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Pedicab Safety Evaluation

by M Dodd, D Divall, T Smith, C Willis and A Mellor

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PEDICAB SAFETY EVALUATION

Version: 1.0

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Prepared for:	**Project Record:**	**Pedicab Safety Evaluation**
	Client:	**Licensed Taxi Drivers Association (LTDA) (Bob Oddy)**

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Executive summary

Following discussions with the Licensed Taxi Drivers Association (LTDA) regarding the safety of Pedicabs used in London, it was proposed that TRL conduct research to assess the specific safety concerns of this type of vehicle. Several different assessments of the Pedicab were undertaken in order to cover as many aspects of primary and secondary safety as possible. TRL was asked to focus the evaluation on passenger safety rather than rider safety because members of the public might expect a certain level of safety from a mode of transport they are paying to use, without having to consider the practical aspects of the vehicle they are travelling in.

A literature review considered existing regulations and standards that could be applied to Pedicabs and found that although both construction and use regulations and the Highway Code could be applied to Pedicabs, no specific mention of them was made in either. The Pedicab tested failed to comply with certain aspects of the regulations reviewed. The review also considered literature covering Pedicabs in a number of settings, and found that the use of Pedicabs does have many potentially positive effects relating to environmental and sustainability issues. However, these benefits can only be achieved if Pedicabs become an integral part of the transport system, replacing journeys that would otherwise be undertaken by motorised vehicles. Anecdotal evidence indicates that Pedicabs in London are used mainly for short entertainment journeys not usually undertaken in buses or taxis within the City. This suggests that currently Pedicab journeys tend to replace walking rather than motorised transport and therefore have little, if any, environmental benefit.

Braking and Handling trials tested the braking performance and stability of the Pedicab under various conditions. The braking performance of a laden Pedicab was found to be significantly lower than that of a car. For example, if a Pedicab was following a car at 15km/h (9miles/h) with a headway of 2m and the car braked heavily then the pedicab would still be travelling at approximately 13km/h (8miles/h) when it hit the rear of the car (assuming rider reaction time to be 0.5 to 1 second). This would give a resultant impact speed of approximately 8km/h (5miles/h). A number of handling instabilities were also noted, particularly when the Pedicab was unladen, although stability with a single passenger was also a concern. All tests were conducted at a maximum speed of 15km/h (9 miles/h) for reasons of safety; it was noted that the quality of braking and handling performance would reduce considerably if the Pedicab was ridden at a higher speed.

A Primary and Secondary Safety Audit was undertaken to cover the crash performance of the Pedicab. This initially took the form of an assessment of the physical construction and features of the Pedicab, considering possible outcomes for a number of accident scenarios. Subsequently a full-scale crash test was conducted between the Pedicab and a passenger car travelling at 30miles/h. **It was concluded that the passenger compartment would provide little or no protection in the event of almost any accident and was likely to put the passengers in as much danger of injury in the event of an impact with a motor vehicle as if they were pedestrians.** It was also noted that the lap belt provided with the Pedicab would be unsuitable to restrain a child due to the loading it would apply to the child's abdominal region and the resulting injuries it could cause.

The above findings imply that the safety comparison between Pedicab journeys and pedestrian journeys they replace is likely to be dominated by differences in the risk of a collision occurring rather than by differences in crash protection. While not a matter covered by this project, it is clear that the skills and behaviour of Pedicab riders will play a key part in determining this risk.

1 Introduction

Following discussions with the Licensed Taxi Drivers Association (LTDA) regarding the safety of Pedicabs used in London, it was proposed that TRL conduct research to assess the specific safety concerns of this type of vehicle. Currently, Pedicabs are classified as "stage carriages" and as such are not subject to licensing regulations. The safety features of such vehicles are covered under regulations for "Construction and Use". TRL also understands that the Transport for London Cycling Centre of Excellence (CCE) are investigating primary safety issues concerned with Pedicab use such as correct driver behaviour and access for customers. TRL was asked to focus the evaluation on passenger safety rather than rider safety because members of the public might expect a certain level of safety from a mode of transport they are paying to use, without having to consider the practical aspects of the vehicle they are travelling in.

1.1 Literature Review

Since the current legislation adopted for the regulation of Pedicab safety is limited to construction and use regulations, further information was required to determine baseline safety criteria with which the Pedicab should comply. A literature search of existing regulations was conducted to provide information on existing safety requirements. It was recommended that primary safety be addressed within this section of the research.

1.2 Braking and Handling Trials

Two key areas of Pedicab primary safety are the braking and handling and a programme of testing was formulated.

The straight line braking performance was assessed on both wet and dry road surfaces in both laden and unladen conditions. The performance was measured in terms of acceleration (mean fully developed deceleration), stopping distance and stopping time for given test velocities. The performance was then compared to that of other similar road vehicles to give context to the findings.

The handling was assessed in terms of vehicle stability when turning, on both wet and dry road surfaces and in both laden and unladen conditions. The tests included steady state and transient turning manoeuvres at a range of test speeds. These results were also reported in the context of other similar vehicles.

1.3 Primary and Secondary Safety Audit

This includes assessing aspects of Pedicab safety such as seatbelt use, child safety and pedestrian impact. It was anticipated that there would be aspects of Pedicab safety which were beyond the limited scope of this investigation. TRL therefore proposed to ensure that the most significant areas for potential safety investigation were identified both from the perspective of making the evaluation of Pedicab safety as complete as possible and in order to identify areas for potential further consideration.

1.4 Full-scale Car to Pedicab Crash Test

As a result of the Primary and Secondary Safety Audit it was concluded that the Pedicab appeared to be particularly vulnerable to impact from a motor vehicle. It was decided to conduct a full-scale, car to Pedicab crash test to assess the basic level of protection afforded to the Pedicab passengers during this simulated accident scenario. Due to the risks of equipment damage, the dummies used were uninstrumented and the results of the test were analysed based on vehicle and passenger kinematics determined by analysis of the high-speed video.

2 A Review of literature relevant to the use of Pedicabs

2.1 Introduction

A review of literature associated with the design and use of bicycle rickshaws (Pedicabs) in relation to safety on the road was carried out. In cities such as London, Bath and Edinburgh, Pedicab services have been expanding in recent years. However, safety concerns have been raised since July 2001 when it was reported in The Scotsman and by the BBC (9/7/2001) that a passenger using a Pedicab service in Edinburgh had been seriously injured in an incident in which her scarf had become entangled in one of the vehicle's wheels. Also, one of the largest Pedicab operators (BugBugs) suspended two of their drivers after incidents of unsafe riding.
(http://www.workbike.org/news/bugbugswin.html)

Despite these concerns for safety, to date, literature is limited and the majority lies within specific regulations for the design, construction and use of a Pedicab. However, research is currently being undertaken by Government organisations on the best way to regulate Pedicabs with the aim of improving safety, if indeed they require regulation. Although this information may be a useful addition to this review, reports are unpublished at present and therefore TRL are unable to include these.

2.2 Legislation/Regulations

The design and construction of pedal cycles sold or used in the UK is governed by several Statutory Instruments. It is considered that most Pedicabs would also be subject to these regulations and those that are applicable to Pedicabs are summarised below:

2.2.1 The Pedal Bicycles (Safety) Regulations 1984 (S.I. 1984/145)

Pedal cycles should comply with British Standard 6102: Part 1, be marked with this Standard together with the manufacturer's name or code. This requirement does not apply to bicycles previously supplied and used on the road; bicycles with a saddle height of less than 635 millimetres; any competition bicycles; tradesman delivery bicycles or tandem bicycles.

In these Regulations a "tandem bicycle" means a bicycle which is designed to carry two or more persons, at least two of whom can propel the vehicle at the same time. A tradesman's delivery bicycle means a bicycle which is designed primarily or entirely for the carriage of goods in the course of a trade. Most Pedicabs do not meet any of these exemptions (although some recumbent designs may be exempt against the saddle height criteria) therefore this regulation would apply to most Pedicabs.

2.2.2 The Pedal Bicycles (Safety) Regulations 2003

This assessment estimates the costs and benefits associated with The Pedal Bicycles (Safety) Regulations 2003 which will replace The Pedal Bicycles (Safety) Regulations 1984 and The Pedal Bicycles (Safety) (Amendment) Regulations 1984. At the time of this assessment, there was no requirement for bicycle retailers to ensure that the bicycle was correctly adjusted at the point of sale, although in practice responsible retailers have made efforts to ensure this. The new regulations require retailers to correctly adjust the brakes of a bicycle in accordance with the manufacturer's specification before allowing the customer to use the cycle. The regulations will also ensure that a bell is fitted to the bicycle when purchased or provided, in the case of a kit bicycle that will be assembled by the buyer.

These regulations would apply to Pedicabs.

2.2.3 *The Pedal Cycles (Construction and Use) Regulations 1983 (S.I. 1983/1176).*

These Regulations revoke the Brakes on Pedal Cycles Regulations 1954. They apply to pedal cycles and also to Electrically Assisted Pedal Cycles.

- Every bicycle shall have at least one braking system (unless the pedals act directly on the wheel or axle without gearing or a chain).
- All bicycles or tricycles with a saddle height greater than 635 millimetres and every cycle with four or more wheels shall be as follows:-
  - Cycles which have no 'free wheel' require a front brake if they have one front wheel or 2 front brakes if they have 2 front wheels.
  - Cycles which have a 'free wheel' require brakes on at least two front and two back wheels depending on the design of cycle.

These regulations would apply to Pedicabs.

2.2.4 *The Electrically Assisted Pedal Cycle Regulations 1983 (S.I. 1983/1168).*

These regulations state that electrically assisted bicycles shall not have a kerb weight above 40 kilograms, an output of more than 0.2 kilowatts and cannot propel the bicycle at more than 15 mph. For tandem bicycles and tricycles the permitted kerb weight is 60 kilograms and an output of 0.25 kilowatts and cannot propel the bicycle at more than 15 mph. These regulations would apply to electrically assisted Pedicabs.

2.2.5 *The Highway Code*

The rules set out in the Highway Code apply to all road users and many of them are legal requirements. The Highway Code is designed to provide guidance that improves road safety and reduces accidents. Some of the advice provided is specific to cycling and Pedicab riders should pay detailed attention to this section.

2.3 Additional Literature

There are very few Pedicab operators who have openly recognised their responsibilities towards ensuring the safety of their riders and passengers. One UK business that has is BugBugs and who have written guidance on how associated risks are managed. Guidance produced by BugBugs, who have a fleet of over 60 Pedicabs (http://www.bugbugs.co.uk/Health_and_Safety_Policy.pdf, Smallwood C 2001), seeks to ensure safety by complying with legislation, introducing reward and disciplinary systems, undertaking risk assessments, and setting safety standards. Although there is a policy in place, it would require an audit of safety within the organisation to determine how effectively the policy has been implemented in practice.

Documents similar to that produced by the National Cycling Strategy entitled *'Cycling and Social Exclusion'* (http://www.nationalcyclingstrategy.org.uk/fileuploads/ncsb/NCSB54.pdf Rosen and Cavill 2003), address many issues, for example the implications for cycling professionals, but fail to tackle the key issue of safety, either of the passengers or riders. Equally, *'Assessing the Viability of Sustainable Freight Distribution in Urban Areas Using Work Bikes'* (http://www.workbike.org/research/index.html Rodgers 2001) discusses the Government's policy on sustainable transport. Although it aims to show how safe cycling is statistically, it still fails to identify a proactive approach to improving the road safety of riders or passengers.

There are a number of other research documents to be found on the Internet that highlight environmental issues relating to the use of Pedicabs. These fail to highlight any accident/casualty data and/or address issues relating to road safety, for example that of John Whitelegg of Liverpool John Moores University, and Nick Williams of University of Aberdeen (http://www.workbike.org/research/calcutta.html). '*Non-motorised Transport and Sustainable Development: Evidence from Calcutta*' outlines the important role that non-motorized transport plays in urban sustainability. Evidence shows that if Pedicabs were not used in Calcutta, levels of air pollution and poverty would increase. However, it is important to note that Pedicabs are an integral element of the transport system within Calcutta, but are not in London. Pedicab journeys in London are used more for short entertainment value and are not specifically intending to replace any of the existing modes of transport.

Interestingly, a report by Charles Henry, Urs Michel and Theo Schmidt, '*PedalLine, a new VeloTaxi concept*', does address environmental transport issues relating to the use of Pedicabs, but also points out that there is no legislation for 'workbikes' in most countries and it is likely that it will take a serious accident to force a review of this (http://www.workbike.org/research/pedalline.html).

2.4 Conclusion

At present, the UK has a number of regulations that aim to ensure an appropriate standard of construction of Pedicabs designed to be used on the public highway. Although the Highway Code does not mention Pedicabs directly, Pedicab riders, along with all other road users, are expected to comply with the Code in the same way as other road users and are open to prosecution if they do not comply.

However, as with all forms of transport, accidents do happen as highlighted above. As the use of Pedicabs increases, there becomes a greater need to work towards minimising all associated risks. Government bodies are currently undertaking studies that should provide an effective way of undertaking this task. The level of regulation is difficult to gauge, however, it must take into account current low levels of control and include communication with Pedicab operators.

The use of Pedicabs does have many potentially positive effects relating to environmental and sustainability issues, such as that shown through the example given in Calcutta. However, this can only be achieved if Pedicabs become an integral part of the transport system, replacing journeys that would otherwise be undertaken by motorised vehicles. Anecdotal evidence suggests that Pedicabs in London are, as stated above, used more for short entertainment journeys and therefore have little, if any effect on the environment. Such short journeys are not usually undertaken in buses or taxis within the City and therefore, the use of a Pedicab is more likely to be replacing walking as a mode of transport than any other. None of this should detract from addressing any safety concerns that are identified through future research and collision data analysis.

3 Braking and Handling Trials

3.1 Introduction

As part of this project TRL have carried out a series of braking and handling tests on a sample Pedicab, supplied to TRL by the LTDA. The straight line braking performance was assessed on wet and dry road with the vehicle unladen and laden. The handling performance was assessed in terms of stability when turning, on both wet and dry roads, with the vehicle unladen and laden.

3.2 Test vehicle

The LTDA supplied TRL with a sample Pedicab as illustrated in Figure 1.

Figure 1: Test Vehicle

The vehicle weighed 75kg, had a wheelbase of 1.85m and a track of 1.2m. The vehicle was equipped with an eight speed derailleur driving a three speed hub. The vehicle was equipped with a chain driven differential driving a hollow rear axle. The front wheel had a hydraulic rim brake and the rear wheels had hydraulic disc brakes using 185mm diameter discs.

The rear seating compartment was fitted with one lap belt designed to restrain the passengers. It should be noted that although it is most common for a Pedicab to carry two passengers, they can carry three, all of which would be restrained by the single lap belt.

3.3 Test equipment

The Pedicab was fitted with a GPS speed sensor capable of measuring the vehicles speed and position 20 times every second. From this data the sensor can then calculate the longitudinal and lateral accelerations of the vehicle. The speed of the vehicle was monitored by the rider using a small LED display mounted on the handlebars.

The laden test condition was simulated by placing un-instrumented crash test dummies in the rear seating compartment. The dummies weighed approximately 74kg each.

3.4 Test methods

Three different tests were carried out on the TRL research track to assess the Pedicab's braking and handling performance:

- Straight line braking tests
- Steady state cornering tests
- Lane change tests

These tests were carried out in both wet and dry conditions, and with the vehicle in both unladen and laden conditions. This section describes the test methods for these tests.

The maximum speed used for the braking and handling tests was 15km/h (9miles/h). It is appreciated that this is a relatively low speed for a Pedicab and that, in practice, some are ridden at higher speeds, however in the interests of health and safety it was decided to limit the test speed to 15km/h.

3.4.1 Straight line braking tests

The purpose of these tests was to assess the straight line braking performance of the Pedicab in both wet and dry conditions, and with the vehicle both unladen and laden. The test surface was approached at a constant speed of 15km/h (9miles/h), with the rider seated and maintaining a constant pedal speed. Once the vehicle was completely on the test surface the rider stopped pedalling and applied both the front and rear brakes as quickly as possible until the vehicle came to a complete stop. Six tests were carried out in both wet and dry conditions, and with the vehicle both laden and unladen. Table 1 summarises the straight line braking test programme.

Table 1: Straight Line Braking Summary

Road Surface	Vehicle Load	N° of tests
Dry	Unladen	6
Dry	Laden	6
Wet	Unladen	6
Wet	Laden	12
	TOTAL	36

For the unladen tests the vehicle was ridden without passengers in the rear seats. For the laden tests the vehicle was ridden with two 50th-percentile male dummies seated in the rear. Six tests were carried out with the dummies restrained using the vehicle's lap belt and six tests were carried out with the dummies unrestrained.

3.4.2 Steady state cornering tests

The purpose of these tests was to assess the stability of the Pedicab when continuously turning in both wet and dry conditions. For the steady state cornering tests, the Pedicab was ridden at a constant speed of 5km/h (3miles/h) in a clockwise direction in a circular path with a steering angle of 10°. The steering angle was slowly and smoothly increased until the inside rear wheel started to lift from the road surface or another sign of instability was exhibited. Six tests were carried out in both wet and dry conditions, and with the vehicle both unladen and laden. This test procedure was repeated at speeds of 10km/h (6miles/h) and 15km/h (9miles/h). Table 2 summaries the steady state cornering test programme.

Table 2: Steady state cornering summary

Road Surface	Vehicle Load	N° of tests	
Dry	Unladen	6	
Dry	Laden	6	
Wet	Unladen	6	
Wet	Laden	6	
	TOTAL	24	x 3 speeds = 72 tests

For the unladen tests the vehicle was ridden without any passengers in the rear seats. For the laden tests the vehicle was ridden with one 50th-percentile male dummy secured with the vehicle's lap belt in the nearside of the rear seats, as this represented the configuration most likely to cause the offside wheel to lift during the tests.

3.4.3 Lane change tests

The purpose of these tests was to assess the stability of the Pedicab during a sudden lane change manoeuvre.

The Pedicab was manoeuvred, in an unladen condition, at a constant speed through a lane as illustrated in Figure 2. The initial speed for this manoeuvre was 15km/h (9miles/h).

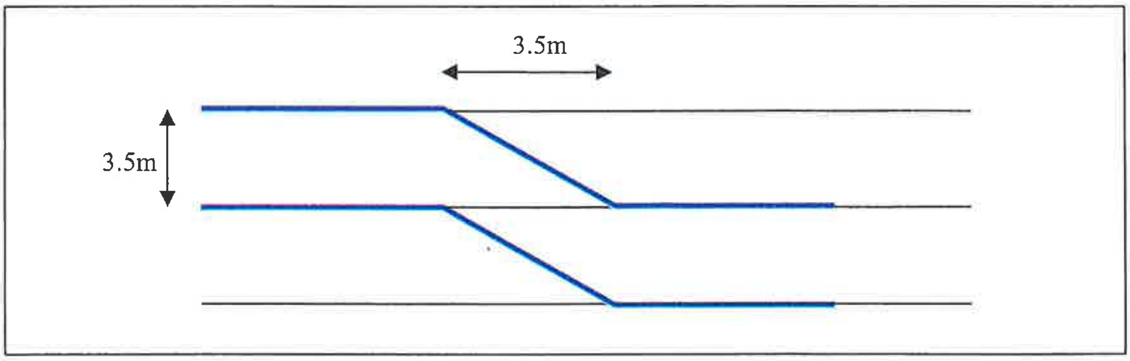

Figure 2: Lane change test configuration

Visual observations determined whether any of the vehicle's wheels lifted from the ground at any point during the test, and whether the rider was required to make any corrective steering to avoid the vehicle turning over. These tests were repeated five times (a total of 6 tests). The vehicle was re-tested in a laden condition. In addition all tests were repeated on a wet surface, as summarised in Table 3 below.

Table 3: Lane change summary

Road Surface	Vehicle Load	N° of tests
Dry	Unladen	6
Dry	Laden	6
Wet	Unladen	6
Wet	Laden	6
	TOTAL	**24**

For the unladen tests the vehicle was ridden without any passengers in the rear seats. For the laden tests the vehicle was ridden with two 50th-percentile male dummies secured with the vehicle's lap belt in the rear seats.

3.5 Test results

This section describes the results of the braking and handling tests carried out on the TRL Research Track.

3.5.1 Straight line braking tests

For each of the four test conditions detailed in Table 1, six tests were carried out. From these tests the stopping distance, stopping time and deceleration were recorded. Table 4 summaries the results of the straight line braking tests.

Table 4: Straight line braking results

Road Surface	Vehicle Load	Mean Test Speed (km/h)	Mean Stopping Distance (m)	Mean Corrected Stopping Distance (m)	Mean MFDD (g)	Mean Average Deceleration (g)	Mean Stopping Time (sec)
Dry	Unladen	15.5	3.0	2.8	0.49	0.32	1.3
Wet	Unladen	15.6	4.2	3.8	0.43	0.23	1.6
Dry	Laden	15.6	4.3	4.0	0.37	0.22	2.0
Wet	Laden	15.6	4.3	4.0	0.37	0.22	1.9

The influence of the test speed can have a substantial effect on the stopping distance; therefore it is desirable to eliminate this variation from the results. This was achieved by calculating an average deceleration for each test based on the actual recorded test speed and stopping distance. This value of average deceleration was then used to calculate a "corrected" stopping distance from the precise nominal test speed of 15km/h (9miles/h).

Figure 3 shows corrected stopping distances for the straight line braking tests. The results show that the Pedicab had the shortest stopping distance when unladen on a dry road surface. When the brakes were fully applied in these tests both the rear wheels locked causing the vehicle to skid to a complete stop. The front brakes did not have enough power to lock the front wheel at any point. When the wheels lock, the braking performance of a vehicle becomes limited by the coefficient of friction of the road. When the road surface was wetted, the friction was reduced and so the stopping distance of the Pedicab increased by approximately 35%.

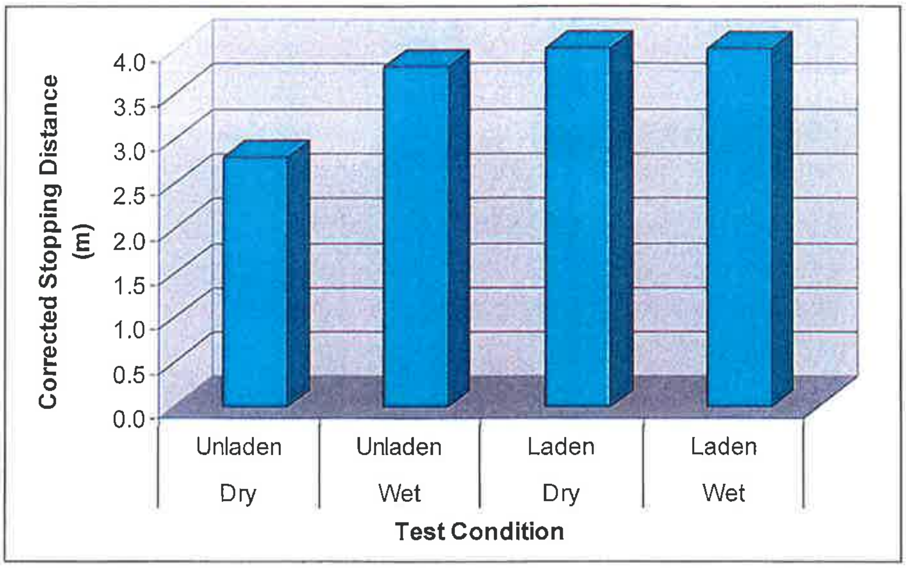

Figure 3: Corrected stopping distances

The results of the laden tests, with the two adult-sized crash test dummies restrained using the lap belt in the rear seating compartment, show that compared to the corrected stopping distance when unladen on a dry road surface, the stopping distance of the Pedicab increased by nearly 43%. For the laden tests the brakes did not have enough power to lock any of the wheels and so the braking performance was limited by the performance of the brakes rather than the friction of the road surface. This is confirmed by the almost identical results for the tests on a wet and dry road surface when laden.

The laden straight line braking tests were repeated with the dummies unrestrained in the rear seating compartment to investigate whether the dummies would fall from the Pedicab under braking if the lap belt was not used to restrain them. The laden tests, with the dummies restrained by the lap belt, had showed that the braking performance of the Pedicab was the same in both wet and dry conditions it was only necessary to test in one of these conditions.

Table 5 shows the results of the straight line braking tests with the dummies unrestrained in comparison with the test results for the laden tests with the dummies restrained with the lap belt. It can be seen that the results are very close indicating similar conditions for both sets of tests.

Table 5: Comparison of restrained and unrestrained test results

Vehicle Load	Mean Test Speed (km/h)	Mean Stopping Distance (m)	Mean Corrected Stopping Distance (m)	Mean MFDD (g)	Mean Average Deceleration (g)	Mean Stopping Time (sec)
Restrained	15.6	4.3	4.0	0.37	0.22	1.9
Unrestrained	15.7	4.6	4.2	0.38	0.21	1.9

Figure 4 shows the normal seating position of the dummies. It can be seen that, in their natural seating position, the dummies were leaning slightly backwards, as indicated by the green line. The use of the lap belt did not change the movement of the dummies as in both cases (with and without the lap belt) the lower half of the dummies remained seated throughout the tests. Under braking, the upper body of the dummies rotated forward until they were approximately upright. Also the lower leg of the dummies lifted slightly from their resting position. The approximate position of the dummies under braking is shown by the red line in Figure 4.

The results suggest that if the normal seating position of the dummies had been more upright then the likelihood of ejection under braking would have been greater.

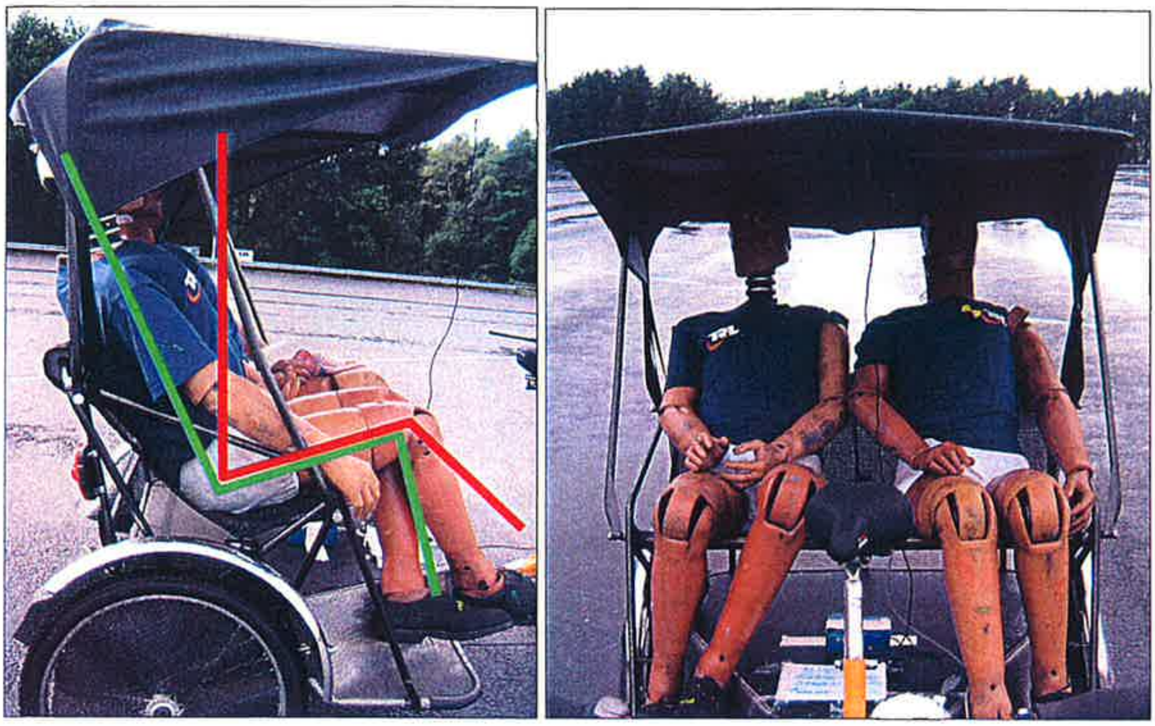

Figure 4: Seating position of dummies

Whilst the dummies offer a close representation of an adult their physical movement is more limited than that of a human and so it is possible that a relaxed adult seated in the rear of the Pedicab might move about more under braking than the dummies. However it is unclear whether, based on the maximum levels of deceleration possible from the vehicles brakes (just below 0.4g), the extra movement would result in a person falling from the Pedicab if unrestrained.

If the Pedicab were subjected to a higher rate of deceleration, possibly as a result of an impact with another object such as a car, then this would increase the likelihood of an unrestrained passenger falling from the Pedicab.

The results of the track tests show that the Pedicab took approximately two seconds to come to a complete stop from 15km/h (9miles/h) when laden with two crash test dummies in the rear. Past research carried out by TRL has shown that, under heavy braking, a typical road car will decelerate from 48km/h (30miles/h) with an average deceleration of 0.6g, and come to a complete stop in approximately 15m.

If it were assumed that a laden Pedicab was following a car at 15km/h (9miles/h), with a headway of 2m, then if the car braked heavily and it took the rider of the Pedicab between 0.5sec and 1.0sec to react and brake without steering, then the Pedicab would still be travelling at between 12.3km/h (7.7miles/h) and 13.9km/h (8.7miles/h) when it hit the rear of the car. At this time the car would also still be moving and so the resultant impact speed would be between 7.8km/h (4.9miles/h) and 8.7km/h (5.4miles/h). This shows that when laden the braking performance of a Pedicab is significantly lower than a car.

3.5.2 Steady state cornering tests

Tests were carried out in each of the four test conditions at three different speeds, 5km/h (3miles/h), 10km/h (6miles/h) and 15km/h (9miles/h). The vehicle was ridden in a clockwise direction in a circular path with a steadily increasing steering angle until the inside rear wheel started to lift from the road surface or another sign of instability was exhibited.

Table 6 summarises the results from the tests, showing the mean values of lateral acceleration and the mean radius of the path when wheel lift first occurred.

Table 6: Steady State Cornering Results

Road Surface	Vehicle Load	5km/h		10km/h		15km/h	
		Mean Lateral Acc (g)	Mean Radius (m)	Mean Lateral Acc (g)	Mean Radius (m)	Mean Lateral Acc (g)	Mean Radius (m)
Dry	Unladen	0.20	1.1	0.26	3.2	0.25	7.8
Wet	Unladen	0.20	1.1	0.27	3.0	0.25	7.1
Dry	Laden	0.17	1.2	0.23	3.5	0.21	8.5
Wet	Laden	0.17	1.1	0.22	3.4	0.22	8.4

A statistical analysis of the results shows that there was no significant difference between the mean lateral accelerations on the dry road surface to those on the wet surface, at each test speed. This is not unexpected as the inside rear wheel of the vehicle started to lift before the limit of sideways grip of the tyre was reached. This shows that the vehicle does not understeer but instead has a tendency to suffer roll instability.

For the laden tests, one crash test dummy was restrained, using the Pedicab's lap belt, in the nearside rear seat. The results show that the mean peak lateral acceleration that was reached before the inside rear wheel lifted was reduced by approximately 15% compared to the unladen tests. This reduction is caused by the additional weight of the crash test dummy on the nearside of the vehicle which changes the position of the centre of gravity of the vehicle, such that the onset of roll instability occurs at a lower speed for a given corner radius..

It should be noted that the values recorded during these tests are for the point at which the inside rear wheel first lifts from the ground and not the point at which the Pedicab would roll over. The rider stated that at the point of wheel lift, the loss of grip from the inside wheel meant that when any force was put through the pedals there was greater tendency for the inside wheel to spin. This effectively limited the speed of the Pedicab.

3.5.3 Lane change tests

For the lane change tests the Pedicab was ridden through a lane of cones as described in section 3.4.3. The test speed for these tests was 15km/h (9miles/h). Table 7 summarises the results for these tests, showing the mean peak values of lateral acceleration during the first and second turns of the manoeuvre.

Table 7: Lane Change Results

Road Surface	Vehicle Load	Lateral Acc (g)		Speed (km/h)	
		1st Peak	2nd Peak	1st Peak	2nd Peak
Dry	Unladen	0.29	0.28	14.5	14.1
Wet	Unladen	0.29	0.28	14.8	14.3
Dry	Laden	0.29	0.28	14.4	13.9
Wet	Laden	0.28	0.28	15.2	13.9

Table 7 shows that the peak values of lateral acceleration reached by the Pedicab were very similar for all the test configurations. What cannot be seen from Table 7 is the different way in which the vehicle behaved during the tests. When in its unladen state, the inside wheel of the Pedicab lifted off the road surface during each test, and in some cases the rider had to provide a small amount of corrective steering, however when the Pedicab was laden there was no longer any wheel lift during the manoeuvre, instead the change in direction caused the rear wheels to slide laterally across the surface as the Pedicab travelled through the lane. For the laden tests in the dry the sliding of the rear tyres left tyre marks on the road surface.

The maximum speed used for the handling tests was 15km/h (9miles/h). It is appreciated that this is a relatively low speed for a Pedicab and that, in practice, some are ridden at higher speeds. This speed was limited in the interest of health and safety and hence the handling problems seen in the tests are likely to be worse when the Pedicab is actually in use at a higher speed.

3.6 Conclusions

When laden the stopping distance of the Pedicab was approximately 35% longer than when unladen. There was no significant difference in stopping distance between the tests on the dry road surface and those on a wet road surface.

When unladen the rear wheels of the Pedicab locked during the straight line braking tests. This meant that the deceleration of the Pedicab was limited by the friction of the road. When laden, the wheels did not lock as the brakes could not apply sufficient torque. It is possible that an improvement in braking performance could be achieved when laden by upgrading the brakes.

When laden, the maximum deceleration (from 15km/h, 9miles/h) of the Pedicab was not high enough to cause an unrestrained crash test dummy to fall from the Pedicab.

The Pedicabs worst case stopping time of two seconds is comparable to a car stopping from 48km/h (30miles/h).

When a crash test dummy was seated on the nearside of the rear passenger seat, the lateral acceleration that the Pedicab could achieve before the inside rear wheel first lifted was decreased by approximately 15% compared to the unladen tests.

During the lane change manoeuvre the inside wheel lifted when the Pedicab was unladen, but this did not occur when it was laden. The rider stated that the Pedicab felt more stable through the lane change manoeuvre when laden.

The results suggest that the condition most likely to cause roll instability is when the Pedicab has one passenger in the rear seating compartment and this person is seated on the opposite side of the vehicle to the direction in which it is turning (i.e. seated on the left side when turning right). The test results suggest that when two people are seated in the rear the Pedicab the onset of roll instability will occur at a higher speed for a given corner radius.

4 Primary and Secondary Safety Audit

4.1 Introduction

The purpose of this audit is to identify areas not covered by the literature review and braking and handling trials and to evaluate the primary safety (systems to help prevent an accident) and secondary safety (protection afforded in the event of an accident) of the Pedicab by assessment of the construction, geometry and features.

4.2 Primary Safety

Aspects of primary safety cover accident avoidance as far as possible. In the case of the Pedicab, braking and handling capabilities, proper maintenance and use, durability and occupant behaviour could all affect the likelihood of accidents occurring. It is not within the remit of this report to cover maintenance and use, durability or occupant behaviour; however, some comments have been made relating to these aspects where obvious concerns have become apparent through the course of other investigations.

The braking and handling capabilities have been assessed and reported in Section 3. This investigation was limited to testing which could be carried out without the risk of injury to the Pedicab rider. (For example, sudden manoeuvring tests with unrestrained dummies could not be conducted because of the risk of the rider being struck by one of the dummies.)

Maintenance and use should be covered by the Pedicab having suitable instructions and this is discussed more fully below.

Requirements for durability are covered in the regulations identified in the Literature Review (Section 2); however, no tests have been carried out to ensure the Pedicab actually complies with these regulations (this would require disassembling and component testing the Pedicab, possibly to destruction). It should also be noted that the regulations identified would not cover the construction of the seat and lap belt and that no durability tests have been conducted on this part of the Pedicab.

4.2.1 Regulations

The regulations identified in the Literature Review (Section 2) were largely designed to cover bicycles rather than tricycles and a more detailed examination of these regulations has revealed the following possible areas where the Pedicab requires its own specific regulation and safety testing.

4.2.1.1 Reflectors

A bicycle is required to have orange reflectors on both pedals and either wide-angle reflectors on the spokes of the wheels or a continuous circle of reflective material on both sides of the wheel. Pedicabs have pedal reflectors but no side reflectors on the wheels and it could be argued that such reflectors are not entirely appropriate in this case since most Pedicabs are equipped with wheel cages to prevent passengers' trailing clothing from becoming caught in the wheels. However, as the Pedicab is significantly longer and higher than a standard bicycle, appropriate side reflectors are required but this is not covered by current regulations.

4.2.1.2 Instructions

BS 6102-1 states that each bicycle shall be provided with a set of instructions containing information on: preparation for riding (including adjustment of seat and handlebar height); recommended tightening of any fastenings on the handlebar and seat system and any quick release mechanisms; lubrication; chain, brake and gear adjustment; spares; accessories; recommendations for safe riding.

The Pedicab used for testing purposes here came with the following instruction manuals:

- Disc Brake Installation and Service Manual – covering regular maintenance as well as assembly and installation.
- Fitting and Operating Instructions for the Lights
- Installation and Maintenance Instructions for the Headset
- Fitting and Operating Instructions for the Dynamo
- Maintenance and Care Instructions for the Gear Assembly

Each of these manuals is comprehensive and full of useful tips and safety instructions. However, it is necessary to read all of each manual to be sure of the various regular maintenance checks that should be performed to ensure safe operation of the entire Pedicab. There are also no instructions for adjustment or maintenance of the front calliper brake or for maintenance of the tyres, seat, chassis or lap belt. There is also no overall manual to give advice on riding or storing the Pedicab.

4.3 Secondary safety

There are a variety of possible accident scenarios in which the Pedicab could be involved; it should be noted that there may also be the potential for passengers to be injured during the normal operation of the Pedicab. The current study is only concerned with the protection provided to passengers by the Pedicab. The rider is not considered as this was not within the original remit of this investigation.

4.3.1 Accident conditions

There are a variety of circumstances in which the passengers or pedestrians could be injured. The scenarios to be considered are listed below; in each scenario there are a variety of outcomes to consider, some of which would pose little or no threat to the Pedicab's passengers, some of which could result in serious injury.

Accident Conditions:

- The Pedicab collides with a stationary object (road furniture or vehicle)
- The Pedicab collides with moving vehicle
- The Pedicab overturns without collision occurring
- The passengers are ejected during braking or manoeuvring
- The Pedicab collides with a pedestrian

Possible Accident Outcomes:

- The Pedicab sustains the accident with no deformation and the passengers are restrained by the seatbelt.
- The Pedicab is pushed into the path of oncoming traffic by a collision with a moving vehicle or by rebounding from an impact with a stationary object (with the passengers still restrained inside).
- The Pedicab is deformed by the accident
- The passengers are fully or partially ejected from the Pedicab
- The driver is thrown into the passengers by the accident
- A pedestrian is pushed into the path of other traffic by an impact with the Pedicab

The Pedicab is evaluated in relation to the various possible outcomes below.

4.3.2 *Pedicab sustains an accident without deformation and passengers are restrained*

If the Pedicab sustains the accident with the passenger compartment intact and the passengers are restrained, there are still some potential risks to the passengers. Firstly, the interior of the passenger compartment showed the following flaws which could result in injury:

- The seat-belt is a single lap belt covering the whole of the width of the seat. It is not known how effective this would be for restraining the passengers in an impact but it is likely that there would be some risk of at least partial passenger ejection, especially in the case of single occupancy because of the width of the belt. Further testing is required to verify the effectiveness of the lap belt.
- The seat-belt is anchored below the level of the mesh seat and hence if there was more than one passenger in the Pedicab, those seated at the edges of the seat could be injured by the seatbelt buckle or anchorage.
- There are several points where contact with the frame of the passenger compartment could result in injury; this is due to protrusions.
- Excursion through the variety of holes and gaps in the frame of the passenger compartment is quite likely during an accident, even if the passenger compartment is completely intact and the passenger is restrained by the set-belt.
- The back of the seat could allow the passengers to contact the rear light fittings which have a variety of sharp protrusions.

Secondly, the seatbelt is an inertia reel lap belt, so that although it is not anticipated that the Pedicab passengers would see large accelerations due to emergency braking, an impact with an oncoming motor vehicle could result in a velocity change of between 30 and 50mph. In this case the lack of a shoulder belt could result in complete or partial passenger ejection and very likely some abdominal bruising for an adult. In the case of a child passenger it is unlikely that the lap belt would provide any restraint in the event of an impact, as children under approximately eleven years of age have insufficient pelvic development to be adequately restrained by an adult restraint system without injury. In the case of a lap belt, it is likely that there would be nothing to prevent the child from being ejected over the top of the belt and that the belt itself could cause serious injury to the child.

4.3.3 *Pedicab is pushed into the path of oncoming traffic*

The main risk to the passengers in this instance is from other vehicles colliding with the Pedicab due to its position. This is particularly a risk if the Pedicab has been pushed onto its side or roof, or the passenger compartment has been deformed. There is also a risk of injury from the motion itself since if the Pedicab is forced onto its side or roof and then pushed along by an impact with a heavier vehicle, there is nothing to prevent the passengers from being partially ejected and dragged along in direct contact with the road surface.

4.3.4 *Deformation of passenger compartment*

The Pedicab appears to have been designed and manufactured with no crash protection and therefore deformation or intrusion into passenger compartment is very likely in the event of an impact with a moving motor vehicle.

The following gives an overview of the design and build of the frame and the key features of the Pedicab's construction:

- The frame is made from what appears to be tubular steel, based on specifications given (seat frame is not distinguished from chassis) and general appearance. The frame is welded together at a few points as illustrated in Figure 5.

- The passenger compartment is anchored to the chassis in three places with 3 bolts.
- The roof frame is bolted to the rest of the frame with three restraining bolts at the back of the Pedicab and supported by a single strut on one side of the Pedicab (Figure 5).
- The floor of the passenger compartment is riveted to the frame as shown in Figure 6.
- The passengers' weight is supported entirely by a plastic mesh, strung between two supports. These supports and the roof structure are all there is to prevent the Pedicab deforming under loading from the side (Figure 7).
- The seat belt anchorages are thin pieces of steel held in place with a single weld (Figure 8).

If the passenger compartment structure deforms the passengers could be impacted directly by part of the vehicle or subjected to loading focussed by the deforming structure. In order to assess the effect of an impact from a moving vehicle on the passenger compartment, a full-scale crash test has been performed, the results of which are documented in Section 5.

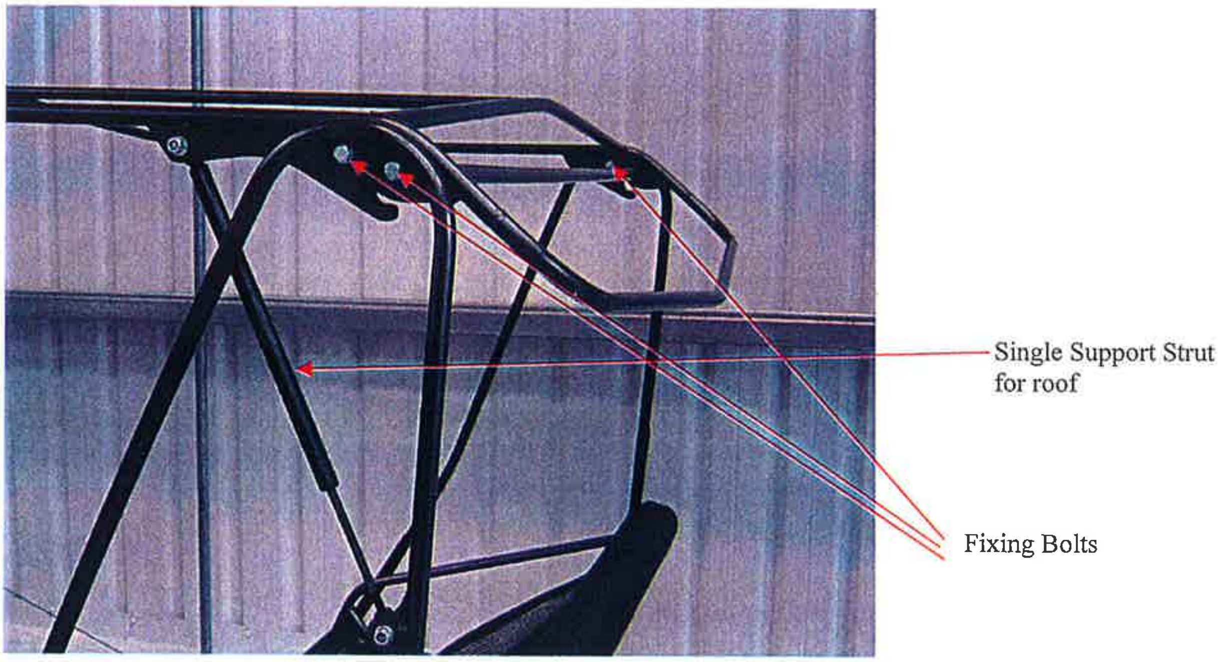

Figure 5: Roof Frame Attachment to Seat Frame

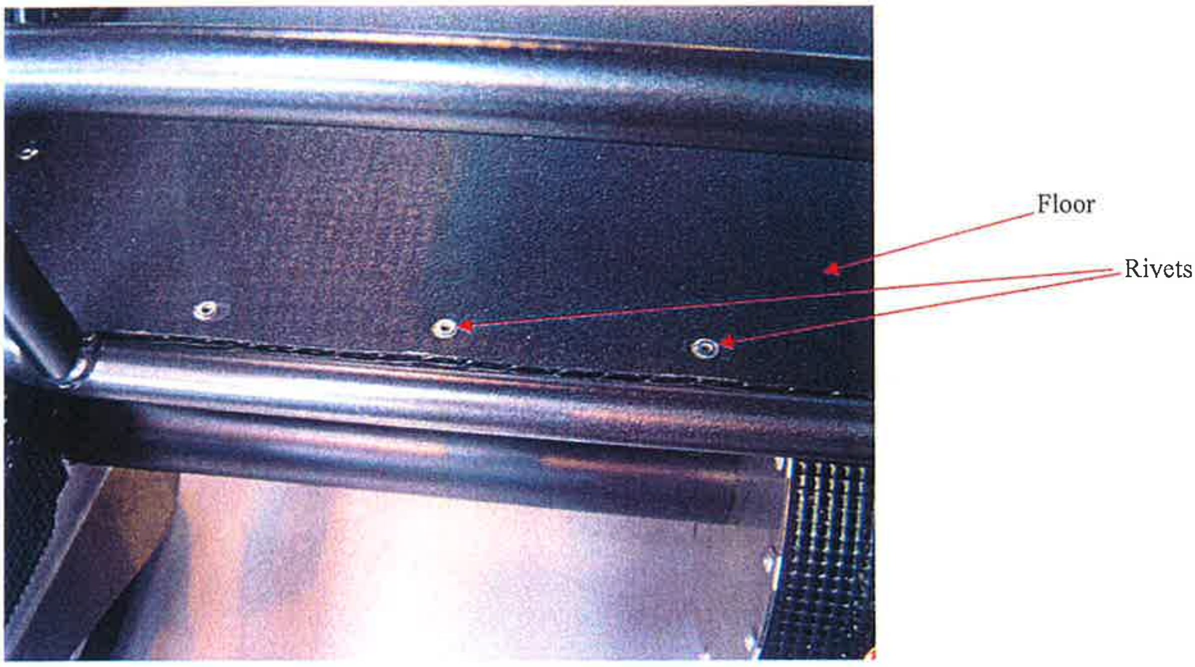

Figure 6: Floor Attachment to Seat Frame

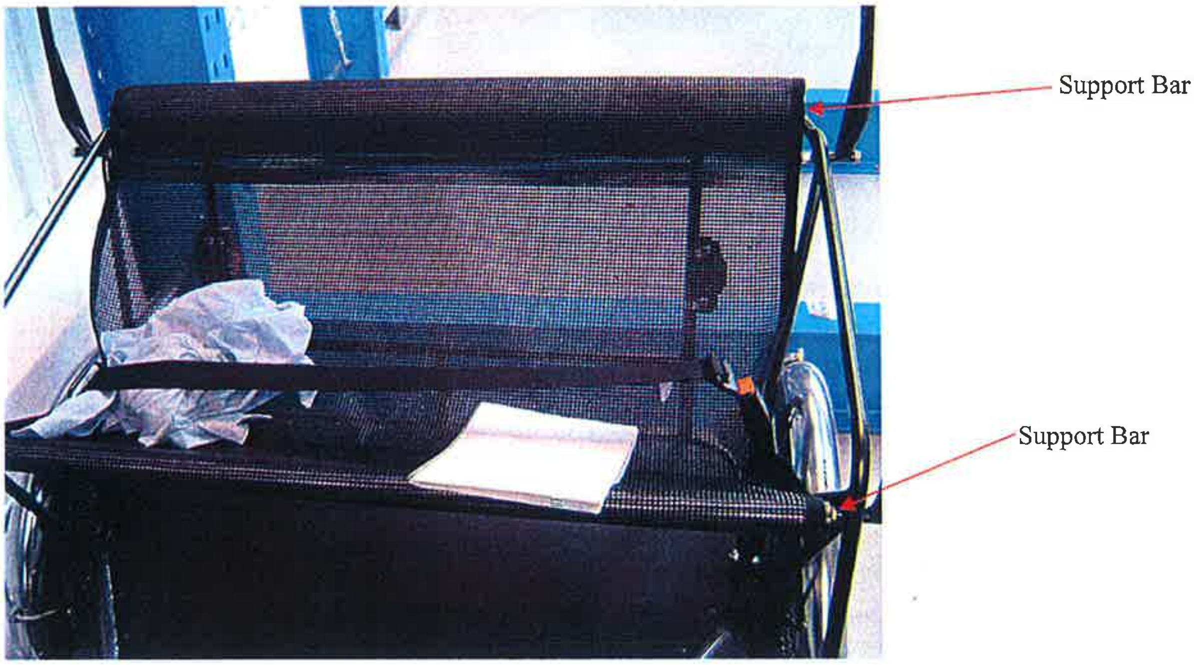

Figure 7: Seat Design

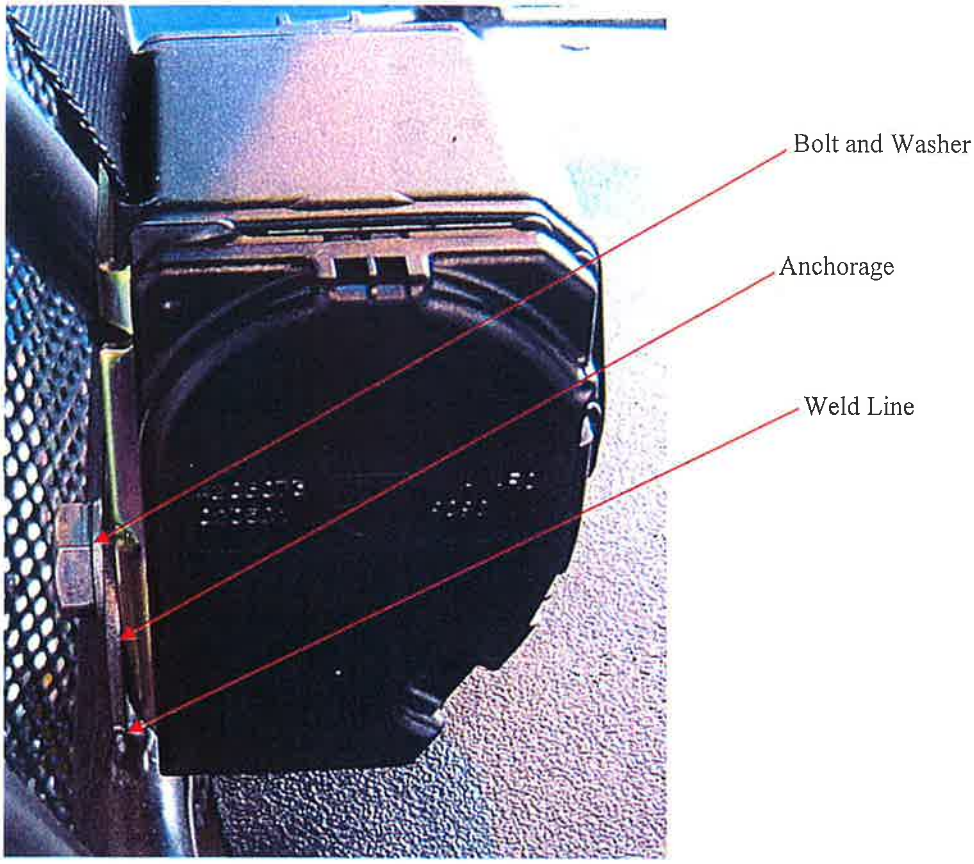

Figure 8: Seat Belt Anchorage

4.3.5 Passengers are ejected from the Pedicab

This scenario is the most likely result of almost any of the accident scenarios listed above as there is no legal requirement for the Pedicab to have a seatbelt, but although most do, pictorial evidence from various Pedicab websites suggests the vast majority of passengers choose not to wear one. It is also likely that a child would not be adequately restrained by the existing seatbelt in the event of an accident, partly because it is a restraint system designed for adults and partly because it is likely that children will be accompanied by an adult, thus the seatbelt will be deformed around the adult's pelvis and not come in contact with the child. It is also unlikely that adult passengers would be adequately restrained by the lap belt in the event of an impact (Section 5).

Passenger ejection also carries the potential for secondary accidents to occur if the passenger is thrown into the path of other traffic by an impact.

4.3.6 The rider is thrown into the passengers

Rearwards rider ejection is possible if the Pedicab is hit at speed from behind. However, the injuries the passengers are likely to sustain as a result of being hit by the rider are in addition to the injuries they would sustain as a result of the impact itself. In the case of a rear impact sufficient to eject the rider into the passengers, these would be caused by the vehicle intruding into the passenger compartment, causing both contact and acceleration injuries to the passengers.

4.3.7 Pedestrian impact

It is difficult to assess the effect that an impact from a Pedicab would have on a pedestrian, but it is likely the pedestrian would be injured and could be thrown into the path of other vehicles by the impact. However, if the pedestrian were hit by the passenger compartment rather than the front wheel it is possible they could be hit or run over without the driver realising it was a person that had been hit. It is also possible that if the passenger compartment hit a pedestrian the Pedicab itself could tip over, causing injury to the passengers.

4.3.8 Passengers are injured during transit

Most Pedicabs have complete mesh covers over the rear wheels to prevent passenger clothing from being caught in the wheels during the journey, however, part of the inside of the wheel is left exposed at the back (Figure 9). There is no guard on the chain as it runs under the passenger compartment (Figure 10). The shape of the seat means that it is unlikely that even children would be ejected during normal motion, however, emergency manoeuvres or high speed motion downhill could make this more likely. It should also be noted that since driver and passenger behaviour are unregulated there is nothing to prevent a passenger from choosing to stand during transit, which would obviously make them much more vulnerable to being thrown out of the Pedicab whilst it was still in motion.

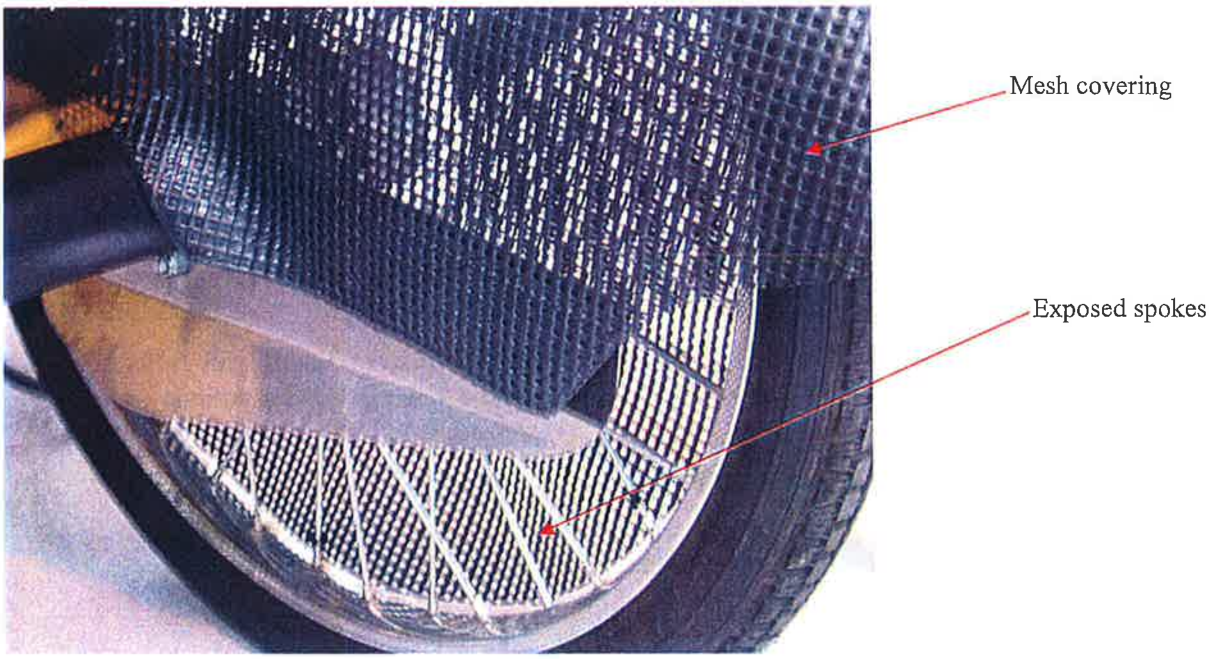

Figure 9: Exposed spokes at rear of Pedicab

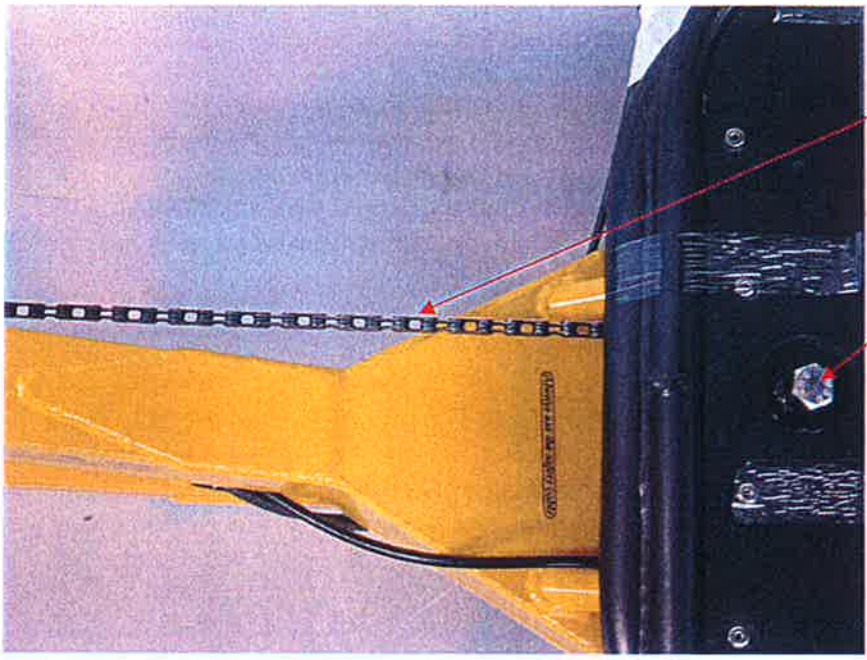

Figure 10: Exposed chain

4.4 Conclusions

- The Pedicab could protect the passengers in the event of a frontal impact with a stationary object, provided they were not ejected from the passenger compartment and the Pedicab remained upright. However, without further testing it is not known how effective the restraint system would be at restraining the passengers in this instance.
- If the passengers were children it is more likely that the seatbelt would not prevent them from being ejected completely from the Pedicab.
- If the Pedicab had a side impact with a stationary object, the passengers might not be adequately protected because of the risks of rollover and intrusion into the passenger compartment.
- Any accident which caused the Pedicab to roll over would have the potential to cause full or partial passenger ejection and therefore injury.
- Any impact by a moving vehicle is likely to result in injury to the passengers. This actual level of protection afforded by the passenger compartment is analysed in Section 5.

4.5 Possibilities for further research

The level of risk to unrestrained passengers in the event of a Pedicab manoeuvring sharply, overturning, or in the event of an impact is not known. It is difficult to test these scenarios with someone actually riding the Pedicab because of the risk to the rider being impacted by unrestrained crash test dummies. The alternative would be to conduct a small number of sled based tests, using a mock-up of a Pedicab seat and seatbelt to ascertain how far passengers could be thrown in the event of an impact. This type of testing could also be used to assess the effectiveness of the seatbelt for restraining children.

Impacts using instrumented dummies might also give an indication of any injury risk associated with the Pedicab impacting a stationary object.

5 Full-Scale Car to Pedicab Impact Test

In order to evaluate the crash protection provided by the Pedicab when impacted by a car, a full scale crash test was performed. This section of the report describes the objectives, test method and observations from the impact.

5.1 Objectives

The objective of the test was to demonstrate the crash protection provided to the passengers of a Pedicab during a simulated urban-environment collision with a passenger car.

5.2 Test methodology

The test aimed to simulate a collision where a Pedicab is impacted, at a junction, by a passenger car travelling at 48km/h (30miles/h). The angle between the longitudinal axis of the car and the longitudinal axis of the Pedicab was chosen to be 45 degrees, to represent the Pedicab turning right at, say, a cross-road junction, and being struck by a car travelling from left to right across the junction.

The test was performed in a large outdoor test area at TRL and the pre-impact positions of the two vehicles are shown in Figure 11 below. For the purpose of this test, the Pedicab was stationary prior to the impact.

Figure 11. Pre-impact vehicle positions

Two un-instrumented 50th percentile dummies were positioned in the passenger seat of the Pedicab and restrained by the lap belt. The dummies were positioned with an 'in-service' posture with their inboard feet positioned on the raised platform. Key features on the dummies were painted with slow drying paint to assist with identifying the contact points between the dummies and the vehicles. These included the knees, shins, shoulders and top of head.

In order to represent the mass of the rider of the Pedicab, sand ballast of mass 75kg was positioned close to the seat position. The sand ballast was designed to be frangible in order to separate from the Pedicab during the impact. The car was fitted with an un-instrumented 50th percentile dummy in the driver's seat with the restraint system fastened. During the test, the car impacted the near-side of the Pedicab at 30miles/h. The centre of the car was aligned with the central axis of the Pedicab between the hip point of the dummies. The car brakes were applied at approximately two seconds after t-zero.

The test was filmed with five high speed cine cameras at 400 frame/s. The camera views are shown in Figure 12.

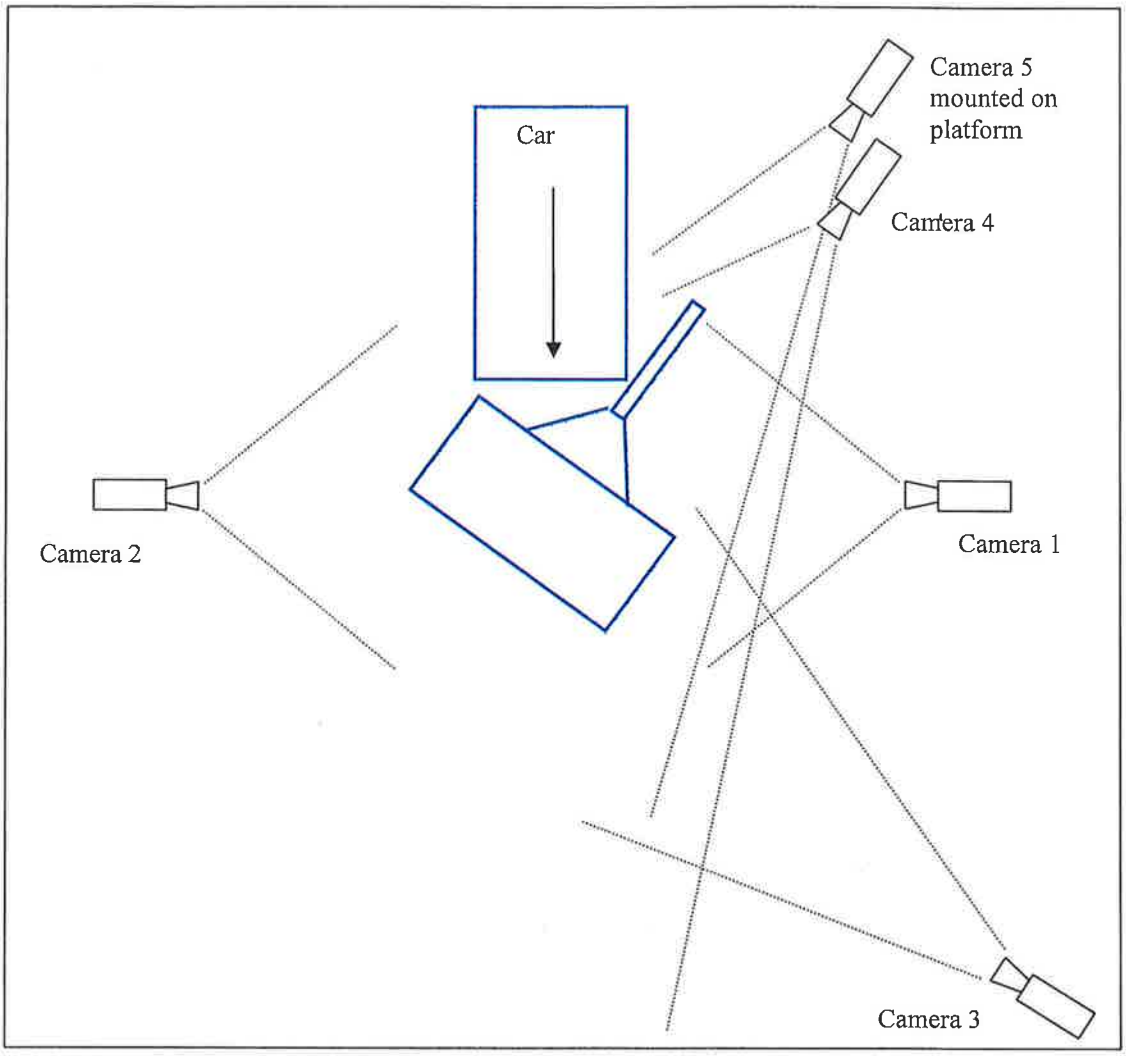

Figure 12. Camera views

5.3 Observations from test

The outputs from the test were:

- High speed camera footage
- Still photographs
- Contact marks

As the dummies were not instrumented no attempt has been made to quantify the injuries sustained by the Pedicab occupants.

The following observations of the impact were made, some of which are illustrated in Figure 13:

- During the early phase of the impact (t-zero until 70ms), the Pedicab becomes coupled to the car and starts to move sideways. The dummies are effectively decoupled from the Pedicab during this phase and remain stationary relative to the ground reference.

- The first contact between the car and the Pedicab occupants occurs at 25ms when the leading edge of the car bonnet contacts the left lower leg of the nearside occupant. Although this contact does not cause any movement to the torso of the dummies, it may induce very large forces into the lower limbs of the nearside occupant.
- The offside wheel of the Pedicab lifts at 50ms
- The second significant contact between the car and the Pedicab occupants occurs at 75ms when the front of the car interacts with the upper legs and pelvis of the dummies. Although it is not until 100ms that the dummies begin to translate sideways with the car.
- From 100ms to 200ms the Pedicab is lifted completely off the ground and rotates about the leading edge of the car bonnet and the dummies are accelerated to a velocity close to that of the car.
- The head of the nearside occupant makes contact with the bonnet of the car approximately 160ms after the initial contact between the vehicles
- The offside occupant is separated from the seat of the Pedicab, but this is restricted by the lap belt. However, the lap belt is directed into the joint between the hip and femur.

Figure 13. Observations during impact

Figure 14 and Figure 15 show the car and the Pedicab in their final resting positions. The contact marks from the dummy paint and damage to the car windscreen are shown in Figure 14.

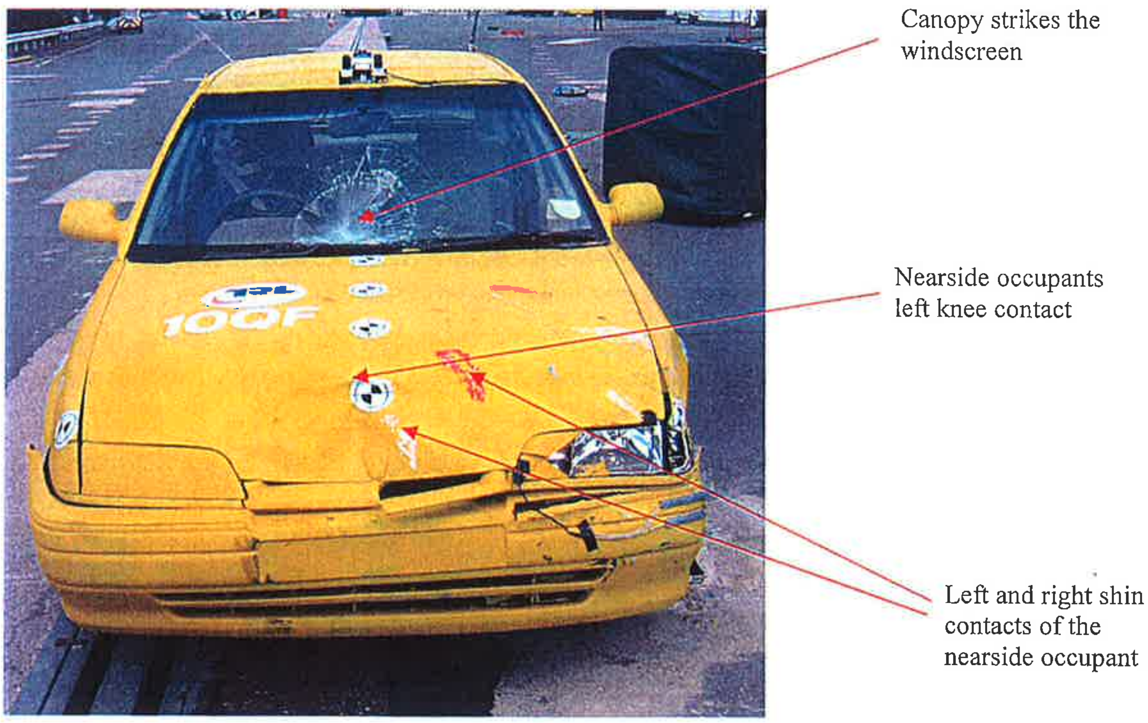

Figure 14. Damage to car and contact points

- The canopy prevents the head of the offside occupant impacting the car. There was contact between the heads of both of the dummies and the canopy
- There was also considerable abrasion to the rear of the head and shoulders of the nearside occupant where the Pedicab slid across the ground after it separated from the car.

Figure 15. Pedicab and occupants in final resting position

After the impact the passenger compartment remained in one piece with the seatbelt anchorages remaining attached to the frame. The lap belt was directed into the joint between the hip and femur on both of the occupants. For the nearside occupant, there was a failure in left femur-hip joint. The cross-member of the seat was deformed by loading from the dummies. Damage to the nearside of the occupant compartment was caused by loading from the occupants. This damage is shown in Figure 16.

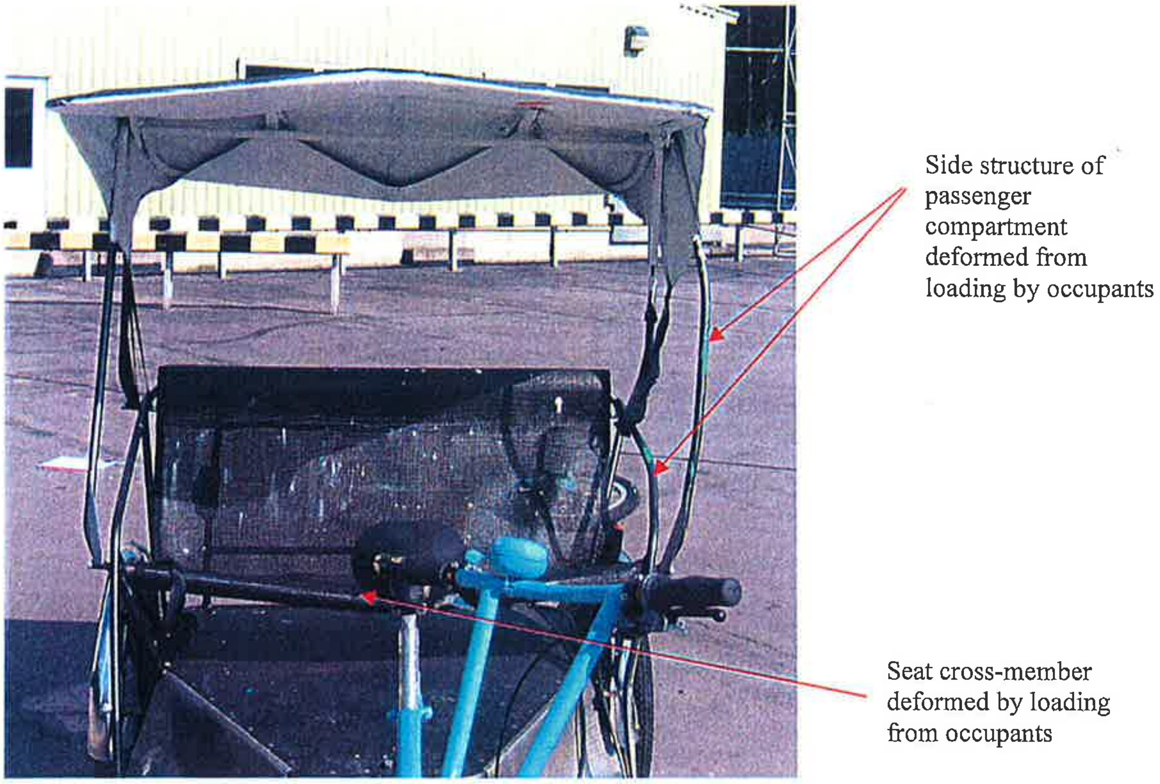

Figure 16. Damage to Pedicab passenger compartment

5.4 Conclusions

- The passenger compartment did not provide any significant protection to the occupants and the loads exerted were likely to be very similar to those on a pedestrian or cyclist during similar impact conditions.
- After the main impact event, after the Pedicab had separated from the car, the occupants suffered partial ejection from the Pedicab chassis and, therefore, the risk of impact and abrasion injuries would be significant.
- The seatbelt prevented the occupants from being ejected from the vehicle. However, this may not have been desirable given the lack of a crash worthy structure to control the loads imparted to the occupants. Furthermore, the seatbelt webbing was directed into the hip-femur joints of both dummies. In reality, this localised loading may cause abdominal injuries.

6 Conclusions

6.1 Primary Safety

- Existing Regulations covering Construction and Use of Bicycles could also be applied to Pedicabs but do not refer to them specifically. The Pedicab tested to produce this report did not comply with all regulations documented here.
- Pedicab riders are subject to the Highway Code but again, are not referred to specifically. No code of conduct exists for Pedicab riders except for guidelines issued by the Pedicab operators themselves.
- Although Pedicabs have the potential to have a positive effect on the environment this can only be achieved if they become an integral part of the transport system, i.e. a viable alternative to buses or taxis.
- The braking performance of a laden Pedicab is significantly lower than that of a car; at 15km/h (9miles/h) with two adult passengers the wheels failed to lock in emergency braking and the stopping distance would have been longer than that of a car travelling at the same speed. This distance would obviously increase with the speed of the Pedicab.
- The Pedicab was found to have roll instability when turning, especially when laden with a single passenger.
- In a lane change scenario the unladen Pedicab was found to require corrective steering to avoid tipping at 15km/h (9miles/h). The Pedicab was found to be more stable when laden with two adult passengers. It is not known what would happen if the Pedicab were travelling faster than 15km/h and laden unevenly with one passenger but it is likely that there would be a risk of instability and roll-over in a lane change manoeuvre.

6.2 Secondary Safety

- It was found that under emergency braking at 15km/h (9miles/h), the seat design did more to hold the passengers in the Pedicab than the lap belt.
- During an impact with a passenger car, the lap belt held the occupants within the vicinity of the passenger compartment. Given the lack of a crashworthy structure, this may not benefit the protection to the occupants.
- Based on known accident scenarios where children have been restrained using an adult belt system in a car, it is unlikely that the lap belt would have any effect in restraining a child in the event of an impact.
- In the event that the Pedicab turned over as the result of an accident, the passengers would be fully or partially ejected, resulting in injury.
- Any impact with a motor vehicle is likely to result in serious injury to both passengers and rider.

The above findings imply that the safety comparison between Pedicab journeys and pedestrian journeys they replace is likely to be dominated by differences in the risk of a collision occurring rather than by differences in crash protection. While not a matter covered by this project, it is clear that the skills and behaviour of Pedicab riders will play a key part in determining this risk.

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