A study of front-mounted bicycle racks on buses

Prepared for Charging and Local Transport Division, Department for Transport

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Executive Summary

Following the publication of the Government White paper *A New Deal for Transport: Better for Everyone* (DETR, July 1998) attention was focused on the integration of transport modes. As a result, a number of cycling initiatives were launched. One of these, *Scottish Cycle Challenge*, included a project examining the integration of bicycles with public transport, in which one of the options being considered was the integration of bicycles and buses. The study reported here investigated the safety implications for pedestrians involved in impacts with buses and coaches that had bike racks fitted on the front. It was carried out by TRL Limited on behalf of the Department for Transport (DfT).

An extensive literature search was conducted to identify existing research which studied the impact of bus mounted bicycle racks on pedestrian injuries. It was concluded that there was currently no published research on the safety implications of folding bicycle racks mounted on the front of buses. However, results of pedestrian tests to steel bull-bars, which bear some similarity to a bike rack, predicted a significant increase in the injury severity, particularly for the head of a child, when compared with the vehicle without bull bars fitted. While not directly transferable to the concept of bicycle racks fitted to the fronts of buses, the evidence produced by bull bar studies provided a preliminary indication of how cycle racks fitted to buses could increase the severity of pedestrian injuries. The particular shape and structural properties of the bicycle racks, and indeed the bicycles fitted to them, affects the impact forces on a pedestrian during a collision.

An analysis of fatal pedestrian accidents involving the fronts of buses and coaches revealed that these accidents occurred at a variety of velocities, some as low as 5 mph. Results of tests to bull bars show that the injury risk for bull bars increases more rapidly with speed than the injury risk for the vehicle without bull bars. It was therefore concluded that ideally the bus and coach, with and without a bike rack fitted, should be assessed over a range of velocities, although this was not possible within the scope of this project. The analysis of fatal pedestrian accidents with buses and coaches suggested that the average impact speed was about 20mph. This velocity was selected for subsequent pedestrian impact simulations and tests.

The net result of the mathematical modelling analysis indicated that the pedestrian's head is likely to be accelerated towards the vehicle, resulting in an additional velocity of up to approximately 4 m/s and a rearwards and downwards motion of the head.

After consultation with the customer, two vehicles of relatively new design were selected for the testing and examples were hired for the test programme. One was a bus, a Dennis Dart with a Plaxton Pointer body and the other was a coach, a Dennis chassis with a Plaxton Javelin body. The coach, whilst of a slightly older design than the bus, was still in current production and therefore, both vehicles were thought to be probably still present in the UK fleet for a further 5-10 years.

A technical officer from the Vehicle Inspectorate was invited to TRL to conduct an informal inspection of the selected coach with the front mounted bike rack fitted. The vehicle was inspected in accordance with the Road Vehicles (Construction and Use) Regulations 1986 and the Road Vehicles (Lighting) Regulations 1989. Diagrams and photographs of the bus fitted with a bike rack and with pedestrians in close proximity were also examined. In the informal opinion of the Technical Officer, the vehicle failed to meet several safety requirements with the rack deployed. It was also noted that the construction of the rack, and the inevitable protrusions from any bikes carried, could cause serious impact injuries to pedestrians and other road users.

A series of tests were conducted on a bus and coach, with and without a rack fitted, using European Enhanced Vehicle Safety Committee (EEVC) adult pedestrian legform and child and adult headform sub-system impactors. These tests were carried out for a number of bike and bike rack configurations and the results were compared to those for an 'equivalent point' impact on the coach or bus with no rack fitted. This 'equivalent point' was chosen to represent the point where the vehicle would have hit a pedestrian had the bike rack not been fitted.

These tests show that modern buses and coaches, of the type tested here, offer good pedestrian protection in much of their frontal structure and give very few bad results. The fitting of the bike rack, with two bikes in place, however, dramatically increased the risk of serious injuries over the unequipped vehicles. For the unequipped bus, the risk of potentially fatal child head injuries at four out of the five impact locations tested was well below 20%; the one exception gave a risk of 90%. Whereas impacting a bike on the rack resulted in a risk of life threatening child head injuries at four out of five locations of over 95%, although the remaining point tested gave a risk of only 7%. However, it is anticipated that this location, on the pedal, would have given worse results had the bike tested been fitted with a steel pedal crank rather than an aluminium one.

For the coach, the difference between the risk of life threatening child head injuries with impacts on the unequipped coach, compared with impacts with the bike rack fitted, showed the same pattern as the bus, although the effect was less marked. It was pointed out that many of the points tested on the bike with the child and adult headforms would only hit a pedestrian's head in the most unfortunate combination of pedestrian stature and lateral position. Therefore, the number of such accidents is likely to be small. Nevertheless, the very high values recorded in the child test suggest that such a combination will often result in a fatal injury, and that the risk of life threatening head injuries for children, if they are of such a stature to be hit by the features tested, is dramatically increased.

The relative heights of pedestrians and the crossbar of a rack-mounted bicycle mean that it will strike most adult and taller pedestrians on the chest or abdomen. Furthermore, the handlebar will make contact with the chest of most adult pedestrians and with the neck of the smaller females and children. Taking into account the under-reporting of injury risk when using rigid headforms to test bicycle and rack parts that produce concentrated loads, the adult headform results also show that fitting a bike rack increases the risk of life-threatening adult head injuries, if they are of a stature to be hit by the features tested.

The results of the adult legform tests to the leading edge of the rack, fitted to the bus and coach, show that the safe knee acceleration and bending requirements were exceeded by a large margin. These results indicate that the fitting of a bike rack of the type tested here dramatically increases the risk of long-term disabling leg injuries for both adult and child pedestrians.

It should be noted that the impactors used were designed to test against large contact areas such as those commonly found on the front of cars. The rack and bike configurations used in these tests resulted in a large number of tests to small contact areas that would be expected to compound injuries by penetration. The impactors used are not designed to simulate penetrative injuries. Therefore, the results of the bike rack tests should be regarded as underestimates of the true injury severity. The damage inflicted on the flesh of the headform impactor gives some indication of the high local contact forces.

The EEVC impactors are suitable for testing bus and coach fronts. For a procedure to test bike and rack configurations, alternative impactors designed to measure the additional penetrative injuries would provide a more effective determination of the true severity. The use of cadavers or animal parts for assessing the injury risk from the crossbar and handlebar contact was considered the best method, but this was rejected on ethical grounds. Instead the characteristics of the impact and the available biomechanical data were considered to produce an informed opinion on the injury risks from this type of contact.

The maximum contact force in the tests between the adult headform and the handlebar can be estimated from the headform acceleration and mass. These calculations give a force of approximately 8 kN for the test to the handlebar of the front bike, where there are two bicycles in the rack. For the headform test to the handlebar of one bike in the rear position, the calculations show a force of approximately 11 kN. The result for the handlebar of the rear bike is higher because it makes contact with the front of the vehicle. These high contact forces, acting over the small area of the end of a bike handlebar tube, appear to confirm the suggestion that there is a high risk of penetrative injuries to the chest of a pedestrian in the event of an accident.

Overall, these test results suggest that modern buses and coaches, of the type tested here, offer a high level of pedestrian protection in their frontal structure. The fitting of bike racks and bikes, of the type tested here, would dramatically increase the risk of life-threatening head and chest injuries and long-term disabling leg injuries, particularly for children, in accidents involving pedestrians. Many of the points tested on the bike with the child and adult headforms would only hit a pedestrian's head in the most unfortunate combination of pedestrian stature and lateral position, subsequently the number of such accidents is likely to be small. Nevertheless, the very high values recorded in the child tests suggest that such a combination would normally result in a fatal injury. Therefore, it is recommended that the alternatives of re-designing or relocating bike racks should be considered. Suggestions have been offered in this report for re-designing the bike racks to make them more pedestrian-friendly.

1 Introduction

Cycling as a mode of transport has received increasing attention in the past decade as an effective means of reducing congestion, pollution and general environmental degradation. Since the White Paper *This Common Inheritance* (DoE, 1990) the Government has made a number of key policy commitments in the transport and environment sectors which have helped to raise the profile of cycling. There is potential for increasing the modal share of the bicycle, which fell from 37% of all road traffic in 1949 to just 1% by 1995.

Following the publication of the Government White paper *A New Deal for Transport: Better for Everyone* (DETR, July 1998), attention has been focused on the integration of transport modes. Consequently, a number of cycle challenge initiatives have been launched: of these, *Scottish Cycle Challenge,* includes a project examining the integration of bicycles with public transport. The integration of bicycles and buses is one of the options being considered.

This study aimed to investigate the effects on pedestrian safety of installing cycle racks on the front of buses. The study was initiated following a proposal to install cycle racks on bus fronts, as opposed to the rear. There have been a number of studies undertaken within the United Kingdom looking at the carriage of bicycles on the rear of the vehicle. One of the problems highlighted by these studies was the time it would take for the bicycle user to walk from the front of the bus to the rear, load the bicycle onto the rack, and return to the front of the vehicle to board. TRL was asked to investigate the likely effects of moving the rack to the front of the bus on the safety of pedestrians who might be involved in impacts with the bus. Some of the developmental stages of the work were previously reported by Brook-Carter and Kersloot (1999).

Lawrence (1990) states that in a collision between a car and a pedestrian, the location and severity of impact to the pedestrian vary considerably with respect to the shape of the car front. It may, therefore, be the case that by adding a bicycle rack and thereby changing the shape and stiffness of the front of a bus, the severity of the impact will be altered.

This report presents the results of a combination of investigations carried out during this study. A comprehensive review of existing literature was conducted in order to identify relevant research and accident data. An analysis of accident databases was carried out, and conclusions have been drawn. A mathematical model was used to identify the head trajectory of an adult pedestrian dummy when struck by a bus front, with and without a cycle rack fitted. A series of sub-system impact tests were undertaken using an adaptation of the EEVC WG17 (EEVC Committee, 1998) pedestrian test methods intended for cars. These tests using the child and adult headform impactors and the adult legform impactors were carried out on the vehicle front and on the cycle rack fitted to the vehicle. Different combinations of bicycles installed on the rack, and the rack in its stowed position were investigated. The positions tested on the cycle rack and bicycles were selected to cover the whole structure and to test any apparent danger points. The positions tested on the vehicle front, without the rack fitted, were selected to provide results appropriate for comparison with the results of the cycle rack. The test conditions for the pedestrian sub-systems impactors, impact velocity and direction were adjusted from the EEVC requirement for a 25-mph pedestrian accident with a car, to represent a 20-mph accident with a bus. A 20-mph test speed was identified as appropriate from an analysis of the fatal pedestrian accidents, involving a bus front, drawn from the TRL database of police reports of fatal road accidents. These adjustments are described in more detail in Section 5.3.

In summary, the objectives of this study were as follows:

1 To carry out a literature review to locate any existing research and accident data relating to bicycle racks mounted on buses and their effect on pedestrian injuries.

2 To carry out an analysis of accident data for fatal pedestrian accidents involving buses, and to determine the impact speed distribution to aid the selection of an appropriate speed at which to carry out the mathematical modelling and impact testing.

3 To assess the ability of two representative buses with front mounted cycle racks to meet the legal requirements placed on them.

4 To determine test procedures which can be used to provide an assessment of the aggressiveness to vulnerable road users of bus fronts with and without cycle racks.

5 To carry out pedestrian sub-system impact tests to two representative buses, so that injury risk to pedestrians in accidents with buses, with and without a cycle rack fitted, can be compared.

6 To advise on methods of reducing the aggressiveness of front mounted cycle racks.

2 Accident analysis

2.1 Total casualty analysis

As stated above, the impact test programme was designed to compare the relative safety of buses with, and without, bike racks and to give an indication of the likely severity of a pedestrian accident, should one occur. In order to be able to assess the probability of the occurrence of such an accident, a basic search was made of the STATS19 database. The total number of pedestrian casualties, resulting from accidental impact with the front of PSVs over the past five years, was retrieved and sub-divided by severity of injury (all STATS19 accidents are injurious accidents). These data, including the annual means, are given in Table 2.1.1.

These data show that the numbers of pedestrians sustaining accidental injuries in collision with the fronts of PSVs have remained fairly level over the five years reviewed, although it is noticeable that the figures for 1999 were the highest for almost every category. It is also clear from Table 2.1.2 that the proportions for each category have remained remarkably stable since 1995.

Table 2.1.1 Numbers of pedestrian accidents with the front of PSVs, by severity

	Severity of accidental injury			
Year	*Fatal*	*Serious*	*Slight*	*Total*
1999	51	228	688	967
1998	34	206	599	839
1997	45	238	645	928
1996	40	198	655	893
1995	44	185	583	812
Total	214	1,055	3,170	4,439
Mean	42.8	211.0	634.0	887.8

Table 2.1.2 Pedestrian accidents with the front of PSVs, by severity (%)

	Severity of accidental injury (%)		
Year	*Fatal*	*Serious*	*Slight*
1999	5	24	71
1998	4	25	71
1997	5	26	70
1996	4	22	73
1995	5	23	72

2.2 Analysis of impact speed: Summary

A more thorough accident analysis was carried out in order to discover information concerning bus and pedestrian impacts, such as the distribution of the age of pedestrians struck, bus impact speeds, impact location on the bus, and injury severity. Of these, the most important were the impact speeds and injury severity distributions, as they would enable the selection of an appropriate speed for the mathematical modelling and pedestrian sub-system impact tests. Ideally an accident information database was required which contained sufficient information to determine these distributions. However, few accident databases contained information on the vehicle impact speed and many only held data on car accidents. After reviewing the available data, it was concluded that the TRL database of police reports on fatal road accidents was the best source, but this only provided information on the speed distribution for fatal bus/pedestrian accidents. Data on the speed distribution of accidents involving pedestrians struck by the fronts of cars are available for fatal, serious and minor injuries, but this was not applicable to bus/pedestrian impacts because the speed distributions for cars are very different from those for buses. For example, for buses, nearly 90% of pedestrian fatalities occur at impact speeds up to 30mph (48km/hr) whereas for cars, only 43% of fatalities occur at speeds up to 30mph. It should be noted that this comparison does not necessarily imply that buses are more dangerous than cars, but is more likely to be due to the fact that buses rarely travel at high speed.

Ideally for this test programme, the impact speed should be selected at a speed at which the majority of pedestrian accidents occur and at which the injury risk is significant, but at which only a small proportion of accidents would be fatal. In this way, the test severity would be representative of real life accidents. However, as the only accident data available that included impact speeds were from a fatal accident database, the analysis did not permit a definitive test speed to be determined. It was noted that the median speed of the fatal accidents was at about 20mph (32km/hr) and that a significant number of fatal accidents occurred at very low speeds (speed range 0-5mph). With insufficient accident data available to select a definitive speed for tests, the alternative of testing the bus front to find the maximum 'safe' speed could have been used to find an appropriate speed for the test programme, though this would have required a large test programme in itself. The tests were primarily intended to produce results that would permit comparison between the relative safety of the bus with and without cycle racks, and not to represent some specific accident severity. Therefore, it was decided to use the 20mph median speed of the fatal accidents for the simulation and sub-systems tests.

The analysis that led to this decision is described in detail below.

2.3 Background to analysis

A preliminary analysis of just over 14,000 fatal accidents from the TRL fatal accident files showed 257 accidents involving a bus striking a pedestrian. Of these, 93 had already been coded for the detailed Fatals Databases (Enhanced Database (EDB) and Intermediate Database (IDB)). Information from these databases allowed 33 of the 257 accidents to be eliminated, as they were unsuitable. The remainder were screened for suitability (using page 1 of the bus/pedestrian accident analysis form, Appendix D) which resulted in the rejection of a further 79 accidents. Table 2.3.1 indicates the reasons for all of the rejections, and the number of rejections in each category.

Table 2.3.1 Unsuitable accidents

Reason	*Number*
Pedestrian not dead	1
Suicide	5
Died of natural causes	1
Not a road traffic accident	3
Pedestrian fell while boarding/alighting from bus	5
Pedestrian hit by car, not bus	45
Pedestrian hit by car as well as bus	3
Bus hit something else first	2
Pedestrian tripped and fell under side of bus	5
Pedestrian hit by open luggage door	2
Pedestrian crushed between bus and solid object	4
'Bus' was a Ford Transit-type minibus	27
'Bus' was a tram	4
Not frontal impact	3
File not available	2
Total	112

One hundred and forty five accidents in which a pedestrian died owing to being hit by a bus remained. In those accidents, the bus or the pedestrian did not hit anything else, the pedestrian was not attempting suicide, and there were no other unusual circumstances. Further impact cases, which were non-frontal, were eliminated at this stage, while others were eliminated at a later stage in the analysis.

Data related to these 145 accidents were collected from the accident and vehicle data forms (Appendix D). In addition, for those accidents that had not been coded for the EDB/IDB, data were extracted from the forms that were completed following the accident (Appendix D). These data were related to buses and pedestrians only and corresponded to relevant IDB fields.

At this stage, those accidents for which the cruising speed of the bus was known and where frontal impacts occurred, were selected. In addition, one accident where the cruising speed was unknown, but where a reasonable estimate of the impact speed was available, was included. This gave a total of 132 accidents in which 134 pedestrians died. The data from these accidents were coded. Injury data were also coded for 57 pedestrians for whom a post-mortem was available. A subjective assessment of the cause of death was carried out for those cases where a post-mortem was not available. The Occupant/Casualty form (Appendix D) was used to identify the body area containing the most severe injuries.

2.4 Analysis of cruising speed

Estimates of cruising speed and/or impact speed were available for the 132 accidents. Forty eight of the cruising speed estimates were derived from tachographs or police accident reconstruction, while the remainder were derived from witnesses or from bus drivers themselves. The speed estimate given by the vehicle driver was only approved if it had been accepted by the investigating police officers as being reasonable in the circumstances. Table 2.4.1 gives the distributions of cruising speeds, both overall and broken down by source of estimate.

The police only investigate vehicle speed if there is an initial suggestion of speed being a factor in the accident. It is, therefore, not surprising that there is a higher average speed in the police-reconstructed accidents. In addition, tachograph charts are more difficult to analyse at low speed, so their evidence is quoted less frequently in the accident reports concerning low-speed cases.

Table 2.4.1 Cruising speed distributions

	Witness/Driver only			*Police/Tacho*			*Overall*		
Speed band (mph)	*No.*	*%*	*Cum %*	*No.*	*%*	*Cum %*	*No.*	*%*	*Cum %*
0-5	11	13.3	13.3	2	4.2	4.2	13	9.9	9.9
6-10	9	10.8	24.1	3	6.3	10.4	12	9.2	19.1
11-15	10	12.0	36.1	1	2.1	12.5	11	8.4	27.5
16-20	12	14.5	50.6	4	8.3	20.8	16	12.2	39.7
21-25	23	27.7	78.3	8	16.7	37.5	31	23.7	63.4
26-30	14	16.9	95.2	13	27.1	64.6	27	20.6	84.0
31-35	0	0.0	95.2	2	4.2	68.8	2	1.5	85.5
36-40	3	3.6	98.8	3	6.3	75.0	6	4.6	90.1
41-45	0	0.0	98.8	3	6.3	81.3	3	2.3	92.4
46-50	0	0.0	98.8	4	8.3	89.6	4	3.1	95.4
51-55	1	1.2	100	1	2.1	91.7	2	1.5	96.9
56-60	0	0	100	0	0.0	91.7	0	0.0	96.9
61-65	0	0	100	2	4.2	95.8	2	1.5	98.5
66-70	0	0	100	2	4.2	100	2	1.5	100
Total	83	100	–	48	100	–	131	100	–
Not known	0	–	–	0	–	–	1	–	–
Mean speed		20.5			31.4			24.5	

Figure 2.4.1 illustrates the distributions of cruising speeds. The frequency shows the percentage of buses driving at each given speed.

2.5 Impact speed

Depending on the situation, the driver may have had time to brake before impact. Table 2.5.1 gives the distributions of all impact speeds, regardless of braking behaviour, together with the breakdown by source of estimate.

Figure 2.5.1 illustrates the distributions of all impact speeds, regardless of braking behaviour.

Sixty-seven of the 132 accidents involved situations where the driver did not have time to brake before impact. In these cases the impact speed can be taken to be equal to the cruising speed. The speeds of these 67 buses are set out in Table 2.5.2.

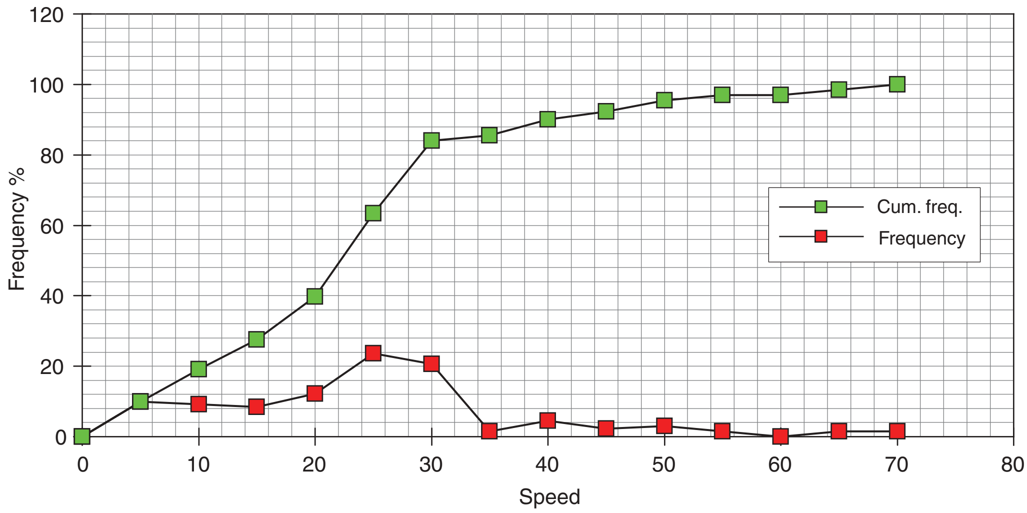


Figure 2.4.1 Speed distribution of cruising speed (mph)

Table 2.5.1 Impact speed distributions

Speed band (mph)	Witness/Driver only No.	%	Cum %	Police/Tacho No.	%	Cum %	Overall No.	%	Cum %
0-5	10	17.9	17.9	3	10.0	10.0	13	15.1	15.1
6-10	7	12.5	30.4	3	10.0	20.0	10	11.6	26.7
11-15	11	19.6	50.0	1	3.3	23.3	12	14.0	40.7
16-20	9	16.1	66.1	4	13.3	36.7	13	15.1	55.8
21-25	11	19.6	85.7	7	23.3	60.0	18	20.9	76.7
26-30	5	8.9	94.6	5	16.7	76.7	10	11.6	88.4
31-35	0	0.0	94.6	0	0.0	76.7	0	0.0	88.4
36-40	2	3.6	98.2	1	3.3	80.0	3	3.5	91.9
41-45	0	0.0	98.2	1	3.3	83.3	1	1.2	93.0
46-50	0	0.0	98.2	2	6.7	90.0	2	2.3	95.3
51-55	1	1.8	100	0	0.0	90.0	1	1.2	96.5
56-60	0	0	100	0	0.0	90.0	0	0.0	96.5
61-65	0	0	100	1	3.3	93.3	1	1.2	97.7
66-70	0	0	100	2	6.7	100	2	2.3	100
Total	56	100	–	30	100	–	86	100	–
Not known	0	–	–	0	–	–	46	–	–
Mean speed		18.2			27.5			21.5	

Table 2.5.2 Impact speed distributions (when no time for braking was available)

Speed band (mph)	Witness/Driver only No.	%	Cum %	Police/Tacho No.	%	Cum %	Overall No.	%	Cum %
0-5	9	19.1	19.1	2	10.0	10.0	11	16.4	16.4
6-10	5	10.6	29.8	3	15.0	25.0	8	11.9	28.4
11-15	8	17.0	46.8	2	10.0	35.0	8	11.9	40.3
16-20	6	12.8	59.6	4	20.0	55.0	8	11.9	52.2
21-25	11	23.4	83.0	4	20.0	75.0	15	22.4	74.6
26-30	5	10.6	93.6	0	0.0	75.0	9	13.4	88.1
31-35	0	0.0	93.6	1	5.0	80.0	0	0.0	88.1
36-40	2	4.3	97.9	0	0.0	80.0	3	4.5	92.5
41-45	0	0.0	97.9	1	5.0	85.0	0	0.0	92.5
46-50	0	0.0	97.9	0	0.0	85.0	1	1.5	94.0
51-55	1	2.1	100	0	0.0	85.0	1	1.5	95.5
56-60	0	0	100	0	0.0	85.0	0	0.0	95.5
61-65	0	0	100	1	5.0	90.0	1	1.5	97.0
66-70	0	0	100	2	10.0	100	2	3.0	100
Total	47	100	–	20	100	–	67	100	–
Mean speed		19			28.8			21.9	

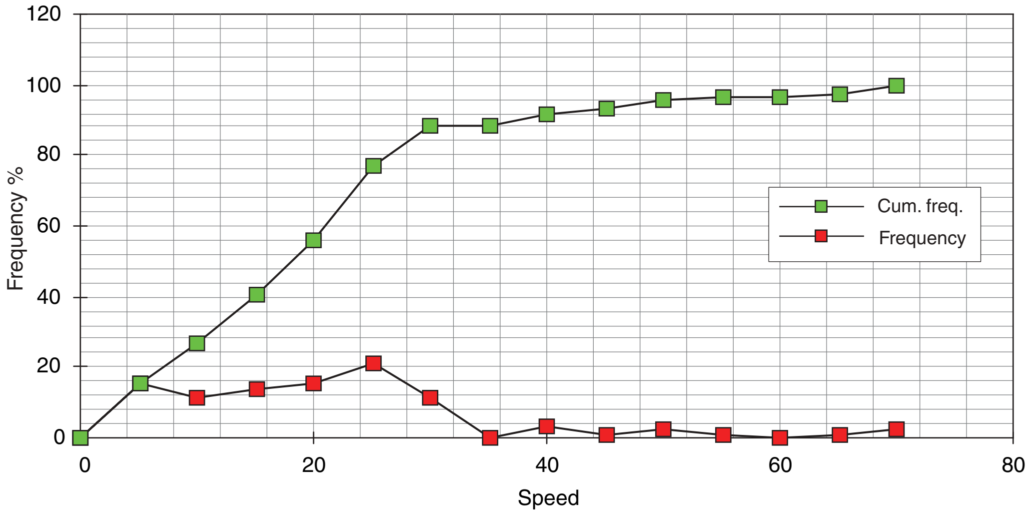


Figure 2.5.1 Speed distribution of impact speed (mph)

An estimate of the actual impact speed was available for 19 cases of the remaining 65 accidents. In these cases some braking took place before impact. Table 2.5.3 gives the impact speeds of these 19 cases.

This left 46 accidents with unknown impact speed. Table 2.5.4 gives the distribution of cruising speeds for these cases. No estimate of the impact speed was available.

Table 2.5.5 gives a summary of the mean speed data. It shows the mean speed data for the cruising speed of the buses in all different cases, the cruising speed of the buses where the impact speed was not available, and the impact speed for all cases where this was known, which includes the following two rows where braking was, and was not, applied prior to impact.

Figure 2.5.2 presents a summary of the mean speed.

2.6 Impact location

Table 2.6.1 shows the distribution of impact locations of the pedestrians on the fronts of the buses. These were considered by dividing the front of the bus into thirds, which were labelled Nearside, Centre and Offside. Two further categories allowed for cases where the pedestrian was struck by the corner of the front of the bus.

2.7 Shape of front of bus

The vast majority of the buses (127) had flat, vertical fronts. Four had flat, sloping fronts, and one was irregular.

Table 2.5.3 Impact speed distributions (when some time for braking was available)

Speed band (mph)	Witness/Driver only			Police/Tacho			Overall		
	No.	%	Cum %	No.	%	Cum %	No.	%	Cum %
0-5	1	11.1	11.1	1	10.0	10.0	2	10.5	10.5
6-10	2	22.2	33.3	0	0	10.0	2	10.5	21.1
11-15	3	33.3	66.7	1	10.0	20.0	4	21.1	42.1
16-20	3	33.3	100	2	20.0	40.0	5	26.3	68.4
21-25	0	0	100	3	30.0	70.0	3	15.8	84.2
26-30	0	0	100	1	10.0	80.0	1	5.3	89.5
31-35	0	0	100	0	0	80.0	0	0	89.5
36-40	0	0	100	0	0	80.0	0	0	89.5
41-45	0	0	100	1	10.0	90.0	1	5.3	94.7
46-50	0	0	100	1	10.0	100	1	5.3	100
Total	9	100	–	10	100	–	19	100	–
Mean speed		14.1			24.8			19.7	

Table 2.5.4 Cruising speed distributions (impact speed was not known)

Speed band (mph)	Witness/Driver only			Police/Tacho			Overall		
	No.	%	Cum %	No.	%	Cum %	No.	%	Cum %
0-5	2	6.9	6.9	0	0	0	2	4.3	4.3
6-10	4	13.8	20.7	0	0	0	4	8.7	13.0
11-15	2	6.9	27.6	0	0	0	2	4.3	17.4
16-20	6	20.7	48.3	1	5.9	5.9	7	15.2	32.6
21-25	8	27.6	75.9	4	23.5	29.4	12	26.1	58.7
26-30	7	24.1	100	4	23.5	52.9	11	23.9	82.6
31-35	0	0	100	1	5.9	58.8	1	2.2	84.8
36-40	0	0	100	2	11.8	70.6	2	4.3	89.1
41-45	0	0	100	1	5.9	76.5	1	2.2	91.3
46-50	0	0	100	3	17.6	94.1	3	6.5	97.8
51-55	0	0	100	0	0	94.1	0	0	97.8
56-60	0	0	100	0	0	94.1	0	0	97.8
61-65	0	0	100	1	5.9	100	1	2.2	100
Total	29	100	–	17	100	–	46	100	–
Mean speed		20.9			34.4			25.9	

Table 2.5.5 Mean speeds (mph)

Condition	Wit/Driver Mean	Wit/Driver No.	Pol/Tacho Mean	Pol/Tacho No.	Overall Mean	Overall No.
Cruising speed (all cases)	20.5	83	31.4	48	24.5	131
Cruising speed (unknown imp speed)	20.9	29	34.4	17	25.9	46
Impact speed (all cases)	18.2	56	27.5	30	21.5	86
Impact speed (no time for braking)	19.0	47	28.8	20	21.9	67
Impact speed (after braking)	14.1	9	24.8	10	19.7	19

Table 2.6.1 Impact locations

Impact location	Number	Percent
Nearside corner	33	25.0
Nearside	35	26.5
Centre	38	28.8
Offside	17	12.9
Offside corner	9	6.8
Total	132	100

2.8 Type of bus operation

Most of the buses in the sample (113) were 'ordinary' service buses. Five were on regular inter-city service operations, and 14 were touring coaches. The impact speed distributions for the ordinary buses and the touring coaches are shown in Tables 2.8.1 and 2.8.2 respectively. Of the five inter-city buses, impact speed was estimated for only three, at 5, 48 and 55mph (estimates from tachograph, police reconstruction and witnesses respectively).

Figure 2.8.1 illustrates the impact speed distributions of ordinary service buses.

Figure 2.8.2 illustrates the impact speed distributions of touring coaches.

2.9 Discussion of accident speed analysis

TRL has previously investigated the safety of bull bars. That study aimed to determine the highest speed at which a car without bull bars could be travelling without most people being seriously injured by the parts of the base

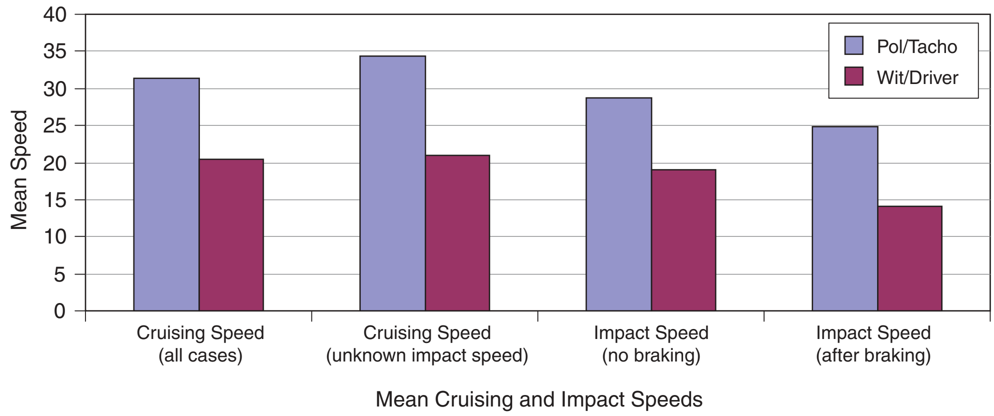


Figure 2.5.2 Presents a summary of the mean speed

Table 2.8.1 Impact speed distributions (ordinary service buses)

Speed Band (mph)	*Witness/Driver only*			*Police/Tacho*			*Overall*		
	No.	*%*	*Cum %*	*No.*	*%*	*Cum %*	*No.*	*%*	*Cum %*
0-5	10	19.2	19.2	2	10.0	10.0	12	16.7	16.7
6-10	7	13.5	32.7	3	15.0	25.0	10	13.9	30.6
11-15	11	21.2	53.8	0	0	25.0	11	15.3	45.8
16-20	8	15.4	69.2	4	20.0	45.0	12	16.7	62.5
21-25	10	19.2	88.5	6	30.0	75.0	16	22.2	84.7
26-30	4	7.7	96.2	5	25.0	100	9	12.5	97.2
31-35	0	0	96.2	0	0	100	0	0	97.2
36-40	2	3.8	100	0	0	100	2	2.8	100
Total	52	100	–	20	100	–	72	100	–
Mean speed		17.1			20.0			17.9	

Table 2.8.2 Impact speed distributions (touring coaches)

Speed band (mph)	*Witness/Driver only*			*Police/Tacho*			*Overall*		
	No.	*%*	*Cum %*	*No.*	*%*	*Cum %*	*No.*	*%*	*Cum %*
11-15	0	0	0	1	12.5	12.5	1	9.1	9.1
16-20	1	33.3	33.3	0	0	12.5	1	9.1	18.2
21-25	1	33.3	66.7	1	12.5	25.0	2	18.2	36.4
26-30	1	33.3	100	0	0	25.0	1	9.1	45.5
31-35	0	0	100	0	0	25.0	0	0	45.5
36-40	0	0	100	1	12.5	37.5	1	9.1	54.5
41-45	0	0	100	1	12.5	50.0	1	9.1	63.6
46-50	0	0	100	1	12.5	62.5	1	9.1	72.7
51-55	0	0	100	0	0	62.5	0	0	72.7
56-60	0	0	100	0	0	62.5	0	0	72.7
61-65	0	0	100	1	12.5	75.0	1	9.1	81.8
66-70	0	0	100	2	25.0	100	2	18.2	100
Total	3	100	–	8	100	–	11	100	–
Mean speed		25.0			46.5			40.6	

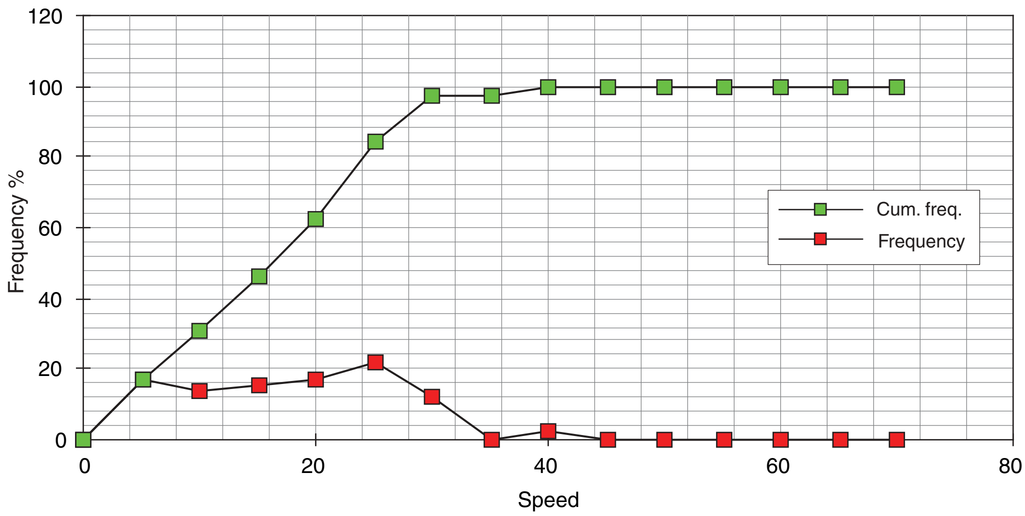


Figure 2.8.1 Illustrates the impact speed distributions of ordinary service buses (mph)

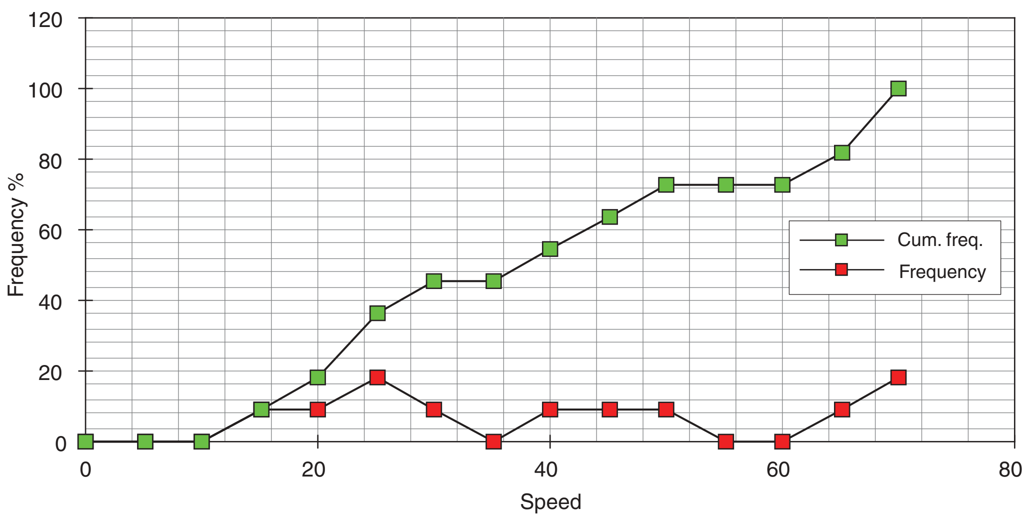


Figure 2.8.2 Impact speed distribution of touring coaches (mph)

vehicle which would otherwise lie behind the bull bar on impact. The study then considered how many of those people would be seriously injured if bull bars were fitted. Despite attempts to predict this speed, in practice it was necessary to determine it by full-scale testing of the base vehicle at a range of speeds.

Similar difficulties are faced when attempting to predict this speed for the current project. Knowledge of the speed distributions for serious and slight injury cases, and fatalities is required. These are not available from the TRL Fatal File collection, nor are they available from Stats19. Available data for cars are not applicable to bus/pedestrian impacts because the speed distributions for cars are very different from those found for buses. Table 2.5.1, for example, shows that nearly 90% of pedestrians are killed at impact speeds below 30mph (48km/hr), with the median at about 20mph (32km/hr). The current analysis, therefore, does not permit a definitive test speed to be determined.

In addition, the low median impact speed for fatalities implies that the test speed may need to be as low as 10mph. However testing at such a low speed implies that it is expected that the racks will be detrimental, thus pre-judging the issue and possibly producing a circular argument. The experience gained by TRL on bull bars is not transferable to cycle racks on buses because bull bars do not actually change the general profile of the vehicle front significantly, whereas cycle racks do.

Ideally, the base vehicle should be tested at a range of speeds (10, 15, 20 and 25mph), but this was not possible within the budget for this project. The expectation was that 20mph would finally emerge as a suitable test speed, and was therefore recommended as the test speed to be used in the mathematical modelling.

3 Mathematical modelling

3.1 Summary

The purpose of this analysis was to produce pedestrian kinematics data to help select appropriate impact conditions for the sub-systems tests to the bus with and without a bike rack fitted. For a bus front and some parts of the front of the bike rack, the near vertical profile meant that the directions and severity of the impact with critical pedestrian body regions could be predicted without the need for additional information. These predictions were used to set the impact conditions for the sub-systems test. However, the fitting of a bike rack made the bus shape more like a car, causing most adult pedestrians of normal stature to wrap around or dive over the bicycle and hit their head on either the bus or the rear bicycle. For these pedestrians the head impact conditions could not be predicted from existing knowledge. Therefore, mathematical simulations of the bus and full pedestrian were used to determine the head trajectory and velocity. This information was then used to set appropriate sub-system test conditions for the adult headform tests.

Finite element analysis was used to determine the kinematics of a 50th percentile male pedestrian dummy during an impact with the front of a bus with a cycle rack fitted. The kinematics predicted by the model indicated the likely speeds, directions and points of impact of the head and provided additional data for other body parts. Full details of the modelling exercise, first described by Brook-Carter and Kersloot (1999), follow this summary.

Initially three impact simulations were carried out with an adult pedestrian being struck on the side by a generic bus. The bus was fitted with a bicycle rack containing either two bicycles, a single bicycle in the front position or a single bicycle in the rear position. All impact simulations were run for a sufficient period of time to assess the complete impact between the pedestrian and the vehicle.

A clear pattern was established in all three simulations. Head impact velocity was not particularly sensitive to the number of bicycles or their position in the rack. This is because the dummy was hit in the area of the knee by the front part of the rack and the bikes were pushed back, causing the pedestrian to pivot about the front edge of the rack at around bumper level. This caused the legs to rotate rapidly away from the vehicle, and the head and upper body to be rotated towards the on-coming vehicle. The net result of this analysis was to indicate that the head is likely to be accelerated towards the vehicle and downwards, resulting in an additional velocity.

Following the selection and procurement of a bus and coach for the test programme, and the design of a mounting system for the bike rack, further simulations were carried out. For these, the dimensions of the simulated vehicles were adjusted to represent the actual bus and coach tested with the bike rack fitted. The results were used to determine the velocity, direction and impact location for the 50th percentile adult male headform sub-systems tests on the bus and coach to represent the head impacts with a rack fitted. The outputs of head motion for these additional simulations are given in Appendix B of this report.

3.2 Summary conclusions

This analysis showed that, for the 50th percentile male pedestrian and the vehicles and bicycle racks tested, the head was likely to be accelerated towards the vehicle and downwards, resulting in an additional velocity of up to about 4 m/s. The results from these simulations indicated that the 50th percentile adult head impact velocity was not particularly sensitive to bicycle position or number because the bikes were pushed back, causing the pedestrian to pivot about the front edge of the rack at around bumper level.

However, it should be noted that these simulations do not represent the full range of head impact conditions likely to occur in real life. Most adult pedestrians will wrap around or over the bicycle and hit their head on either the bus or the rear bicycle. In an accident, the exact nature of the pedestrian's kinematics, for the head impact in particular, depends on the pedestrian's stature. Differences in the pedestrian's stance and motion before impact, the mass, strength and number of cycles, and their attachment to the rack will also affect the head impact conditions. Some indication of the large range of likely head impact conditions can be found from the range of statures found in the adult population which ranges from 1.539 to 1.894 metres for the 5th percentile female and 95th percentile male respectively (Peebles and Norris, 1998).

3.3 Background to modelling

The purpose of this work was to produce pedestrian kinematics data to enable physical sub-system testing of the installed bicycle rack. The test team required information regarding the trajectory and impact velocity of the head and legs of the dummy. The information that most realistically represents a likely impact event between a pedestrian and a vehicle equipped with the bicycle rack was used in the test.

3.4 Method

Finite element analysis was used to determine the kinematics of a pedestrian dummy during an impact with the front of a bus (with or without a cycle rack). The kinematics predicted by the model have been used to indicate the likely speeds, directions and points of impact of various body parts with the impacting structure and will therefore aid in the definition of the subsequent physical tests.

Impacts with a 50% male pedestrian dummy were considered along with the following configurations of the bus/coach and cycle rack:

- Cycle rack deployed with 1 cycle in the forward position.
- Cycle rack deployed with 1 cycle in the rear position.
- Cycle rack deployed with 2 cycles.

The dimensions of the simulated vehicle, rack and bicycles were all adjusted to match those of the bus and coach used later for the impact study. Impacts were considered between a single, centrally positioned pedestrian and a rack containing various combinations of bicycles, (two bicycles, single front and single rear).

All impacts were analysed at the same speed of 20 mph as this was indicated to be the median speed by the analysis of accident data.

Images of each model, just before the impact, are given in figures 3.4.1 to 3.4.3 showing the pedestrian, bike rack and a generic coach front for the three configurations of bicycles simulated. Figure 3.4.4 shows the two bike arrangement at the time that the pedestrian's head makes contact with the front of the generic coach.

It was noted that the pedestrian dummy model might become unstable when penetrating contacts occur in the abdominal region. This was due to limitations in physical dummies where the abdomen is simply represented by regions of foam. As a result some judgements were made when interpreting the results under these specific circumstances.

In order to obtain the correct interaction between the dummy and the bus/cycle rack, the stiffness of the system was needed. This was derived from the analysis with the exception of the cycle's stiffness within the rack. To obtain the cycle's stiffness some preliminary push tests on a cycle mounted on the rack were carried out.

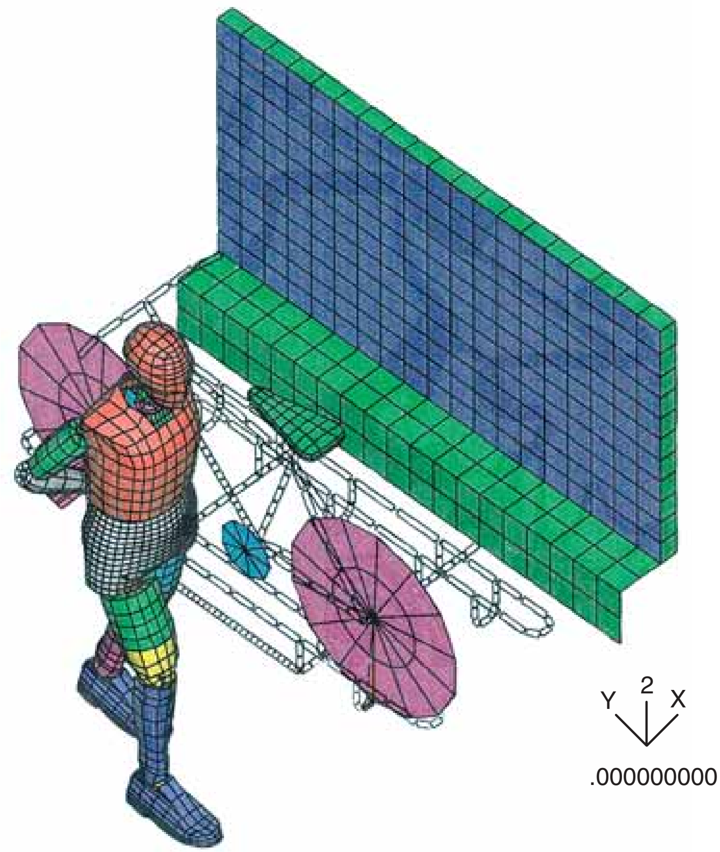


Figure 3.4.1 Rack deployed – Front bicycle only

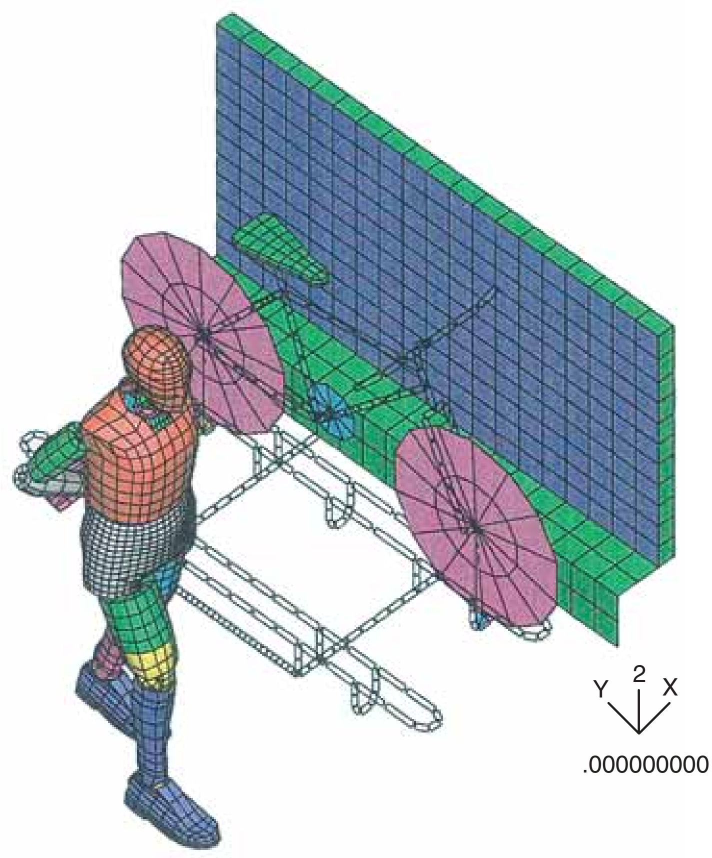


Figure 3.4.2 Deployed rack – Rear bicycle only

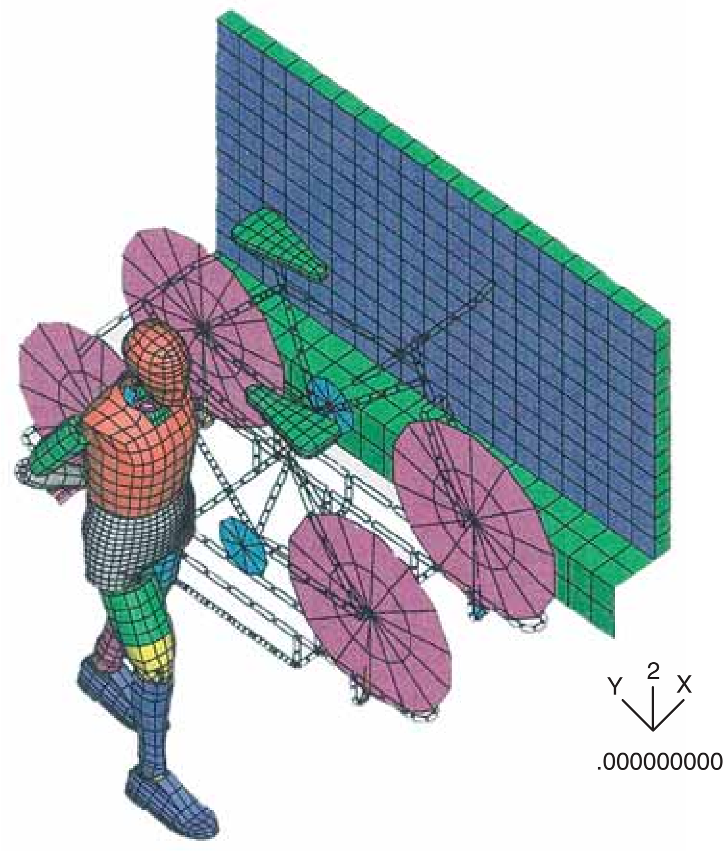


Figure 3.4.3 Rack deployed – Two bicycles

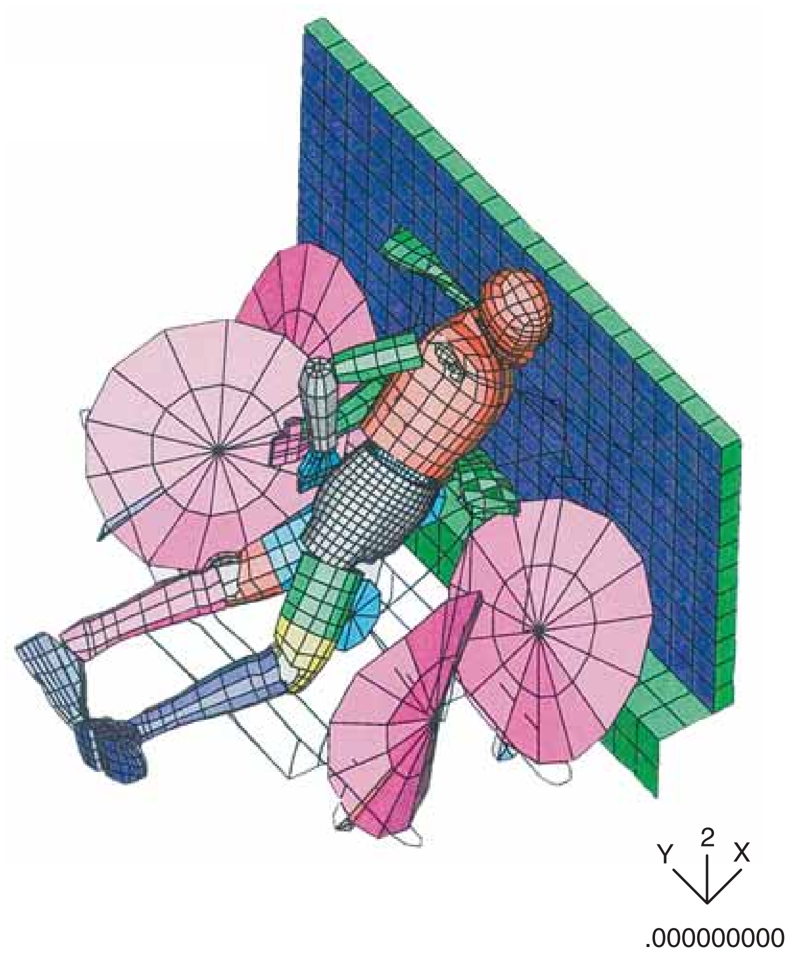


Figure 3.4.4 Sample impact at 20 mph

3.5 Model development

The finite element analysis (FEA) technique was chosen as a means of predicting the performance of the components and the pedestrian kinematics. Finite element analysis is capable of solving structural and biomechanical problems of this type with a relatively high level of detail and accuracy. The modelling was performed using the proprietary finite element analysis code Oasys LS-Dyna version 7.0. LS-Dyna uses a solution technique, which facilitates the modelling of dynamic events. These features enable the solution of problems where a human (a highly non-linear biomechanical system) interacts with a vehicle structure.

Analysis of this problem required three separate models to be used, a pedestrian dummy model, a bicycle model and a model of the bicycle rack and vehicle front-end. Once these preliminary models were developed it was then necessary to combine them into a final overall model.

3.6 Pedestrian dummy model

The pedestrian dummy was a model that could be deformed. It was an articulated model of a 50th percentile adult male with appropriate degrees of freedom and stiffness at all the major joints. The dummy was based upon the FTSS/ARUP HYBRIDIII dummy model, but with substantial modifications to the lower body and arms to make it more biofidelic. The standard FTSS/ARUP HYBRIDIII dummy model was used for analysis of occupant injuries during frontal impacts and incorporates a flexible 'ribcage' and fully jointed limbs (with the exception of the upper legs). Considerable modifications have been made to the legs of the dummy for more realistic articulation and joint stiffness. Further modifications were made to the damping of the foam material to stabilise it where localised impacts occurred with the rack and bicycle frames. The dummy incorporated a modified EuroSID neck for improved behaviour during a vehicle strike from the side of the dummy. Constraints have been added to the dummy's feet to represent sliding friction with the road surface during the impact. The final pedestrian dummy model as used contained approximately 7000 elements.

3.7 Bicycles

The bicycles were modelled from the geometry of the bicycles purchased for the physical test. Material data was obtained from the manufacturer's specification sheets. The mass of all the structures in the model was validated against the test items. The bicycles were optimised as a series of fixed ended beams. The beams were uniform with rotational joints to give appropriate freedom to the handlebars and front forks. Areas of the bicycle likely to cause impalement injury, such as pedals and brake-levers, were not modelled. Impalement is a special type of injury that would have required a considerable amount of specific modelling and test correlation that was considered to be beyond the scope of this study. Care was taken to ensure that the models were of the correct mass and mass distribution; the inertia of the bicycles during the impact would be significant to the dummy's behaviour.

3.8 Bicycle rack

The bicycle rack was modelled with the same approach as that used for the bicycles themselves. A physical push test using a hydraulic ram was used to calibrate the stiffness of the mounting system that holds the bicycle in the rack. This test produced a force deflection curve for the bicycles within the rack. The stiffness obtained from the test was incorporated into the model when the bicycles were added to the rack. At the back of the rack a wall was added to represent the bus front. The presence of the bus front was there solely to calculate the point of impact and was not intended to be of representative stiffness. Without modelling the bus front in a highly detailed manner with exact design geometry, including sub-surface structure, it was not possible to make predictions of the forces occurring during impact with the bus. The purpose of this analysis was to provide the test team with sufficient information to obtain data from physical tests on the bus.

3.9 Combining models

The most significant aspect of combining the models was the positioning of the rack relative to the pedestrian and the bus. The mounting position of the rack on the bus was controlled by the following factors: driver's visibility, obstruction of vehicle lights and control of the vehicle's forward ramp angle. Determining the correct position for the ramp relative to the ground plane was critical for correct pedestrian kinematics. As the dummy's centre of gravity was approximately at the height of its pelvis, impacts at any distance from the pelvis are likely to cause the dummy to rotate about its centre of gravity. The rotational force was in proportion to both the severity of the impact and the distance of the impact to the pelvis. It was anticipated that the initial impact to the dummy would be from the leading edge of the rack, which was why the rack height is so significant.

3.10 Results

Three impact simulations were carried out for each vehicle with an adult pedestrian being stuck from the side by the bicycle rack containing two bicycles, a single bicycle in the front position and a single bicycle in the rear position. All three impact simulations have been run for a sufficient period of time to assess the complete impact between the pedestrian and the vehicle.

A clear trend for the three different rack configurations can be seen from the graphs of the pedestrian's head velocity, with the head moving towards the impacting vehicle. This can be seen in Figures B1, B2, B3, B4, B5 and B6 for the coach, and B7, B8, B9, B10, B11 and B12 for the bus in Appendix B. The graphs show the head velocity towards the vehicle (x) and towards the ground (as indicated by the negative z displacement). The velocity magnitude line shows the resultant head velocity in the two planes. The resultant head velocity, relative to the vehicle, was then calculated using the head (x) horizontal and head z vertical velocity (at the moment of head contact). The relative head velocity was found to be fairly consistent for each configuration, ranging from just under 3 m/s to just over 4 m/s.

3.11 Modelling conclusions

This analysis shows that, for the 50th percentile male pedestrian and the vehicles and bicycle racks tested, the head is likely to be accelerated towards the vehicle and downwards, resulting in an additional velocity of 4 m/s. The results from these simulations indicate that the 50th percentile adult head impact velocity is not particularly sensitive to bicycle position or number. This is because the bikes were pushed back causing the pedestrian to be pivoted about the front edge of the rack at around bumper level.

However, it should be noted that these simulations do not represent the full range of head impact conditions likely to occur in real life. Most adult pedestrians will wrap around or over the bicycle and hit their head on either the bus or the rear bicycle. However, in an accident, the exact nature of the pedestrian's kinematics, for the head impact in particular, depends on the pedestrian's stature. Differences in the pedestrian's stance and motion before impact, the mass, strength and number of cycles, and their attachment to the rack will also affect the head impact conditions. Some indication of the large range of likely head impact conditions can be found from the range of statures found in the adult population, which ranges from 1.539 to 1.894 metres for the 95th percentile female and 95th percentile male respectively (Peebles and Norris, 1998).

4 Literature review

An initial literature review was carried out in the early stages of this project to discover any relevant reported research relating to the consequences of pedestrian accidents involving bike racks on buses, or similar situations. The search was subsequently broadened to include all available relevant library databases and the Internet. Databases searched included DIALOG, IRRD (International Road Research Documentation) database of which TRL is the English language co-ordinator and TRIS (Transportation Research Information Services) database. Following the completion of the test programme, this search was repeated to ensure that no recently published material had been missed. The information gained from these reviews is summarised below, but the search found no reported research that had specifically investigated bus/ pedestrian impacts.

Despite the long-term existence of bicycle racks fitted on buses in the US, the development of which has taken place over the last 20 years (Millar, 1999), no published research appears to be available concerning their safety implications. A widespread exploration of the transportation research databases, Internet sites and press reports did not reveal any articles that directly referred to the implications for pedestrian impact injury severity. It emerged from discussions with the US National Highway Traffic Safety Administration that no research had been carried out on the effects of cycle racks on pedestrian safety, and that it was impossible to differentiate between buses with and without front-mounted cycle racks in the US national accident databases.

Articles associated with the carriage of bicycles on buses concentrate on local schemes where bicycle racks on buses have been introduced. These schemes have been particularly popular in the US, where it is estimated that between 2 and 4% of passengers on buses equipped with bicycle racks travel with their bicycles, mainly for commuting purposes (Millar, 1999). The type of bicycle rack most frequently used in the US is a front mounted folding rack, of the type used in this study, that will accommodate two bicycles, or can be folded against the front of the bus when not in use. Loading can be carried out quickly and within view of the bus driver. Further information about these bicycle racks can be obtained from the references listed at the end of this section.

None of the US schemes have reported concerns about pedestrian safety or appear to have considered this issue, beyond advising users to alert the bus driver to their presence when loading and unloading their bicycles and to stand clear at other times. Many articles report that the design of the bicycle racks has been improved. However, these improvements refer to the benefits for users in terms of ease of use, practicalities such as the time taken to load and unload, the security of bicycles carried, and ensuring a clear field of view for the driver and unobstructed operation of windscreen wipers (Davenport, 1995). None of the articles discuss design improvements for reduced pedestrian injury severity.

There has been less enthusiasm for this type of scheme in the UK, where the carriage of bicycles on buses, whether in modified luggage boots or on rear-fitted bicycle racks, tends to be limited to long distance routes and tourist areas. The use of front mounted racks in particular has been frowned on (Millar, 1999), although again, no research was uncovered by this search that investigated the safety implications for pedestrians of front mounted bicycle racks.

Due to the apparent lack of research that directly related to the impact of bicycle racks fitted to the front of buses on pedestrian injuries, a review was undertaken of parallel studies on bull-bars. These studies, which mostly refer to metal bull-bars rather than the more compliant plastic type, have investigated the altered injury mechanisms to pedestrians when bull-bars are fitted, compared to when they are not.

The information is not directly transferable to cycle racks, since the location, size and shape of bull-bars, and thus the points of impact will be different. However, some assumptions may be made, based on the underlying premise that any rigid structure, mounted on the front end of a vehicle, will alter the impact dynamics and thus the injury mechanisms for pedestrians.

In areas such as rural Australia, where a collision with an animal such as a kangaroo could immobilise a driver in a remote location, bull-bars are legitimately used to minimise vehicle damage and help ensure mobility. Since the fitting of bull-bars has been shown by crash impact and simulation studies to increase injury severity to pedestrians (Fountain and Tomas, 1993; Tomas, 1994; Zellmer and Otte, 1995; Zellmer and Friedel, 1994), and to negate research carried out to design vehicle front ends that are more pedestrian friendly (Chiam and Tomas, 1980), it is hardly surprising that their use in urban areas has become a controversial subject.

As early as 1978, it was recognised that bull-bars altered the profile of a vehicle front end, making it potentially more aggressive in pedestrian collisions (Chiam and Tomas, 1980).

A number of crash simulation studies have been conducted using pedestrian dummies and vehicles equipped with and without bull-bars, to investigate the altered injury mechanisms and kinematics involved. One of these utilised a high speed film shooting at 500 frames per second to demonstrate that when bull bars are fitted to vehicles, there are a number of consequences for pedestrian injury type and severity (Reilly-Jones and Griffiths, 1996). Bull-bars prevent pedestrians from wrapping around and over the bonnet, increasing the rotation of pedestrians away from the vehicle, and consequently increasing their impact with the road, as they fall from a greater height and at a greater velocity (Tomas *in* Griffiths and Reilly-Jones, 1994). Head injuries are therefore likely to be more severe, and there is the additional danger of being run over by the vehicle after the initial impact (Dicker, 1999). Bull-bars present an increased risk of severe injury to the femur in adults and to the head and neck of children (Zellmer and Friedel, 1994; Zellmer and Otte, 1995), while injuries to the pelvis and abdomen are also likely to be more severe in adults (Zellmer and Friedel, 1994), as are injuries to the thorax in children (Hardy, 1996).

The impact on pedestrian injury mechanisms of this altered front-end profile can also be applied to scenarios involving bicycle racks carried on buses. Two particular vehicle design features have a significant effect on injury severity following pedestrian impact. These are the surface material properties of the front of the vehicle and bonnet at the main point of impact in terms of its compliance and shape (Chiam and Tomas, 1980; Tomas *in* Griffiths and Reilly-Jones, 1994) and the presence of any attachments, for example, a bull bar or bicycle rack.

The impact surface of a bull-bar is rigid and much stiffer than a vehicle body, deforming less on impact, and consequently absorbing less energy. This increases the impact force on the pedestrian, with more serious consequences for injury severity (Hardy, 1996). The impact surface is also relatively narrow with a smaller impact area compared to the compliant surface of a vehicle, thus concentrating the severity of the impact force, also increasing injury severity (Hardy, 1996). Both of these factors would also be attributable to pedestrian impacts with bicycle racks.

Despite suggestions that accidents involving bull-bars are largely under-reported, in 1994 1,056 injury accidents were reported where a vehicle involved was fitted with bull-bars. Of these, 89 involved pedestrians, of which 6 were fatally injured. Of an estimated 35 pedestrian and two-wheeled rider fatalities and around 316 seriously injured casualties in accidents involving bull-bar equipped vehicles, it is estimated that the bull-bars were responsible for 2 to 3 additional fatalities, and around 40 additional serious casualties. Consequently, an estimated saving of 6% of fatalities and 21% of seriously injured casualties could be achieved for pedestrians hit by vehicles if bull-bars had not been fitted (Hardy, 1996).

5 UK and overseas market information on bike racks for buses

Following extensive searches of library databases, a search of the Internet revealed a wealth of anecdotal information, but it also became clear that the 'bikes on buses' concept has been widely adopted by public transport operators in the USA. The Internet search was, therefore, concentrated on bus operators, bike rack suppliers, and on the development of the carriage of bicycles on buses.

5.1 Background

The Federal Transit Administration (FTA) provided resources through its Transport Equity Act for the 21st century (TEA-21) to prompt states and metropolitan areas to develop innovative transportation plans and programmes which improve the integration of public transport, bicycle facilities and other modes of travel into the existing transportation system. Projects that improve this integration are eligible for funding from programmes administered by both FTA and FHWA (Federal Highway Administration). The FTA's principal capital funding programs - the Capital Program, the Urbanized Area Formula (UAF) Program and the Formula Program for Non-Urbanized Areas - are available for bicycle transit linkages.

TEA-21 also created a new category of transit enhancement activities. One percent of UAF program funds apportioned to urban areas of at least 200,000 population is set-aside for transit enhancements, as follows.

- bicycle access, including bicycle storage facilities and installing equipment for transporting bicycles on mass transportation vehicles;
- pedestrian access and walkways;
- historic preservation, rehabilitation, and operation of historic mass transportation buildings, structures, and facilities (including historic bus and railroad facilities and canals);
- bus shelters;
- landscaping and other scenic beautification;
- public art;
- projects that enhance access for people with disabilities to mass transportation.

Many transit agencies applied for funds administered by the Federal Highway Administration (FHWA) such as the Transportation Enhancements program and Congestion Mitigation and Air Quality Improvement (CMAQ) program to pay for bike racks on buses and other projects. Bicycle improvements, such as projects to better integrate bicycles and transit, remain eligible for most of the federal-aid highway funding programs established by ISTEA in 1991. These programs are continued in the new TEA-21 legislation. Numerous bike racks on buses programs have been funded from the CMAQ program and the Transportation Enhancement program.

TEA-21 further encourages transit agencies to invest in linking bicycles and mass transportation by increasing the federal share of transit enhancement grants to 95 percent of the project costs. Bicycle projects using other transit funds may be funded at up to the 90% federal matching level. Non-bicycle related transit enhancement activities have 80% for federal/local funding. There are currently 44 states each offering at least one bikes-on-buses system.

The six leading states are:

Position	State
1	California
2	Washington
3	Florida
4	Colorado
5=	New York
	Pennsylvania

Source: Bikemap.com

Adoption of the bikes-on-buses system is most conspicuous on both the east and west coasts of the USA. Naturally, population density plays a considerable role, as other states in the centre of the country offer cyclists relatively few options, with the notable exception of Colorado, popular with Americans for active vacations. BikeMap.com has constructed a map indicating the systems on offer across the country, which can be seen in Appendix C. Three hundred and fifty public transport operators can apparently accommodate bikes on their vehicles, but this includes train, coach and ferry operators. There are approximately 231 carriers that offer bus-mounted bike racks, and 18 Transit Agencies require bike permits for bikes to be carried onto buses. Some agencies are contemplating scrapping the permit system because the administration costs exceed the revenues earned from permit sales. Appendix C also includes statistics gathered between 1996 and 2000 on the number of bike boardings from a selection of Transit Agencies across the USA.

5.1.1 Consultation sources

A consultation exercise was conducted with the companies listed below, in order to investigate how far bike racks have been incorporated into the operational environment and to find out more about their operational record, including, if possible, any accident statistics. The information received is presented in the following pages of this section. It consists mainly of details of products and their use, but one company (Tri-Met) was willing to provide some statistics from the company claims department, which are given in Table 5.4.1.

Company contacted	*Company representative*
King County Department of Metropolitan Service Seattle (USA)	Robert Flor Market Development Planner
Tri-Met, Portland, Oregon (USA)	Beth Erlendson Tri-Met marketing
City of Phoenix PTA, Arizona (USA)	Mr Mike Nevaraz Operations Manager for the City of Phoenix Public transit department
Sportworks Woodinville (USA)	Lisa Robinson Product Manager
Transportation Management Solutions, (UK)	Dave Holladay Owner

5.2 Bike racks

A substantial market for bike racks was indirectly created following the above-mentioned federal programmes (Transportation Enhancements and Congestion Mitigation and Air Quality Improvement (CMAQ) programmes). Transit authorities recognised the potential to obtain funding to invest in operations that could improve service, and, ultimately, revenues.

As bike racks were at an early development stage, some transit authorities attempted to manufacture their own racks, with varying degrees of success, whereas others put out their requirements to competitive tender. Several bike rack manufacturers presented their products and only a few were successful on a large scale.

At the very beginning, the racks had to be 'retro-fitted' and were rudimentary in design, but served their purpose. As demand increased, bike rack suppliers were able to enhance the products, although the original design of the successful racks has not changed very much. New buses for fleet replacement are now being equipped with bike racks on the production line, as operators take advantage of capital cost subsidies provided from the FTA.

Bike racks come in different forms:

- rear mounted;
- front mounted;
- roof mounted;
- suspension mountings - where a bike hangs from a rack frame;
- rail mountings - where the bike sits on top of a rack frame.

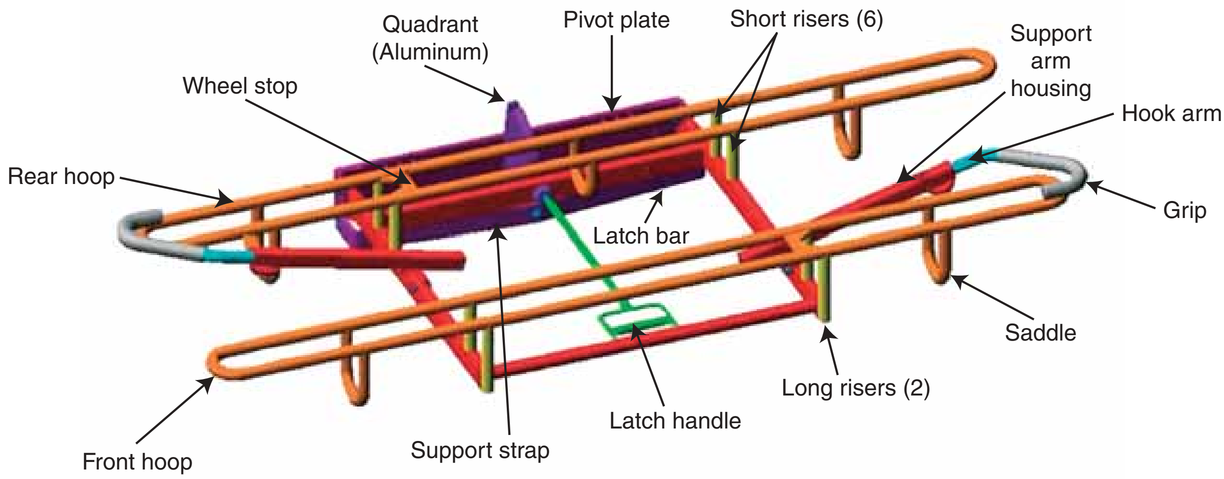
Today's market leader, so perceived both by the company itself and by some of the contacts TRL has consulted, is Sportworks.

5.2.2 Sportworks

Sportworks was founded in March 1990. Over the past nine years, Sportworks' customer base has grown significantly and the company now produces products such as Bike-Rack-for-Buses (commercial market) and Quick-load bike racks (consumer market).

The Bike-Rack-for-Buses product resulted out of an interest in making bicycling accessible to more people. One of Sportworks' first Bike-Rack-for-Buses customers was King County Metro (Metro) in Washington State, which includes the city of Seattle. Metro fitted over 1,200 buses with bike racks and paved the way for transit agencies across the country in increasing multi-modal opportunities for their riders. Customers range from single bus companies to those with as many as 2,000 buses e.g. Los Angeles County MTA.

The product:



Source: www.swnw.com

The Sportworks product in operation on the front of a Tri-Met bus:

Usage instructions, provided by Tri-Met:

Loading:

- Lower rack by squeezing the handle at the top.
- Lift bike up and place wheels in wheel trough.
- Raise the spring-loaded bar up over and onto the top of the front tire.

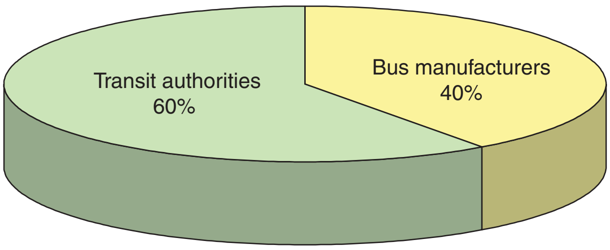
Unloading:

- Lower the spring-loaded bar off the front tire.
- Lift bike off the rack.

The rack allows only two bicycles at a time to be loaded, but these are independent of each other, meaning that they can be loaded or unloaded without moving a loaded bike to gain access.

Sportworks has sold over 30,000 bike racks since 1993. This represents a considerable market share of 43%, as there is a total of approximately 70,000 publicly owned buses in the USA. Sales elsewhere around the world have not followed the USA experience, except in Canada. Issues surrounding motor vehicle safety regulations have prevented sales growing in Australia and New Zealand, and Europe has reacted tentatively towards the benefits of bike racks as opposed to safety considerations.

Bike racks vary in price between $550.00 and $720.00 and are sold direct to bus manufacturers and transit authorities.



Estimated customer sales profile for Sportworks

Sportworks' sales average approximately 150 units per week and 8,000 units were sold during 2000. Bus replacement programmes help sales to remain buoyant, although the private market offers greater opportunity for sales.

5.2.3 Yakima

This company was founded in Yakima, Washington in the late seventies, beginning from small engineering roots. Yakima Industries made light utility racks for pruning equipment and the occasional canoe. Yakima then moved to Arcata, California, where rack systems were designed for outdoor recreation sports equipment.

Yakima racks have been fitted to TRI-MET buses. However, the Portland Transit Authority has made a decision to move to the Sportworks product, mainly owing to users preferring the Sportworks ease of use, and the operators' relative ease in obtaining parts.

The product:

The Yakima product on the front of a TRI-MET bus

Loading:

- Press down on the release lever by foot and lower the rack by hand.
- Lift bike up and place wheels in wheel trough. The clamp arm should be pointing toward the rear wheel.

- Raise the clamp arm and position the clamp so it grasps the bike frame.
- Turn the red handle clockwise (about six turns) with the handle straight out, until it's snug.
- Flip the handle over and press it flat.
- Snap the securement strap into place.

Unloading:

- Unsnap the securement strap.
- Pull the red handle straight out and twist counterclockwise until the clamp clears the bike frame.
- Lift bike off of the rack.

The procedure is more complex than that of the Sportworks product, suggesting that the rack is more cumbersome and time-consuming for users to operate.

The Yakima website does not actively market racks for buses and information provided to TRL suggests that the company has withdrawn from the bus market, focussing now on the private recreational market.

5.3 King County Department of Metropolitan Service

Over the past twenty years, Seattle has developed one of the largest and most successful 'bikes on buses' programmes in the USA. Before the funding programmes were available, Seattle Metro had implemented a bike rack programme during the late 1980s. The company developed its own racks, but offered a limited route service, which was primarily geared towards assisting passengers with bikes to cross a bridge that had no pedestrian walkway. The prototype racks were heavy to operate, the positioning of bikes was awkward and the racks had to be removed each time buses were washed. The programme lacked sufficient funds to be rolled out across the fleet. Spurred on by developments in federal policy and funding, Metro applied for a grant based on environmental and modal integration and received $1.3 million to support the bikes on buses programme.

Metro implemented a 3-4 month testing period covering operational activities and formed a bike rack committee which looked at issues such as:

- Operations (timetable impacts).
- Safety.
- Mechanics.
- Driving.
- Community group requirements.

Metro opted for front mounted racks because rear mounted racks attracted time penalties and other liabilities such as unacceptable safety or nuisance issues when bike riders or rollerbladers would hold on to the back of the bus while it was in motion. Despite the greater capacity of rear mounted racks, the liabilities were considered to outweigh the benefits of front-mounted racks.

Since 1994, all 1,200 Seattle Metro buses have been equipped with bike racks, as well as approximately 33% of the 700 vehicle vanpool fleet. The bus bike racks hold up to two bicycles (the vanpool racks from 2 to 4 bicycles). So far Seattle Metro has attracted approximately 500,000 bike rack users per year and now demand is becoming an issue, as bike rack availability cannot match demand. This program has been successful, in part, because of its large promotion and information campaigns, including brochures on the overall programme, and instructions on how to load and unload bikes from the racks. Information is also available over the Internet.

The programme has not been without a few problems. In its first year of bike rack operation, Seattle Metro experienced 35 accidents and 2 thefts (no other thefts have been reported since 1994). The accidents were due to drivers shunting other buses because the rack had not been folded flat when it was not in use. Drivers are trained to leave little headway (approximately one foot) between the bus in front when queuing at stops in the city centre. The bike rack protrudes at least three feet in front when unfolded. This was soon remedied by using high-visibility reflective masking tape around the edges to attract the driver's attention. A custom folding flag was to be developed, but the development costs outweighed the damage caused to racks. It is reported that since the rack's introduction, two pedestrians/passengers have been knocked over, receiving only light injury (bruising). This was apparently owing to their stepping in front of the bus without waiting for the bus to come to a full stop.

A further issue is that some passengers forget to take their bikes with them when they get off the bus. In response, Seattle Metro has developed educational programs and brochures to address 'lost and found', as well as safety issues for those removing and loading bicycles. There are also cases where people utilise the service to dispose of unwanted or stolen bikes. Metro has assisted in setting up a youth bike repair/spare parts programme, to assist in the disposal of unwanted bikes and to offset storage costs. Metro prepared for 5 bikes per month, but this has now reached 30 a month.

No extra charge is made for using the racks and no permit system is in place. The Seattle Metro experience has been referred to as a role model for developing bikes-on-buses programmes in other cities.

More details of the bike on buses programme are presented in Appendix C.

5.4 Tri-Met, Portland, Oregon

All Tri-Met's 800 buses are equipped with a front-mounted bike rack that can hold two bikes and use is not restricted by time or route. There are two types of bike racks on Tri-Met buses - the Sportworks rack and the Yakima rack. Tri-Met is in the process of replacing the Yakima racks with the newer, easy-to-use Sportworks racks. There are currently 600 buses equipped with the Sportworks product and the remaining 200 with the Yakima rack.

Tri-Met has 22,600 bike permit holders who have signed up during the seven years the programme has been running. Each permit costs $5 and has to be presented each time the rack is used. To receive a permit, the individual has to receive some basic bike rack training. However, Tri-Met intends eliminating the permit requirement in the near future as very few transit agencies require one anymore, and by removing bike permit requirements, the objectives of simplifying the use of the transit system and improving access can be met. Tri-Met still intends to provide training on using the racks on a voluntary basis at several locations throughout the region.

Tri-Met's marketing department was not aware of any accidents occurring involving the bike racks, but personal injury claims are handled by a different department, which was able to furnish the statistics presented in Table 5.4.1. These show records of a number of personal injury claims handled by the company over a five-year period. Significantly, although forty or fifty injuries a year have been noted, most of these do not appear to involve persons in front of the bus, and to judge from the cost of the claims, none can have been serious. It can also be seen that these data are tabulated together with statistics such as the number of bikes damaged by the rack.

Typically many users transfer from all bike, or all car journeys to bike-bus-bike and a survey of 3600 users in Portland identified 24% of journeys as completely new ones. A bike rack carries three bikes per day per vehicle on average, representing a 2-4% enhancement of passenger loading.

5.5 City of Phoenix Public Transit Department, Arizona

Following a forward-looking citizen planning consultation programme, which was conducted in 1990, a 'bikes on buses' requirement was recognised and a dedicated task force was established to investigate its viability. Phoenix referred to a project that started in San Diego, and was therefore able to avoid some of the teething troubles that had already been encountered there. It was decided to avoid rear-mounted racks owing to issues such as:

- Maintenance - engine access.
- Safety.
- Security.
- Time delays.
- Suspended racks - awkward unloading as each bike was dependent on the other.
- Damage to bike paint work.

As no suitable product was available on the market, Phoenix commissioned a custom-built front mounted rack. The bike racks were designed by a local company with input from the transit operator, government agency staff, and cyclists. The racks allow two bicycles to be loaded and unloaded without touching the other bicycle. They have proved durable and do not interfere with bus maintenance and cleaning, but once the current manufacturing contract expires, Phoenix will open up the supply of racks to competitive tender.

In 1991, the Phoenix Transit Department installed racks on the front of 40 city buses, each able to carry two bicycles. The pilot programme, financed by the City of Phoenix and Arizona Department of Transport, became popular quite quickly, with 5,500 riders using the racks in the six-month trial period. Later that year, the city matched local funds with Urbanised Area Formula program Federal Transit dollars to fit racks to all 400 buses in the fleet. The City of Phoenix Transit Department has estimated that approximately 35,000 passengers use the bike racks per month.

There have been bus-to-bus rear shunts and one known passenger injury (the bus rolled forward a few inches and inflicted bruising to the lower leg of a passenger who was unloading a bike). Theft of bicycles and damage to bicycles after falling off racks have also been recorded, and the timetable schedule has been impacted slightly. However, the Transit Agency regards this as relatively low risk or low cost in comparison to the benefits.

Table 5.4.1 Incidents involving buses with bicycle racks and their passengers (Tri-Met, Portland, Oregon, USA)

Fiscal year	*4301*	*4302*	*4310*	*4311*	*4320*	*4321*	*4322*	*4323*	*4324*	*4325*	*4330*	*4331*	*4332*	*Total*
Number of incidents														
FY97	40	1	0	0	0	0	0	0	0	3	1	0	0	45
FY98	51	2	0	0	0	0	0	0	2	2	1	0	0	58
FY99	54	4	0	0	1	0	0	0	0	0	0	0	0	59
FY00	43	1	0	0	0	0	0	0	1	0	0	0	0	45
FY01	3	0	0	0	0	0	0	0	0	0	0	0	0	3
Total	191	8	0	0	1	0	0	0	3	5	2	0	0	210
Costs of incidents USD														
FY97	312	0	0	0	0	0	0	0	0	0	0	0	0	312
FY98	3,061	0	0	0	0	0	0	0	10,215	0	0	0	0	13,276
FY99	1,680	15	0	0	0	0	0	0	0	0	0	0	0	1,695
FY00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FY01														
Total	6,508	15	0	0	0	0	0	0	10,215	0	0	0	0	16,739

Loss code definitions

4301 Bike falls off
4302 Bike damaged by rack
4310 Passenger on board injured by bike
4311 Passenger on board property damaged by bike
4320 Rack damaged, bus strikes fixed object
4321 Rack damaged, bus strikes object
4322 Rack damaged, leaving bus stop
4323 Rack damaged, entering bus stop
4324 Person injured, loading/unloading bike on rack
4325 Rack damaged, bus/other vehicle
4330 Bike taken from tbe bus rack
4331 Bike taken from MAX
4332 Bike taken from rack/locker

The diagram below shows how the bike racks differ in operation from those used by Tri-Met and Seattle Metro. This particular rack utilises a one-inch Velcro strap to secure the bikes in place. However, it should be noted that the climate in Arizona makes material choice an issue - plastic can melt and metal becomes hot to touch.

5.6 Other USA Experiences

5.6.1 Hawaii

All 500 buses of the Oahu Transit Services City transit fleet are equipped with bike racks and usage is popular. For example, in June 1998 there were approximately 12,000 bicycle loadings alone. Following its introduction, the 'Bikes-on-Buses' programme had a 156% growth rate and was the fastest growing ridership segment of the local market.

5.6.2 Santa Clara

Valley Transportation Authority provides services throughout Santa Clara County and partners with other systems for bus and rail service between Santa Clara County and the counties of Alameda, Santa Cruz, San Mateo and San Francisco. VTA operates approximately 520 buses serving a 326 square mile urban area. The 28.6-mile light rail system is operated with a fleet of 50 cars.

VTA has equipped all buses with exterior bike racks that can accommodate up to two bicycles. When the rack is filled, up to two bicycles will be allowed inside the bus subject to the driver's discretion and when passenger loads are light. Only express buses will not allow bicycles inside the vehicle.

5.7 Australian experience

Canberra's bus company, ACTION, was one of the first companies to test bike racks on buses in Australia, in February 1997. The racks were fitted to the front of two buses in a similar fashion to Seattle's Metro design and were tested off public roads. The racks could securely carry two bicycles of almost any style and were shown to be quick and easy to load and unload. Preliminary tests on the bicycle racks showed that the bicycles remained securely fixed in place, even under heavy braking. The racks would have been fitted to all 33 ACTION articulated buses, had the five-month trials been successful. The implementation cost would have been approximately Aus$45,000.00. TransAdelaide's Morphettville Depot also considered a similar venture.

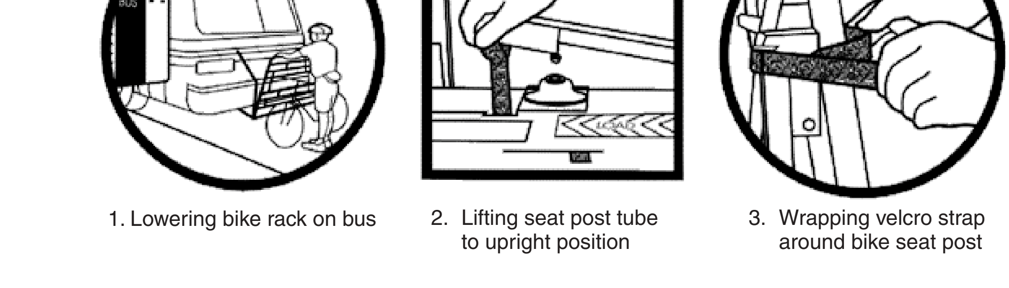
However, concerns by the Federal Office of Road Safety ended the bike rack trials and concept, as they were perceived to be too hazardous to be introduced on the front of buses, despite their increasing use in the USA. The bike rack trial was finally abandoned in late 1997, when advice from the Federal Office of Road Safety stated that 'bicycle racks fitted to the front of buses are not technically essential for the operation of the buses and are likely to increase the risk of bodily injury to persons e.g. pedestrians. They did not comply with clause 12, External and Internal Protrusions, of ADR42/03 and were not to be fitted.

5.8 Transportation Management Services, UK

There are already examples of bus and express coach services that have capacity to carry cycles using under-floor side or rear lockers. The 'bike in the boot' system is thought to lead to potential damage to bikes, or other luggage tangling together during loading. Special loading systems can delay a bus, especially on an intensive service, and special 'cyclists' buses' have not been recognised as a commercially sustainable option. So far, bike-bus services have been sponsored by grants.

An example of a bike-on-bus project was a rural application in Cumbria that involved a public and private partnership together with the support of a cycling group. Following the *Cycle Challenge* programme in mid 1995, a bid for the Cumbria Cycle Bus was successfully submitted to demonstrate the US style rack on a local bus service, a project running in parallel with an urban application in Brighton. Cumbria County Council was able to support the scheme, in principle, with staff time and resources of the Public Transport Unit, where appropriate. Additional funding came through the Rural Development Commission's (RDC) Rural Transport Development Fund. Stagecoach Cumberland provided its Carlisle workshops, together with a vehicle and staff time, to develop a system acceptable to the Department of Transport's Vehicle Inspectorate. A trial was then conducted to test the viability in Cumbria.

However, the Vehicle Inspectorate's concerns lead to the abandonment of the front mounted rack until further testing and research could be completed. To overcome this, the rack was fitted to the rear of a bus, and CCTV monitoring was installed for safety and security reasons. The trial continued, and demonstrated that this system was probably unsuitable for an intensive urban service, but was more applicable to a rural route.



1. Lowering bike rack on bus
2. Lifting seat post tube to upright position
3. Wrapping velcro strap around bike seat post

Training and awareness were supported through a video, which instructed users on how to use the racks, while promoting the concept. In addition, promotional leaflets were distributed around local information centres, shops and bike hirers.

The trial resulted in approximately one bike per day being loaded, without any reported operational problems. The low levels of use were probably a result of:

- Route choice.
- Time - cycling could match the bus time over the route's length.
- Unfamiliarity with the bike rack system.
- Loading times due to rear mounting.

It was recognised by cycling pressure groups that front mounted racks would provide the benefits of faster loading times, simpler and cheaper equipment, with easier and more direct observation of the loading and unloading by the drivers.

5.9 Review conclusions

The findings concerning bull-bars support the basic proposition that attaching an additional structure to the front of a vehicle will alter its structural dynamics, and may negate work carried out to improve vehicle front-end design to make it more pedestrian friendly. While not directly transferable to the concept of bicycle racks fitted to the fronts of buses, the evidence produced by bull bar studies does provide an indication of how cycle racks fitted to buses could increase the severity of pedestrian injuries. The particular shape and structural properties of the bicycle racks and indeed, the bicycles fitted to them will affect the impact forces sustained by a pedestrian during a collision.

There is currently a lack of evidence directly relating to the safety implications of folding front mounted bicycle racks on buses. However public concern about the impact of bull-bars on pedestrian injury severity will undoubtedly have implications for the likely success of introducing a folding front-mounted bicycle rack to buses.

In view of the apparent popularity of front-mounted cycle racks in the USA, it is worth noting that, not only were no independent studies found that might have raised concerns in the USA, but that, in any case, driving conditions there are very different from those in Europe. There are typically far fewer pedestrians in American towns and cities, and urban driving speeds are lower, while carriageways are wider. The bus routes operated by the companies consulted would generally include long stretches in very rural areas, where few, if any pedestrians would be encountered. These factors may be important when considering the overall safety of fitting cycle racks, given the acknowledged health and environmental benefits of cycling.

6 Vehicle and bike rack selection

Two types of vehicle, representative of those used within the United Kingdom were used: a coach type as used on inter urban routes in Scotland (to support the Scottish Office initiative, *Scottish Cycle Challenge*), and a modern city bus. It was proposed by DfT that the target vehicle for the coach operation should be an Alexander PS body on a Volvo B10 chassis. However this particular vehicle was ruled out due to the additional requirement that the vehicle should be representative of current design and be likely to be in service for the next 5 to 10 years.

The coach market is varied, ranging from the luxury touring coaches, which are unlikely to be used in inter urban service operation, to vehicles that have been re-bodied with a modern saloon on a chassis that is no longer in current manufacture. This created considerable problems when selecting the vehicle for testing. It was hoped that the vehicle might be hired from UK bus and coach service providers. Whilst in principle the operators were willing to consider this possibility, its feasibility was undermined by the need to take the vehicle out of service and subject it to a series of impacts followed by a rebuild. As a result the vehicles were hired from a major fleet hire company servicing the bus and coach industry.

The first of the vehicles selected was a bus, a Dennis Dart with a Plaxton Pointer body. This, being a comparatively new design, met the above requirement. It had the added advantage that the vehicle is currently being sold in British Columbia, where it is modified to enable bicycles to be carried on a front mounted rack of the same type selected for testing.

The coach selected was a Dennis Chassis with a Plaxton Javelin body. Whilst of a slightly older design than the bus, it is an example of a vehicle in current production and therefore will still be present in the UK fleet for the required time.

Due to the nature of the testing to be undertaken, the ability to source and replace body panels and windscreens was a major influence. Plaxton is a UK based company with a good supply chain and linked windscreen replacement service. This enabled headform tests on the screen to be carried out sequentially with the screen being replaced after each test with the minimum of delay. It should be noted that the vehicle selection was agreed with the customer prior to commencement of testing.

A search was made of European suppliers of bike racks. Only one supplier (Sportsworks Northwest, Inc) and one rack model was found. As this was the same rack and supplier being considered for the *Scottish Cycle Challenge* initiative this rack was selected for the test programme.

BSA West Coast 19" bicycles were acquired from Berkshire Cycle Company, Crowthorne, for use in the tests. They were fitted with alloy pedals.

Ideally it would have been better to test a range of different types of bicycle, however, within this test programme it was only possible to test one type. The main influence of different types of bicycle was thought to be weight, with heavier bicycles likely to cause higher loads on the pedestrian. Therefore, it was decided to select a model that was at the heavier end of the normal range in order to establish a reasonable indication of worst case.

7 Visual inspection of bike rack installation

The vehicles were fitted with the bike racks following the recommendations of the rack suppliers and the operational requirement to maintain a minimum ramp angle of eight degrees (the angle from the front wheel ground contact to the underside of the rack, when deployed to carry bicycles). This required the use of an additional purpose-made frame attached to the front cross-member of the vehicle chassis.

A technical officer from the Vehicle Inspectorate was then invited to TRL to offer an informal opinion of the selected vehicles with the front mounted bike racks fitted. The main concerns and observations that arose from this inspection are detailed as follows, with reference to the applicable Regulations:

7.1 The Road Vehicles (Construction and Use) Regulations 1986

7.1.1 Regulation 3

This Regulation specifies the maximum overall length of a vehicle, which is currently 12m. The overall length of the vehicle inspected was 12.7m with the rack deployed. A receptacle, which is not more than 2.5m in length, can be excluded. However, the bike rack was difficult to classify as a receptacle and, therefore, would need to be taken into account when determining the overall length. It was noted that there was no 'legal' definition of receptacle in the regulations, so further advice might be needed from DfT on this issue.

7.1.2 Regulation 13

Regulation 13 refers to a vehicle's turning circle. It was evident from the diagrams enclosed with the comments of the Technical Officer that the turning circle of the vehicle would be increased by the addition of a front mounted bicycle rack. However, this could not be assessed during the inspection.

7.1.3 Regulation 30

This requires the driver to have an adequate view of the road. On the vehicle inspected the bicycles intruded significantly into the area of windscreen that was swept by the windscreen wipers.

7.1.4 Regulation 100

This Regulation requires that a vehicle should be in such a condition that no danger is caused or likely to be caused to any persons. In the opinion of the Technical Officer the construction of the rack, and the inevitable protrusions from any bikes carried, had the potential to cause serious impact injuries to pedestrians and other road users. It was noted that even when the vehicle was stationary, there was every possibility that a pedestrian turning abruptly in front of the vehicle could be injured by those protrusions.

7.2 The Road Vehicles (Lighting) Regulations 1989

7.2.1 Schedules 2 and 7

These Schedules specify angles of visibility for front position lamps and direction indicators. The vehicle's front position lamps and direction indicators were completely obscured by the bicycles at certain specified angles. In addition, the bicycle wheels partially obscured and diminished the light from the headlamps. This might also have had an adverse effect on the headlamp dipped beam pattern, but the equipment was not available to check this during the visit. The bicycles were conventionally constructed with spoked wheels and without any attachments such as panniers. Obviously, consideration would have to be given to the carriage of any bicycles equipped with features that could obscure the lights more seriously.

7.2.2 Schedule 7

Schedule 7 also contains the positional requirements for direction indicators. The side repeater indicator must be within 2.6m of the front of a vehicle and in the opinion of the Technical Officer the vehicle's side repeaters were significantly further back than this when the rack was deployed. However, if the rack should eventually be classified as a receptacle, this objection might be countered.

7.2.3 Regulation 21

This Regulation refers to projecting loads or equipment. If the load or equipment extends beyond the front of the vehicle by more than 1m then additional lamps, and possibly white reflectors, are required. With the bicycles in position on the rack, the foremost bicycle certainly projected by more than 1m and therefore additional lamps would need to be considered, if the rack were not classified as a receptacle. Even if it were, the handlebars of the foremost bicycle extended beyond the leading edge of the rack, so the receptacle could not be said to enclose its contents entirely.

8 Pedestrian impact test of bus and bike rack

8.1 Methodology justification

Certain bicycle features, such as the ends of the handlebars, appear more likely to injure pedestrians in an impact and these are likely to produce very concentrated loads, which may increase the risk of local penetrative injuries or impalement. The head, chest and abdomen of pedestrians are considered the body regions most at risk of suffering life-threatening injuries from the bike rack and bikes, and the legs are likely to suffer injuries that result in long term disablement. However, the actual impact location, of specific parts of the bike and bike rack, on the body of a pedestrian, are dependent on the stature of the pedestrian and the position of the bikes and rack above the ground.

The use of cadavers or animal parts for assessing the injury risk of a bike rack arrangement was considered the best method, but this was rejected on ethical grounds.

Pedestrian dummies were also thought suitable for the assessment but, for both dummies and cadavers, the statures likely to be available would not cover the range required to assess all the features of interest on the rack and bikes. A pedestrian subsystem test method, drawn up by EEVC Working Groups 10 and 17 for testing cars, was also considered suitable for adapting to test the bikes and bike rack. The EEVC pedestrian test method makes use of individual impactors to represent the pedestrian. The impactors consist of an adult and child head, an adult upper leg and an adult complete leg with knee joint. However, for this use the EEVC test methods would provide limited data because the test tools are limited to those body parts most at risk of serious or fatal injury in a car impact, and do not include impactors to represent the abdomen and chest. Both pedestrian dummies, and the subsystem impactors, have limitations in their ability to assess the risk of penetrative or impalement injuries. However, the subsystem tests have the advantage over the other test methods in that they can be aimed at selected test points. It was therefore decided to use the subsystem child and adult headform and the adult legform impactors for the assessment of the bus and coach, with and without bike rack and bikes, in the test reported here. However, it should be noted that the relative heights of typical adult pedestrians and the handlebar and crossbar of the bicycles are such that these bicycle parts will most often contact the pedestrian's upper body in an accident. No suitable tool, apart from cadavers or animal parts, could be found for assessing the injury risk for these parts. As these methods were rejected on ethical grounds, only bio-mechanical data and engineering judgement could be used for assessing the injury risk for this most common impact (see later discussions of this in Section 10).

The philosophy of the test reported here was to test matched pairs of points on the vehicle with the bike rack and bikes fitted, and on the vehicle with no rack fitted. For each point tested with a headform on the bicycle, or on the stowed rack, a point was also chosen on the coach and bus for comparative purposes. The point on the vehicle was selected at the position that would have contacted the head of a pedestrian (of the same stature) had no rack been fitted. These comparative points are called 'paired points' in this report. The features of the bicycle and bike rack that were selected for headform testing were chosen on the grounds that they appeared dangerous and were at such a height that they could strike the heads of children and small adult pedestrians. The aim of the test was to represent a child or small adult pedestrian of such a stature that they would make a direct head impact with the test point. Because these features were at different heights each test will represent a pedestrian of a different stature. The test results for these points therefore represent a worst case accident for the head. However, as discussed earlier, pedestrians of normal adult stature are likely to wrap around or over the bicycle and hit their head on either the bus or the rear bicycle. In this case, the combination of possible head impact locations is almost infinite, depending on many variables including the pedestrian's stature. It was therefore decided to simply replicate a 50th percentile male for the 'wrapping around' case.

The front of the bike rack, when deployed for use, is similar in height and shape to a normal car bumper and is likely to strike the legs of pedestrians. The EEVC working group considered the need for both child and adult impactors to test the bumper area of cars. They concluded that only an adult impactor was necessary because their longer leg bones make them more vulnerable to injury from bumper impacts than children. Because of its similarity to a car bumper it was concluded that the legform impactor should be used to test the front of the bike rack.

The impact conditions required by the EEVC WG17 pedestrian test method are intended for cars, and are not necessarily appropriate for testing the taller and more upright fronts of the bike rack, and the bus and coach without bike rack. However, it was concluded that the test methods could be adapted to assess the bike rack and bus and coach front by making appropriate adjustments to the impact conditions. These adjustments should take into account the fatal accident data, the effects of vehicle shape and pedestrian stature, and the computer simulation results discussed above. Nevertheless, the limitations of the test method, in fully assessing the relative injury risk for the bike rack and the bus without the rack, should also be taken into account when considering the test results.

8.2 Test method

The EEVC WG17 test methods and subsystem impactors are intended to replicate a 40km/h car to pedestrian accident. It was therefore necessary to adapt the impact conditions for the tests to the bus and coach. For the legform the only change required was to reduce the test velocity from 40 to 30 km/h to reflect a velocity more typical for a bus accident, as found in the analysis of fatal bus accidents. For each vehicle and bike rack configuration the impact conditions for the headform tests were also adjusted to represent a 30km/h pedestrian accident. The methods used to derive the headform impact conditions for each shape are described in the following sections.

8.2.1. Headform impact conditions

The highest and lowest bike features selected for testing were the handlebar end and the pedal spindle respectively. For the bus, these were 1339mm and 700mm above the road. For the coach, they were 1362mm and 723mm above the road. For the rack stowed, the height of the top tubes and tops of the uprights was 1110mm for the bus and 1133 for the coach. These parts could strike the heads of children and the higher points could also strike the heads of short adults.

The EEVC pedestrian test methods use child and adult headform impactors of 2.5 and 4.8kg mass respectively, and the switch from the child to adult headform test occurs at a wrap around distance of 1500mm. For the front bicycle and the stowed rack, their near vertical shape means that the vertical dimensions to the test points can be regarded as approximately equal to the wrap round distance used in the EEVC method. Therefore, it would appear reasonable to test all the selected features with just the child head. However, when testing cars, the continuous nature of the bonnet structure means that the child and adult test requirements overlap to some extent. This provides a more gentle transition between the child and adult head requirements than would occur with the discontinuous features of the bicycles and rack. It was therefore decided to test the bicycle cross bar tube with both the child and adult head, and the handlebar end, with just the adult headforms.

The EEVC pedestrian test method requires child headform tests to start at a wrap around distance of 1000mm. This results in protection for pedestrians, other than the smallest child pedestrians, who might be involved in pedestrian accidents. However, in the case of the bike rack tests, a single case of a serious or fatal injury to a young child might be considered unacceptable. Therefore, it was decided to test features down to a height of 700mm, which should cover most children able to walk.

8.2.1.1 Pedestrians of such a stature to make head contact to front bicycle features or stowed rack

For pedestrians of such a stature to make head contact with the front bicycle or the stowed rack, these parts would effectively be a vertical face making near simultaneous contact along the length of the pedestrian's body. The vehicle front without a rack fitted is also near vertical and would also make near simultaneous contact with the pedestrian's body. Therefore, the velocity and direction of the head impact will be horizontal at the speed of the bus (30km/h). These conditions were used for the headform tests to the front bicycle (with and without a rear bicycle), the stowed rack and the matched points on the vehicle without the rack. The test results therefore represent the worst case where the head impact severity was not mitigated by a first contact to the shoulder or upper body.

- *Paired points:* Paired points on the bus and coach were found for each bike and stowed rack feature tested. The paired points for the tests to the coach and bus, without rack fitted, were chosen at positions where a pedestrian of the same stature would have been hit on the head by the coach or bus had the bike rack and bicycle(s) not been fitted. For the tests to the front bicycle features, the points were found by transferring each test point back onto the vehicle front face at the same vertical and horizontal location. For the headform tests to the stowed rack, the test positions were all found to lie close to the points selected to match front bicycle features. Therefore, the vehicle test points, which were a closest match to each stowed rack test, were selected as paired points.

8.2.1.2 Pedestrians of such a stature to make head contact to a single bicycle in the rear position in the rack

With a single bicycle in the rear position, the front edge of the bike rack would act in a similar manner to a car's front bumper, causing the pedestrian to fold over the rack. Ideally, a series of mathematical simulations, with the pedestrian's stature and lateral position adjusted iteratively to achieve head impact with each chosen test feature, would be the best method of determining the head impact conditions for the headform tests. However, a simulation study of this size was not practical within this test programme. It was therefore decided to make a pragmatic decision on headform direction and velocity. For the child headform tests, the EEVC child headform impact angle of 50 degrees to the horizontal, and the 30km/h-bus impact speed, were used. The stature likely to result in an adult pedestrian making head contact with the crossbar or handlebar end would be less than the 50th percentile male stature mathematically simulated. Nevertheless, estimates of the direction and velocity of the head impact were made from these simulation results for each vehicle, with one bicycle in the rear position. These estimates were made by taking the head velocity and direction relative to the vehicle at the moment that the head passed above the bike features. The estimates were used for the adult headform tests.

- *Paired points:* Specific tests to the vehicles without a rack, to exactly match the rear bicycle tests, were not carried out. Instead, approximate paired points were selected from the tests to match front bicycle features. The approximate paired points for the tests without a rack fitted, were chosen at positions where a standing pedestrian (of such a stature to have wrapped around and hit the rear bicycle feature tested) would have been hit on the head by the coach or bus.

8.2.1.3 Fiftieth percentile male adult pedestrians

The results of the mathematical simulations were used to select the impact conditions for the 50th percentile male folding over the bike rack and hitting his head on the front of the vehicle. The horizontal and vertical velocities of the head were combined with the vehicle velocity. This was done in order to identify the head velocity and direction relative to the vehicle, and the height of the head impact on the vehicle. These head impact conditions were found for both the bus and coach fitted with the bike rack, carrying bicycles in the three possible configurations (two bicycles, one bicycle in the front position or one bicycle in the rear position). The conditions were used for the headform tests to the vehicle.

As before, for the 50th percentile male, the vehicle front without a rack fitted had a near vertical shape, so it would make nearly simultaneous contact along the length of the pedestrian's body. Therefore, the velocity and direction of the head impact would be horizontal at the speed of the vehicle (30km/h). These conditions were used for the headform tests to the front of the vehicle without a rack.

To aid the comparison of these tests, with and without a bike rack, which all resulted in a head impact to the windscreen, all the tests were carried out at the same lateral position on the windscreen. The lateral position on the bus was selected to avoid the apparently weak middle joint between the two halves. The windscreens were replaced after each test.

- *Paired point:* One paired point was selected on each vehicle at the standing head height of a 50th percentile male and at the same lateral location used for the folding over the rack tests.

8.2.1.4 Fiftieth percentile legform to rack feature:
The vehicle with and without a bike rack fitted was also tested with the legform impactor. This impactor represents an average 50th percentile adult male. The front edge of the rack, or the bumper of the vehicle without a rack, would make first contact with the legs of a pedestrian. Therefore, the impact direction would be horizontal at the speed of the vehicle (30 km/h). These impact conditions were used for the legform tests. The height of the impact on the vehicle, relative to the knee of the impactor, is dictated by the requirement for the foot of the impactor to be at ground level. Two lateral positions were selected for the legform tests to the rack when deployed and stowed. These were on the centreline and at the junction of the main members (the fore/aft members when deployed).

- *Paired point:* Two paired points were selected on each vehicle at the same lateral locations as used in the tests to the deployed and stowed racks.

8.2.2 Test equipment

The impactors were propelled into the selected targets using the TRL Pedestrian Impact Propulsion System (PIPS) facility, which was specifically designed to meet the requirements of the EEVC test methods. The EEVC test methods, as specified by EEVC WG10 Report (1994), with the adaptations on impact conditions described above, were followed for the headform and legform tests.

Both the child and adult EEVC headform impactors used were of a truncated spherical shape, with the flat on the rear face. As required by the EEVC test methods, the headforms were fitted with a silicon rubber skin to represent the flesh covering of a human head. The headform impactors were fitted with a tri-axial accelerometer located at the centre of the sphere. This was used to measure the acceleration of the headform throughout the impact. The Head Injury Criterion (HIC 15) value was then calculated from the acceleration time history for each test, using the specified algorithm.

The legform consists of a tibia and femur section joined by a mechanical knee joint. The two leg sections are made to match the length, mass and weight distribution of a 50th percentile male. The knee joint properties are such that it will deform laterally in bending and shearing at similar forces to those found with the human knee loaded laterally. The knee joint is instrumented to record the knee bending, shear displacements, and the lateral acceleration of the leg, at a point just below the knee.

The correct performance of the head and legform impactors was confirmed by carrying out the appropriate EEVC certification procedures at the specified times.

8.2.3 Headform and legform tests

The vehicle was set at its normal ride height for both the marking up of impact points and the test firings. The impactors, vehicle, propulsion system and data acquisition equipment were soaked (i.e. equilibrated) at a temperature in the range of 16°C to 24°C for at least 2 hours prior to the testing.

As recommended in the legform user instructions, a new piece of foam flesh was fitted to the legform before each test, and the outer neoprene skin was refitted over the new foam.

The headform and legform skins were examined for damage before each test and replaced as necessary.

Pre- and post-test photographs were taken of most tests. Notes were made of the damage to the impactor flesh and impacted parts. In the case of the impacts to the bicycles on the first vehicle tested (which was the bus), possible or definite interactions between the bicycle and the vehicle were also noted. This information was used so that these tests to the bicycles could be repeated on the coach and the effects of interactions with the coach could be found. For all other bicycle features, where no interactions occurred, the bus results were considered to be typical for the rack mounted securely on any vehicle, as the deformation was limited to just the bicycles and did not involve the bike rack.

Legform test: The PIPS gun was aligned with the impact position on the vehicle or bike rack so that the legform was fired at the required velocity in a direction parallel to the vehicle centreline. The height of the legform at release was set to take account of the action of gravity while the legform was in free flight to ensure that the 'foot' end of the impactor was at ground level on impact with the vehicle. A shallow slot in the floor was used to prevent unwanted foot to ground interactions during the impact with the vehicle, as required by the EEVC method.

Headform test: The PIPS gun was aligned so that the headform would impact the test point on the vehicle, bike rack, or bicycle feature. The headforms were propelled in a direction parallel to the vehicle centreline. The angle, velocity and angle of the propulsion system were set to achieve the required headform impact conditions selected for each site. These propulsion system settings included an allowance for the effects of gravity in the free flight phase.

8.2.4 Injury parameters

8.2.4.1 General
Any damage to the impactor skin and flesh caused by the nature of the impact with the bike rack, the bicycles, or the vehicle front were recorded so that some indication of the penetrative injury risk could be deduced.

8.2.4.2 Limits
The test results were compared with the EEVC WG17 acceptance criteria for each test tool in order to obtain a measure of the likely injury severity. The WG17 acceptance criteria are given as follows:

Headform HIC not to exceed	1000
Legform shear displacement not to exceed	± 6 mm
Legform bending angle not to exceed	± 15 degrees
Legform acceleration not to exceed	± 150 g

Vehicles that meet these criteria are unlikely, in impacts with pedestrians, to cause life threatening head injury or disabling leg injuries at impact velocities up to that used in the tests. For cars, the EEVC test methods represent an accident at 40 km/h. However, as described above, the test speed for this programme of tests to the bus and coach has been reduced to represent an accident at 30 km/h.

9 Test results

Figure 9.1.1 is a scale drawing of the coach with the bike rack fitted with two bicycles in place. Figure 9.2.1 is a scale drawing of the bus, without the bike rack fitted, marked with the paired test points. Figures 9.2.2 to 9.2.4 give the test locations on the bicycles and the stowed rack for all the combinations on the bus. Similarly, Figure 9.3.1 is a scale drawing of the coach, without the bike rack fitted, marked with the paired test points, and Figures 9.3.2 to 9.3.4 give the test locations on the bicycles and the stowed rack for all the combinations on the coach. The results of the tests to the front of the bus and coach are compared in the following figures and tables with the results of the bus and coach fitted with a bike rack in the following configurations.

As described in the method section the points were first determined on the bikes and bike racks and then an equivalent 'paired' point was determined on the coach and bus. The tests were carried out on each vehicle in five phases. The first two digits of each test site, given in the tables, identifies the test phase:

P1 = Test to the vehicle front without rack fitted.

P2 = Test to the rack and to a front bicycle, with a second bicycle in the rear position, with the rack attached to the vehicle.

P3 = Test to a front bicycle, with no bicycle in the rear position, with the rack attached to the vehicle.

P4 = Test to a rear bicycle, with no bicycle in the front position, with the rack attached to the vehicle.

P5 = Test to the rack in the stowed position, with the rack attached to the vehicle.

The test results are given below in the following sections, both in tables and graphically. The figures include some duplication of test results for comparative purposes. This is because many of the test points on the vehicle were suitable for pairing with different combinations of bicycle and bike rack tests. For the child tests to the front of two bicycles in the rack on the bus, no interactions were seen between either the front and back bicycle or between the bicycles and the vehicle front. It was therefore concluded that repeating these tests for the coach and one bicycle in the front was unnecessary, as it would give the same results. Therefore, these results have been duplicated in the tables for comparison purposes.

9.1 Bus with bike racks fitted

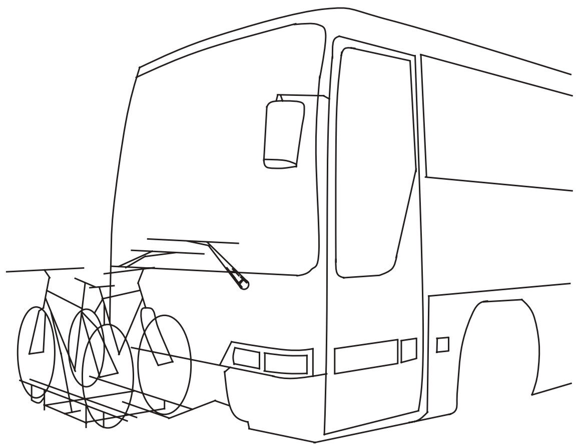


Figure 9.1.1 Typical vehicle and bike rack arrangement (coach with bike rack and two bicycles)

9.2 Test Points for bus

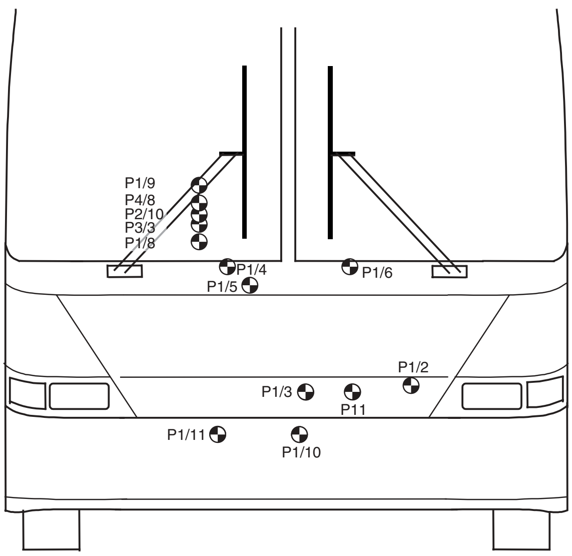


Figure 9.2.1 Impact points on bus

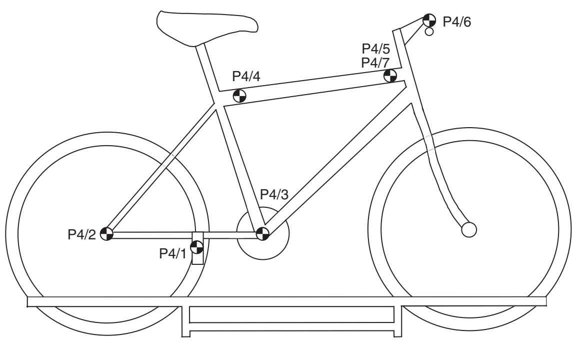


Figure 9.2.2 Impact points on bike in front of rack

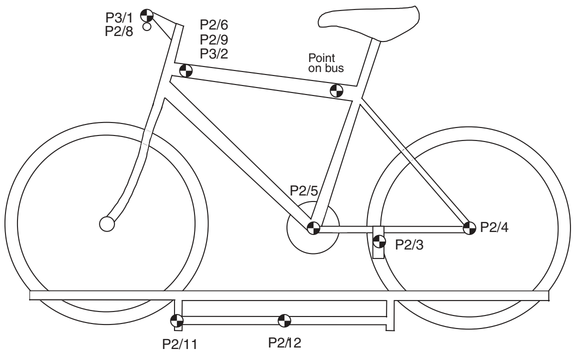


Figure 9.2.3 Impact points on bike in rear of rack

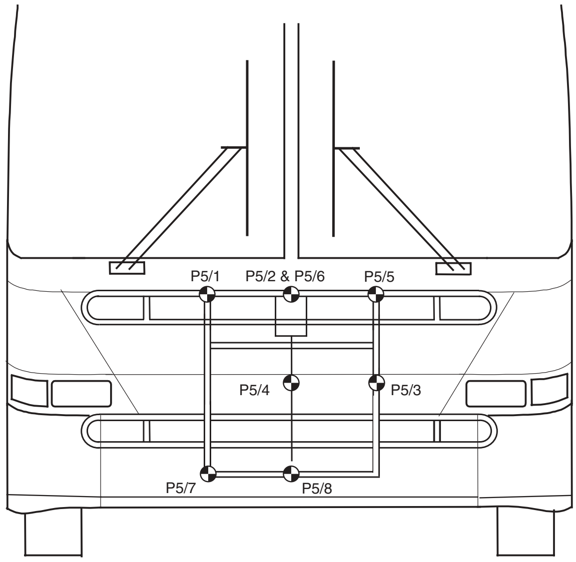


Figure 9.2.4 Impact points on bus with rack stowed

9.3 Test points for coach

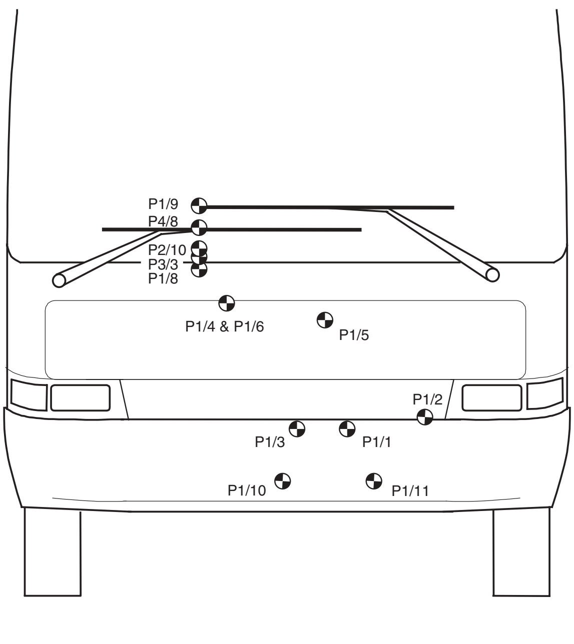


Figure 9.3.1 Impact points on coach

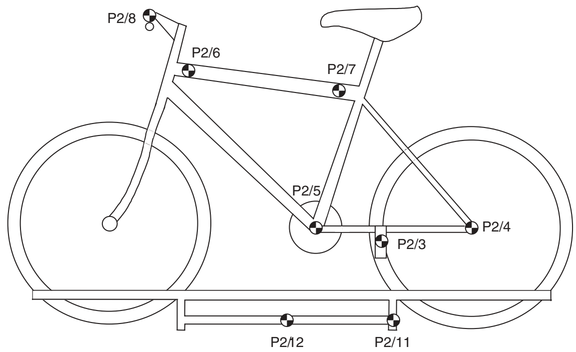


Figure 9.3.2 Impact points on bike in front of rack on coach

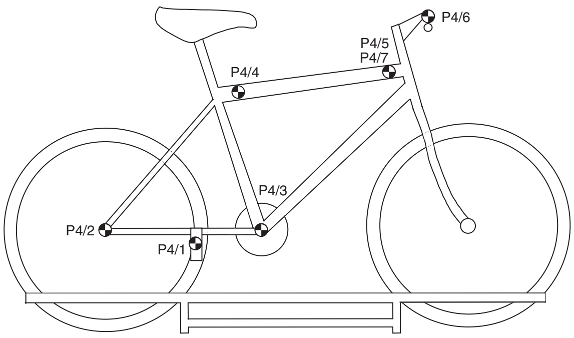


Figure 9.3.3 Impact points on bike in rear of rack on coach

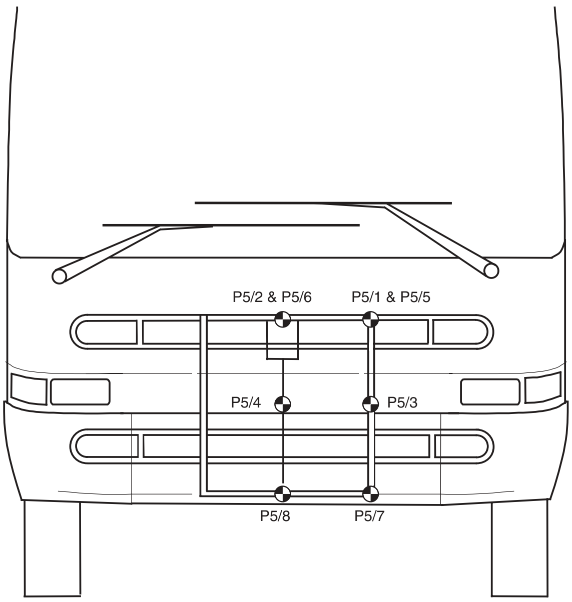


Figure 9.3.4 Impact points on coach with rack in stowed position

9.4 Tables comparing the bus results with and without bike rack fitted (note: shaded areas indicate safe criteria exceeded)

Table 9.4.1 Comparison of results for bus with and without bike rack with two bikes on rack

Impactor – Description of point		*Impact conditions*				*Test results*				
		Bike impact		*Bus impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On bus*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Bus*	*Unit*	*Bike*	*Bus/rack*
Child head Centre of pedal, front bike (P2/3).	Lower part of front cover (P1/1).	8.96	0	9.00	0	833	325	HIC 15	Pedal and crank bent.	Minor signs of flexing.
Child head Rear wheel nut, front bike (P2/4).	Lower part of front cover (P1/2).	8.90	0	9.10	0	6981	835	HIC 15	Hole in head skin.	Minor signs of flexing.
Child head Bottom bracket, front bike (P2/5).	Lower part of front cover (P1/3).	8.91	0	8.86	0	5174	223	HIC 15	Chain came off.	Access panel damaged.
Child head Crossbar (handlebar end), front bike (P2/6).	Just below wind screen (P1/4).	8.93	0	9.01	0	3595	934	HIC 15	Bent bike frame.	Protruding body saved windscreen.
Child head Crossbar (saddle end), front bike(P2/7).	Front below windscreen (P1/5).	8.92	0	8.96	0	2324	2101	HIC 15	Bent bike frame.	Minor signs of flexing.
Adult head 'short' End of handlebar, front bike (P2/8).	Windscreen(P1/8).	8.86	0	8.68	0	134	926	HIC 15	Bent handle bar and slide in its clamp.	Windscreen broken.
Adult head 'short' Crossbar (handlebar end), front bike (P2/9).	Just below windscreen(P1/6).	8.7	0	8.86	0	1025	831	HIC 15	Bent bike frame, brakes and forks.	Protruding body work split but windscreen OK.
Adult head 50th % Hitting bus windscreen after folding over rack (P2/10).	Windscreen(P1/9).	12.2	32.1	9.05	0	314	1438	HIC 15	Windscreen broken.	Windscreen broken.
Legform 50th % Rack leading edge (Offside end) (P2/11) .	Lower bumper 310mm offside of centre(P1/11).	8.86	0	9.0	0	-393 -5.75 21.5	-58 -0.95 2.2	Tib accel. (g) Knee shear (mm) Knee bending (°)	Bent rack.	Bumper broken.
Legform 50th % Rack leading edge (Centre)(P2/12).	Lower bumper centre(P1/10).	8.89	0	8.86	0	-152 -4.30 17.2	-99 -1.47 6.1	Tib accel. (g) Knee shear (mm) Knee bending (°)	Bent rack.	Bumper broken.

Table 9.4.2 Comparison of calculated peak headform contact force for bus with and without bike rack with two bikes on rack

Headform		*Description of point*		*Peak headform resultant acceleration (g)*		*Calculated contact force (kN)*	
Type	*Mass(kg)*	*On bike*	*On bus*	*Bike*	*Bus*	*Bike*	*Bus*
Child	2.5	Centre of pedal, front bike (P2/3)	Lower part of front cover (P1/1)	187	126	4.6	3.1
Child	2.5	Rear wheel nut, front bike (P2/4)	Lower part of front cover (P1/2)	861	129	21.1	3.2
Child	2.5	Bottom bracket, front bike (P2/5)	Lower part of front cover (P1/3)	602	121	14.8	3.0
Child	2.5	Crossbar (handlebar end), front bike (P2/6)	Windscreen (P1/4)	372	113	9.1	2.8
Child	2.5	Crossbar (saddle end), front bike (P2/7)	Front below windscreen (P1/5)	352	166	8.6	4.1
Adult	4.8	End of handlebar, front bike (P2/8)	Windscreen (P1/8)	166	207	7.8	9.7
Adult	4.8	Crossbar (handlebar end), front bike (P2/9)	Windscreen (P1/6)	203	154	9.6	7.2
Adult	4.8	Hitting bus windscreen after folding over rack (P2/10)	Windscreen (P1/9)	224	230	10.6	10.8

Table 9.4.3 Comparison of results for bus with and without bike rack with one bike on front

Impactor		*Impact conditions*				*Test results*				
Description of point		*Bike impact*		*Bus impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On bus*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Bus*	*Unit*	*Bike*	*Bus/rack*
Adult head 'short' End of handlebar (P3/1).	Windscreen(P1/8).	8.86	0	8.68	0	120	926	HIC 15		Windscreen broken.
Adult head 'short' Crossbar (Handlebar end) (P3/2).	Windscreen(P1/6).	9.15	0	8.86	0	1137	831	HIC 15	Bent bike frame and brakes.	Protruding bodywork split but windscreen OK
Adult head 50^{th} % Hitting bus windscreen after folding over rack (P3/3).	Windscreen(P1/9).	13.19	25	9.05	0	1166	1438	HIC 15	Windscreen broken.	Windscreen broken.

Table 9.4.4 Comparison of results for bus with and without bike rack with one bike in the rear position on rack and none in the front position

Impactor		*Impact conditions*				*Test results*				
Description of point		*Bike impact*		*Bus impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On bus*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Bus*	*Unit*	*Bike*	*Bus/rack*
Child head Centre of pedal, rear bike (P4/1).	Lower part of front cover (P1/2).	8.85	50	9.10	0	114	835	HIC 15	Chain came off.	Minor signs of flexing.
Child head Rear wheel nut, rear bike (P4/2).	Lower part of front cover (P1/2).	8.95	50	9.10	0	1790	835	HIC 15	Bent chain set and spilt head skin.	Minor signs of flexing.
Child head Bottom bracket, rear bike (P4/3).	Lower part of front cover (P1/2).	8.85	50	9.10	0	527	835	HIC 15	Bent spindle.	Minor signs of flexing.
Child head Crossbar (saddle end), rear bike (P4/4).	Just below windscreen (P1/4).	8.91	50	9.01	0	2749	934	HIC 15	Bent bike frame.	Protruding bodywork saved windscreen.
Child head Crossbar (handlebar end), rear bike (P4/5).	Just below windscreen (P1/4).	8.95	50	9.01	0	6	934	HIC 15	Bent bike frame.	Protruding bodywork saved windscreen.
Adult head 'short' End of handle bar, rear bike (P4/6).	Windscreen (P1/8).	8.95	4	8.68	0	626	926	HIC 15	Bent handlebar and split skin.	Windscreen broken.
Adult head 'short' Crossbar (handlebar end), rear bike (P4/7).	Windscreen (P1/8).	10.73	0	8.88	0	1352	926	HIC 15	Bent bike frame and handlebars.	Windscreen broken.
Adult head 50th % Hitting bus windscreen after folding over rack (P4/8).	Windscreen (P1/9).	12.72	18	9.05	0	849	1438	HIC 15	Windscreen broken.	Windscreen broken.

Table 9.4.5 Comparison of results for bus with and without bike rack with the rack in the stowed position

Impactor		Impact conditions				Test results				
Description of point		*Bike impact*		*Bus impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On bus*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Bus*	*Unit*	*Bike*	*Bus/rack*
Child head Top of offside member of rack intersection with tube end (P5/1).	Front below windscreen(P1/5).	9.15	0	8.96	0	930	2101	HIC 15	Cut head skin and bent rack.	Minor signs of flexing.
Child head Centre of rack top cross member(P5/2).	Front below windscreen (P1/5).	9.15	0	8.96	0	1788	2101	HIC 15	Dented rack.	Minor signs of flexing.
Child head Halfway up nearside member of rack(P5/3).	Lower part of front cover (P1/1).	8.94	0	9	0	6356	325	HIC 15		Minor signs of flexing.
Child head Halfway up centre of rack(P5/4).	Lower part of front cover (P1/3).	8.93	0	8.86	0	587	223	HIC 15	Bent rack.	Access panel damaged.
Adult head Centre of rack top cross member (P5/5).	Windscreen (P1/6).	9.02	0	8.86	0	720	831	HIC 15	Broken cap on rack.	Protruding bodywork split but windscreen OK.
Adult head Top of nearside member of rack intersection with tube (P5/6).	Windscreen (P1/6).	8.86	0	8.86	0	635	831	HIC 15	Bent rack.	Protruding bodywork split but windscreen OK.
Legform Offside of rack leading edge(P5/7).	Bumper offside (P1/11).	8.65	0	9.0	0	-174 -5.36 6.2	-58 -0.95 2.2	Tib accel. (g) Knee shear (mm) Knee bending (°)	Hole in leg skin and foam flesh.	Bumper broken.
Legform Centre of rack leading edge (P5/8).	Bumper centre (P1/10).	8.91	0	8.86	0	-157 5.70 20.3	-99 -1.47 6.1	Tib Accel. (g) Knee shear (mm) Knee bending (°)	Bent rack.	Bumper broken.

9.5 Tables comparing the coach results with and without bike rack fitted

Table 9.5.1 Comparison of results for coach with and without bike rack with two bikes on rack

Impactor — *Description of point*		*Impact conditions*				*Test results*				
		Bike impact		*Coach impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On coach*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Coach*	*Unit*	*Bike*	*Coach/rack*
Child head Centre of pedal, front bike * (P2/3).	Top of bumper (P1/1).	8.96	0	8.74	0	833	1842	HIC 15	Pedal and crank bent.	Minor signs of flexing.
Child head Rear wheel nut, front bike * (P2/4).	On bottom of access panel, just above bumper (P1/2).	8.90	0	9.94	0	6981	3856	HIC 15	Hole in head skin.	Rear frame torn from access cover (v. weak attachment).
Child head Bottom bracket, front bike * (P2/5).	Top of bumper (P1/3).	8.91	0	8.81	0	5174	1319	HIC 15	Chain came off.	Minor signs of flexing.
Child head Crossbar (handlebar end), front bike * (P2/6).	Top of access cover (P1/4).	8.93	0	8.76	0	3595	911	HIC 15	Bent bike frame.	Rear frame torn from access cover (v. weak attachment).
Child head Crossbar (saddle end), front bike * (P2/7).	Towards top of access cover (P1/5).	8.92	0	8.87	0	2324	701	HIC 15	Bent bike frame.	Rear frame torn from access cover (v. weak attachment).
Adult head 'short' End of handlebar, front bike (P2/8).	Just below windscreen (P1/8).	8.86	0	8.95	0	226.8	2139	HIC 15	Bent handle bar.	Protruding bodywork saved windscreen.
Adult head 'short' Crossbar (handlebar end), front bike (P2/9).	Top of access cover (P1/6).	8.86	0	8.85	0	898.3	441	HIC 15	Bent bike frame, brakes and forks.	Rear frame torn from access cover (v. weak attachment).
Adult head 50th % Hitting coach windscreen after folding over rack (P2/10).	Windscreen (P1/9).	12.60	28	8.92	0	2258	918	HIC 15	Windscreen broken.	Windscreen broken contact with dashboard.
Legform 50th % Rack leading edge (nearside end) (P2/11).	Nearside of bumper (P1/11).	9.0	0	9.00	0	-130 7.94 16.5	-88 3.55 -1.0	Tib accel. (g) Knee shear (mm) Knee bending (°)	Bent rack.	Minor signs of flexing.
Legform 50th % Rack leading edge (Centre)(P2/12).	Centre of bumper (P1/10).	8.87	0	9.00	0	-91 7.84 16.4	-51 2.00 -1.5	Tib accel. (g) Knee shear (mm) Knee bending (°)	Bent rack in 2 places.	Bumper cracked and bent bike.

* *Indicates results from the P2 tests with rack on the Bus used because the performance for these points would be the same for both vehicles. This is because there was no interaction between the bikes and the vehicle front.*

Table 9.5.2 Comparison of calculated peak headform contact force for coach with and without bike rack with two bikes on rack

Headform		*Description of point*		*Peak headform resultant acceleration (g)*		*Calculated contact force (kN)*	
Type	*Mass(kg)*	*On bike*	*On coach*	*Bike*	*Coach*	*Bike*	*Coach*
Child	2.5	Centre of pedal, front bike * (P2/3)	Top of bumper (P1/1)	187	236	4.6	5.8
Child	2.5	Rear wheel nut, front bike * (P2/4)	Bottom of access cover (P1/2)	861	326	21.1	8.0
Child	2.5	Bottom bracket, front bike * (P2/5)	Top of bumper (P1/3)	602	258	14.8	6.3
Child	2.5	Crossbar (handlebar end), front bike * (P2/6)	Top of access cover (P1/4)	372	158	9.1	3.9
Child	2.5	Crossbar (saddle end), front bike * (P2/7)	Towards top of access cover (P1/5)	352	152	8.6	3.7
Adult	4.8	End of handlebar, front bike (P2/8)	Just below windscreen (P1/8)	167	392	7.9	18.5
Adult	4.8	Crossbar (handlebar end), front bike (P2/9)	Top of access cover (P1/6)	200	102	9.4	4.8
Adult	4.8	Hitting coach windscreen after folding over rack (P2/10)	Windscreen (P1/9)	242	246	11.4	11.6

* *Indicates results from the P2 tests with rack on the bus used because the performance for these points would be the same for both vehicles. This is because there was no interaction between the bikes and the vehicle front.*

Table 9.5.3 Comparison of results for coach with and without bike rack with one bike on front

Impactor		*Impact conditions*				*Test results*				
Description of point		*Bike impact*		*Coach impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On coach*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Coach*	*Unit*	*Bike*	*Coach/rack*
Adult head 'short' End of handlebar * (P3/1).	Just below base of windscreen(P1/8).	8.86	0	8.95	0	120	2139	HIC 15		Protruding bodywork saved windscreen.
Adult head 'short' Crossbar (Handlebar end) * (P3/2).	Top of access cover(P1/6).	9.15	0	8.85	0	1137	441	HIC 15	Bent bike frame and brakes.	Rear frame torn from access cover (v.weak attachment).
Adult head 50th % Hitting coach windscreen after folding over rack * (P3/3).	Windscreen(P1/9).	13.19	25	8.92	0	1166	918	HIC 15	Windscreen broken.	Windscreen broken.

* *Indicates results from the P3 tests with rack on the Bus used because the performance for these points would be the same for both vehicles. This is because there was no interaction between the bikes and the vehicle front.*

Table 9.5.4 Comparison of results for coach with and without bike rack with one bike in the rear position on rack and none in the front position

Impactor		*Impact conditions*				*Test results*				
Description of point		*Bike impact*		*Coach impact*		*Impactor results*			*Damage to impactor and target*	
On bike	*On bus*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Coach*	*Unit*	*Bike*	*Coach/rack*
Child head Centre of pedal, rear bike * (P4/1).	On bottom of access panel, just above bumper (P1/2).	8.85	50	8.87	0	114	701	HIC 15	Chain came off.	Rear frame torn from access cover (v. weak attachment).
Child head Rear wheel nut, rear bike * (P4/2).	Towards top of access panel (P1/5).	8.95	50	8.87	0	1790	701	HIC 15	Bent chain set and spilt head skin.	Rear frame torn from access cover (v. weak attachment).
Child head Bottom bracket, rear bike * (P4/3).	Towards top of access panel (P1/5).	8.85	50	8.87	0	527	701	HIC 15	Bent spindle.	Rear frame torn from access cover (v. weak attachment).
Child head Crossbar (saddle end), rear bike * (P4/4).	n/a	8.91	50	n/a	n/a	2749	n/a	HIC 15	Bent bike frame.	n/a
Child head Crossbar (handlebar end), rear bike * (P4/5).	n/a	8.95	50	n/a	n/a	6	n/a	HIC 15	Bent bike frame.	n/a
Adult head 'short' End of handle bar, rear bike (P4/6).	Windscreen (P1/8).	8.92	4	8.95	0	293	2139	HIC 15	Bent handlebar and split skin.	Protruding bodywork saved windscreen.
Adult head 'short' Crossbar (handlebar end), rear bike (P4/7).	Windscreen (P1/9).	10.67	0	8.86	0	1470	898	HIC 15	Bent bike frame and handlebars.	Windscreen broken.
Adult head 50^{th} % Hitting coach windscreen after folding over rack (P4/8).	Windscreen (P1/9).	13.23	21	8.86	0	1255	898	HIC 15	Windscreen broken.	Windscreen broken.

* *Indicates results from the P4 tests with rack on the Bus used because the performance for these points would be the same for both vehicles. This is because there was no interaction between the bikes and the vehicle front.*

Table 9.5.5 Comparison of results for coach with and without bike rack with the rack in the stowed position

Impactor		Impact conditions				Test results				
Description of point		Bike impact		Coach impact		Impactor results			Damage to impactor and target	
On bike	*On bus*	*Speed(m/s)*	*Angle(°)*	*Speed(m/s)*	*Angle(°)*	*Bike*	*Coach*	*Unit*	*Bike*	*Coach/rack*
Child head Top of offside member of rack intersection with tube end (P5/1).	Towards top of access cover (P1/5).	8.95	0	8.87	0	3184	701	HIC 15	Rack contacted coach, sprung back with no damage.	Rear frame torn from access cover (v. weak attachment).
Child head Centre of rack top cross member(P5/2).	Towards top of access cover (P1/5).	8.87	0	8.87	0	1445	701	HIC 15	Rack bent and contacted coach.	Rear frame torn from access cover (v. weak attachment).
Child head Halfway up nearside member of rack(P5/3).	Top of bumper (P1/1).	8.87	0	8.74	0	5479	1842	HIC 15	Rack contacted coach, sprung back with no damage.	Minor signs of flexing.
Child head Halfway up centre of rack(P5/4).	Top of bumper (P1/3).	8.8	0	8.1	0	687	1319	HIC 15	Rack release handle broken and bent.	Minor signs of flexing.
Adult head Centre of rack top cross member (P5/5).	Top of access cover (P1/6).	8.82	0	8.85	0	189	441	HIC 15	Rack bent and contacted coach.	Rear frame torn from access cover (v. weak attachment).
Adult head Top of nearside member of rack intersection with tube (P5/6).	Top of access cover (P1/6).	8.76	0	8.85	0	471	441	HIC 15	Rack bent and contacted coach.	Rear frame torn from access cover (v. weak attachment).
Legform Rack leading edge, nearside (P5/7).	Bumper nearside (P1/11).	8.87	0	9.00	0	-156 7.59 17.7	-88 3.55 -1.0	Tib accel. (g) Knee shear (mm) Knee bending (°)	Rack bent and contacted.	Minor signs of flexing coach.
Legform Rack leading edge, centre (P5/8).	Bumper centre (P1/10).	8.87	0	9.00	0	-234. -7.61 34.8	-51 2.00 -1.5	Tib accel. (g) Knee shear (mm) Knee bending (°)	Rack bent.	Bumper cracked.

9.6 Chart series comparing the bus and coach results with and without bike rack fitted

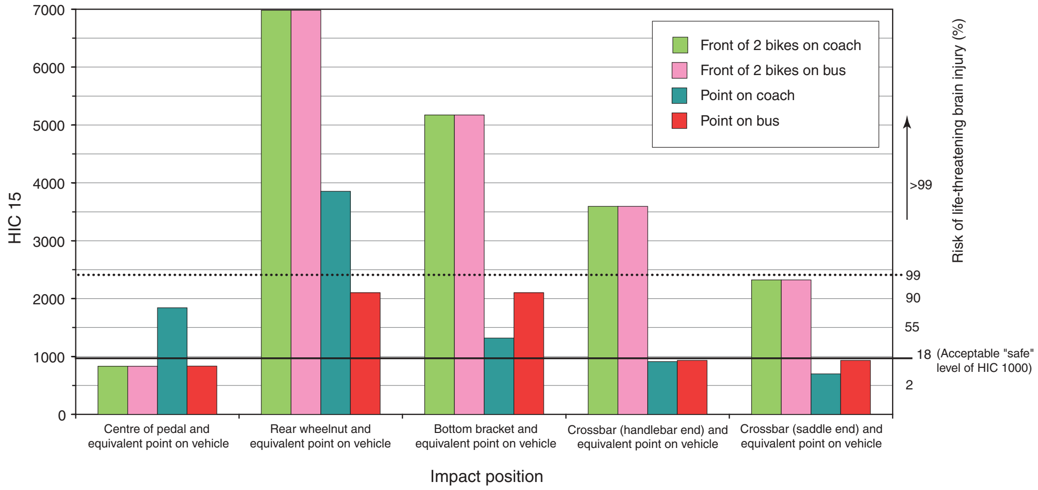


Figure 9.6.1 Child head impactor results for bicycles on rack compared with bus and coach

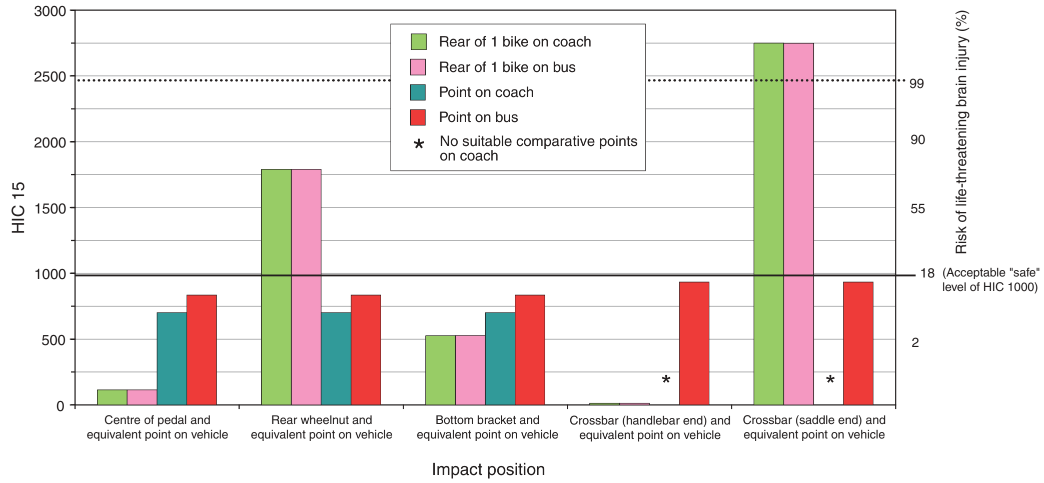


Figure 9.6.2 Child head impactor results for one bicycle in rear position on rack compared with bus and coach

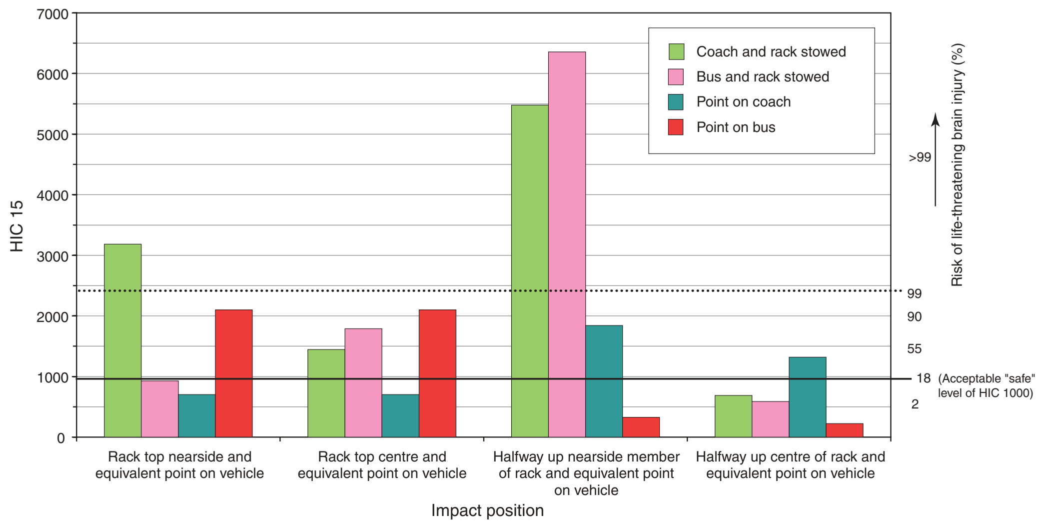


Figure 9.6.3 Child head impactor results for stowed racks compared with bus and coach

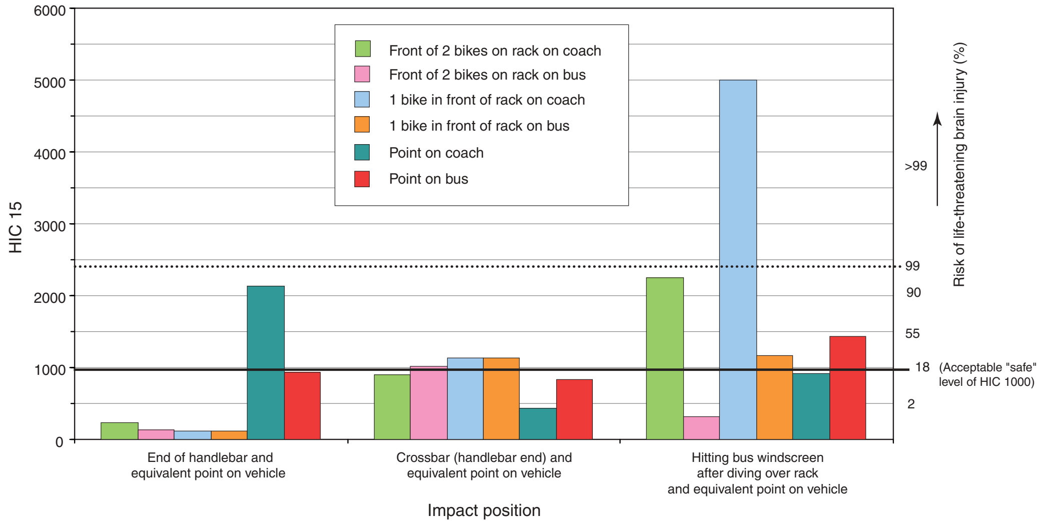


Figure 9.6.4 Adult head impactor results for bicycles on racks compared with bus and coach

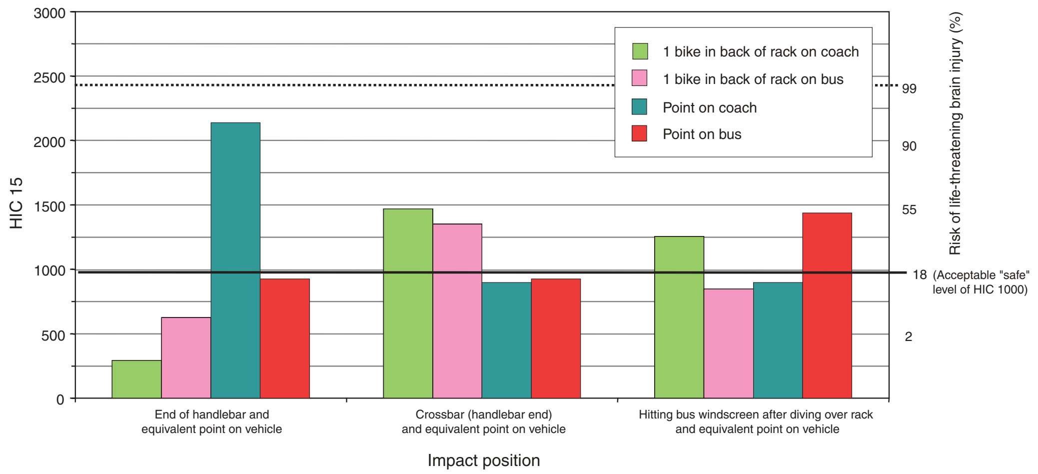


Figure 9.6.5 Adult head impactor results for one bicycle in rear position on rack compared with bus and coach

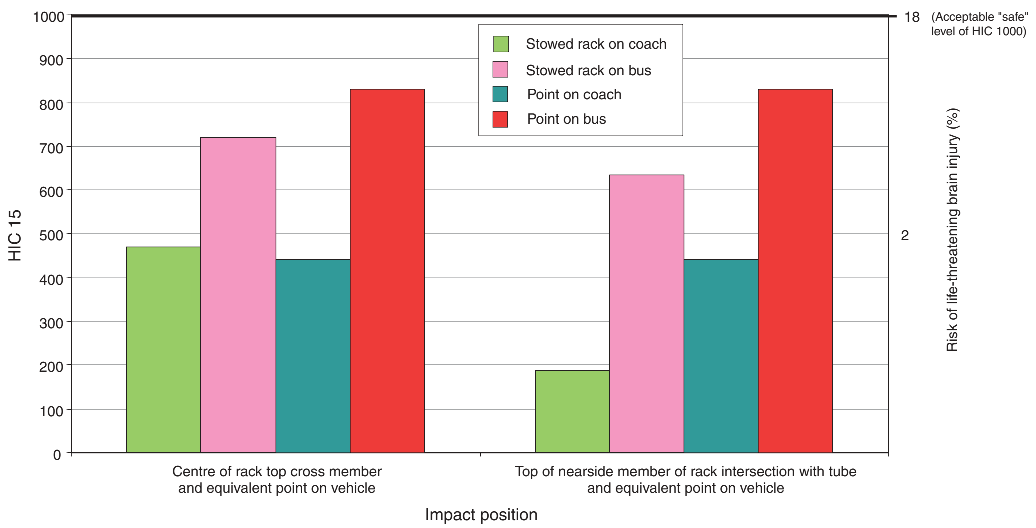


Figure 9.6.6 Adult head impactor results for stowed racks compared with bus and coach

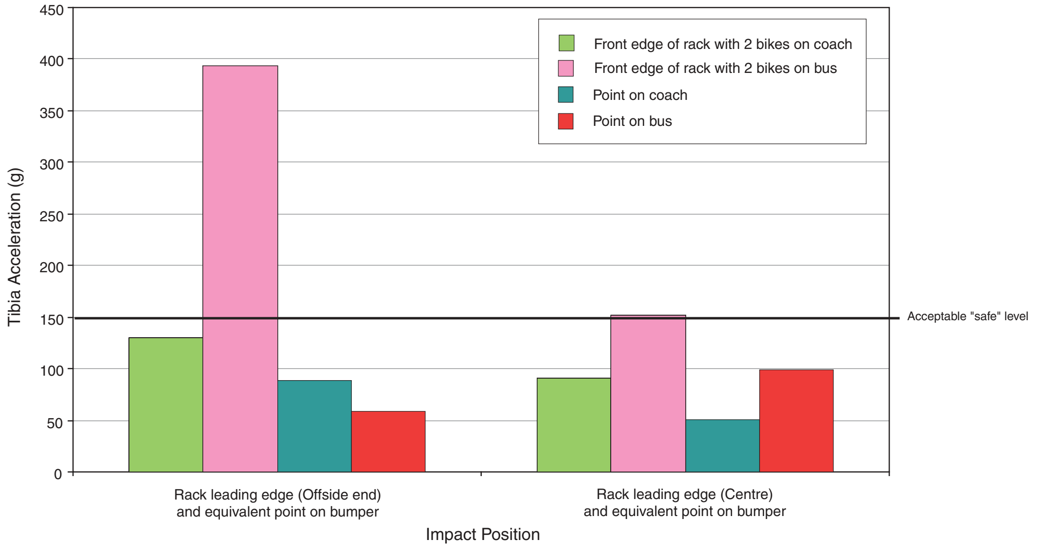


Figure 9.6.7 Legform tests tibia accelerations for front of rack with bicycles compared with bus and coach

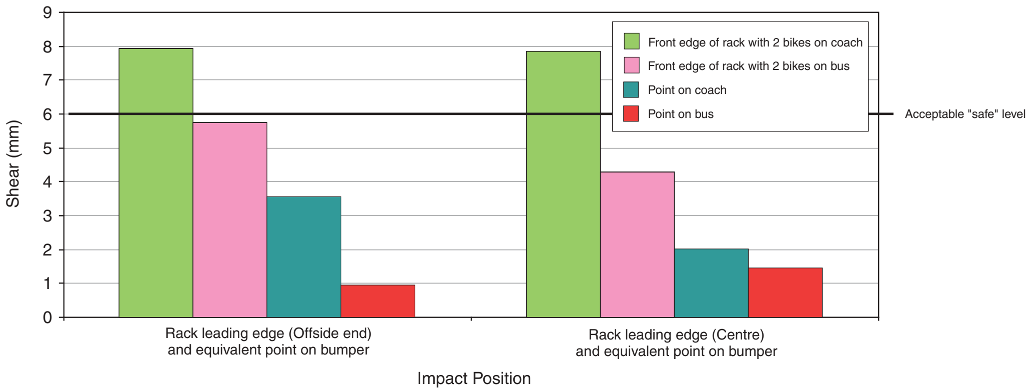


Figure 9.6.8 Legform tests knee shear for front of rack with bicycles compared with bus and coach

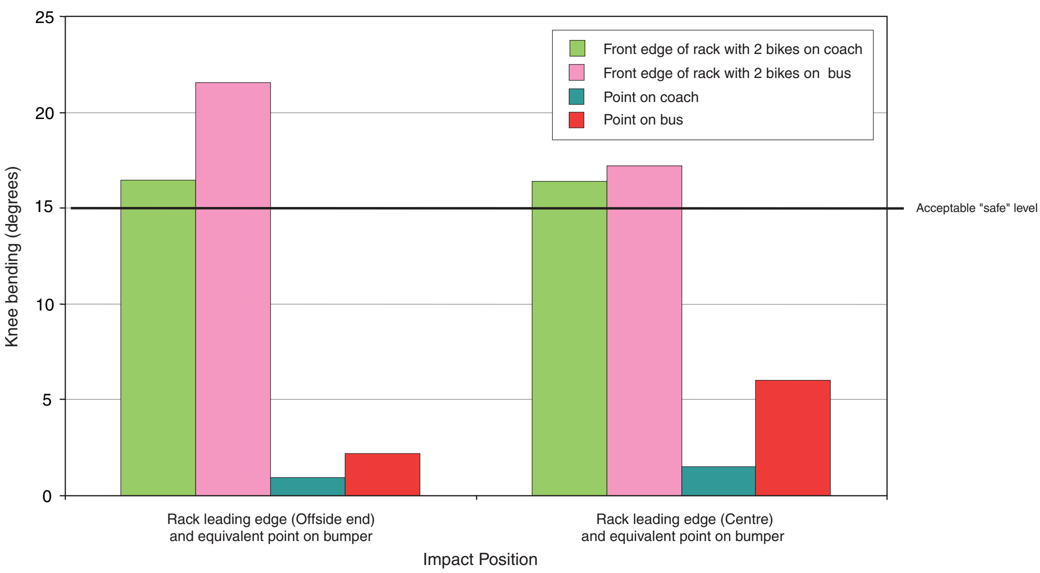


Figure 9.6.9 Legform tests knee bending for front of rack with bicycles compared with bus and coach

9.7 Results of low speed push tests on the bicycles

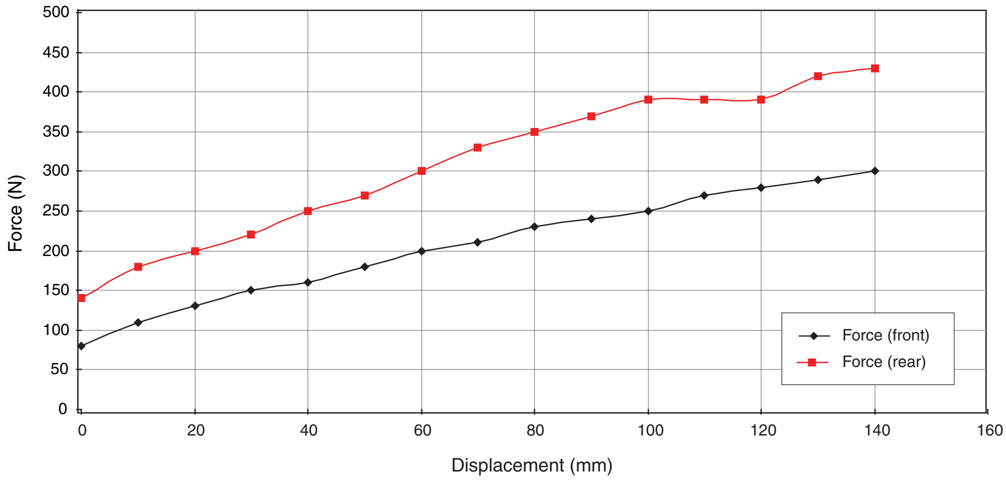


Figure 9.7.1 Low speed push tests on front and rear bikes in rack: force versus rearward displacement

10 Discussion

As described in the test methods, matched pairs of points were tested on the bike rack (fitted to the vehicle) with bicycles in place and on the vehicle front with no rack fitted. These matched points were selected so that the test results, with and without bike rack fitted, could be compared directly i.e. the results would be equivalently indicative of with- and without-rack accidents. As can be seen from the tables and figures of results, the fitting of the bike rack, with a bicycle in the front position, dramatically increases the risk of life threatening child head injuries and long term disabling adult leg injuries over the unequipped vehicles. However, before these results are considered in detail, the limitations of the test method to assess the injury risk should be taken into account.

10.1 Limitations of the tests used for this application

The EEVC pedestrian test methods make use of sub-systems impactors to represent the significant phases of a car-to-pedestrian impact. These are the bumper contact with the legs; the bonnet leading contact with the upper leg or pelvis; and the head contact with the bonnet surface. The method of selecting the test site and specifying the impact conditions takes account of the interactions between the vehicle and the pedestrian and assumes that the vehicle has pedestrian friendly deformation characteristics. However, the impact conditions for bikes on buses are very different. Some of these differences have been taken into account by the adaptations made to the EEVC methods for the test to the bike racks reported here. The limitations of the test methods for this application are discussed further in the following sections. However, it should also be noted that the overlapping contacts of pedestrian's body parts in a full pedestrian impact could cause more significant interactions between the bicycles and the vehicle front, which would increase the injury risk.

10.1.1 Headform impactors

The headform impactor and its acceptance criteria of Head Injury Criterion (HIC) have been developed to predict the risk of skull fractures that are likely to result in life threatening brain injury. The HIC criterion was developed from biomechanical data where the impact to the skull was reasonably evenly distributed (flat of forehead impacted into a flat plate). For car structures likely to meet the HIC criteria, the headform contact is also very likely to be evenly distributed as the bonnet deforms. Therefore, a rigid impactor such as the EEVC used will give a good indication of the risk of skull fractures for such cars. However, the type of bike rack and bikes tested here have a number of forward facing, small, tubular or solid protrusions, many of which would form the first point of contact. Many of these features had little or no surrounding structure and would not provide a well distributed headform contact area. Instead, when these impact a pedestrian's head, they produce very localised stresses in the skull. If the contact force is high, this is likely to result in local shattering or penetration of the skull, which the rigid impactor will not fully indicate. A headform sensitive to stress concentrations (i.e. a frangible headform) would be better able to respond to different stress distributions. However, these headforms have many practical problems and so were not used in this test programme.

Tables 9.4.2 and 9.5.2 compare the calculated headform contact force for the bicycle and bus and coach tests. These show that the headform contact force is between 7.8 and 21.1 kN if the lower force for the pedal is ignored. Biomechanical data are available on the force required to cause local skull fractures, (Allsop, 1993). However, the data summarised by Allsop come from different experimental set-ups and cover different areas of the skull. Typically, the impact forces causing a skull fracture range from 3.5 to 5.8 kN for an impacted area of 6.45 cm^2. None of the features tested on the bicycle are likely to exceed this contact area and many would be smaller. Caution should be used when comparing the calculated contact forces for the headform with those found in biomechanical experiments. Nevertheless, the contact forces for the headform to bicycle tests are so high that it can be concluded that the risk of this type of injury would be very high. Therefore, as all of the bicycle features tested have a small area of contact, serious local head injuries (skull fractures) are likely to occur. This would even be the case when the HIC values recorded with the rigid headform are within the normally accepted criterion of HIC 1000.

The authors have noted that the part of the handlebar grip that covers the end of the handlebar tube is frequently damaged in use, leaving the end of the tube relatively unprotected. The small cross-sectional area of a tube such as this would be very likely to cause penetration injuries when striking a pedestrian. For a head to handlebar impact, even if the impact speed is so low that it does not cause a skull fracture, the handlebar end is still likely to cause serious injuries to the flesh if the handlebar grip fails to protect the end of the tube. This is because the area of the end of the handlebar tube is only about 1 cm^2 and the inertia of the mass of the bicycle means that the contact force will be high. The handlebar grips on the new bicycles tested successfully protected the end of the handlebar tube in the headform tests. However, it is very likely that damaged or less tough handlebar grips might fail in real life. The end of a tube, forming part of the bike rack, was tested with the child headform. This tube was very similar in presentation and dimensions to a handlebar end and was fitted with a tough plastic plug, which failed during the headform test. The consequences of this failure can be seen in Figure 10.1.1. It is anticipated that similar flesh injuries to a pedestrian would often occur in real life if the metal tube of the handlebar end makes contact with the head, even in low speed impacts.

Figure 10.1.1 Headform impactor flesh damage from impact to the end of a tube forming part of the bike rack due to failure of plastic plug

10.1.2 Limitations for pedestrian chest and abdomen

The height of the handlebar end and the crossbar tube mean that these parts are likely to make contact with the head or upper body of many pedestrians. The EEVC test procedures require the bonnet leading edge to be tested with the upper legform impactor. The mass of this impactor is adjusted according to the vehicle shape so that it can represent the adult femur and pelvis. For most shapes of car, the height of the bonnet leading edge is such that it will contact the adult femur or pelvis, but for larger vehicles and smaller pedestrians, the bonnet edge would hit the pedestrian above the pelvis. For tests to cars where the outer surface tends to be continuous and homogeneous, the upper legform test is considered to require protection approximately appropriate for the abdomen and chest. However, the outputs from the impactor are not considered suitable to determine the injury risk above the pelvis if the contact is localised. The upper legform impactor could have been used to test the handlebar end and the crossbar tubes of the bicycles in the rack. Nevertheless, as the handlebar end and the crossbar of the bicycles will make a very small local contact on the pedestrian it was concluded that this test would provide little information on the injury risk to the upper body, hence its exclusion from the test programme.

The push tests on the bicycles in the rack used to provide information for the computer simulations showed that initially that they could be pushed back (slowly) with a relatively small force, see Chart 9.7.1. However, the force seen in a pedestrian impact would be considerably larger owing to the inertia of the mass of the bicycle. The effect of the bicycle's inertia can be seen in the calculated instantaneous contact force for the headform test given in Tables 9.4.2 and 9.5.2. Although these instantaneous contact forces for the head cannot be directly equated to those for other body parts, they are likely to be similar. Some simple estimates of the pedestrian body parts at risk of injury can be made from the relative heights of the bicycle and the pedestrian body areas. The range of heights for pedestrian body parts and the height of the bicycle cross bar and handlebar end are given in Table 10.1.2.

It can be seen from Table 10.1.2 that the crossbar and handlebar end will normally contact adults on their upper body. The cross bar is likely to make line contact with the side of the chest or abdomen. Biomechanical data for these body parts are not available for this type of local loading. However, for the chest and abdomen, the criteria for more distributed loading are a function of penetration depth and penetration speed. The available biomechanical data are summarised by Cavanaugh (Cavanaugh, 1993) and Rouhana (Rouhana, 1993) for the chest and abdomen respectively. From these data, an informed estimate has been made of the potential injury risk. Further, it has been concluded that impacts of the crossbar to the side of the chest may well cause serious injuries in many cases and possible fatal injuries in a few cases. For the abdomen, it was concluded that impacts of the cross bar to the lower ribs, or to the gap between the ribs and the bony pelvis, is very likely to cause serious injuries in most cases. Moreover, there is a significant risk of fatal injuries even in low speed impacts.

Table 10.1.2 Height of pedestrians and bicycle features

Heights of pedestrian body parts (mm)						Height bicycle feature (mm)					
						Crossbar					
*Standing eye height **		*Chest height * Ψ*		*Height of iliac crest * #*		*C/b handlebar end*		*C/b saddle end*		*Handlebar end*	
5th % female	*95th % male*	*5th % female*	*95th % male*	*5th % female*	*95th % male*	*Bus*	*Coach*	*Bus*	*Coach*	*Bus*	*Coach*
1434	1776	1105	1390	876	1118	1183	1206	1118	1141	1339	1362

* *An allowance of 25mm has been made for shoes (Peebles and Norris, 1998).*

Ψ *Measured to the nipple in male subjects and to the bust point in a female subject (Peebles and Norris, 1998).*

\# *The iliac crest is the highest bony part of the pelvis at the side, the unprotected area of the abdomen starts above this (derived from Gaebler, 1964).*

Table 10.1.2 also shows that the height of the end of the handle bar is likely to make contact with the chest of most adult pedestrians, and with the neck of smaller females and some children. Biomechanical data are not available for this type of 'spear-like' contact. However, the handlebar end presents a small cross-section area, particularly if the handlebar grip is damaged. This, combined with the high inertia of the moving bicycle, makes the risk of 'spear-like' impalement injuries very high. Obviously there is a very high risk of fatal injuries in these impalement cases, but this will only occur when the pedestrian's lateral position coincides with the handlebar end.

10.1.3 Summary of the limitations of the tests used for this application

From the above discussion the following can be concluded:

Many parts of the bicycles and the rack have a small contact area, which will cause concentrated loads in a pedestrian accident. Some, such as the handlebar end, the crank, and the wheel spindles, are likely to cause very concentrated loads. These will have the following effects on the headform tests, both reported here and on the real life injuries likely to be found in accidents:

- The headform test to the bike rack and bikes will under report the risk of life threatening head injuries, particularly for the parts likely to cause very concentrated loads.
- The handlebar end is likely to cause flesh wounds to the head even in low speed impacts.
- The height of the crossbar means that it is likely to strike the side of the upper body of most adults and taller child pedestrians. This type of impact has not been assessed in the tests reported here. The biomechanical data available are not directly applicable to this type of contact. However, it has been concluded that contact with the chest may well cause serious injuries in many cases, and possible fatal injuries in a few cases. Contact with the abdomen is thought to be highly likely to cause serious injuries in most cases. Furthermore, there is a significant risk of fatal injuries even in low speed impacts.
- The height of the handle bar end means that as well as striking the head of short adults and some children, it will more frequently strike the adult pedestrian in the side of the chest, and the shorter adult female and taller child in the neck. Biomechanical data are not available for this type of 'spear-like' contact. However, if the lateral position of the pedestrian coincides with the handlebar end, it has been concluded that the risk of 'spear-like' impalement injuries is very high. Impalement will only occur when the pedestrian's lateral position coincides with the handlebar end. Nevertheless, there is a very high risk of fatal injuries in these impalement cases.

10.2 Comparison of bus and coach with and without bike rack fitted

The fitting of a bike rack to a bus or coach will modify an impacted pedestrian's kinematics. The extra length will also change the energy absorbing characteristics of the vehicle front. It is possible that some of these changes may have the potential to improve some aspects of the pedestrian impact in an accident. However, the functional requirements of the vehicle and the rack, and the nature of bicycle construction, make it more likely that the majority of these effects will be detrimental.

It should be noted that many of the points tested on the bike with the child and adult headforms would only hit a pedestrian's head in the most unfortunate combination of pedestrian stature and lateral position. Therefore, the number of such accidents is likely to be small. Nevertheless, the very high values recorded in the child test suggest that such a combination will often result in a fatal injury.

10.2.1 Bus and coach with two bikes

For the unequipped bus, the risk of life threatening child head injuries at four out of the five locations tested is well below 20%; the one exception gives a risk of 90%. Whereas, with impacts on the front bike on the rack, the risk of life threatening child head injuries is over 95% at four out of five locations, although the remaining point tested gave a risk of only 7%. However, it is anticipated that this location, on the pedal, may well have given worse results had the bike tested been fitted with a steel pedal crank rather than an aluminium one. For the coach, the child head injury risk for the front bicycle on the rack was again worse than that for the unequipped coach, although the coach front gave worse results than found with the bus front. Taking into account the effects of concentrated loads on the head, caused by the rack and bicycles, these results show that the bike rack and two bikes on the front of the bus or the coach dramatically increase the probability of causing fatal head injuries to a child.

The adult headform tests to the bicycle handlebar and crossbar of the front bicycle gave better results than the child headform tests. The main reason for this difference is thought to be the headform mass of 4.8 and 2.5 kg for the adult and child respectively. For the heavier adult headform, the overall results are similar for the bike rack and the vehicle. For the unequipped bus and coach, one adult headform test out of three exceeded the head criteria of HIC 1000. The tests to the front bike on both vehicles exceeded the head criteria for the same one out of three tests.

The adult headform tests to the handlebar end on the bus and coach are both well below the head HIC 1000 criteria and the results for the tests to the crossbar are both close to those criteria. However, again the effects of concentrated loads on the head may well mean that these parts are more dangerous than these results imply.

For the test replicating an adult 50th percentile male folded over the rack and hitting his head on the bus windscreen, the HIC value was substantially reduced in comparison to the HIC of an adult head impacting the bus screen horizontally, as it would if no rack were fitted. However, for the coach, the opposite was true. As the head impact velocity was increased in the folding over case, the result for the bus may seem surprising. However, the outcome is dependent on both the initial brittle failure of the glass and the secondary crushing of the glass and stretching of the interlayer. The behaviour of the windscreen can be unpredictable and will be affected by the normal impact velocity, the windscreen shape and the distance from the impact point to the edge of the glass. The position of the impact on the windscreen was very different for with- and without-rack tests. Also, the windscreen shape and distance to the edge of the glass were very different between the bus with its split-screen and the coach with its one-piece windscreen.

The concerns regarding both the significant injury risk for the chest and abdomen from the line loading from the crossbar, and the high risk of fatal impalement injuries for the chest and the neck from the handlebar end, are summarised in Section 10.1.3. It should be noted that the majority of pedestrians, because of their stature, will be hit on the upper body by the bicycle crossbar, handlebar etc, see Table 10.1.2 (in Section 10.1.2). Therefore, these injury risks should also be taken into account when considering the safety of fitting bike racks to buses.

The legform impactor has three separate criteria intended to prevent serious lower leg bone fractures and knee joint injuries with a high risk of long term disablement. However, it is necessary to meet all three criteria to protect against these injuries. The legform impactor results show that the rack leading edge will cause serious injury to pedestrians' legs at this speed, whereas an impact with the bus or coach alone produced good results well within the criteria. It can therefore be concluded that the front edge of the deployed rack dramatically increases the risk of leg injury for adults. Accident data for cars show that the legs of children are less likely than adults to suffer serious injuries (Lawrence *et al.*, 1991). However, the results for the strongest part of the rack, adjacent to the fore/aft members, exceed the adult requirements by such a large margin that it is thought very likely that this part will also seriously injure the legs of children.

10.2.2 Bus and coach with one bike on front of rack

The adult headform tests to the front bicycle handlebar end and cross bar, with two bicycles in the rack, were the most likely to push the first bike into the second. These tests were, therefore, repeated with only one bicycle in the front position. The tests with one and two bicycles in the rack gave very similar results. Therefore, it can be concluded that there was little or no interaction between the two bicycles, or between the bicycles and the vehicle front.

For the test replicating an adult 50th percentile male folded over the rack and hitting his head on the bus windscreen, the computer simulations showed a higher head impact velocity and shallower impact angle than for the two bicycle scenario. This was owing to the single bicycle folding back further and more easily than in the double bicycle arrangement. For the bus, although the HIC value increased over the two-bicycle situation, it was still slightly lower than that found in the test simulating an adult head impacting the bus screen horizontally, as it would if no rack were fitted. However, for the coach the opposite was true. The behaviour of the windscreen to head impacts has been discussed in the previous section and it is thought that the arguments also explain these test results.

10.2.3 Bus and coach with one bike on rear of rack

Caution should be used in interpreting the results of these headform test results. This is because the impact conditions were difficult to predict and those used in this test programme were selected somewhat pragmatically. This was in order to avoid the need for a very large programme of mathematical simulations to determine the head impact conditions. Points tested with the child headform on the front bicycles were also tested on the rear bicycle for consistency. However, as the rear bicycle was further away from the initial impact between the pedestrian's legs and the front edge of the rack, some of these child points might have been more appropriately tested with the adult headform. Nevertheless, these results do provide some indication of the safety with one bicycle in the rear position. Overall it can be seen that the headform results are improved in comparison with the results for the front bicycle. However, they are worse than the matched points on the vehicle.

No legform tests were carried out for this configuration. It is anticipated that they would be very similar to those found with two bicycles on the rack as the primary legform impact only involved the front edge of the rack and not the bicycles. Therefore, there would be a very high risk of serious child and adult leg injuries with one bicycle in the rear position.

10.2.4 Bus and coach with rack fitted in stowed position – No bikes

The child headform impactor results show that the rack has hard and soft points. Whilst some points gave acceptable HIC values, others gave extremely high values. When these are compared to the results for the bus with no rack it can be seen that the number of tests that pass and fail the Head Injury Criteria of no more than HIC 1000 are equal. However, the hard part on the rack gives a HIC of 6356, which compares with a worst HIC of 2101 on the bus. This suggests that this part on the rack would be much more likely than the bus to cause a fatal child head injury in an accident, at a speed lower than that used in these tests. For the coach, the child headform results show the rack to be worse than the coach front. Again, the hard parts of the rack were much worse than the worst point on the coach.

The adult headform tests show that the top of the rack gave very similar results to the paired points on the bus and coach front, and all are within the head injury criteria. However, the comments with regard to localised head, chest and abdomen impacts summarised in Section 10.1.3 mean that the bike rack may well give worse head injuries in real life. Further, the rack is more likely than the vehicles to cause serious abdomen and chest injuries. (The height of the top edge of the stowed rack was 1110 mm for the bus and 1133 mm for the coach.)

The legform tests to the stowed rack leading edge (the heavy hinged bracket at about bumper level) on both the bus and coach showed that the rack failed the leg injury criteria. The results for the rack on the coach were worse than the results for the rack on the bus. These results can again be compared with the tests to the bus and coach without the rack, which produced good results well within the criteria. It can thus be concluded that the front edge of the stowed rack dramatically increases the injury risk for the legs of adults. The injury risk for the legs of children have already been discussed in Section 9.2.1 and it was concluded that the deployed rack edge would also be dangerous for children. These arguments also apply to the stowed rack and it is clear that the stowed bike rack is far more likely to injure the legs of children than the vehicles without a rack.

It should also be noted that the heavy hinged bracket had some very strong forward facing protrusions at each end and in the middle. These were protected to some extent by a comparatively lightweight metal strip running horizontally. Nevertheless, these parts would also be likely to cause very serious flesh and possible bone injuries if the lateral position of pedestrians' legs were to coincide with them.

11 Possible methods of improving the pedestrian protection of bicycle racks

Both generally acknowledged environmental considerations and current UK government policy recognise the need for greater use of public transport and sustainable modes of individual transport. Furthermore, cycling has demonstrable health benefits and is to be encouraged, not just as a means of purposeful transport, but as a leisure activity. It is therefore desirable that a satisfactory means of integrating public transport by bus and private use of bicycles can be found. As has been reported, the use of front-mounted bicycle racks on buses has become popular in the USA, but it has also been noted that conditions of use in the USA are quite different from the UK. Perhaps more significantly, no independently conducted studies of the safety of these American racks have been identified, although it has been found that official safety concerns apparently prevented their general implementation in Australia. It would therefore be desirable to find a demonstrably safe means of transporting bicycles on buses, at a minimal extra cost, that is easy to use and does not significantly disrupt bus schedules.

Both the rack frame and the bicycle features have been shown to increase the risk of pedestrian injuries. It is obviously impractical to require the bicycle fleet to be replaced with bicycles with pedestrian friendly features just for these racks. Therefore, the front of the rack needs to provide protection in front of the bicycles. The pedestrian's legs are particularly vulnerable to impacts with the very solid rack leading edge, which should be made taller and weaker to reduce its risk of seriously injuring the legs of pedestrians. In order to be pedestrian friendly, the rack would need an energy absorbing front face. However, this front face could still be ineffective if it were pushed back onto, and was penetrated by, the bicycle handlebar end, pedals, etc. This problem could be overcome by making the front face support and attachments to the vehicle so strong that the front could not be pushed back onto the bicycles. Alternatively, having a strong load-distributing interface between the front face and the bicycles might also address this problem.

A combination of these two strategies might be used. Because of the discontinuous nature of the bicycles, a continuous energy absorbing front face would be required. However, there is also a need to avoid obstructing both the driver's view and the lights of the vehicle. This might be achieved by the use of a metal or plastic mesh stretched on an additional front frame. Tests to plastic bull bars made from large diameter polymer tubes have shown that these have the potential to be pedestrian friendly (Lawrence, Rodmell and Osborne, 2000). The possibility of using this material for the additional front frame could be explored.

However, it must be acknowledged that it will be very difficult to meet all these conflicting requirements for a front mounting rack without compromising the vehicles' operational needs. It might, therefore, be more profitable in the long-term, to encourage manufacturers to think in terms of utilising carrying space within or under the vehicle, or to explore the possibilities of trailers, which would have the advantage of much greater carrying capacity.

12 Conclusions

1 Data on bus and coach accidents with pedestrians have been analysed and the range of impact speeds determined.

2 A literature review and Internet search for information on the use of bikes on buses have been completed. However, the available literature only provided operational data and gave no information about studies of the risk to pedestrians in accidents.

3 Mathematical modelling has been carried out in order to determine the effect on the trajectory of the average height male of being struck by a bus and coach equipped with a front mounted rack.

4 Bike racks have been fitted to a modern bus and coach. A technical officer from the Vehicle Inspectorate was invited to TRL to offer an informal opinion of the selected coach with the front mounted bike rack fitted. The inspector concluded that the vehicle failed to meet several safety requirements with the rack deployed. He also noted that the construction of the rack, and the inevitable protrusions from any bikes carried, had the potential to cause serious impact injuries to pedestrians and other road users.

5 The vehicles with racks fitted were tested using an adaptation of the EEVC pedestrian headform and legform test methods for cars.

6 The vehicles without the racks have also been tested so that the results can be compared with those obtained with the bike rack. These tests show that modern buses and coaches, of the type tested here, offer good pedestrian protection in much of their frontal structure and give few very bad results.

7 The child headform test results show that the fitting of a bike rack, of the type tested here, dramatically increases the risk of life threatening head injuries for children, if they are of such a stature to be hit by the features tested.

8 Taking into account the under reporting of injury risk when using rigid headforms to test bicycle and rack parts, which produce concentrated loads, the adult headform test results show that the fitting of a bike rack increases the risk of life threatening head injuries for adults if they are of such a stature to be hit by the features tested.

9 Many of the points tested on the bike with the child and adult headforms would only hit a pedestrian's head in the most unfortunate combination of pedestrian stature and lateral position. Therefore, the number of such accidents is likely to be small. Nevertheless, the very high values recorded in the child test suggest that such a combination will often result in a fatal injury.

10 The relative heights of pedestrians and the crossbar of a rack-mounted bicycle mean that it will strike most adult and taller child pedestrians on the chest or abdomen. Furthermore, the handlebar end will make contact with the chest of most adult pedestrians and with the neck of the smaller females and some children. The characteristics of the impact and the available biomechanical data were considered to produce an informed estimate of the injury risks from this type of contact. It was concluded that the risks of fatal and serious injuries, from these contacts, were high.

11 The adult legform results show that the fitting of a bike rack of the type tested here dramatically increases the risk of long-term disabling leg injuries for both adults and children, in accidents involving pedestrians.

12 Suggestions have been offered for re-designing the bike racks to make them more pedestrian friendly.

13 Acknowledgements

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Appendix A: Photographs of the bus and coach

Plate A.1 The test bus fitted with the rack and two bicycles

Plate A.2 Two bicycles in the rack, showing their positions in relation to the bus headlamps

Plate A.3 The empty rack in a stowed position

Plate A.4 Cyclist loading a bicycle into the outermost rack position

Plate A.5 Female pedestrian (1700 mm tall) alongside the stowed rack

Plate A.6 Female pedestrian alongside the handlebar of the outermost bicycle.

(N.B. When the bus was in motion, the bicycles tended to sway, sometimes bringing the innermost handlebar closer to the bus windscreen).

Appendix B: Graphical outputs from the mathematical modelling

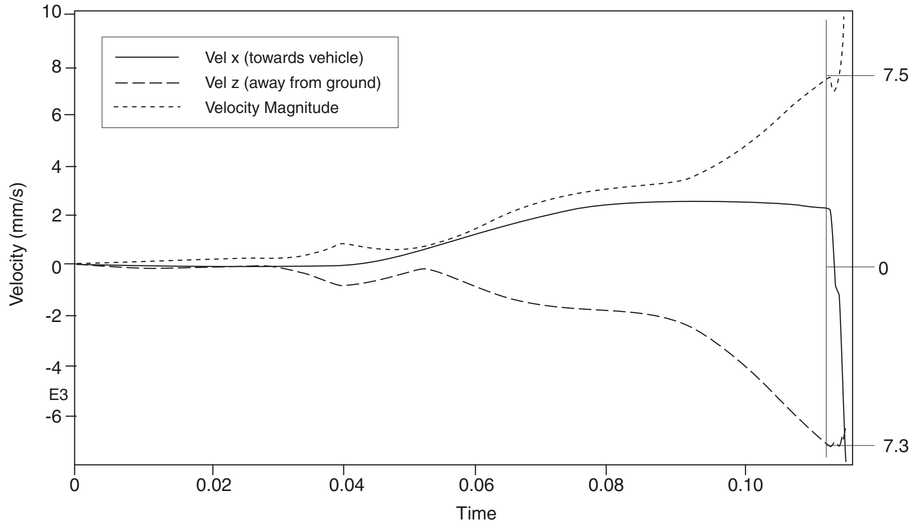


Figure B.1 Head velocity for front bicycle struck at 20 mph – Coach

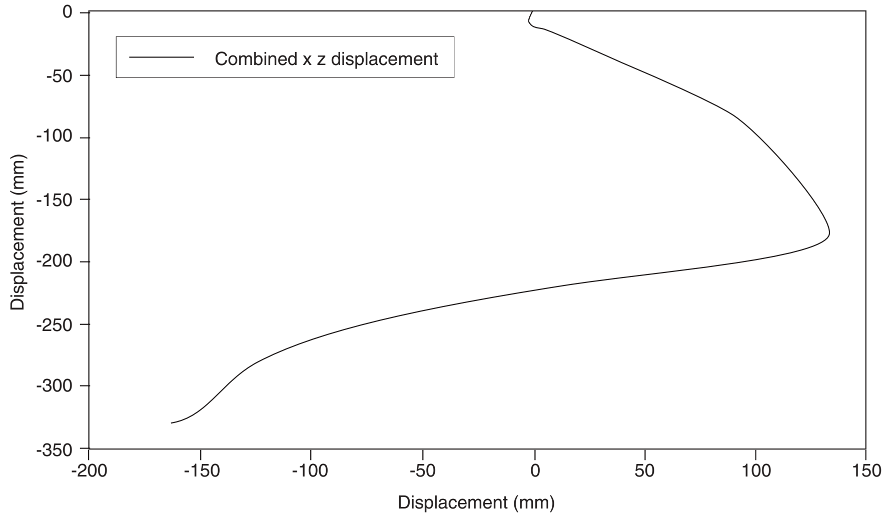


Figure B.2 Head trajectory for front bicycle struck at 20 mph – Coach

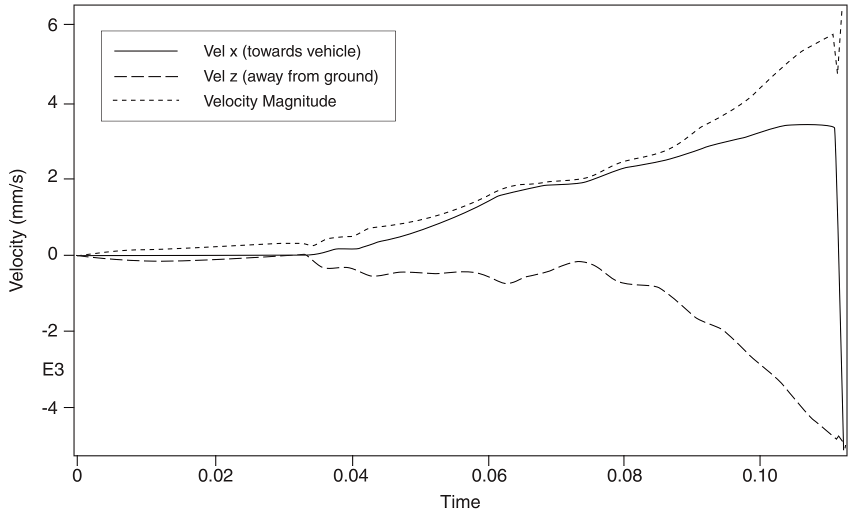


Figure B.3 Head velocity for rear bicycle struck at 20 mph – coach

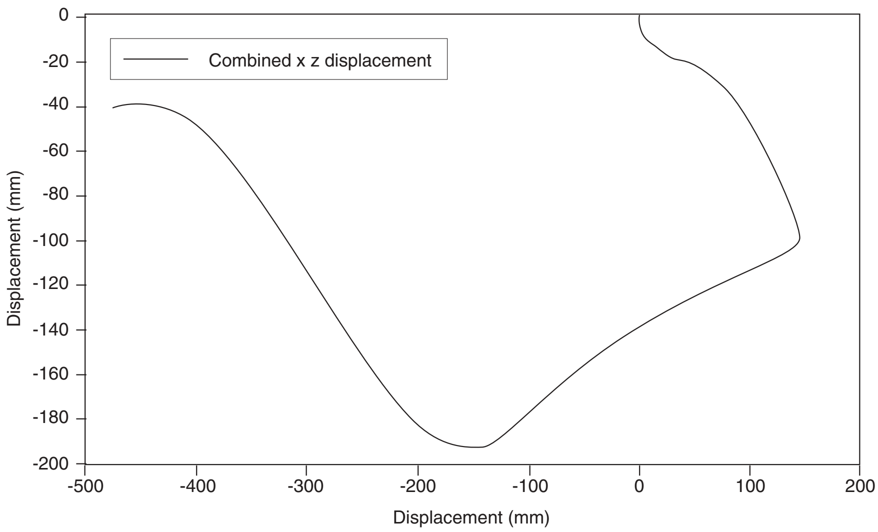


Figure B.4 Head trajectory for rear bicycle struck at 20 mph – Coach

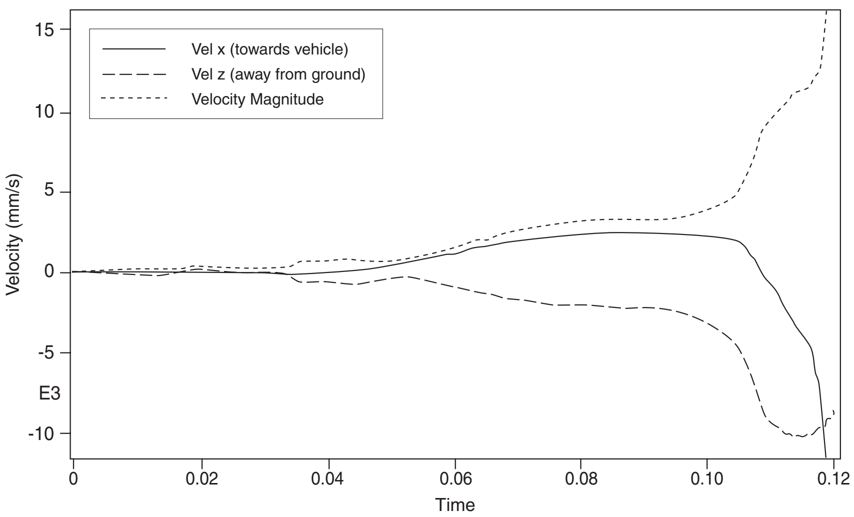


Figure B.5 Head velocity for two bicycles struck at 20 mph – Coach

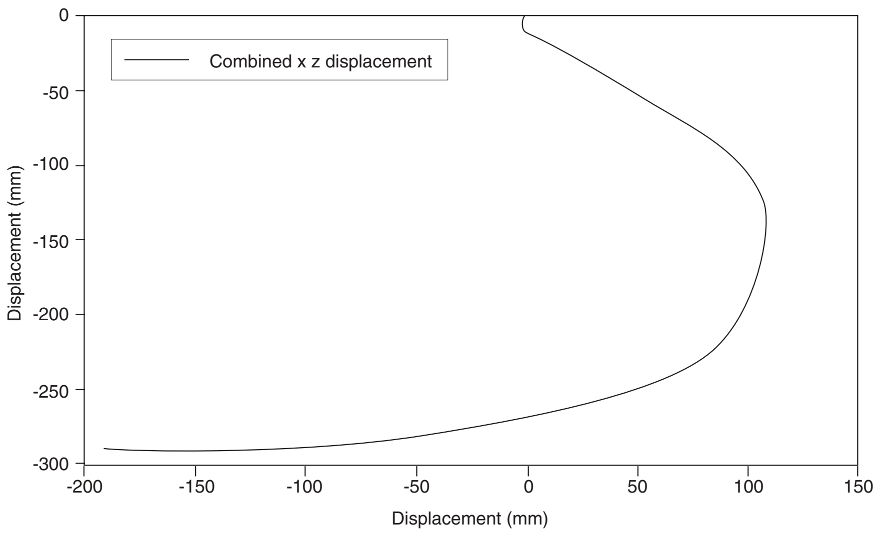


Figure B.6 Head trajectory for two bicycles struck at 20 mph – Coach

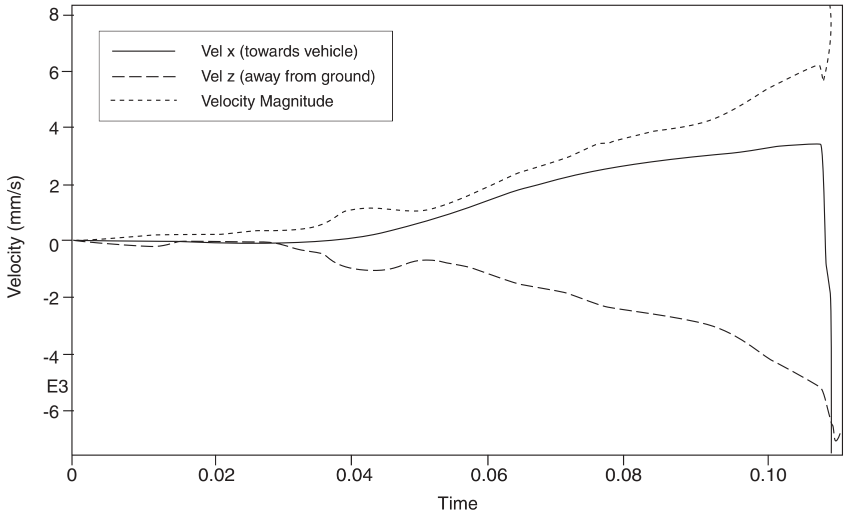


Figure B.7 Head velocity for front bicycle struck at 20 mph – Bus

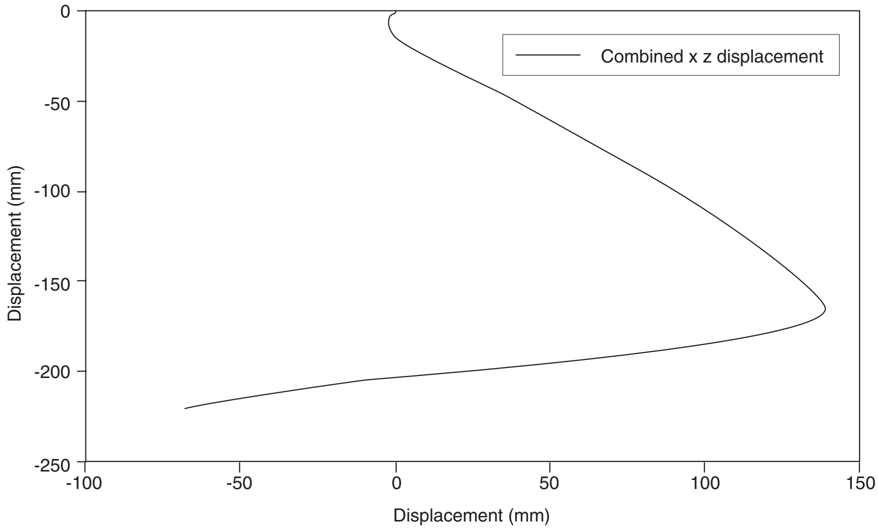


Figure B.8 Head trajectory for front bicycle struck at 20 mph – Bus

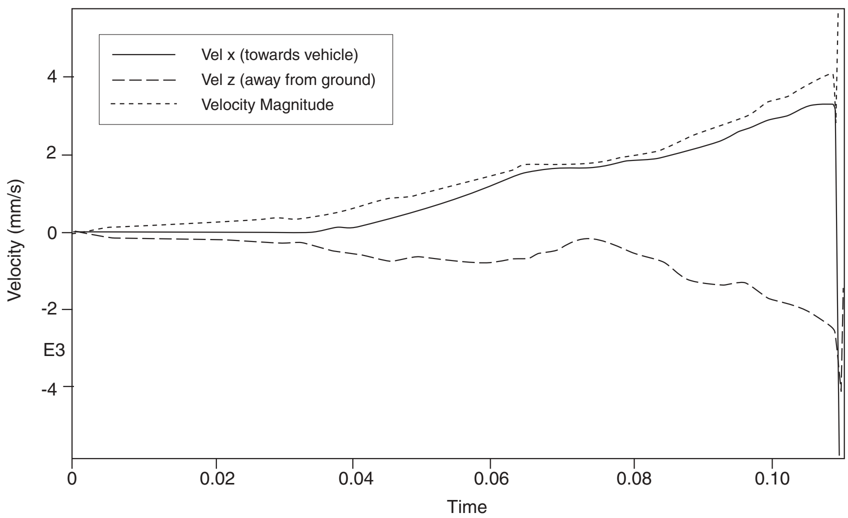


Figure B.9 Head velocity for rear bicycle struck at 20 mph – Bus

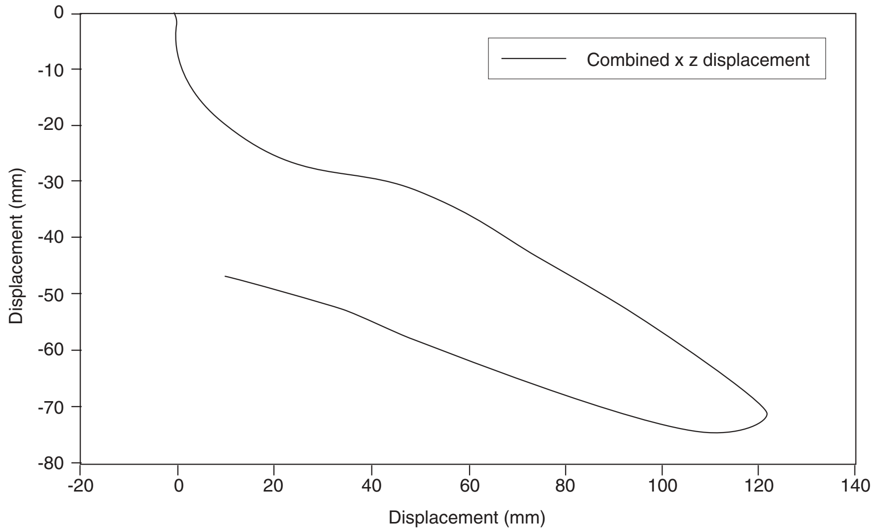


Figure B.10 Head trajectory for rear bicycle struck at 20 mph – Bus

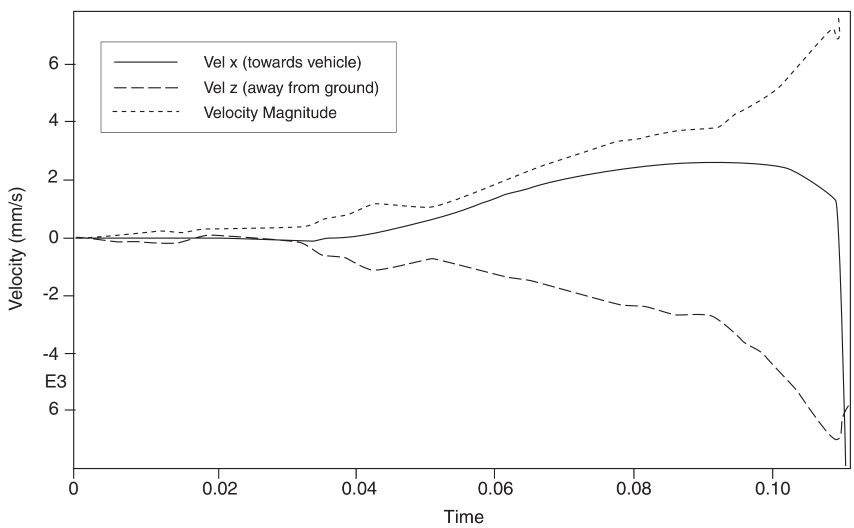


Figure B.11 Head velocity for two bicycles struck at 20 mph – Bus

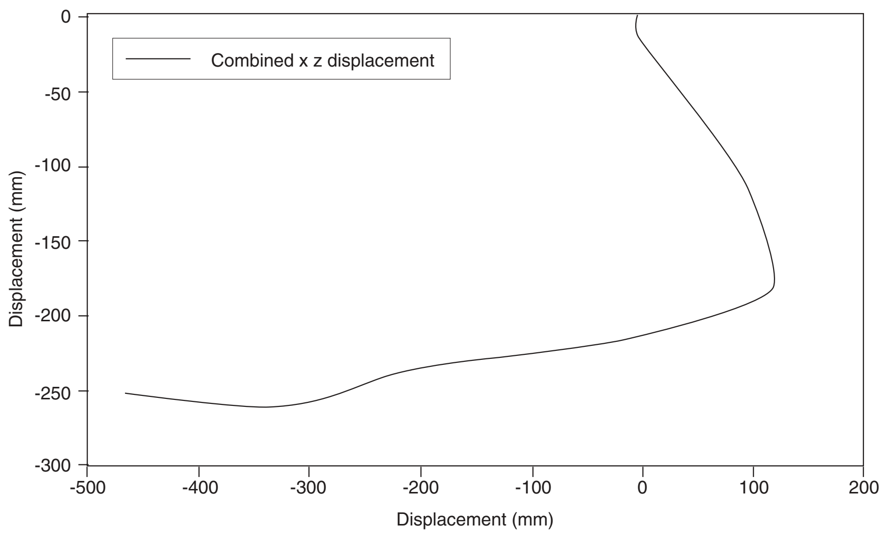


Figure B.12 Head trajectory for two bicycles struck at 20 mph – Bus

US Bikes on Transit Index

Alabama
none

Alaska
1 MACS
2 Denali Camper Bus
3 Alaska Backpacker Shuttle
4 People Mover
5 Kodiak Transit
6 Capital Transit
7 Alaska State Ferries

Arizona
1 Pine Country Transit
2 Valley METRO
3 Sun Trans

Arkansas
none

California
1 Humboldt Transit Authority
2 Arcata Transit
3 Redding Area Bus Company
4 Tehama County Transit
5 Yolo Bus
6 MTA (Mendocino)
7 Napa Valley Transit
8 Sonoma County Transit
9 Susanville Transit
10 Golden Gate Transit
11 AC Transit
12 BART
13 VTA
14 Caltrain
15 SamTrans
16 Wheels
17 ACE Rail
18 Storer Transit
19 Highway17 Express
20 Santa Cruz Metro
21 Monterey - Salinas Transit
22 CCAT
23 Stanislaus Transit
24 Pasa Robles Transit
25 Lompoc Transit
26 Plumas County Transit
27 Fresno Area Express
28 Golden Empire Transit
29 METROLINK
30 Roseville Transit
31 SBMTD
32 Beeline
Glendale
33 AVTA
34 Foothill Transit
35 LA MTA
36 RTA
37 Omnitrans
38 Sun Line Transit
39 Coaster RR
40 OCTA
41 NCTD
42 SDMTD
43 Chula Vista Transit
44 TART
45 Placer County Transit
46 Muni
47 RT
48 Fairfield Suisan
49 Bay Ferries
50 Catalina Ferries
I Capitols
J San Joaquins
K San Diegan
Y Yosemite Shuttle

Colorado
1 Avon Town
2 Crested Butte Shuttle
3 Loveland Transit
4 RFTA
5 TELL-U-RIDE
6 Springs Transit
7 Steamboat Springs Transit
8 Summit Stage
9 Vail Transit
10 RTD
11 TRANSFORT

Connecticut
1 Metro North RR
E Peter Pan/Greyhound

Delaware
1 SEPTA
2 DART
5 Cape May Ferry
C Vermonter
E Peter Pan/Greyhound

Florida
1 Escambia Transit
2 TalTran
3 Gainesville Transit
4 JTA on the move
5 Space Coast Transit
6 LYNX
7 Lakeland MTD
8 Hillsboro Transit
9 PSTA
10 Manatee Co. Transit
11 LeeTrans
12 Tri Rail
13 Broward Co. Transit
14 Miami Dade Metro

Georgia
1 MARTA
2 Athens Transit

Hawaii
1 The Bus
2 State Ferries

Idaho
1 Boise Urban Stages
2 Ketchum/Sun Valley Shuttle
3 Pocatello Urban Transit"

Illinois
1 Bettendorf Transit.
2 CUMTD
3 Madison Transit
4 Bi-State
F Cardinal
H Loop
I Illini
J MO/IL Trains

Indiana
1 Hammond Transit
2 Lafayette PTC
3 Ft. Wayne PTC
F Cardinal

Iowa
1 Bettendorf Transit

Kansas
1 JCTA

Kentucky
1 Northern Kentucky Airport
2 LEXTRAN

Louisiana
1 Jefferson Transit
2 Good Earth Transit

Maine
1 SACO/Biddeford
2 S Portland Bus
3 Portland METRO
4 Augusta
5 The Bus
6 Downeast
7 Casco Bay Ferry
8 Chebeague I. Bus/Ferry
D Concord Trailways

Maryland/DC
1 MTA
2 RIDE ON
3 METRO
C Vermonter
E Peter Pan/Greyhound

Massachusetts
1 Berkshire
2 U Mass/PVTA
3 MVRTA
4 MBTA
5 GATRA
6 CCRTA
7 MV Shuttle
8 Nantucket RTA Shuttle
9 Island Ferries
E Peter Pan/Greyhound

Michigan
1 Bay Area Transit
2 GRATA
3 Muskegon Tran.
4 CATA
5 SS. Badger
6 Makinac Isl. Ferry

Minnesota
1 DTA
2 St Cloud Transit
3 Mankato Transit
4 UMN Campus Bus
5 METRO
6 Minnesota Val. Transit
7 Moorhead Transit

Mississippi
none

Missouri
1 JCTA
4 Bi-State
J MO/IL Trains

Montana
1 MET Transit
2 Mountain Line

Nebraska
none

Nevada
1 Citibus
2 City Bus

New Hampshire
1 Advance Transit
2 Coos Connection
3 Coast
D Concord Trailways

New Jersey
1 NJ Transit
2 PATCO
3 SEPTA
4 Cape May Ferry
5 3 Forts Ferry
E Peter Pan/Greyhound

New Mexico
1 Santa Fe Trails
2 Sun Tran
3 Pecos Trails

New York
1 MTA
2 LIRR
3 Metro North RR
4 New London Ferry
5 NFTA
6 RTS
7 CENTRO
8 Tomtrans
9 Glans Falls
A Adirondack
B Ethan Allen
E Peter Pan/Greyhound

North Carolina
1 APPALCART
2 Chapel Hill Transit
3 DATA
4 Triangle Transit
5 WSTA
6 North Carolina Ferries
G Piedmont

North Dakota
1 Fargo Transit

Ohio
2 MVRTA
3 Clark Co. Transit
4 Cincinatti METRO
5 Toledo Transit
F Cardinal

Oklahoma
none

Oregon
1 Tri Met
2 SMART
3 Corvallis Transit
4 Linn-Benton Loop
5 Lane Transit
6 Rogue Valley Transit
7 Klamath Falls Transit
8 Cherriots
L Cascade Corridor
M Thruway Bus

Pennsylvania
1 SEPTA
2 Port Authority
3 Red Rose Transit
4 CAT
5 LANTA
6 CATA
7 AMTRAN
8 CCTA
9 EMTA
E Peter Pan/Greyhound
N Lehigh Valley Bus

Rhode Island
1 RIPTA
2 Block Island Ferries
E Peter Pan/Greyhound

South Carolina
1 Clemson Transit

South Dakota
none

Tennessee
1 Johnsonburg Transit
2 KAT

Texas
1 METRO
2 Capitol METRO
3 Via Transit
4 DART
5 Ft Worth Transit
6 Citibus - Lubbock

Utah
1 Logan Transit
2 Park City Transit
3 UTA

Vermont
1 CCTA
2 CCVTA
3 Newport, RPTA
St. Johnsburg, RPTA
4 Advance Transit
5 Moover
6 Lk Champlain Ferries
7 Colchester Bike Ferry
B Ethan Allen
C Vermonter
V Vermont RR

Virginia
1 VRE
2 CTA
3 METRO
4 FRED
5 GRTC
6 Williamsburg Shuttle
7 Peninsula Transit
8 Blacksburg Transit
9 Lynchburg Transit
F Cardinal

Washington
1 Island Transit
2 Whatcom County Transit
3 Skagit Area Transit
4 King County METRO
5 Pierce Transit
6 Intercity Transit
7 Twin Transit
8 Community Urban Bus Service
9 C-Tran - Portland and Vancouver
10 Jefferson Transit
11 Clallam Transit
12 West Jefferson Transit
13 Grays Harbor Transit
14 Pacific Transit
15 Link Transit
16 Yakima Transit
17 Spokane Transit Authority
18 Grant Transit Authority
20 Kitsap Transit
21 Mason County Transit
22 Community Transit
23 Ben Franklin
24 WHECO
25 State Ferries

West Virginia
1 Morgantown Transit
F Cardinal

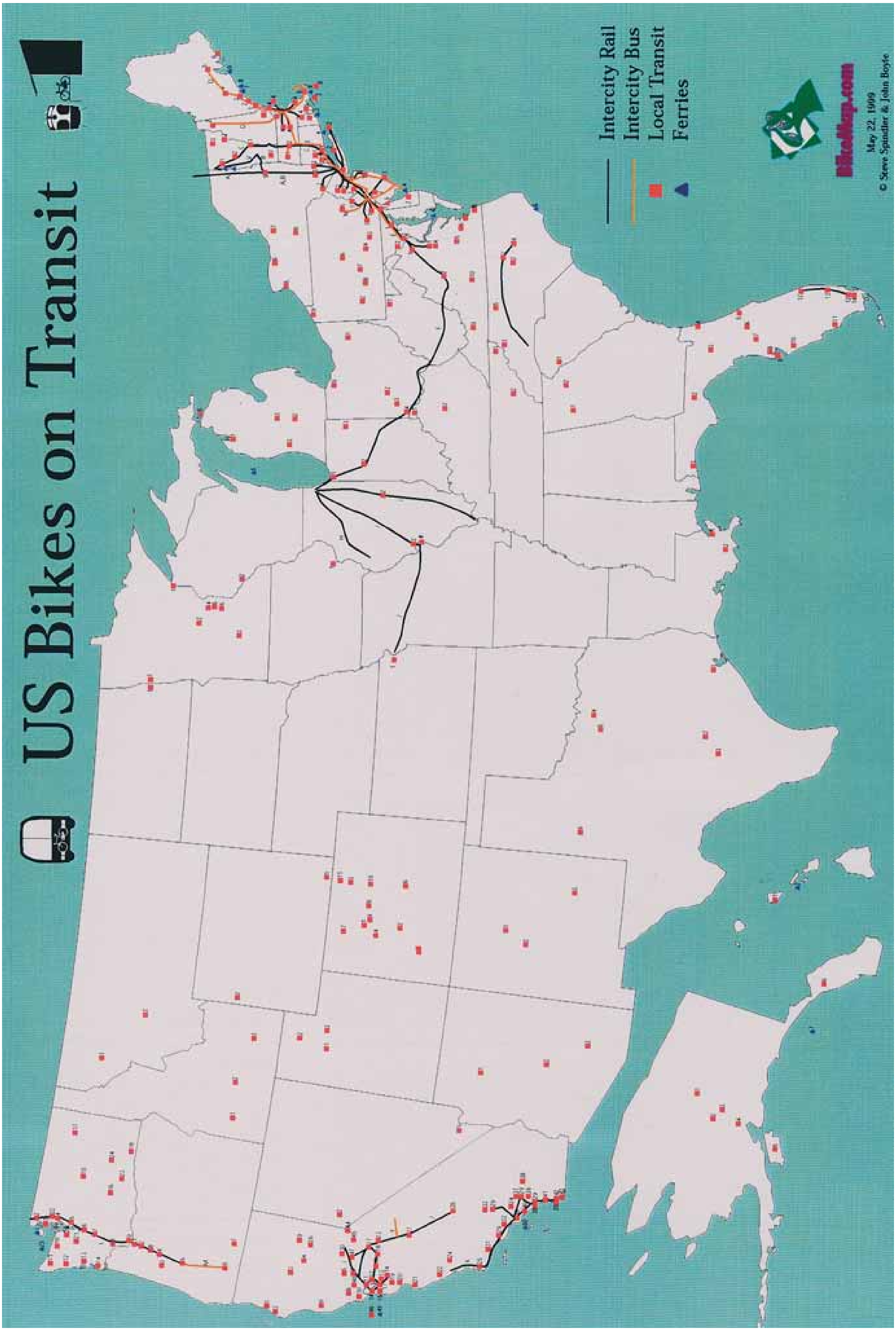
Wisconsin
1 DTA
2 LaCrosse Transit
3 SS Badger

Wyoming
1 Cheyenne Transit
2 START

BikeMap.com

May 22, 1999

215-985-2839


US Bikes on Transit
Intercity Rail
Intercity Bus
Local Transit
Ferries
May 22, 1999
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USA Bikes on Transit Ridership Statistics - Bike Boardings 1996-2000

Agency	*Mode*	*Bike boardings*	*Survey period*	*% of riders*
SD MTD, San Diego CA	Bus	2,500	Average per day over one week period May 1998	0.02
Denver RTD	Bus and light rail	2,300	Per Summer weekday	
Caltrain, San Mateo CA	Commuter rail	1,961	Per day September 1997	0.06
King County Metro Seattle	Bus	60,000	Per month	
BART	Rapid transit	1,600	Per day	
CAT, Las Vegas	Bus	35,000	Per month	
Valley Metro Phoenix	Bus	608,434	Fiscal year 1998	
SCMTD, Santa Cruz CA	Bus	19,000	October, 1999	
Lane Transit, Eugene, OR	Bus	13,000	Per month	
The Bus, Honolulu, HI	Bus	12,000	Per month	
Omnitrans, San Bernadino CA	Bus	6,000	Per month	
C-Tran Vancouver WA	Bus	5,500	Per month	
FAX, Fresno CA	Bus	5,000	Per month	
Sun Line, Palm Springs CA	Bus	5,000	Per month	
Hartline, Tampa FL	Bus	5,000	Per month	
Metro Rail Washington DC	Rapid transit	1,834	15 day survey period 1998	
SCAT, Sarasota FL	Bus	175	Per day	
NJ TRANSIT	Bus	100	Per day	
COASTER, San Diego CA	Commuter rail	100	Per day	
CCTA Burlington VT	Bus	1,900	Per month	
AVTA, Lancaster, CA	Bus	1,400	Per month	
MCAT	Bus	147	Per month - June ’96	
Bradenton		795	Per month - January ’98	
Florida		1166	Per month - April ’98	
Santa Barbara MTD, CA	Bus	60	Per day (note bike racks are only on 3 routes)	
People Mover, Anchorage AK	Bus	14,000	From April to October ’98	
Mountain Line, Missoula MT	Bus	8,135	All of 1997	
TCAT, Ithaca NY	Bus	1,145	Per month	
RTA, Rochester NY	Bus	895	Per month	
Transfort, Ft Collins CO	Bus	283	Per month	
MVRTA, Dayton, OH	Bus	232	Per month	

Source: www.bikemap.com/transit/rstats.htm

Metropolitan King County Bicycle Programmes - Talk presented by Robert Flor

Good Morning! I'm pleased to be here today to describe how King County Metro is integrating bicycle and pedestrian programs into the design of our facilities and as part of our regular system planning process.

Objectives

- Overview of Bicycle Rack Program.
- Status of Bicycle Parking Program.
- Progress of Administration.
- Issues.

Seattle Metro provides public transportation services within King County, an area covering 2,000 square miles. The potential market for bicycle/pedestrian transportation within the County is great. 75% of the population lives within 1/4 mile, walk distance to a bus zone. 85% of the residents live within two miles, easy biking distance, of a park and ride lot.

For the past several years, Metro has been working hard to capture more of the bicycle pedestrian market.

Goals

The goals of our bicycle/pedestrian program are to:

- promote alternatives to the single-occupant vehicle in support of our regional transportation policies;
- extend our customer draw area by facilitating access to riders beginning or ending their trip beyond typical walking range (about 1,000 feet) to bus stops and;
- reduce parking demand at transit facilities, such as park and rides, which are often close to capacity, with little opportunity for expansion;
- provide safe and secure program.

In 1991, as part of the Regional Transit Project, Parson Brinkerhoff conducted a non- motorised access study for the RTA. This study considered the potential for incorporating bicycle and pedestrian access as part of the planning for the regional transit system. The report concluded that such access could be provided through relatively modest capital expenditures. Metro's Six Year Plan, published this year, has incorporated planning for bicycle/pedestrian systems. The Plan recommends spending $200,000 per year for access improvements at transit facilities.

Bicyclists and pedestrians have some very basic needs, which are common to both groups. These include:

- Being able to take the most direct route.
- Having a safe, pleasant environment.
- Having linkages that connect neighborhoods and cul-de-sacs.
- Security, lighting, and visibility.
- Weather protection, and
- Elimination of obstructions and barriers.

Background

1978 - Metro adds bike racks on SR-520 Service.

1991 - Non-Motorised Access Study completed.

1993 - Bicycle Transit Improvement Program funded.

1994 - Bicycle Parking Demonstration funded.

1995 - Six Year Plan and Pedestrian/Bicycle Access Program funded.

1996 - Application to expand vanpool rack program.

Safety and security program.

Proposed demonstration on SR-520 of dedicated bike bus service.

To improve the environment for bicyclists and pedestrians, Metro is working in several areas. The first involves working with local jurisdictions to encourage supportive policies.

Last year, we conducted a Policy Inventory, reviewing the comprehensive plans of 19 King County jurisdictions. Market Development staff looked at local policies in eight different areas.

As part of the parking policy review, we looked at local jurisdiction requirements for bicycle parking. We found that 40% of the Eastside jurisdictions required bicycle parking, while none of the south King County jurisdictions even had a bicycle parking requirement. Obviously, this is one area that could be improved. On a positive note, most King County jurisdictions are in the process of reviewing or revising their parking codes within the next two years.

To provide guidance for local governments on how to translate comprehensive plan policies into transit-supportive codes, Metro organized a series of four workshops early last year. These workshops, co-sponsored with WSDOT's Office of Urban Mobility, featured speakers, debates, and panel discussions on topics ranging from parking and site design to implementation strategies, mixed use and densities.

One product of the workshops was a compendium of codes, standards and guidelines that could be used as a model by jurisdictions as they draft new zoning codes and off-street parking standards. The model language was compiled by staff of the Municipal Research and Services Center of Washington.

We are also continuously working to ensure that Metro's policies and facilities support local codes. This is accomplished in several ways — through the development of innovative products tailored to local markets, through the development and implementation of the Six Year Plan, which involves many changes to the way we currently do business, and through our work with individual local governments on a day-to-day basis as problems are brought to our attention.

Besides our work with local jurisdictions to encourage supportive policies, Metro is working on several other fronts to promote bicycle/pedestrian transportation.

Bicycle transit improvement program

One of these areas is our bus bike rack program. As of November 1994 Metro had fitted its entire fleet of transit coaches (1,175 buses) with Sportworks, Inc. racks. This made Metro's fleet the largest in the country to be fitted with bicycle racks.

(*Note: New fleet purchases include bicycle racks as part of the standard equipment. Metro's current fleet is over 1,200 buses all equipped with racks.)*

These racks are now being used by several other U.S. transit systems. The Sportwork racks are much easier to maintain than our old rack, which had to be removed when buses were washed. They are also easier for the customer to use. They simply pull down, the bike is lifted onto the rack and an arm pulled over the front wheel to secure the bicycle. Two bicycles can be accommodated at a time on each bus.

Metro has also installed racks on 37 subcontracted buses, such as our DART service in Federal Way and the new Issaquah shuttle. These racks are modifications of the Sportwork rack. They were shortened to fit the smaller vehicles and to meet safety requirements.

Although this slide says 66 vanpool vehicles are fitted with racks, the number has grown to 77 out of a total fleet of 695 vehicles. (622 of these vehicles are in active service as vanpools or loaners.) The racks on the vanpools are Hollywood racks, installed on the rear of the vehicles. They are capable of holding two or four bicycles. The vanpool rack is available on demand. Over 100 cyclists are currently using them. These racks cost $250 apiece compared to the average cost $20,000 for a park and ride stall. We have applied for a $25,000 additional funds as part of a request to increase the vanpool fleet to continue expansion of the very, very attractive program.

(Note: About 220 vans have now been equipped with the rack or about 31 percent of the vanpools on the road.)

To promote the bicycle rack program, Metro is using several different approaches, including flyers, brochures, and giveaways. This flyer announces our bike to work week promotion last May in which cyclists were invited to try the bus rack and send this form to Metro to receive a free sports wallet. Over 300 of these wallets were sent out. In addition, Metro has provided bicycle clubs with portable display racks for hands-on demonstration of how to use the rack. Metro's Employer Transportation Representatives also use a portable rack when they visit employer worksites.

So with all the racks on all our buses, you may be wondering how well the program is doing. Until now, we have not had a very good handle on use. In October 1995, we conducted a survey which randomly sampled operator assignments throughout the system. We also conducted a special bike rack use count on SR-520, the Evergreen Point Bridge, in cooperation with WSDOT, NowBike, and the Cascade Bicycle Club.

Operator counts were conducted over two weekdays and one weekend. By extrapolating backwards over 240 days to early March 1995, we projected a conservative estimate of 256,000 to 294,000 bike related trips in the system. The count is considered conservative because:

1 it applied counts taken during the Fall to Spring and Summer when cycling is highest because of weather and light;

2 it was conducted on a voluntary basis by operators which means that all operators may not have completed cards.

The count was conducted during the first year that racks were installed on the fleet. It is likely that cyclists were affected by a 'learning curve' and were still familiarising themselves with the equipment. In workshops, cyclists often mentioned that they were intimidated by the potential for holding up a bus while they learned how to use the rack. These trips represent 1/2 of 1 percent of trips taken in the system over the same time period.

(*Note: The bicycle rack has become second nature to cyclist by YR2000. We suspect that utilisation is much higher than the ½ percent reported in the 1995 survey and more likely Metro is transportation in excess of 500,000 bicycle related trips annually.)*

Evergreen Point Bridge was constructed without pedestrian/bicycle facilities and it is impossible for bikes to cross. There is high demand on this bridge for ability of bikes to cross because it serves eastside cities of Bellevue, Redmond, Kirkland, Woodenville and In the west: the University of Washington and downtown Seattle.

Metro anticipated potential capacity problems on the facility because the first bicycle racks built in 1978 were focused on routes that crossed it. We had informal feedback from both cyclists and transit operators about capacity problems associated with the new racks.

Comments focused on the following issues:

- lack of capacity on the SR-520 corridor;
- disagreement with the policy restricting bike loading in the ride free area;
- the inability of operator to see racks when they are deployed and not carrying a bike;
- safe and secure use of the racks.

To address the lack of capacity, Metro is considering using deadhead trips across the bridge to carry bicycles inside. Three a.m. and three p.m. trips would operate between the Montlake area on the west and the Overlake area on the east.

There are no plans to change the bike loading policy because it results from a problem of short zones in the Seattle CBD and a potential safety problem. We needed room for buses in the zones, so operators are trained to stop within a few feed of the bus in front of them. For safety reasons, we want to limit the incidence of cyclists between buses.

To resolve the problem of operator inability to see deployed racks, the racks are being striped with yellow visibility tape and a safety indicator is being designed that will improve visibility.

Bicycle parking demonstration program

The third major area of Metro's bicycle/pedestrian program involves installation of bicycle parking at transit facilities. Early last year, Metro installed six bike banks and 10 lockers at the Greenlake PandR. Those first lockers were pulled because they were substandard. They were replaced with a different locker with a more substantial locking mechanism.

We are now experimenting with an array of lockers and racks at park and rides throughout the system. We have installed lockers in six (6) transit facilities and have planned installations in five (5) additional ones. Newer model bicycle racks have been installed in eleven other transit facilities. Additionally, we may experiment with a bicycle lid in one or two other facilities.

In one example of a joint project, Metro, the City of Seattle and WSDOT will be installing racks and lockers at the Montlake flyer stop. The City is testing three types of racks and Metro will provide the lockers.

The purpose of the demonstration is to:

- determine the most suitable equipment for Metro facilities (what the type and mix should be);
- establish guidelines for the level of bicycle parking that should be in facilities under different land use conditions and 3) address administrative issues related to the bike facilities.

Bicycle parking facilities will be evaluated on several criteria: equipment quality, demand — both long and short term, user satisfaction and administration. Our goal is to be able to set guidelines for these facilities, to priorities facilities in the future and to meet customer demand.

A visual survey was conducted in early 1995 at our park and ride lots to determine where access improvements are needed and where we should install bicycle parking facilities for the demonstration. The survey helped determine demonstration sites along with a set of criteria that were developed. The criteria included: connections with bicycle paths, attractions and productions in census tracts surrounding the facility, different types of land uses and densities (urban, suburban, rural).

Administration

In terms of administration of bicycle parking, Metro surveyed transit agencies around the country and found three different models. Some agencies operated the program themselves with either full or part-time staff. This was common. Other agencies, such as Tri-Met, contracted with a public entity, such as the City of Portland to administer the lockers. A third option was to use a private group, such as a bicycle organisation to administer the program. Vancouver B.C. contracts with the Vancouver Bicycle Association to administer their lockers.

Metro initially used its Customer Services and its Lost and Found staff for daily administration of the program. Late last year, we contracted with the Northwest Bicycle Federation (*formerly NowBike name changed to the Bicycle Alliance*) for management of the lockers. NowBike represents 19 bicycle clubs and agencies in Washington State. Their contract provides for handling contracts with cyclists, locker inspections, reporting vandalism, and handling of lost and found bicycles. Lockers at this time are available to cyclists for a $25 refundable key deposit.

The most surprising problem with our bicycle programs has been around Lost and Found issues. We typically intake 4 to 5 bicycles per week and it is not unusual to have 15 to 20 bicycles in storage. The claiming rate has stayed at about 30 percent. NowBike has developed a computer program, which notifies all local police agencies of the bicycles that we are holding. We will be undertaking an aggressive marketing and education program to attempt to reduce the number of lost bicycles.

(Note: *The number of bicycles left on buses has climbed to about 30 per month in YR1999 which is probably an indication of increased growth and rack utilisation.*)

Safety

This year, Metro will be carrying out an aggressive education and marketing campaign aimed at improving safe and secure use of the bicycle racks. While the program has been warmly received throughout the Seattle area and continues to grow, we want users to learn to use the racks correctly. We have had a few small incidents of unnecessary carelessness.

We are working with NowBike, Cascade Bicycle Club, our school program in taking a multi-media approach to education. This will include flyers, press releases, articles in school and college papers, appearances at bicycle events, inserts in bicycle papers, a safety video, posters rider alerts, interior transit cards...all aimed at getting a safety and security message across.

Safety tips

Some examples of safety tips include:

- Waiting on the curb for the bus to come to a complete stop.
- Not approaching bus from the operator side.
- Informing the operator that you will be loading or unloading.
- Getting his/her acknowledgement.
- Fold rack into upright position.
- Wear a helmet.

Security

We have had two incidences where bicycles were stolen from the racks. People are learning that these can be taken very easily. Operators are not able to watch each bicycle and they will not know who belongs to them. We want to encourage cyclists to:

- Lock their tires before putting the bike on the rack (Not to lock the bike to the rack.)
- Ride in the front section of the bus and;
- Watch their bicycles.

Future directions

The last element in Metro's bicycle/pedestrian program are access improvements which include several projects:

- Programs will be evaluated to see where improvements can be made.
- A bus zone improvement project to make the system more accessible and safe for transit riders with disabilities. More than 87% of the bus fleet is wheel chair lift equipped and 95% of trips are served with coaches equipped with lifts. 6,500 of Metro's 10,000 bus zones meet ADA standards.
- Non-motorised access improvements will be made to transit facilities. Metro has received a grant for $380,000 over a two year period to retrofit existing transit facilities to maximise access, supplement bicycle parking facilities, and improve safety and circulation within facilities.
- We will work with jurisdictions to see where bicycle/pedestrian connections with transit facilities can be improved. We will propose barrier removals, additional signage and bike lane improvements and co-operative parking arrangements.

Metro has demonstrated a commitment to non-motorised access through provision of bike racks on buses, improved bicycle parking facilities and non-motorised access improvements throughout the system. While funding currently exists to support an aggressive program, future funding is uncertain in an increasingly competitive world. Consideration of bicycle/pedestrian needs early in the planning process is becoming more of a fact of life at Metro and will continue to characterise our way of doing business.

BUS/PEDESTRIAN ACCIDENT ANALYSIS

Accident Number _ _ _ _ _ _

Did the Pedestrian die?	Yes	...1
	No	...2

If the answer is "No", ignore this accident.

What Type of Bus was Involved?	Van-type mini-bus	...1
	Bigger mini-bus (perhaps about 20 seats or more)	...2
	Full-size bus or coach	...3

If the answer is "1", ignore this accident.

What was the (dead) Ped struck by?	Not struck (fell in or near bus)	...1
	Another vehicle (bus not involved)	...2
	Bus (before other vehicle)	...3
	Bus (after other vehicle)	...4
	Bus (after bus struck other object)	...5
	Bus only	...6
	Other unusual circumstances (inc. crush between bus and fixed object)	...7

If the answer to the above question is not "6", ignore this accident.

ACCIDENT DATA

Accident Location	Urban (centre - densely built-up)	...1
	Urban (fast road/expressway)	...2
	Urban (residential outskirts)	...3
	Village	...4
	Rural	...5

VEHICLE DATA

Body Type (May be on S19 print-outs) _ _ _ _ _

Number of Seats (May be on S19 print-outs) _ _ _ _ _

Bus Type	"Ordinary" service bus	...1
	Inter-City regular service bus	...2
	Touring Coach	...3

BRIEF DESCRIPTION OF ACCIDENT

....

....

VEHICLE DATA

Estimated Impact Speed		_ _ _ _ _
Source of Estimate	Tachograph	...1
	Police	...2
	Witnesses	...3
	Driver	...4
Braking	Braked before impact (no wheel lock)	...1
	Braked before impact (wheels locked)	...2
	Braked before impact (N/K wheel lock)	...3
	No braking before impact	...4
Road Surface Conditions	Dry	...1
	Damp	...2
	Wet	...3
	Icy	...4
	Slippery for some other reason (eg diesel contamination)	...5
Bull Bars	Present	...1
	Absent	...2
Shape of Bus Front	Flat (Vertical)	...1
	Flat (Sloping)	...2
	Irregular	...3
If Flat (Sloping), where does the sloping area start?	Bumper level	...1
	Below adult waist level	...2
	Between adult waist & shoulder level	...3
	Head level	...4
	Higher	...5
Impact Location (Imagine the bus front divided into thirds)	N/S Corner	...1
	N/S	...2
	Centre	...3
	O/S	...4
	O/S Corner	...5

PEDESTRIAN DATA

Height		_ _ _ _ _
Weight		_ _ _ _ _
Direction Facing	Offside of Road (as seen by bus driver)	...1
	Nearside of Road (as seen by bus driver)	...2
	Facing Bus	...3
	Facing Away from Bus	...4
Posture at Moment of Impact	Upright	...1
	Crouched/Stumbling	...2
	Lying on Road	...3
Trajectory after Impact (Rel. to Dir. of Travel of Bus)	Forwards	...1
	To Nearside	...2
	To Offside	...3
	Up & Over top of bus	...4
Body Region Making Main Contact with Road	Head	...1
	Thorax/Upper Limbs	...2
	Pelvis/Lower Limbs	...3
Blood Alcohol Content (From PM)		_ _ _ _ _
Alcohol Suspected (if BAC not available)	Yes	...1
	No	...2
Drugs Suspected	Yes	...1
	No	...2

VEHICLE FILE

ACCIDENT NUMBER

VEHICLE NUMBER

SEVERITY (1=Fatal; 2=Serious; 3=Slight; 4=Uninjured)

NUMBER OF OCCUPANTS

MAKE OF VEHICLE

MODEL OF VEHICLE

MODEL VARIANT

Pedal Cycles: Go to Page B3.

REGISTRATION LETTER (Letter, or 8=No reg. letter; 9=N/K)

SUFFIX OR PREFIX (1=Suffix; 2=Prefix; 3=Cherished; 4=Genuine pre-alphabet; 8=Other - see Stats19 entry)

PSV TYPE (1=PSV single deck; 2=PSV double deck; 3=PSV minibus - Supplement to Stats19)

CAR BODY TYPE (1=Saloon; 2=Hatchback; 3=Estate; 4=Forward control; 5=Car derivative; 6=Multi-purpose/Off-road; 7=Sports)

DRIVING POSITION	└┘	(1 = RHD; 2 = LHD: m/c→0)
DOORS	└┘	(1 = 2 Side doors: 2 = 4 Side doors: 3 = 3 Side doors: m/c→0)
FUEL TYPE	└┘	(1 = Petrol; 2 = Diesel)
FUEL SUPPLY	└┘	(1 = Carburettor; 2 = Injection)
SOFT/OPEN TOP	└┘	(1 = Top up; 2 = Top down)
"BULL BARS"	└┘	
Airbag		
DRIVER'S	└┘	(1 = Present; 2 = Deployed)
PASSENGER'S	└┘	(..)
REAR o/s	└┘	(..)
REAR n/s	└┘	
Side Impact Bag		(..)
FRONT OFFSIDE	└┘	(..)
FRONT NEARSIDE	└┘	
REAR o/s	└┘	
REAR n/s	└┘	(1 = Present; 2 = Activated)
		(..)
Pretensioner/Web Lock		
DRIVER'S	└┘	
PASSENGER'S	└┘	
REAR o/s	└┘	
REAR centre	└┘	
REAR n/s	└┘	
OTHER SPECIAL SAFETY FEATURE (describe)	└┘	

Vehicle/Accident Details

NUMBER OF IMPACTS		(1, 2; 3 or more = 3)
ORDER OF IMPACTS N/K		
MOST SEVERE IMPACT		(1st, 2nd; 3rd or later = 3)
UNDERRUN		
FIRE		
ROLLOVER		(1 = Before 1st impact; 2 = After 1st impact; 3 = No impact)
FIRST OBJECT HIT		(1 = Car/car derivative; 2 = 2-wheeler; 3 = Multi-purpose/other LGV; 4 = HGV/PSV/other lge veh; 5 = Pole/narrow obj < 42cm (16½"); 6 = Wide obj; 7 = Pedestrian; 10 = Animal; 11 = Trailer/caravan; 12 = Occ/rider detached from vehicle)
SECOND OBJECT HIT		
THIRD OBJECT HIT		
1st IMPACT DIRECTION		(1 = Front; 2 = O/s oblique; 3 = N/s oblique; 4 = O/s; 5 = N/s; 6 = Back; 7 = Top/underside)
2nd IMPACT DIRECTION		
3rd IMPACT DIRECTION		
1st IMPACT LOCATION		(1 = Front; 2 = O/s; 3 = N/s; 4 = Back; 5 = Roof; 6 = Compartment)
2nd IMPACT LOCATION		
3rd IMPACT LOCATION		
TRAVEL SPEED		
SRCE OF ESTIMATE	(1) (2) (3) (4)	(1 = Tachograph; 2 = Police reconstruction; 3 = Witnesses; 4 = Driver. Mixed sources - combine these)

INADEQUATE LIGHTS
(For conditions)

Vehicle Defects

NO DEFECTS	└┘	(not punched)
TYRE DEFECT/PROBLEM	└┘	(1 = Present; 2 = Contributary)
STEERING DEFECT	└┘	(1 = Present; 2 = Contributary)
SUSPENSION DEFECT	└┘	(..)
WHEEL LOSS	└┘	
BRAKE DEFECT	└┘	(1 = Present; 2 = Contributary)
MECHANICAL FAILURE	└┘	(1 = Present; 2 = Contributary)
ELECTRICAL FAILURE	└┘	(..)

CORE OCCUPANT/CASUALTY FILE

ACCIDENT NUMBER	└─┴─┴─┴─┴─┘	
VEHICLE NUMBER	└─┴─┴─┘	
OCC/CASUALTY NUMBER	└─┴─┴─┘	
SEVERITY	└─┘	
CASUALTY CLASS	└─┘	(1=Car/lge veh driver; 2=Car etc passenger; 3=M/c rider; 4=M/c pillion rider; 5=M/c sidecar pass; 6=Pedal cyclist; 7=Pedestrian)
SEX	└─┘	(1=Male; 2=Female; 3=Pregnant)
AGE	└─┴─┘	(Years)
APPROX AGE	└─┘	(C=Under 12; T=Teenager; A=Adult)
SEAT BELT USAGE	└─┘	(0=Not car or van; 1=Belt in use; 2=Belt fitted, not used; 3=Belt not fitted; 4=Child belt/harness fitted & used; 5=CBH fitted, not used; 6=CBH not fitted)
PSV PASSENGER	└─┘	(1=Boarding; 2=Alighting; 3=Standing passenger; 4=Seated passenger)
CRASH HELMET	└─┘	(1=Worn; 2=Not worn; 3=Came off in acc. Inc pedal cyclists)
SEATING POSITION:		
ROW	└─┘	(1=Row1; 2=Row2; 3=Row3; 4=>Row3)
POSITION	└─┘	(1=O/S; 2=Centre; 3=N/S)
DIRECTION FACING	└─┘	(1=Front; 2=Rear; 3=Sideways)
IN LOAD AREA, NO SEAT	└─┘	
OTHER OCCUPANT BEHIND	└─┘	(1=Restrained; 2=Unrestrained; 3=Present, Restraint N/K)
OTHER OCCUPANT BESIDE	└─┘	(..)
LUGGAGE/GOODS BEHIND	└─┘	(..)
LUGGAGE/GOODS BESIDE	└─┘	(..)
EJECTION	└─┘	(1=Partial; 2=Full)
EJECTION ROUTE	└─┘	(1=Windscreen; 2=Rear screen; 3=Side windows; 4=Open door or hatch)

UNINJURED		*(Ignore rest of form if this box ticked)*
Cause of Death, or Body Area Injured (for non-fatal cas):		
HEAD INJURY		
NECK INJURY		
THORAX INJURY		
ABDOMEN INJURY		
ARMS		
LEGS (INC HIPS & PELVIC BONES)		
INJURY COMPLICATION		
MULTIPLE		
BURNS		
DROWNING		
ASPHYXIATION		
LONG-TERM DISABILITY		
N/K		
SOURCE OF INJURY DATA		(1 = Post-mortem: 2 = other)
HOSPITALISATION		(Record no of days as inpatient or to death. DOA = 50: Died within 24hr = 0: > 30 days (non-fatal cas) = 40. Inpatient but no. of days N/K = 60. Injured but not treated = -2: Outpatient = -1: Uninjured - leave blank. If nothing known, code 99)
INJURY AGENT		(1 = Vehicle interior - no intrusion: 2 = Intruded veh interior: 3 = External object after ejection: 4 = intruding ext object: 5 = Exterior front of veh: 6 = Exterior side or rear of veh: 7 = Exterior w/screen or header rail: 10 = Road/footpath etc: 11 = run over by wheels) NB: Cyclists. m/cyclists. pedesrians. use only codes 5. 6. 7. 10. 11

Abstract

This study, commissioned by the Department for Transport, assesses the potential for increased risk and severity of injuries to pedestrians involved in collisions with buses fitted with front-mounted bicycle racks.

An extensive literature search was conducted to identify any research investigating the impact of bicycle racks, mounted on buses, on pedestrian injuries. A lack of previously published information was found that directly related to the safety implications of folding front mounted bicycle racks on buses.

After analysis of the TRL database of police files of fatal accidents involving buses and coaches, and a mathematical modelling exercise, speed and impact points were recommended for impact testing. A bus, a coach and a front-mounted bike rack were selected for testing, and an informal opinion concerning these vehicles fitted with a bike rack was offered by the Vehicle Inspectorate.

Adult and child headform and legform impact tests were carried out on the vehicles, with and without the rack, and with and without bikes and the results of testing the various combinations were analysed and compared. The limitations of the impact testing methodology used in revealing the severity of impalement are discussed.

Related publications

TRL460 *Assessment and test procedures for bull bars* by G Lawrence, C Rodmell and A Osborne. 2000 (price £35, code J)

TRL402 *Bikes on trains – a study of potential users* by N Guthrie and G Gardner. 1999 (price £25, code E)

TRL243 *A study of accidents involving bull bar equipped vehicles* by B J Hardy. 1996 (price £25, code E)

LR843 *Cycle ownership and use in Great Britain* by A Stores. 1978 (price £20)

CT15.2 Planning for pedestrians and cyclists update (1999-2001) *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

CT48.3 Crashworthiness: vehicle structure and safety update (2000-2003) *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

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