to identify key risk factors and countermeasures associated with all vehicles involved, the infrastructure, road users and road safety management.

The paper presents an analysis of fatal cyclist collisions that took place in London in the years 2007 to 2011. Case materials included police reports, witness statements, vehicle inspections, scene plans and photographs, collision reconstructions, post-mortem and other medical reports. The sample comprised a total of 53 fatal cyclist collisions that occurred during the five year period.

The most common collision type resulting in a fatal cyclist was an impact with a large vehicle >3.5T including 27 lorries and 3 buses. The most common manoeuvre involved the large vehicle turning left resulting in a low speed interaction with the cyclist. Generally impacts occurred to the front left side or left front side of the truck (24 cases, 89%). Insufficient direct vision of the cyclist was a factor in all of these cases with additional risks associated with driver attention and mirror limitations. The availability of Class V side and Class VI front mirrors did not prevent all fatalities.

12 (45%) of the lorries were equipped with side guards while 11 were exempt, however all of the fatally injured cyclists were on the ground before any side-guard interaction could have occurred and side guards were not seen to be effective in this sample.

INTRODUCTION

Although there has been a longer term reduction in fatalities of all road users in Great Britain, between 2009 and 2013, the number of pedal cycle fatalities fluctuated between 100 and 120 with some evidence of a slight upwards trend (DfT 2013). This has led to an increased focus on cycle safety in the UK – especially in areas such as London where there has also been an increase in the number of pedal cyclists on the road as a result of healthy mobility initiatives.

Cyclists, along with pedestrians and motor-cyclists are considered to comprise the group of "Vulnerable Road Users". Compared with the occupants of motorised vehicles they have very few opportunities for protection and injury mitigation and casualty reduction measures focus predominantly on collision avoidance measures. Unlike other vulnerable road users however cyclists frequently do not have the segregation from traffic experienced by pedestrians but they do have increased conflicts with motorised vehicles due to the frequent speed differentials.

This paper describes the results of a study conducted on behalf of Transport for London that examined fatal along with a small number of very serious injury pedal cyclist crashes that occurred in London between 2007 and 2011 (Talbot et. al. 2014).

SYSTEMS APPROACH

The first step in developing countermeasures to road traffic crashes is to identify what factors contributed to their occurrence in the first place. Accident causation models have been developed to improve the safety of industrial processes for many years. An early model of accident causation was developed in the context of industrial accidents by Heinrich (1931). The model explained an accident as a step in a sequential chain of events or circumstances, each of which was dependent on the previous event. By removing one of the events the consequent circumstance would be avoided and the accident prevented. More recent models of accident causation developed for industrial processes have come to consider the development of risks within a closely coupled, integrated system of which humans are a part. All components of all systems have a variation in performance whether they are human, mechanical or algorithmic. Systems that are increasingly tightly coupled are less resilient to the effects of adverse circumstances. Humans in the control loop have the opportunity to adapt behaviour to enable the system to accommodate adverse conditions but in a tightly coupled system a minor human error can result in a major outcome.

In considering the behaviour of systems Reason (2000) identified two types of error that may occur. Active failures are unsafe acts that are committed by people who are components in the system. He states that they may take a variety of forms including slips, lapses, fumbles, mistakes, and procedural violations. Secondly he identifies latent conditions, which represent attributes of the system – design, functionality, operation. Normally these deficiencies have no consequence and there are no adverse outcomes. However when the trigger of an active failure aligns with the latent conditions of the system it may result in an adverse outcome.

The principles of the accident causation models discussed above have guided the approach used in the collection of data, the analysis of that data, as well as the identification of potential countermeasures. To this end, it can be said the crashes are failures in a road traffic system made up of four components:

- Environment: This includes aspects such as infrastructure and weather conditions.
- Vehicle: All vehicles (including bicycles), their design and safety systems.
- Road user: The human behaviour element in the system - drivers, pedestrians, pedal cyclists, motorcycle riders etc.
- Management: These are the indirect influences of the system including legislation, policy and procedures e.g. licensing, congestion charging, fleet management, which in turn influences factors such as who is on the road and when.

These components are not considered in isolation as they are all interlinked and each component can affect another in the system. For example a driver may drive differently (road user) in different weather conditions (environment) or misinterpret unfamiliar infrastructure.

METHODOLOGY

In the UK, specialist police officers, who are trained in road traffic crash investigation methodologies, attend crashes that are fatal or considered to be life threatening. They conduct detailed investigations and where possible reconstructions to gain as thorough as possible understanding about the crash and how it occurred. Data was collected from the resulting police files that were accessed in paper form at a London police station under conditions of a confidentiality agreement. A set of key documents from which the most data could be extracted were identified:

- the police collision investigation report;
- scene and vehicle photographs;
- scene plan and reconstruction;
- CCTV images;
- driver interview transcripts;
- witness statements;
- Post-mortem reports.

A simple database was created to allow quantitative data to be recorded such as time and date of crash, vehicle type, age, gender, impairment, as well as more detailed qualitative descriptions such as crash description, vehicle defects, information about road narrowing and route information. Other supplementary information such as mirror positions and vehicle damage was recorded on paper and copies of scene plans and photos were also obtained. Injury data collected from post-mortems and hospital consultant witness statements were recorded separately including Abbreviated Injury Scale (AIS, 2005) codes, injury descriptions, toxicology and date of death. Transport for London also provided context data such as the number and type of crashes that had occurred at each crash location during the previous three years.

A case review approach was adopted to analyse the crashes whereby the complete dataset (including the database variables, scene plan, photos, injury and context data) for each crash was reviewed by two or more researchers to identify factors that contributed to the crash. Contributory factors were not assigned according to a pre-defined list but the system approach as previously discussed was used to ensure factors relating to the environment, road user, vehicle and management were identified as appropriate.

RESULTS

Seventy-nine fatal and very serious crashes occurring in London were investigated by specialist police offices between 2007 and 2011. Of these, 53 were available for data collection. Forty-six were fatal pedal cyclist crashes, using the internationally accepted definition of death within 30 days. A further 7 involved a seriously injured pedal cyclist whose injuries were considered to be life threatening at the time of the crash. In the following results and analysis, the fatal and serious crashes have been grouped together the characteristics of the serious crashes, in terms of crash causation, were very similar to those of the fatal crashes.

Some differences were observed between the sample of 53 crashes occurring in London and the fatal pedal cyclist crashes occurring in Great Britain as a whole (See Figure 1). In London there were

- Fewer cyclist crashes in the summer months, more in winter (73% London, 42% GB)
- Fewer weekend crashes (7% London, 31% GB)
- A larger early morning peak (8:00 – 10:00) in collisions (25% London,12% GB)
- More cyclist crashes on A-roads (76% London, 53% GB)
- More cyclist crashes in 30 mph speed limits (89% London, 48% GB)
- More cyclist crashes on or on the approach to junctions (74% London,48% GB)

Collision partner

Table 1 shows the primary collision partner for the 53 fatal and serious crashes examined and the manoeuvres conducted by the two vehicles. The primary collision partner is defined as the vehicle that was involved in the initial interaction with the pedal cyclist. The most common collision partner was a goods vehicle corresponding to 29 (55%) of the total collisions while 15 (28%) of the collisions were with a car. In 17 crashes a motorised vehicle turned left across the path of the cyclist and 15 of these were goods vehicles. A further four collisions occurred when the cyclist and motorised vehicle were both turning left and three of these again involved a goods vehicle. In nine collisions the bicycle was struck in the rear by another vehicle and three of these involved goods vehicles.

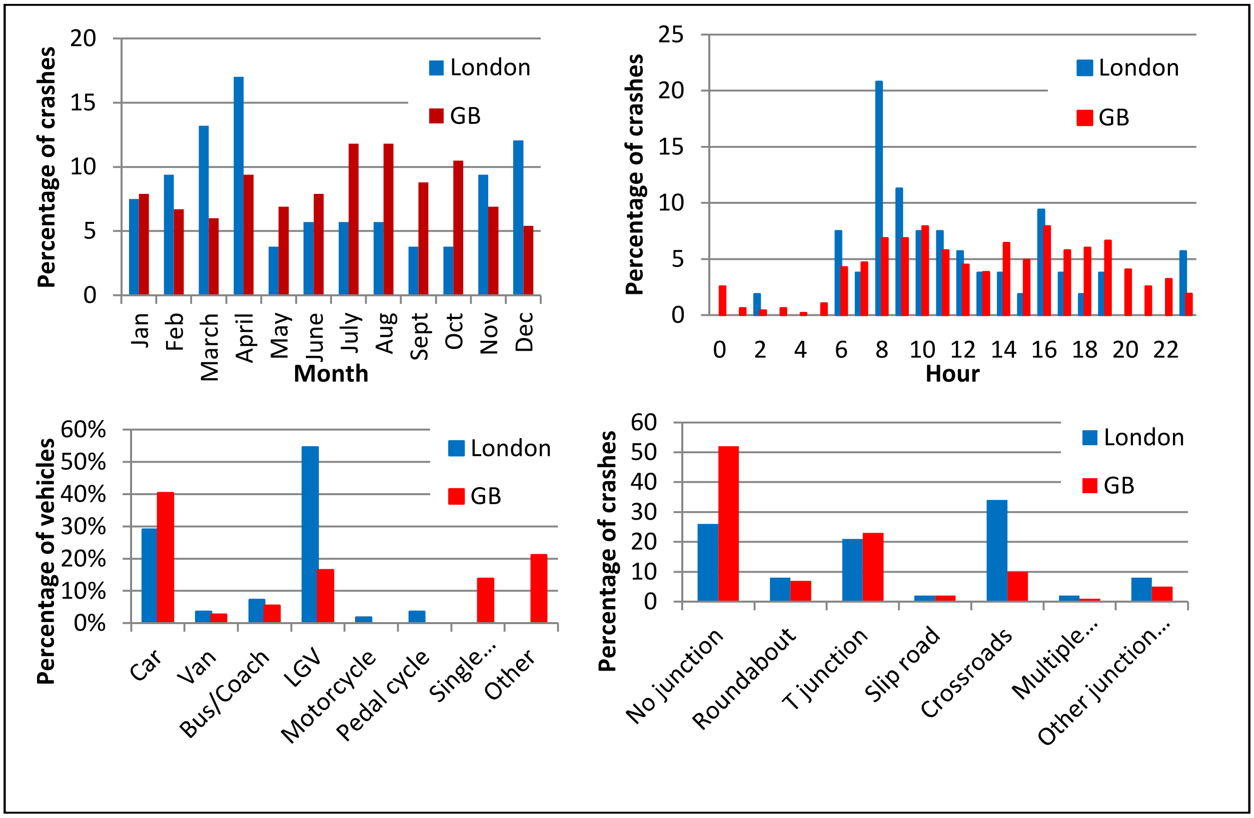


Figure 1. Comparison of London and GB accident circumstances

Table 2 shows the distribution of the relative movement between the cyclist and the large vehicles within the sample. There were 32 large vehicles, lorries and buses, of which the motion was identified in 30 cases. Most commonly the cyclist was undertaking – moving forward relative to the large vehicle – on the vehicles left-side, closest to the kerb. Out of the 32 cases there were 20 in which the cyclist undertook the large vehicle and a further three cases where the large vehicle overtook the cyclist. There were only two cases where the cyclist passed the large vehicle on its right side.

Direct and indirect vision of the cyclist

Each case file was examined in order to identify evidence relating to the location of the first contact between the large vehicle and the cyclist. Figure 2 shows the location of the first contact between the large vehicle and the bicycle for the 29 cases where there was information available within the case material. In the UK vehicles drive on the left side of the road and the most locations of the contact with the fatally injured cyclists were clustered around the front left corner either on the front or the side face of the large vehicle.

At the time of the analysis it was compulsory for large vehicles to be fitted with Class IV wide angle side mirrors and Class V close proximity side mirrors with very few exemptions and Table 3 shows that only one large vehicle was identified without one fitted. Fitting in a further three cases was unknown. Large vehicles manufactured after January 2007 were also required to be equipped with a front mounted Class VI mirror to identify close situated road users. Table 3 shows the numbers of contacts between cyclist and vehicle distributed to the relevant zone for each combination of mirrors. There were 26 large vehicles were the type of mirrors fitted was known and only one was not equipped with a class V mirror while only 14 were equipped with Class VI mirrors.

Eight of the 14 cyclists with first contacts on the side of the vehicle were in zones S1, S2 which were judged to lie within the vision zone of Class V mirrors according to the specification (European Commission regulation 2003/97/EC) and all of these vehicles were equipped with Class V mirrors. 13 of the 15 cyclists struck by the front of the vehicle were in zones F2 and F3, the area covered by Class VI mirrors and in eight of the 13 cases Class VI mirrors were available.

Table 1

Crash manoeuvre by collision partner

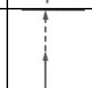
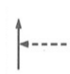
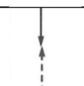
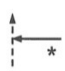
Manoeuvre	Diagram	Car	Van	Bus/ Coach	Goods vehicle >=3.5 T	Other	Total
Other vehicle turns left across the path of P/C		1			15	1	17 (32%)
Other vehicle runs into rear of P/C		2	1	1	5		9 (17%)
P/C and other vehicle travelling alongside each other		1			3	1	5 (9%)
P/C fails to give way or disobeys junction control & collides with other vehicle		4					4 (8%)
P/C and other vehicle collide when both turning left				1	3		4 (8%)
Head on collision between P/C and other vehicle		2					2 (2%)
Other vehicle fails to give way or disobeys junction control & collides with P/C		1			1		2 (2%)
No other vehicle hit by P/C. Various manoeuvres or loss of control only						2	2 (2%)
Other		4	1	1	2		8 (15%)
Total		15 (28%)	2 (4%)	3 (6%)	29 (55%)	4 (8%)	53 (100%)

Table 2
Relative movement of cyclists and large vehicles at point of collision

Relative motion	Number of crashes
Cyclist overtaking stationary large vehicle	2
Cyclist overtaking moving large vehicle	0
Cyclist undertaking stationary large vehicle	11
Cyclist undertaking moving large vehicle (not turning)	1
Cyclist undertaking moving large vehicle which was turning right	0
Cyclist undertaking moving large vehicle which was turning left	8
Both moving together (similar speed)	2
Large vehicle overtaking stationary cyclist	0
Large vehicle overtaking moving cyclist	3
Other crash configuration	3
Unknown	2
Total	32

Table 3
Mirror fitting and contact zone

Zone	Mirrors Fitted				Total
	No Class V or VI	Class IV or V only	Class IV, V & VI fitted	Not known	
F1	0	0	0	1	1
F2	1	0	3	1	5
F3	0	4	3	1	8
F4	0	1	0	0	1
S1	0	1	1	0	2
S2	0	2	4	0	6
S3	0	1	1	0	2
S4	0	2	2	0	4
Total	1	11	14	3	29

Table 4
HGV and 3.5-7.5 tonne truck types included in sample

HGV/3.5-7.5 tonne type	Image	Number of HGV/3.5-7.5 tonne	Side guard		
			Fitted	Not fitted	Unknown
Tipper		11 (37%)	0	9	2
Flat or drop side		5 (17%)	4		1
Box		4 (13%)	3		1
Skip carrier		3 (10%)		3	
Curtain sided articulated vehicle		3 (10%)	3		
Refuse Lorry		2 (7%)		2	
Tractor Unit only		1 (3%)		1	
Cement mixer		1 (3%)		1	
Total		30	10	16	4

SIDE UNDERRUN GUARDS

Table 4 shows the body style of the 30 goods vehicles involved in the collisions. 11 (37%) of the vehicles were tipper lorries and overall 19 of the vehicles – tipper, flat/drop side and skip carriers – were related to the construction industry and 12 were not fitted with side guards.

The trajectory of the interaction of the cyclist in the interaction with the lorry was established by reviewing the locations of contact marks and the final rest position of the cyclist. In 29 of the 30 cases the cyclist was run over by the wheels of the lorry sustaining the fatal injuries. Only four cyclists collided with the lorry in a zone that was a candidate and all of these were run over by a rear wheel.

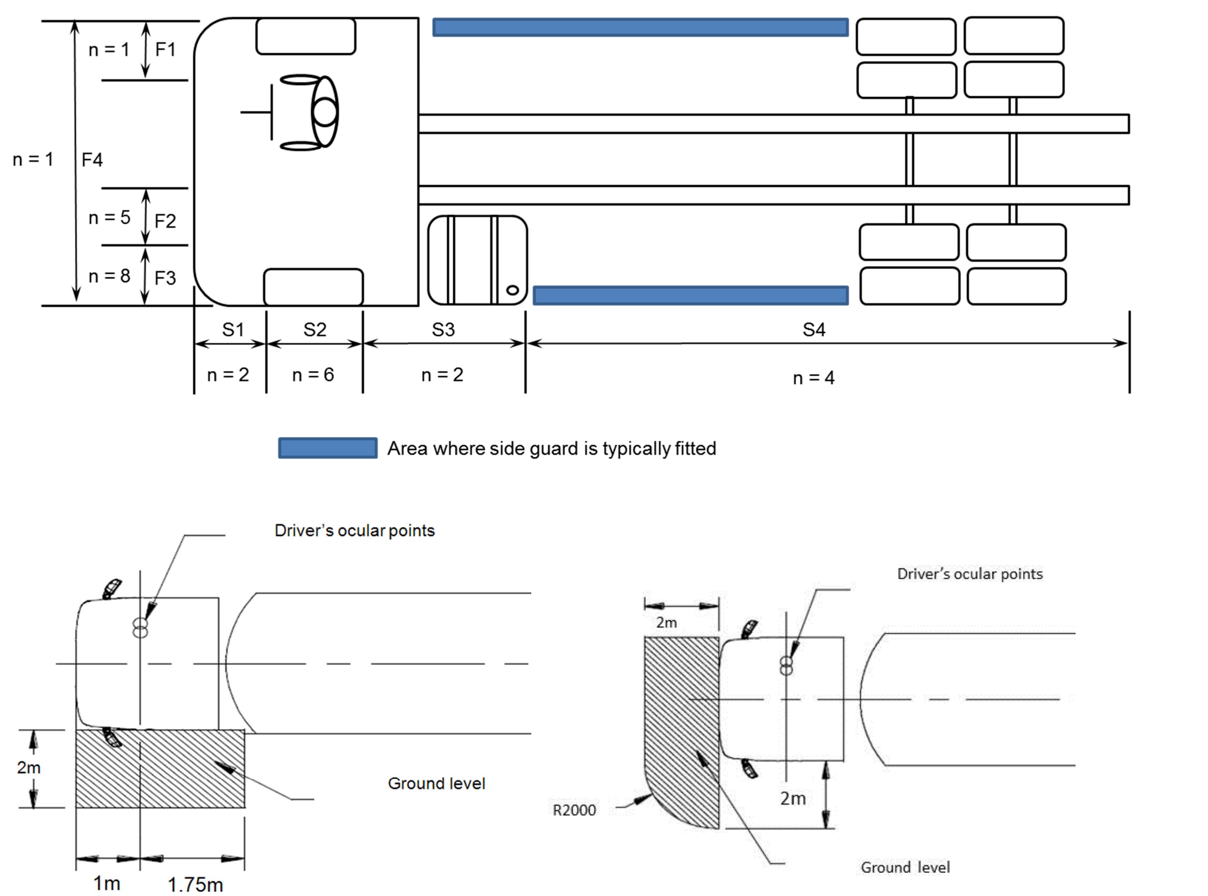


Figure 2: location of first contact point between large vehicle and bicycle and field of view of Class V mirror (left) and Class VI mirror (right) (European Commission regulation 2003/97/EC)

DISCUSSION

This analysis has been part of a wider research programme intended to form the evidence base for a range of actions that will improve the safety of cyclists in London and is reported by Talbot et al. 2014. The main objective was to identify beneficial interventions that could be applied within the context of the Metropolitan region. The approach, based on a systems analysis of all related factors, has enabled the principal road, vehicle and user factors to be fully established and their interactions to be identified. Using the systems analysis Talbot et al identify several risk factors related to the causation of lorry collisions with cyclists including

- conflicts between cyclists and lorries due to an overlap in peak lorry and cyclist traffic at specific times of the day and week
- installation of cycle lanes on roads with high lorry traffic
- road infrastructure design that increases the conflicts between cyclists and left-turning lorries
- lorry driver workload at busy junctions
- the entry points and design dimensions of Advanced Stop Lines
- late or no left turn signalling by lorry

This analysis has focussed on the interactions between cyclists and lorries to provide a more detailed description of the precise nature of the safety problem and support the development of new countermeasures.

The analysis is based on the data contained within the police accident records. In the UK fatal crashes are investigated by specialist police officers and the nature of the examination and reconstructions results in a detailed, reliable source of information. The 53 fatally injured cyclists in the sample form one of the largest groups of in-depth studies of cyclists available and the detailed nature of the data has been used to examine specific accident and injury risk factors.

The comparison between fatal cyclist collisions in London and elsewhere in Great Britain has identified that there are differences, mostly related to the characteristics of London. In particular a greater proportion of collisions occurred during weekdays, during the winter months, near junctions and on A-class roads. Therefore the overall distributions of the key accident risk factors may not be generalizable to the UK, however the present analysis focusses on the nature of the interaction between cyclists and large vehicles and therefore is highly relevant when considering the revision of the EU lorry dimensions (see EU Directive 96/53/EC). The data analysed only concerns fatally injured cyclists and therefore all crashes in the sample can be considered system failures, this means that the results cannot be taken to provide estimates of the effectiveness of safety systems.

The in-depth analysis of the fatal collisions indicates the typical sequence of events prior to the collision (see Figure 3). In Figure 3a the cyclist moves towards a lorry that is moving slowly or stopped at a junction and decides to pass on the left side, dedicated cycle paths or the availability of an advanced stop line may encourage the cyclist. The lorry driver intends to turn left but is either not indicating or the indicators are not visible to the cyclist. The cyclist moves to a zone around the front left corner of the lorry, either to the left side front or the front left, as illustrated in Figure 3b. The cyclist intends to continue ahead or to turn left but is not observed by the lorry driver who steers the lorry around the corner, being a long vehicle the front end takes a wider curve than the rear which moves close to the curb. The bicycle is struck at slow speed as the lorry moves away, the cyclist falls to the ground and passes underneath any side underrun guards to be run over by the following wheel either on a second front or a rear axle as in Figure 3c.

The conflict that leads to the collision typically occurs when the lorry driver is unable to perceive the presence of the cyclist and the cyclist does not recognise that the lorry is about to turn left. Schoon et al (2007) examined the Dutch national accident data to identify the frequency with which right-turning (in the case of the Netherlands) lorries collided with cyclists. They surmised that poor direct vision of the cyclist and insufficient field of view of side mirror systems was a relevant risk factor. Cook et al (2011) used human modelling methods and identified the presence of significant blind spots to the side of the lorry, even when equipped with both Class IV and Class V mirrors. Niewohner and Berg (2005) similarly identified blind spots associated with side mirrors and proposed a range of countermeasures. Nevertheless there has been little research on the real-world performance of class VI mirrors.

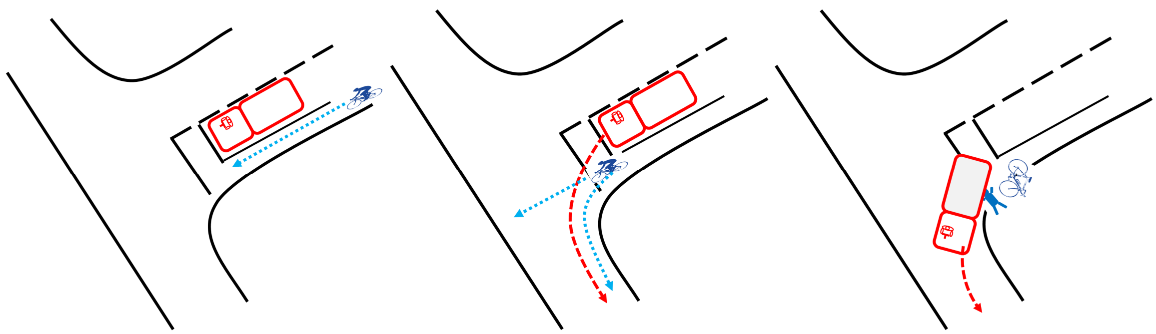


Figure 3a *Figure 3b* *Figure 3c*

Cyclist – lorry collision sequence

This analysis has shown that fatal collisions with cyclists occur despite the presence of Class V and Class VI mirrors and where contact zones are expected to be in view. 14 cyclists had their initial contact with the side of the lorry and eight of these were in zones expected to be covered by Class V mirrors. There was no definitive evidence available in the case reports of the reasons why the cyclists were not detected by the lorry drivers however some drivers reported the demands on attention of a busy traffic environment, others reported they did look at the mirrors but did not see the cyclist. It was observed that the frequent relative movement between the cyclist and the lorry meant that the cyclist would only be visible in a Class V mirror for a short period of time if moving at a normal speed due to the convex profile. The lorry driver would then have to be looking at the mirror during this time in order to detect the cyclist. Further anecdotal problems of the lorry driver identified in the case reports included incorrect mirror adjustment and incorrect understanding of the purpose of the mirrors.

The current EU requirements (2007/38/EC) for Class V mirrors were introduced in 2007 and the Directive included the requirement to retrofit older vehicles. Class VI mirrors were introduced in 2003 but there was no requirement for retrofit. This analysis has shown that Class VI mirrors were only fitted to 14 of the 29 lorries in the sample and 15 cyclists died after being struck by the front of the lorry. 13 of these were located in the zone covered by Class VI mirrors which were fitted to eight of these vehicles. This indicates that Class VI mirrors do not completely prevent fatal cyclist collisions with the front left of the lorry, cyclists can be located in this position yet still not be observed by the driver. There were six cases where no mirror was available however it cannot be concluded these would have been prevented the fatality.

Side underrun

Side underrun guards have been primarily developed to reduce the risks of injury to car occupants when in collision with the side of a lorry or its trailer. Pedestrians and cyclists are assumed to have protection by being diverted away from the rear wheels when colliding with the vertical face of the guard. This protection is determined on the basis that the cyclist or pedestrian will be vertical at the time of impact. The performance is specified in Council Directive 89/297/EEC which defines the dimensions of the underrun guard and requires the height above ground to be no more than 550mm. The present analysis has shown that 14 of the 29 fatally injured cyclists were in collision with the side of the lorry however only 4 of these contacts were in a zone covered by a side underrun guard and only one of these case files showed clear evidence of cyclist contact on the underrun guard. Overall the case reviews indicated that the cyclists struck by the side of the lorry, together with many of those struck by the front, were already on the ground before the approach of the following axle. Only 10 of the lorries were known to be equipped with side underrun guards, the remainder being considered exempt as a result of their purpose. It cannot be concluded that side underrun guards do not offer any protection for cyclists since this data sample does not include collisions involving non-fatal cyclists. However the protection is considered to be limited and further investigation is recommended of the protection offered by a side guard to a cyclist lying on the ground.

CONCLUSIONS

This paper has examined the case reports of 53 fatally injured cyclists died in London between 2007 and 2011. The main conclusions are

1. Lorries are the most frequnt collision partner and further actions are necessary to reduce crsh risks
2. There is no single countermeasure that is available that will prevent all fatal cyclist collisions with lorries, a systems approach is required including veicle design measures
3. The most common crash scenario involves a slow-moving lorry turning across the path of an unidentified cyclist, the cyclist having a contact around the are of the front left corner of the lorry, falling off the bicycle and then being run over by the lorry wheels.
4. Even when Class V and Class VI mirrors are available on trucks the cyclist may not be observed by the driver
5. Many lorries are not equipped with side underrun guards
6. Side underrun guards do not prevent cyclists being run over by the rear wheels of lorries

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