PUBLISHED PROJECT REPORT PPR076

DEVELOPMENT OF MEASURES FOR IMPROVING CHILD PROTECTION IN MINIBUSES, BUSES AND COACHES

Version: Final

by G J L Lawrence and W M S Donaldson (TRL Limited)

Prepared for: Project Record: S0016/VF – Seatbelt Requirements for Minibuses and Coaches

Client: Transport Technology and Standards Division, Department for Transport (Mr Ian Knowles)

Copyright TRL Limited February 2006

This report has been prepared for Department for Transport, Transport Technology and Standards Division. The views expressed are those of the authors and not necessarily those of the Department for Transport.

Published Project Reports are written primarily for the Customer rather than for a general audience and are published with the Customer's approval.
This report has been produced by TRL Limited as part of a Contract placed by the Department for Transport. Any views expressed are not necessarily those of the Department for Transport.

TRL is committed to optimising energy efficiency, reducing waste and promoting recycling and re-use. In support of these environmental goals, this report has been printed on recycled paper, comprising 100% post-consumer waste, manufactured using a TCF (totally chlorine free) process.
CONTENTS

Executive summary i

Abstract 1

1 Introduction 1

2 Data from initial study (phase one of the project) 2
  2.1 Annual GB exposure estimates 2
  2.2 Accident types 4
    2.2.1 GB accident records for 1999-2001 4
    2.2.2 Injury patterns restrained / un-restrained 5
  2.3 Fitting trials 6
  2.4 Discussion of child restraint requirements and phase one data 7
    2.4.1 Discussion summary 9

3 Design requirements 9
  3.1 Specification for a universal seat (for restraining three year olds up to adults) 10
  3.2 TRL’s outline design solutions 12
    3.2.1 Idea 1a 12
    3.2.2 Idea 1b 12
    3.2.3 Idea 2 13
    3.2.4 Idea 3 13
    3.2.5 Idea 4 15
  3.3 TRL’s more detailed design solution 15
  3.4 Existing products 16

4 Evaluation of the effectiveness of the specification and accident forces 20
  4.1 Sled testing 21
    4.1.1 Sled test results 21
    4.1.2 Discussion of sled test results 25
  4.2 Rollover pendulum rig 29
  4.3 Modelling 31
    4.3.1 Model structure 33
    4.3.2 Model validation 35
    4.3.3 Modelling results 36
    4.3.4 Discussion of simulation results 41

5 Recommendations 42

6 Conclusions 43

Acknowledgements 44

References 45

Appendix A. Rollover pendulum rig – design details 46
Executive summary

Although seatbelts are now required in all new buses registered after 1st October 2001, legally only the passengers in the front seats of the buses are required to wear them. In this context ‘buses’ includes minibuses and coaches as well as buses, except buses for urban use (i.e. standee buses). There have been discussions within the European Union about making the wearing of seatbelts, where provided, mandatory in all minibuses, buses and coaches and the EU has subsequently amended the seatbelt wearing Directive 91/671/EEC, extending its coverage to these vehicles (i.e. vehicles of categories M2 and M3). National governments are required to bring the amendment into force by 9th May 2006. This will have great benefit for adults as seatbelts are designed for adults. However, the benefits of adult seatbelts for children are less clear because they do not fit so well unless additional provisions are made for them. The amended Directive has a number of exceptions including standee buses and children under three years old in M2 & M3 vehicles. However, the European Commission is continuing to study this issue, particularly the exemptions, and will submit appropriate proposals where necessary. National governments would have some freedom to make additional requirements to those of the EU such as not exempting children under three years old or requiring special provisions for children in M2 & M3 vehicles.

This study was conducted in two phases, with the first phase aiming to determine how often and in what circumstances child occupants travel in minibuses, buses and coaches and if, and to what extent, they are being injured. The second phase was to devise appropriate measures for restraining children in minibuses, buses and coaches that reduce the risk of them suffering the injuries identified in phase one and that suit the operational requirements of these large vehicles.

The phase one study was carried out by the Vehicle Safety Research Centre, Loughborough and has identified the groups of children who would have issues of poor fit when wearing adult seatbelts. If the seatbelts do not fit correctly, then there would be a risk that in accidents some child passengers would suffer severe or fatal injuries caused by the seatbelt loading their body in an inappropriate way. The study also provided estimates of the number of journeys undertaken by children in coaches, buses and minibuses. One of the important conclusions from the phase one study was that an unsatisfactory seatbelt fit was observed for the majority of children when sitting in the seat with no aid (no booster cushion, etc.) and wearing the adult seatbelt. The results of the phase one study have been used to define the issues to be addressed by the phase two study and the protection requirements for any design solution.

This report describes the work carried out for the phase two study and highlights the development of different solutions, and the modelling and testing of the most practical solution. It was important when proposing solutions that they were based on the existing adult restraint system and the associated components and fixtures in order to minimise the cost of installing such systems.

The report discusses whether current and likely future child casualty rates from accidents in buses, coaches and minibuses would justify the provision of restraint measures for children. It suggests that although the current rates are low, requiring children to wear poorly fitting adult seatbelts in minibuses, buses and coaches could increase the level of child injuries.

The report recommends that car type child restraint systems (CRSs) be used in coaches and minibuses (and in buses where seatbelts are provided). For the 0 to 3 year old age group it is recommended that these could be provided by the parents (‘universally approved’ CRS) or the coach operator (CRS approved for the vehicle / seat combination or ‘universally approved’). Note, however, that the use in cars of CRSs with ISOFIX attachments is rapidly increasing and ISOFIX products and approval methods are currently still evolving. ‘Universally approved’ CRSs with ISOFIX attachments could not be used in PSV type vehicles unless the seats were also ISOFIX compatible. The provision of CRSs by parents would only be a realistic option if almost all parentally owned CRSs could be used.

If the above recommendation is not considered to be feasible then the permitted exemption from compulsory seatbelt wearing, under the EU Directive, for children of less than three years old, should be taken up.
It also recommends that Public Service Vehicles (PSVs) that carry children should be fitted permanently with an adequate number of seats that can be adjusted to fit any size of occupant from about three years old up to an adult (a universal seat). The number of universal seats fitted in a specific vehicle could be decided by the operator depending on the use cycle that they anticipate.

If it is thought necessary to have a formal approval method for universal seats for use by children then a sled based test method is recommended, this test could be similar to that used in this study and could use the ECE Regulation 44 criteria. (The universal seat, including any integrated seatbelt anchorages, would also have to be approved for use by adults in the same way as a standard coach seat.)

It recommends that consideration should be given to introducing a rollover seat strength test for seats with integral seatbelt anchorages intended for use in minibuses, buses and coaches. The test could use a pendulum rig, similar to that described in the report.

The conclusions from the work were:

Examination of national accident data for children shows that, relatively, very small numbers of children are killed or seriously injured in accidents involving PSVs such as buses, coaches and minibuses.

When national child casualty numbers for buses and coaches are combined with estimates of the number of journeys made, it can be seen that there is a very low child casualty rate per journey, with a killed or seriously injured rate of only 0.13 per million vehicle journeys for all ages of children.

Biomechanically, children are not simply miniature adults. From birth through childhood their needs from a restraint system change as they grow. Young children are less able to withstand local seatbelt loading to their shoulder, chest or pelvis, and infants also need support for their head (to minimise loading of their neck).

Although no examples of injuries induced by poorly fitting seatbelts could be found in the study of accident data, it is thought that poorly fitting adult seatbelts could increase the level of child injuries.

A series of fitting trials have been carried out, using seats typical of those found in PSVs and a sample of child volunteers, to evaluate the fit of the adult belt. The trial also explored what improvements to the fit were brought about by using a range of child restraint aids intended for use in cars.

- The survey found that typically an unsatisfactory seatbelt fit was observed for the majority of the children of ages ranging from 1 to 11 years old, when wearing the adult seatbelt. An unsatisfactory fit of the diagonal part of the belt was the main cause; however, there were a significant number of ‘unsatisfactory fits’ found with the lap belt.
- It was also found that the adult seatbelt will not provide a ‘good fit’ for children of three years old or less.
- The seating trials were then repeated using car-type child restraint aids (booster seats and booster cushions) intended for older children from about 4 years old up to about 11 years old and it was found that these restraint aids could provide a ‘good fit’.
- Use of car-type child restraint systems (CRSs) improved the fit of the adult belt by lifting the child or by both lifting and moving the child forward.
- Fitting a child into an adult’s seat can also be a problem for certain statures of child if the depth of the seat base is such that they cannot bend their knees. For many children their legs would be too long to fit when straight out in front of them and would clash with the back of the seat in front.
- The results of the survey showed that the shoulder height of the seated child offered the best indicator of whether a child restraint was required.

The fitting trial included a survey to determine whether it was feasible to fit car-type CRSs, for the 0 to 3 year old age group, in coaches and minibuses. The study concluded that it would be feasible, but not necessarily easy, to use car type CRSs in these vehicles.
It can be concluded from the fitting trial that if a satisfactory restraint is to be obtained then car type CRSs or similar solutions need to be used for all child passengers (from 0 up to the age of about 11 or 12 years old) carried in buses, coaches and minibuses.

For older children, due to the operational logistics of providing appropriate CRSs in PSVs in sufficient numbers and range of sizes, it is thought not to be practical to use car-type CRSs. It has therefore been concluded that the most practical way of providing a satisfactory restraint would be to fit the vehicles permanently with an adequate number of seats that can be adjusted to fit any size of occupant from about three years old up to an adult (a universal seat).

When the seatbelt wearing Directive has been implemented it will make seatbelt use compulsory for all children of three years old and over and, without some form of appropriate system to adjust the fit of the adult belt, this might, in some circumstances, increase the risk of injury for some children.

A design specification has been produced for a universal seat intended for occupants of three years old up to adult.

A universal seat design has been devised by TRL and other solutions have been found that were made by seat and restraint manufacturers.

Sled testing has shown that the TRL universal seat specification will achieve a ‘good fit’ of the adult belt for occupants of three years of age up to adult. Careful observation and interpretation of the results suggest that the child would have a high risk of suffering severe neck and abdominal injuries on the standard seat but not on the raised seat.

Despite the difficulty in interpreting the results of a child-restraint sled test, this method is considered the best method for final approval of a universal seat for use by children, should a formal approval method be required. The universal seat (including any integrated seatbelt anchorages) would also have to be approved for use by adults in the same way as a standard coach seat.

Mathematical modelling has been used to obtain estimates of the accident forces likely to act on the locked seat adjusting mechanism when occupied by a large child.

By comparing the results of the sled tests with the mathematical modelling it has been concluded that, providing that the occupant model is satisfactory, as was the case with the larger occupant model used, additional valid information can be obtained.

The MADYMO three year old child dummy model used was found to be inadequate for assessing the performance of an adult seatbelt in the universal seat.

If it is considered beneficial to have an adequate mathematical model of a small child occupant, to help design universal seats, then an improved one could be developed. However, the option of using a physical dummy in a sled test to develop and assess a universal seat can be used instead for this age group.
Abstract

Although seatbelts are now required in all minibuses and coaches as well as buses (except buses for urban use, i.e. standee buses) registered after 1st October 2001, legally only the passengers in the front seats of the buses are required to wear them. There have been discussions within the European Union about making the wearing of seatbelts, where provided, mandatory in these vehicles (i.e. vehicles of categories M2 and M3) and the EU has subsequently amended the seatbelt wearing Directive 91/671/EEC, extending its coverage to these vehicles. National governments are required to bring the amendment into force by 9th May 2006. This will have great benefit for adults as seatbelts are designed for adults. However, the benefits of adult seatbelts for children are less clear because they do not fit so well unless additional provisions are made for them.

This study was conducted in two phases, with the first phase aiming to determine how often and in what circumstances child occupants travel in minibuses, buses and coaches and if, and to what extent, they are being injured. The second phase was to devise appropriate measures for restraining children in these vehicles that reduce the risk of them suffering the injuries identified in phase one and that suit the operational requirements of these large vehicles.

One of the important conclusions from the phase one study was that an unsatisfactory seatbelt fit was observed for the majority of children when sitting in the seat with no aid (no booster cushion, etc.) and wearing the adult seatbelt.

This report describes the work carried out for the phase two study and highlights the development of different solutions and the modelling and testing of the most practical solution. It was important when proposing solutions that they were based on the existing adult restraint system and the associated components and fixtures in order to minimise the cost of installing such systems.

1 Introduction

Until the late 1990’s it was unusual for seatbelts to be fitted in large passenger-carrying road vehicles such as minibuses, buses and coaches. Since then, seatbelt fitting rates have increased in new vehicles of this type. Over time, there has been increasing public awareness of the benefits of seatbelts as the savings from compulsory wearing in cars have become obvious. Because of this, the public’s attitude towards seatbelts and other vehicle safety systems has become more positive. As a result of this and Government targets to reduce road casualties, there is an ongoing process of improving vehicle safety and introducing more demanding safety legislation.

Although seatbelts are now required in all new buses registered after 1st October 2001, legally only the passengers in the front seats of the buses are required to wear them. In this context ‘buses’ includes minibuses and coaches as well as buses, except buses for urban use (i.e. standee buses). There have been discussions within the European Union about making the wearing of seatbelts, where provided, mandatory in all minibuses, buses and coaches and the EU has subsequently amended the seatbelt wearing Directive 91/671/EEC (Council of the European Communities, 1991; European Parliament and Council of the European Union, 2003), extending its coverage to these vehicles (i.e. vehicles of categories M2 and M3). National governments are required to bring the amendment into force by 9th May 2006. This will have great benefit for adults as seatbelts are designed for adults. However, the benefits of adult seatbelts for children are less clear because they do not fit so well unless additional provisions are made for them. The amended Directive has a number of exceptions including standee buses and children under three years old in M2 & M3 vehicles. However, the European Commission is continuing to study this issue, particularly the exemptions, and will submit appropriate proposals where necessary. National governments would have some freedom to make additional requirements to those of the EU such as not exempting children under three years old or requiring special provisions for children in M2 & M3 vehicles.

This study was conducted in two phases, with the first phase aiming to determine how often and in what circumstances child occupants travel in minibuses, buses and coaches and if, and to what extent, they are being injured. The second phase was to devise appropriate measures for restraining children
in minibuses, buses and coaches that reduce the risk of suffering the injuries identified in phase one and that suit the operational requirements of these large vehicles.

The phase one study (Grant et al., 2005) was carried out by the Vehicle Safety Research Centre, Loughborough (VSRC) and has identified the groups of children who would have issues of poor fit when wearing adult seatbelts. If the seatbelts do not fit correctly, then there would be a risk that in accidents some child passengers could suffer severe or fatal injuries caused by the seatbelt loading their body in an inappropriate way. The study also provided estimates of the number of journeys undertaken by children in coaches, buses and minibuses. One of the important conclusions from the phase one study was that an unsatisfactory seatbelt fit was observed for the majority of children when sitting in the seat with no aid (no booster cushion, etc.) and wearing the adult seatbelt. The results of the phase one study have been used to define the issues to be addressed by the phase two study and the protection requirements for any design solution.

This report describes the work carried out for the phase two study and highlights the development of different solutions and the modelling and testing of the most practical solution. It was important when proposing solutions that they were based on the existing adult restraint system and the associated components and fixtures in order to minimise the cost of installing such systems.

2 Data from initial study (phase one of the project)

The aim of phase one was to address several questions regarding the safety of children in minibuses, buses and coaches. The main questions to be answered were:

- How often, and in what circumstances, child occupants travel in minibuses, buses and coaches, and what differences there are according to age?
- How often, and in what accident circumstances, child occupants are injured?
- Is there evidence to identify and differentiate between the injury patterns of unrestrained and restrained child occupants?
- Is there evidence to identify seatbelt-induced injury mechanisms for children wearing ‘adult’ seatbelts?
- How well does the geometry of current restraint systems, intended for adults, fit children of different ages and statures?
- On the basis of all of this information, what are the requirements for the restraint of children of different ages?

The data collected from this study were used to define the scale of the problem and the requirements for transporting children safely in minibuses, buses and coaches. The key findings from the study (Grant et al., 2005) are listed in Sections 2.1 to 2.3.

2.1 Annual GB exposure estimates

A survey was carried out to collect data on the number of trips that children of particular age groups undertook in a year on large passenger vehicles (minibuses, buses and coaches). The survey questionnaire was sent to schools and other child groups, such as cubs, brownies, etc. The response to the questionnaire was very limited and hence an accurate picture could not be obtained. Also, only journeys organised specifically for children could be included, so for instance journeys by school bus were included but not those made by public transport. However from the data collected the exposure estimates in Table 2.1 below were calculated. The number of responses for the 0 to 3 year old age group was particularly small; therefore the estimated number of journeys column in Table 2.1 has been shaded to indicate that valid estimates of the number of passenger journeys for this group could not be made.
Table 2.1: Annual GB estimates for the number of journeys organised for children made by 0 to 3 year olds and 4 to 11 year olds in buses, coaches and minibuses (derived from Grant et al., 2005)

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Number of journeys</th>
<th>0 to 3 year olds</th>
<th>4 to 11 year olds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus or Coach</td>
<td>154,960</td>
<td>105,881,529</td>
<td></td>
</tr>
<tr>
<td>Minibus</td>
<td>25,020</td>
<td>12,514,415</td>
<td></td>
</tr>
</tbody>
</table>

Estimates of journeys taken by 4 to 11 year olds have been compared with their casualty numbers in coaches or buses and in minibuses to obtain a casualty rate and a killed and seriously injured (KSI) rate per million journeys and these are given below in Table 2.2 (coaches or buses) and Table 2.3 (minibuses). It must be noted that the journey and casualty data are not strictly comparable, as journey estimates only include journeys organised for children but casualties are those arising from all journeys made by children. Although numbers are also given for 0-3 year olds, valid estimates of the number of passenger journeys and hence of casualty rates for this group could not be made, so these areas have been shaded to indicate their uncertainty. The options being considered can only prevent injuries if the occupant is restrained and this in turn requires that the occupant be seated. Many casualties on buses particularly will be injured when they are standing or when boarding or alighting. For the buses and coaches category only casualties that were seated were included in this analysis. The police are not required to provide this information for minibus casualties so in most cases it was not possible to exclude those who were not seated. However, the few minibus casualties where the police provided data, those that were recorded as standing or boarding or alighting were excluded. Standing, boarding and alighting casualties in minibuses will be a much smaller proportion than they are in bus accidents.

Table 2.2: Estimated GB child casualty rates for travel by coaches or buses, for seated casualties only (derived from Grant et al., 2005)

<table>
<thead>
<tr>
<th>Age</th>
<th>GB population (1000's)</th>
<th>Passenger journeys over 3 years (millions)</th>
<th>Casualty count over 1999-2001</th>
<th>Casualty rate / million journeys</th>
<th>KSI rate / million journeys</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>638</td>
<td>0</td>
<td>0 2 47 49</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>658</td>
<td>0.138</td>
<td>0 5 159 164</td>
<td>1191</td>
<td>36.3</td>
</tr>
<tr>
<td>2</td>
<td>677</td>
<td>0.192</td>
<td>0 2 187 189</td>
<td>985</td>
<td>10.4</td>
</tr>
<tr>
<td>3</td>
<td>689</td>
<td>0.135</td>
<td>0 4 178 182</td>
<td>1345</td>
<td>29.6</td>
</tr>
<tr>
<td>4</td>
<td>709</td>
<td>13.6</td>
<td>0 3 193 196</td>
<td>14.38</td>
<td>0.22</td>
</tr>
<tr>
<td>5</td>
<td>698</td>
<td>17.2</td>
<td>0 2 177 179</td>
<td>10.43</td>
<td>0.12</td>
</tr>
<tr>
<td>6</td>
<td>703</td>
<td>24.0</td>
<td>0 2 101 103</td>
<td>4.29</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>723</td>
<td>29.8</td>
<td>0 4 105 109</td>
<td>3.65</td>
<td>0.13</td>
</tr>
<tr>
<td>8</td>
<td>732</td>
<td>33.3</td>
<td>0 1 178 179</td>
<td>5.38</td>
<td>0.03</td>
</tr>
<tr>
<td>9</td>
<td>759</td>
<td>40.1</td>
<td>0 3 189 192</td>
<td>4.78</td>
<td>0.07</td>
</tr>
<tr>
<td>10</td>
<td>765</td>
<td>46.9</td>
<td>0 6 293 299</td>
<td>6.38</td>
<td>0.13</td>
</tr>
<tr>
<td>11</td>
<td>749</td>
<td>112.8</td>
<td>0 7 388 395</td>
<td>3.50</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>8500</td>
<td>318</td>
<td>0 41 2195 2236</td>
<td>7.03</td>
<td>0.13</td>
</tr>
</tbody>
</table>
### Table 2.3: Estimated GB child casualty rates for travel by minibuses (derived from Grant et al., 2005)

<table>
<thead>
<tr>
<th>Age</th>
<th>GB Population (1000’s)</th>
<th>Passenger Journeys over 3 years (millions)</th>
<th>Casualty # count over 1999-2001</th>
<th>Casualty # rate / million journeys</th>
<th>KSI # rate / million journeys</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>638</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>658</td>
<td>0</td>
<td>1</td>
<td>9</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>677</td>
<td>0.075</td>
<td>0</td>
<td>9</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>689</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>709</td>
<td>2.01</td>
<td>0</td>
<td>15</td>
<td>8.47</td>
</tr>
<tr>
<td>5</td>
<td>698</td>
<td>2.50</td>
<td>0</td>
<td>9</td>
<td>3.60</td>
</tr>
<tr>
<td>6</td>
<td>703</td>
<td>1.25</td>
<td>1</td>
<td>18</td>
<td>14.39</td>
</tr>
<tr>
<td>7</td>
<td>723</td>
<td>2.81</td>
<td>0</td>
<td>27</td>
<td>10.34</td>
</tr>
<tr>
<td>8</td>
<td>732</td>
<td>4.38</td>
<td>0</td>
<td>21</td>
<td>4.79</td>
</tr>
<tr>
<td>9</td>
<td>759</td>
<td>6.82</td>
<td>0</td>
<td>30</td>
<td>4.40</td>
</tr>
<tr>
<td>10</td>
<td>765</td>
<td>6.32</td>
<td>0</td>
<td>33</td>
<td>6.01</td>
</tr>
<tr>
<td>11</td>
<td>749</td>
<td>11.46</td>
<td>0</td>
<td>44</td>
<td>4.19</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>8500</strong></td>
<td><strong>37.6</strong></td>
<td><strong>2</strong></td>
<td><strong>254</strong></td>
</tr>
</tbody>
</table>

# Injured passengers who were not known to be standing, boarding or alighting (information on whether minibus passengers were seated is not available in most cases)

#### 2.2 Accident types

One aim of the phase one study was to obtain typical serious accident scenarios for buses and coaches, from accident data. The intention was that these typical scenarios could be converted into simplified tests that could be used to determine the effectiveness of any protection system developed. Available in-depth accident data for bus or coach and minibus accidents were examined in order to try to determine these scenarios. For most of the accidents investigated, either the files contained too little information, the accidents were not serious or appeared to be too unique for ‘typical’ representative serious scenarios to be identified.

#### 2.2.1 GB accident records for 1999-2001

To enable the risk of injury to children in large passenger vehicles to be assessed it was important to understand the types of accidents that occur for larger vehicles (buses and coaches) and smaller vehicles (minibuses). The data for the GB accident analysis were obtained from the STATS 19 accident database which is compiled from police accident reports. The data, for coaches or buses and minibuses with passenger casualties that were involved in accidents, were sorted into four main accident categories as shown in Table 2.4 below.
Table 2.4: Percentage of coaches or buses and of minibuses involved in accidents with a passenger casualty or casualties (adult or child) by first contact point (1999 to 2001 STATS 19 data) (Grant et al., 2005)

<table>
<thead>
<tr>
<th>First point of contact</th>
<th>Proportion of all vehicles involved for each point of first contact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coach or bus * (%)</td>
</tr>
<tr>
<td>No impact (e.g. braked and passenger fell over, etc.)</td>
<td>54</td>
</tr>
<tr>
<td>Frontal</td>
<td>28</td>
</tr>
<tr>
<td>Side</td>
<td>13</td>
</tr>
<tr>
<td>Rear</td>
<td>5</td>
</tr>
<tr>
<td>All</td>
<td>100</td>
</tr>
</tbody>
</table>

* Coaches and buses with an injured passenger who was seated
# Minibuses with an injured passenger who was not known to be standing, boarding or alighting (information on whether minibus passengers were seated is not available in most cases)

Some of these four types of initial contact for the minibus category given in Table 2.4 would have been followed by the vehicle rolling over. In the three years of GB accident data considered, rollovers represent 10% of all the minibus accidents involving injury to their passenger(s) (TRL analysis, excludes passengers known to be not seated). However, these rollover accidents caused 58% of all fatalities and 38% of all serious injuries to passengers. The high proportions of serious and fatal injuries occurring in rollover accidents show that this is potentially the most dangerous type of accident. It is thought that the provision and use of seatbelts would be particularly effective in reducing the occurrence of these injuries by preventing partial and full ejection of the occupants.

As with minibus accidents some of these four types of initial contact for the bus and coach category given in Table 2.4 would have been followed by the vehicle rolling over but this is very infrequent in Great Britain. In the three years of accident data considered rollovers only represent 0.2% of all the bus and coach accidents involving injury to seated passengers(s) (TRL analysis). No published data for the rollover rate in other European countries could be found but unpublished data, provided in confidence, suggest that the rate may be about 40%, presumably for accidents involving all occupants, which is far higher than the GB rate of 0.2%. One cause of this huge difference may be the very different terrain in Europe and the high number of tourist coach trips to the mountainous regions of Europe.

The numbers of injured seated passengers in coaches or buses and of injured passengers in minibuses, for all known ages and for children aged 0 to 11 years old, are shown by severity in Table 2.5.

2.2.2 Injury patterns restrained / un-restrained

It was not found to be possible to identify and differentiate between the injury patterns of unrestrained child occupants and those restrained because seatbelt use by individual occupants is not recorded in the STATS 19 database and no alternative source of suitable data could be found.
## Table 2.5: Numbers of injured seated coach or bus passengers and minibus passengers # over a three year period (1999 to 2001) by injury severity level for all known ages and for 0 to 11 year olds (STATS 19 data, TRL analysis)

<table>
<thead>
<tr>
<th>Injury severity</th>
<th>Coach or bus</th>
<th>Minibus #</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All ages</td>
<td>Ages 0-11</td>
</tr>
<tr>
<td>Fatal</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Serious</td>
<td>643</td>
<td>41</td>
</tr>
<tr>
<td>Slight</td>
<td>14,629</td>
<td>2,206 *</td>
</tr>
</tbody>
</table>

# Injured passengers who were not known to be standing, boarding or alighting (information on whether minibus passengers were seated is not available in most cases)

* These numbers are slightly higher than those in Tables 2.2 and 2.3 because those tables were each obtained by combining two tables from Grant et al., for casualties on journeys to or from school and those not on journeys to or from school, and a few casualties where this was not recorded were thereby excluded

### 2.3 Fitting trials

A series of fitting trials were carried out using four different types of seat and a sample of child volunteers to evaluate the fit of the adult belt. The trial also explored what improvements to the fit were brought about by using a range of child restraint aids. For the fit of the belt to be judged a ‘good fit’:

- The diagonal part of the belt should cross the rib cage, and apply its principle force to the shoulder (close to, but not on the neck). It should neither slip off the shoulder nor engage or rub against the neck.
- The lap part of the belt should wrap around the bony pelvis, without riding up over the abdomen (noting that the bone iliac crests of the child pelvis are less well developed than an adult, increasing the risk that the belt could ride up onto the abdomen).

Depending on the type of seat, the survey found that typically an unsatisfactory seatbelt fit was observed for over 50% of the children of ages ranging from 1 to 11 years old when sitting in the seat with no aid (no booster cushion, etc.) and wearing the adult seatbelt. An unsatisfactory fit of the diagonal was the main cause; however, there were a significant number of unsatisfactory fits found with the lap belt (average of 19% for the four seats). It was also found that the adult seatbelt will not provide a ‘good fit’ for children who are three years old or less.

The seating trials were then repeated using car-type child restraint aids (booster seats and booster cushions) intended for older children from about 4 years old up to about 11 years old. These improved the fit of the adult belt by lifting the child or by both lifting and moving the child forward. The quality of the fit of the diagonal and lap belt portions of the seatbelt were noted for each combination of aid, seat and child.

Fitting a child into an adult seat can also be a problem for children of a certain stature if the depth of the seat base, from front to back, is longer than the length between the back of the child’s buttocks and the back of their knee, when seated. In this case the child would not be able to bend their knees and would have to sit with straight legs. Alternatively, they could slump in the seat (i.e. with the buttocks forward and the shoulders on the seat back) which would cause the lap belt to ride up into a dangerous position on the abdomen. For many children, their legs would be too long to fit when straight out in front of them and would clash with the back of the seat in front. Therefore, measurements were also taken of the angle between the femur and tibia, in the above fitting trial survey.
The results of the survey were analysed to determine what criteria should be used in deciding when and what type of child restraint should be used. The three main criteria investigated were: age, weight and the height of the shoulder when seated. The results showed that the seated shoulder height offered the best indicator of whether a child restraint was required. The survey also found that many smaller children were unable to bend their knees when using the standard seat or booster cushion due to the length of the cushion.

As the number of journeys in buses, coaches and minibuses is very low for children in the 0 to 3 year old category, one option for this group would be for car-type child restraint systems to be provided by the parent or the vehicle operator. Child restraint aids for this group normally consist of a child seat which is held into the vehicle seat by the adult seatbelt. The child is then restrained in it by a separate harness which is attached to the child seat. As these arrangements can be quite bulky, especially the rearward facing type, which is used for young children, it was not clear whether it would be practical to fit these in the confines of a bus, coach or minibus. Therefore a further study was carried out to determine whether it was feasible to fit this type of seat in real vehicles. The study concluded that it would be feasible, but not necessarily easy, to use car type child seats in these vehicles.

2.4 Discussion of child restraint requirements and phase one data

It would be a mistake to think of children simply as miniature adults. They are proportioned differently and their tissues have different biomechanical properties. From birth through childhood, what they need of a restraint system changes as they grow and although their development follows broad trends, growth rates vary from child to child. A restraint system can, to some extent, be designed to accommodate the growth of a child; however, there are a number of key stages in their development that govern the way a child can be restrained.

During infancy, the skull is made up of a series of broadly spaced elastic bones and it must therefore be protected from direct concentrated loading. Furthermore, motion of the head with respect to the torso must be avoided because the resulting inertial force that is applied through the (immature) neck can cause serious injury. Also, at this stage the shoulder, rib cage and pelvis are very small and elastic and unable to engage with, or withstand the level of loading associated with harnesses or seatbelts. A rear facing child restraint system is therefore the best solution for protecting infants as the restraint forces are distributed over the back (the strongest surface of the body) and the head and neck receive a high level of protection.

It is beneficial for a child to remain rear facing as long as possible; however, the risk of neck injury due to inertial loading from the head is reduced from around 18 months because the muscles and ligaments have developed more strength. In this stage of early childhood a child is able to travel forward facing but the ribs and pelvis are still relatively small and flexible. To minimise the risk of restraint induced injuries, a child receives the best protection in a child restraint with a five-point harness. The fifth point provides a crotch strap which is necessary to keep the lap straps on the pelvis preventing them from riding up onto the soft abdomen.

By the age of four, most children have outgrown this type of child restraint. It is likely their shoulder sitting height has increased beyond the highest position of the harness and their head is higher than the top of the child seat. They may also have grown heavier than the maximum weight allowed for the child restraint. When any of these occur the child must move to a booster seat because they will not be able to achieve the correct placement and fit with the adult seatbelt on its own. Furthermore, the pelvis has still not developed sufficiently and is prone to slip under the lap belt if the fit is poor. A booster seat is needed, therefore, to raise the seating position of the child so that the lap belt passes over the top of the thighs (reducing the risk of abdomen loading) and the diagonal belt crosses the chest and lies flat on the centre of the shoulder.

It might be concluded, from the low KSI (Killed and Serious Injuries) casualty per journey rates in Table 2.2 and Table 2.3 and the low number of child casualties in Table 2.5, that requiring children to wear poorly fitting adult seatbelts in minibuses, buses and coaches would be unlikely to be a serious issue. However, although no examples of injuries induced by poorly fitting seatbelts could be found
in the study of accident data, it is thought that poorly fitting adult seatbelts could increase the level of child injuries.

Therefore, it can be concluded from the fitting trial that if a satisfactory restraint is to be obtained, the provision of car type CRSs, or similar solutions, would be necessary for all child passengers (from 0 up to the age of about 11 or 12 years old) carried in buses, coaches and minibuses. However, when these vehicles are used as PSVs then the use of car type CRSs may not be compatible with the use cycle of these vehicles.

For the 0 to 3 year old age group the estimated number of journeys is very low, see Table 2.1, but it must be noted that it proved impossible to obtain accurate estimates for this age group. The unreliable data for the 0 to 3 year old age group can be seen more clearly in Table 2.2 and Table 2.3 where no journey data were obtained for some groups despite them being represented in the STATS 19 casualty data. Nevertheless, despite this being an underestimate it is likely that the true number of journeys made by 0 to 3 year olds in these vehicles is comparatively small. As described above, infants and young children are less able to withstand local seatbelt loading on their shoulder and chest and they also need support for their head (to minimise loading of the neck). In cars this problem is resolved for 0 to about 3 year olds by the use of a rearward facing child restraint system with side head protection wings and a multi-point harness. In frontal impacts, which are the most frequent type of collision, the back of the rearward facing child seat supports the head and the impact forces are distributed onto the child’s back through the seat back. It is thought that protection for this age group might be provided, most practically, by using car type CRSs in minibuses, buses and coaches. These could be provided by the PSV operator (on loan) or by the child’s parents. It should be noted that the fitting trial showed that car type CRSs for the 0 to 3 year old age group would also fit in PSV type vehicles and that their use was feasible, but not necessarily easy. However, not all CRS are ‘universally approved’ for use with any vehicle / seat combination. Therefore, ideally, only ‘universally approved’ parentally owned CRSs would be used in PSV type vehicles. Also, the use in cars of CRSs with ISOFIX attachments is rapidly increasing. ISOFIX products and approval methods are currently still evolving. ‘Universally approved’ CRSs with ISOFIX attachments could not be used in PSV type vehicles unless the seats were also ISOFIX compatible. The provision of CRSs by parents would only be a realistic option if almost all parentally owned CRSs could be used.

For older children, where the number of journeys and the proportion of child passengers on a vehicle are likely to be higher, the provision of car type booster cushions and booster seats is thought to be impractical. This is because many PSV vehicles will have a very mixed use cycle which would require the CRSs to be fitted and removed many times. For instance a coach might be used for children in the morning and evening and for adults during the day. In this case the logistics of providing appropriate CRSs in sufficient numbers and range of sizes, of fitting and adjusting them to suit the child at the pick-up point and then removing them and storing them, when the vehicle switches to adult use, would make such a solution impractical. Therefore this option would only be feasible if the vehicle was dedicated to carrying children of a limited range of ages and sizes for large periods of time during its use cycle. For vehicles with a mixed use cycle, the most practical solution for PSVs would appear to be to fit the vehicles permanently with adequate numbers of seats (for the use cycle of the vehicle) that can be adjusted to fit any size of occupant from about three years old up to an adult so that both the fit of the adult seatbelt is appropriate and the child can fit in the seating space available (i.e. they can bend their knees so that their feet do not conflict with the back of the seat in front). Examination of car CRSs, for the age range of three years old and upwards, showed that CRSs that use the adult belt to restrain the child improve the fit of the seatbelt by raising the child in the seat (booster cushions) or by both raising and moving the child forward (booster seats). Some booster seats also redirect the diagonal belt outwards, away from the neck. In addition the booster seats provided wings in the head area to protect the head in angled and side impacts.

A lower cost alternative to providing devices to improve child restraints in PSV type vehicles would be to exempt smaller children from compulsory seat belt wearing. The seatbelt fitting trials carried out in the first phase of this project concluded that sitting shoulder height was the best measure of determining a child’s restraint needs. The fitting trial gave the child shoulder heights where the transition occurred between a poor and an acceptable fit with an adult belt; these varied slightly for
the different seats used in the trial but a height of about 420 mm was typical. However, as a borderline poor fit is probably better than no seatbelt, then a slightly lower limit of 400 mm might be better and it could be suggested that children with a seated shoulder height of less than 400 mm could be exempted from compulsory seatbelt wearing. This sitting shoulder height would roughly correspond to a typical six year old child. However, national governments in the EU are constrained by the requirements of the Directive which only allow the exemption of children of less than three years old. Therefore this suggestion could only be allowed if the Directive were amended. At the very least, it is recommended that the permitted exemption from compulsory seatbelt wearing, under the EU Directive, for children of less than three years old, be taken up.

2.4.1 Discussion summary

- Both the use of PSVs by children and the numbers of fatal and seriously injured child casualties in these vehicles are comparatively low.
- Poor fit is likely to increase the occurrence of seatbelt-induced injuries in the more serious types of accidents by loading the neck and/or soft abdomen. For very young children (infants) the risks of serious or fatal neck injuries are further increased due to their large head and weak neck.
- Infants are also less able to withstand local seatbelt loading on their shoulder, chest and pelvis than older occupants.
- The fit of adult belts is poor to unacceptable for the majority of young children from 0 up to the age of about 8 and most need some form of aid to improve the fit of the seatbelt up to the age of 11, therefore:
  - Appropriate car type CRS should be provided in minibuses, buses and coaches for children of ages of 0 to about 3 years old.
  - Some form of adjustment of the seat or seatbelt geometry, to improve the fit of adult belts for children between the ages of 3 up to about 11 years old, should be provided in minibuses, buses and coaches.
- Rollover accidents have a higher rate of serious and fatal injuries than other impact configurations. As this high rate is thought to be linked to ejection, then retaining occupants through compulsory use of well fitting belts will be beneficial in rollover accidents.
- The design of solutions for car type CRSs may inform design solutions for PSVs and it should be noted that:
  - car CRSs for the age range of three years old and upwards, that use the adult belt to restrain the child, improve the fit by raising the child in the seat (booster cushions) or by both raising and moving the child forward (booster seats). Some booster seats also redirect the diagonal belt outwards, away from the neck.
- The typical minibus and coach seat spacing and the depth (front to back) of the seat cushion is such that children of a certain stature range will be unable to bend their knees, causing their feet to foul the seat in front. Therefore for this child group they must either be moved forwards in the seat or the seat base length must be adjustable.

3 Design requirements

As discussed above, the restraint requirements for children are different to those of adults. The decision by the European Union to require compulsory fitment of seatbelts in ‘buses’ (in this context ‘buses’ can mean minibuses, buses and coaches), and their use by those aged three years and over, causes a fit issue for children between the ages of 3 up to about 11 years old, unless provisions are made for children as well as adults. If the proposal to use car CRSs in minibuses, buses and coach for
the 0 to about 3 year old age group is accepted then a solution needs to be found for the group consisting of the larger 3 year olds up to about 11 years old. For this age group the only practical solution in the majority of PSV operational roles would appear to be to fit the vehicles permanently with seats that can be adjusted to fit any size of occupant from about 3 years old up to an adult so that both the fit of the adult seatbelt is appropriate and the child can fit in the seating space available (i.e. they can bend their knees so that their feet do not conflict with the back of the seat in front). The number of universal seats fitted in the vehicle could be chosen by the PSV operator to suit their use of the vehicle.

This part of the project focuses on developing practical design solutions for a universal seat and seatbelt system intended for use in coaches, buses and minibuses. This should provide suitable adjustments to obtain a satisfactory seatbelt fit for a range of statures from that of children aged 3 years old to those of adults. The aim of this part of the project was to suggest a practical outline design specification to be used for all types of minibus, bus and coach seat.

There were three threads to this part of the work. These were to:

- produce a specification for a universal seat
- determine the effectiveness of the specification
- determine the forces acting on a universal seat, to help designers produce solutions of appropriate strength.

### 3.1 Specification for a universal seat (for restraining three year olds up to adults)

Examination of car CRSs for the age range of three years old and upwards that use the adult three-point seatbelt to restrain the child, showed that they improve the fit by raising the child in the seat (booster cushions) or they both raise and move the child forward (booster seats). The effect of moving the child obtains a good fit by:

1. routing the belt such that it lies more over the upper legs of the child rather than on the abdomen;
2. moving the upper part of the diagonal away from the neck and onto the shoulder and chest;
3. resolving the problem of smaller children not being able to bend their knees without slumping in the seat by moving them upwards in a shorter seat or moving the child both upwards and forwards.

Current car type CRSs for the older age group all work by moving the child, however, it should be noted that the same effect for points one and two above could also be achieved by having adjustable belt anchorage locations. Moving the upper anchorage downwards or outwards would move the diagonal belt off the neck. For the lap belt, moving the two lower anchorages down would move the belt more across the thighs and prevent abdominal loading. Providing a movable upper anchorage appears to be feasible. These are seen in many cars, where they are located on the B post, however, it may be more difficult for minibus, bus and coach seats where the upper anchorages are normally part of the seat. In these vehicles the lower anchorages are also normally part of the seat. They are positioned at about the junction of the seat back and seat cushion and it is not clear if providing anchorage position adjustment in this area would be feasible, especially if combined with a seat with a reclining back. Therefore, it was decided to concentrate on producing a specification for solutions that work by raising the child up in the seat. As the smallest child occupant that can safely travel facing forward would need the largest adjustment it was decided to establish what vertical adjustment was needed to obtain a good fit by placing a dummy representing a three year old child in two seats, one typical of that fitted in coaches and one typical of a minibus seat. Wooden packing was then placed in increments of thickness under the child until a satisfactory fit of the seatbelt lap and diagonal was obtained. Figure 3.1 is a picture of the three year old (P3) dummy sitting in a coach seat and it shows how the diagonal of the seatbelt is across the face and neck and the lap section is across the abdomen. Both these problems would be resolved by either of the options of moving the
anchorages down or the child up. Figure 3.1 also shows that the knees of the dummy cannot bend, which, for some statures, would cause the feet to foul the back of the seat in front. This problem may be resolved to some extent by raising the child but to cover all statures it would be necessary, in some cases, to either shorten the cushion or move the child forwards.

![Figure 3.1. P3 dummy sitting in a coach seat with an adult 3-point belt](image1)

![Figure 3.2. P3 dummy in a minibus seat with an adult 3-point belt and raised 100 mm](image2)

Figure 3.2 shows the P3 dummy raised 100 mm in a minibus seat, and the fit of the adult seatbelt was greatly improved, however a slightly larger range in riser adjustment (125 mm is suggested) may be necessary for a universal specification to cover all typical adult seatbelt anchorage geometries. Figure 3.2 also shows an improvement in the knee bending just due to lifting the occupant. However, there was still a need to move the occupant forward or shorten the seat base so that they could sit comfortably. From the seat dimensions and the distance between the seated P3’s back of the buttocks to knee it was decided that a P3 sized occupant should be moved forwards or the cushion shortened by about 150 mm. It was found that the seat base length of the minibus seat was about 50 mm shorter than the coach seat. Instead of the 150 mm shortening, as measured on the coach seat, a more universal requirement would be to specify the seat length in terms of the distance between the back of the buttocks to of the back of the knee. This dimension for a three year old child was found to be about 280 mm by measuring a P3 child occupant dummy.

Therefore as the universal seat is intended for occupants of three years old up to adult the specification proposed is for the cushion to be movable from the normal adult position upwards by 125 mm and for the seat length to be adjustable either by moving all or part of the back cushion forward or by making an adjustable length seat base so that it can be shortened from the adult length to a length of 280 mm or less.

For operational reasons it will be important that the design is universal for occupants between about three years old up to adults. To accommodate this large range of statures, it is likely to be necessary for the seat moving mechanism to be designed so that it can be easily adjusted to suit each occupant’s stature and then locked in place. It is suggested that the maximum locking increment should be about...
25 mm; however, further study may show that larger increments might be acceptable. Robust moving links and locking mechanisms will be needed. The forces found in the sled testing and mathematical simulation results reported in Section 4 can be used, with an appropriate safety margin, to design suitable solutions. It can be seen in Section 4.3.3 that it is recommended that the locked seat mechanism should be designed to withstand a force of 10 kN.

### 3.2 TRL’s outline design solutions

As noted earlier it was thought more practical to opt for solutions that involve moving the child up and forward (or the seat cushion up and rearwards) rather than moving the seatbelt anchorages. The following sections and sketches illustrate TRL’s initial ideas for moving the child relative to the seatbelt anchorages.

#### 3.2.1 Idea 1a

This idea involves the middle of the seat cushion being folded up and rearwards and it is then locked in place, see Figure 3.3. The mechanism to achieve the seat movement could be a rotating arm. Being able to move the seat cushion back removes the need to move the back of the seat forward because it will allow the child’s knees to bend, provided that there is no underlying seat frame to prevent the child’s legs from hanging down. A rotating linkage is simple, but it has the disadvantage that the rear of the seat cushion is thin due to the radius required for it to operate, but this might be resolved by a different or dual action mechanism. However, because the front portion must sit on top of the remains of the cushion, it has no adjustment for different sizes, so it may not provide a universal solution for the whole 3-11 age group, as required.

![Figure 3.3. Diagram of Idea 1a](image)

#### 3.2.2 Idea 1b

This idea uses a linear mechanism to move the seat back and cushion. By providing suitable holes and spring loaded locking pins, both the seat back and cushion could be locked in a number of positions making it universal for the age range selected. The idea is shown in Figure 3.4.
3.2.3 Idea 2

Idea 2 is a variation of Idea 1a where the seat cushion is moved up and back. However, separate mechanisms are used for each motion, one to raise the seat cushion and one to allow it to be slid backwards and forwards. As with Idea 1a, being able to move the seat cushion back removes the need to move the back of the seat, because it will allow the child’s knees to bend, provided that there is no underling seat frame to prevent the child’s legs from hanging down. The cushion can be set to different heights using the seat ‘X’ linkage and linear guide (shown in Figure 3.5) with a series of locking holes and locking pins. The seat squab can be moved horizontally on a separate guide so that the cushion can sit flush with the seat back and like the lifting mechanism, it can be locked in place at varying intervals. Room for the seat to move backwards can be provided by having a hole in the seat back. However, for small children the seat will have to be both lifted and pushed back. The ability of the seat to be lifted and pushed back will be limited by what is an acceptable gap at the bottom of the seat back in the adult position. In practice this may not be a problem because a combination of seat back rake and deforming the cushion of the backrest might eliminate the need for a hole in the seat back. A diagram of Idea 2 is shown in Figure 3.5.

3.2.4 Idea 3

This idea is an adaptation of the Autoliv integrated booster seat in an armrest, shown in Figure 3.6. The principle of TRL’s idea is shown in Figure 3.7 and essentially consists of a section of the seat back which folds out. The top half then folds back to form a seat back which is further forward than in the original arrangement. The Autoliv design, which is currently used in Volvos, has to fit into the back of the centre rear seat of the car. It has to be narrow to fit into the armrest sized hole and as a result it has an additional mechanism where the seat folds out to be about double the width of the arm. When the two halves of the device are left together it forms an armrest for the outer seat occupants. For coach seats, the width is not restricted to that of an armrest, but can extend for much or all of the seat width. The extra folding out of the seat cushion, to increase its width, is not required. The addition of some vertical height adjustment would also be needed to make this idea fit the full range of children.
It might also be possible to provide just a booster cushion using this idea. A booster cushion could be provided by the folded out unit in the un-split position, with a stretched cloth back filling the hole left in the backrest.
3.2.5 Idea 4

Idea 4 is a very simple way of lifting up the child, with the seat cushion put on a series of alternative linear guides set at different heights. With a suitable gap in the seat back and a locked system, both the height of the cushion and its length could be adjusted. However, one problem with this idea is that the cushion guides might interfere with the seat frame. Also as with Idea 2, the amount that the seat can be lifted and pushed back will be limited by what is an acceptable gap at the bottom of the seat back with the seat cushion in the adult position. However, a combination of seat back rake and deforming the cushion of the backrest might eliminate the need for a hole in the seat back. Two slightly different variants of this idea are shown in Figure 3.8. In the left diagram, the guide grooves are fixed at the bottom of the seat, with several optional height blades fixed to the bottom of the movable cushion section. In the right hand diagram, a guide blade is fitted to the bottom of the seat, with optional guide grooves fixed to the bottom of a movable cushion section.

![Figure 3.8. Diagram of Idea 4](image)

3.3 TRL’s more detailed design solution

The principle selected for TRL’s detailed design was essentially Idea 1a above. However, a number of changes have been made, the most important of which were to ensure that the design met the proposed specification, fitted within the available space in the seat and had a feasible working mechanism. This was done using a using a three dimensional software package which included the ability to operate the moving mechanism. This confirmed that the mechanism, cushions, etc. would operate over the full range, as intended, without any clashes of parts.

The TRL design can be seen in Figures 3.9 to 3.11 below in three positions; fully up, partially up, and down. However, with a suitable locking arrangement it could be adjusted in as many increments as is thought to be necessary. The only concern with this design is the back of the cushion in an intermediate position which, although covered to some extent by the stretched fabric closure, might be uncomfortable. However, contact with the very back of the seat will be prevented by the radius of the seated bottom.
3.4 Existing products

The automotive supply company Autoliv, have designed an integrated Booster Cushion that has been used for Volvo S80 and S60 and in the London Taxi LTI. Figure 3.12 shows the integrated booster cushion and a variation on this design could be used in the mechanism for folding out the seat back and cushion. Autoliv’s armrest integrated booster seat has already been shown in Figure 3.6.

An integrated child restraint system produced by the automotive supply company Grammer AG is shown in Figures 3.13 and 3.14. It should be noted that this seat is classified under innovation / van on their website and therefore some further development work might be necessary before it could be used in minibuses, buses and coaches. These developments might include changing the size and shape for use in PSVs, providing suitable pedestal or legs for floor or side wall mounting of the seat and possibly some intermediate locking positions for the raised seat. Nevertheless, it appears that seat manufacturers already have or are very close to having practical designs that can be used for occupants from about 18 months old up to adult by setting it, as appropriate, in one of the four positions provided. The Grammer seat has add-on wings to protect the child’s head, which is
typically of help in side impacts. It may not be feasible to fully match a car type CRS in this respect for a PSV universal seat, if the add on wings need to be stored separately when not being used by children.

Figure 3.10. TRL's design with the seat partially up for use by mid-sized children
Figure 3.11. TRL’s design with the seat fully up for use by small-sized children

Figure 3.12. Autoliv’s integrated booster cushion
Figure 3.13. The Grammer van seat in use

Figure 3.14. The Grammer van seat at each stage of operation
(note stage 3 would suit most larger children)

Grammer has also made a sample seat for use in trains, see Figure 3.15. It can be seen from this photograph that this seat is more appropriate than their van seat for use in minibuses, buses and coaches as it is a twin seat with legs (minibuses, buses and coaches typically use twin seats with legs). It is thought that the Grammer rail seat could adapted for use in these road vehicles by adding adult seatbelt anchorages. Some reduction in seat size might also be necessary for use in road vehicles.
4 Evaluation of the effectiveness of the specification and accident forces

One aim of the phase one study was to obtain typical serious accident scenarios for buses and coaches, from accident data. The intention was that these typical scenarios could be converted into simplified tests that could be used to determine the effectiveness of any protection system or specification developed. However, as noted in Section 2.2, it was not possible to determine from accident data a typical serious crash scenario in terms of accelerations, motions and deflections. Therefore it was decided instead to adapt appropriate existing regulatory requirements. To represent a predominantly frontal impact it was decided to test the ‘universal’ seats using the crash pulse defined by ECE Regulation 80 (Economic Commission for Europe, 1989, as amended). Regulation 80 is intended for testing the seats and seat anchorages of large passenger vehicles (more than 16 passengers). For rollover performance it was decided that the ‘universal’ seats should be tested in a rig which approximately reproduced the loading pulse of ECE Regulation 66 (Economic Commission for Europe, 1986, as amended). Regulation 66 is intended for testing the strength of the superstructure of large passenger vehicles. Descriptions of the tests, results and performance criteria against which their performance was judged are given in Section 4.1. For this study two different pairs of seats were obtained, these being the same make and model of minibus seat and of coach seat as were used in the fitting trials. Using these seats enabled the issues identified in the fitting trials to be addressed directly.

For rollover testing it was decided to design a pendulum rig which would produce similar loadings to a typical whole vehicle subjected to a Regulation 66 test. However, funding was not available at this stage of the study to make this rig and use it to test the seats. Nevertheless, if in the future it is decided that there is a need to have a legislative test of this type, then the availability of a feasible
design will be of assistance. Details of the rollover pendulum rig are given in Section 4.2 and Appendix A.

4.1 Sled testing

For the sled tests the Regulation 80 sled velocity requirement of 30 to 32 km/h was used along with the regulation crash pulse, which is given in Figure 4.1. The intention of the sled tests was to evaluate whether lifting and shortening the seat cushion (squab) of a seat and using a restraint system intended for adults would provide satisfactory protection for children. For this, one half of a pair of double seats was modified by adding supports to the seat frame so that the squab was positioned 150 mm rearward and 100 mm above its original position. As it was not intended to test the adjustment linkage for moving the cushion at this stage, this was achieved by welding a raised rigid support for a shortened cushion. As it was intended to carry out a series of tests and compare the results, it was decided to strengthen the seat to eliminate any risk that seat distortion would confuse the results. The reinforcement consisted of diagonal bracing for lateral loading and external support brackets for the upper seatbelt anchorages. The seat was firmly attached to the sled. For the frontal test, a second double seat was positioned in front of the occupied seat with a typical separation pitch, so that realistic occupant interactions with the seat in front could be produced. Both the raised and standard seats were tested with a three year old P3 child dummy and the standard seat was also tested with a 5th percentile adult female dummy (Hybrid III) which was used to represent an 11 year old child. As well as testing with the seats facing forwards they were tested at 30 degrees to assess the effects of angled impacts on occupant restraint performance. For these tests the seat in front was removed so that a clearer view of the dummy kinematics could be obtained. The sled test matrix is given in Table 4.1; it was noted in the videos of Test 2 that, because the standard seat was too long for the child dummy’s knees to bend, the legs were straight and this caused the feet to make early contact with the seat in front. As the knees were in a stable locked position, this caused the pelvis to be restrained and as a result, the upper body pivoted unrealistically about the pelvis. Therefore this test was repeated with the dummy slumped in the seat, with the buttocks away from the back of the seat, so that the knees could be bent.

![Figure 4.1. The ECE Regulation 80 test pulse requirement](image)

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>Acceleration (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>70</td>
</tr>
<tr>
<td>D</td>
<td>80</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>90</td>
</tr>
<tr>
<td>G</td>
<td>150</td>
</tr>
</tbody>
</table>

4.1.1 Sled test results

The peak seatbelt loads measured in the dynamic sled tests can be seen below in Table 4.2.
### Table 4.1: Test matrix for the dynamic testing of the modified seat

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Direction</th>
<th>Dummies</th>
<th>Test setup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frontal</td>
<td>P3 and 5th pct HIII</td>
<td>P3 positioned in raised seat and HIII in standard seat and there is another seat located in front of launch seat, both with adult belt</td>
</tr>
<tr>
<td>2</td>
<td>Frontal</td>
<td>P3</td>
<td>P3 in standard seat with adult belt there is another seat located in front of launch seat</td>
</tr>
<tr>
<td>3</td>
<td>+30°</td>
<td>P3</td>
<td>P3 in standard seat with adult belt</td>
</tr>
<tr>
<td>4</td>
<td>+30°</td>
<td>P3</td>
<td>P3 in raised seat with adult belt</td>
</tr>
<tr>
<td>5</td>
<td>-30°</td>
<td>P3</td>
<td>P3 in standard seat with adult belt</td>
</tr>
<tr>
<td>6</td>
<td>-30°</td>
<td>P3</td>
<td>P3 in raised seat with adult belt</td>
</tr>
<tr>
<td>7</td>
<td>Frontal</td>
<td>P3</td>
<td>Repeat of Test 2, but with the dummy slightly slumped to enable the legs to be bent.</td>
</tr>
</tbody>
</table>

### Table 4.2: Seatbelt loads (peak values) measured during the dynamic (sled) test programme

<table>
<thead>
<tr>
<th>Location of seatbelt load measurement</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Test 5</th>
<th>Test 6</th>
<th>Test 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagonal (kN)</td>
<td>1.14</td>
<td>3.18</td>
<td>1.93</td>
<td>1.46</td>
<td>1.37</td>
<td>1.72</td>
<td>1.53</td>
</tr>
<tr>
<td>Lap (kN)</td>
<td>1.80</td>
<td>3.55</td>
<td>2.25</td>
<td>2.01</td>
<td>1.96</td>
<td>1.47</td>
<td>1.93</td>
</tr>
</tbody>
</table>
The minimum static anchorage strength requirements of ECE Regulation 14 (Economic Commission for Europe, 1970a, as amended) quasi-static pull test (for protecting adults) do not equate precisely to a dynamic test but they have been included for comparison in Table 4.3. However, the Regulation 80 pulse is approximately equal to the Regulation 14 requirement for M2 vehicles. The main causes of the difference between the sled and the Regulation 14 M2 requirement in this case are the lower occupant mass and the shorter loading duration in the sled tests.

Table 4.3: Static pull test requirements for M1, M2 and M3 seats (ECE Regulation 14)

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lap belt only</td>
<td>22.25</td>
<td>11.1</td>
<td>7.4</td>
</tr>
<tr>
<td>Diagonal section</td>
<td>13.5</td>
<td>6.75</td>
<td>4.5</td>
</tr>
<tr>
<td>Lap section</td>
<td>13.5</td>
<td>6.75</td>
<td>4.5</td>
</tr>
<tr>
<td>Additional load</td>
<td>20 x weight of complete seat</td>
<td>10 x weight of complete seat</td>
<td>6.6 x weight of complete seat</td>
</tr>
</tbody>
</table>

Both dummies had similar instrumentation in the head and chest, and the peak measured outputs are given in Table 4.4 below, along with the head excursion measured from the high speed videos of the tests.

Table 4.4: Results, from the dynamic (sled) testing, for the head and chest

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Dummy type</th>
<th>Head</th>
<th>Chest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum excursion #</td>
<td>Resultant accel. 3 ms exceedance (g)</td>
<td>Resultant accel. (peak) (g)</td>
</tr>
<tr>
<td>1</td>
<td>HIII 5th pct</td>
<td>416</td>
<td>31.9</td>
</tr>
<tr>
<td>1</td>
<td>P3</td>
<td>390</td>
<td>23.0</td>
</tr>
<tr>
<td>2</td>
<td>P3</td>
<td>382</td>
<td>25.8</td>
</tr>
<tr>
<td>3</td>
<td>P3</td>
<td>369</td>
<td>25.1</td>
</tr>
<tr>
<td>4</td>
<td>P3</td>
<td>370</td>
<td>33.4</td>
</tr>
<tr>
<td>5</td>
<td>P3</td>
<td>410</td>
<td>27.9</td>
</tr>
<tr>
<td>6</td>
<td>P3</td>
<td>557</td>
<td>27.8</td>
</tr>
<tr>
<td>7</td>
<td>P3</td>
<td>342</td>
<td>29.5</td>
</tr>
</tbody>
</table>

# Head excursion is the horizontal distance from the C_{I} point (where the seat back plane intersects the seat cushion plane) to the furthest forward part of the dummy’s head.

ECE Regulation 80 is intended for testing the safety of adult occupants in large PSV type vehicles and the upper acceleration limit of the sled test pulse is approximately half of that used in ECE Regulation 44 (Economic Commission for Europe, 1995) to test child restraint systems intended for cars. However, it can be expected that typically larger vehicles such as M3 PSVs, will stop more gently in an accident due to their large mass. Therefore the Regulation 80 pulse, used in these sled tests, is the appropriate one to use when assessing child protection in these large vehicles. However, the occupant protection criteria of Regulation 80 are intended for adults so those of Regulation 44 for
child restraints appear to be the most appropriate to compare the performance of the seatbelts in the standard and raised seats. The Regulation 44 requirements are given below:

**ECE Regulation 44 requirements**

- Maximum Head Excursion: 550 mm
- Resultant Chest Acceleration: 50 g
- Vertical Chest Acceleration (upward): 30 g

(The sign convention is such that upward chest vertical acceleration is shown as negative in Table 4.4)

Regulation 44 also states that an emergency-locking retractor shall satisfy the following conditions:

- It shall be locked when the deceleration of the vehicle reaches 0.45 g.
- It shall not lock for strap accelerations of less than 0.8 g as measured in the axis of strap extraction.
- It shall not lock when its sensing device is tilted by not more than 12° in any direction from the installation position specified by its manufacturer.
- It shall lock when its sensing device is tilted by more than 27° in any direction from the installation position specified by its manufacturer.
- In the tests (set out by Regulation 44) the amount of strap extraction occurring before the retractor locks shall not exceed 50 mm (Note: Regulation 16 (Economic Commission for Europe, 1970b, as amended) has the same requirement).
- If the retractor is part of a lap belt, the retracting force of the strap shall be not less than 7 N as measured in the free length between the manikin and the retractor.
- If the retractor is part of a chest restraint, the retracting force of the strap shall be not less than 2 N or more than 7 N, measured similarly.

The adult belts used in this test programme may not meet all of these requirements as they are intended for adults. In the sled test programme it was noted that the belt payout at the upper anchorage was about 70 mm, it can be seen in Figure 4.2 that the payout is noticeable.

![Position at impact](image1.jpg) ![Position at maximum belt extension](image2.jpg)

**Figure 4.2. Overhead view of the P3 child dummy in a normal seat**

The Regulation 80 requirements are intended for adults but these may also be of interest, they are:
ECE Regulation 80 requirements

- Head HAC not to exceed 500 (this is the same as HIC)
- Chest acceleration not to exceed 30 g
- Femur load – maximum 10 kN compressive force, and 8 kN cannot be exceeded for more than 20 ms

Note there are no pelvis or neck requirements in Regulation 80.

Seatbelt force time histories from the frontal tests for both dummies in the standard seat are given in Figure 4.3. Figure 4.4 compares the force time histories for the child (P3) in the normal and raised seat for frontal and oblique (±30 degrees) tests.

![Comparison of HIII 5% and P3 belt loads in the standard seat](image)

**Figure 4.3. Belt load time histories in the standard seat for all frontal sled tests**

The Hybrid III 5th percentile adult female dummy, used to represent an 11 year old child, has additional instrumentation to record neck and femur loads and pelvis accelerations. The peak values recorded in the frontal test are given in Table 4.5 below.

<table>
<thead>
<tr>
<th>Neck</th>
<th>Femur axial load</th>
<th>Pelvis resultant acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion (Nm)</td>
<td>Extension (Nm)</td>
<td>Tension (kN)</td>
</tr>
<tr>
<td>Test no. 1</td>
<td>30.7</td>
<td>29.2</td>
</tr>
</tbody>
</table>

Table 4.5: Results from the dynamic (sled) tests with the HIII 5th percentile adult female in the standard seat - neck loads, femur loads and pelvis accelerations (peak values)

4.1.2 Discussion of sled test results

The results of the test with the Hybrid III 5th percentile adult female dummy, which was used to represent an 11 year old child, confirmed that the fit of the adult belt in the standard seat was just satisfactory for this stature. However, a slight raising of the cushion would have slightly improved the position of the diagonal belt by moving it completely off the neck.

One of the problems in assessing the performance of child restraint systems for smaller children is the limitations in biomechanical data for children and more critically in the abilities of child dummies to measure the effects of poor fit. Therefore many important aspects of child restraint systems are not
assessed in the Regulation 44 procedure, but are instead provided by the child restraint manufacturers using a combination of experience and common sense.

Figure 4.4. Comparison of seatbelt load for child (P3) in normal and raised seat for frontal and oblique (±30 degrees) tests
Poor fit of the diagonal part of the seatbelt will result in high belt contact (crushing) forces on the child’s neck which will also cause high neck bending and tensile forces due to the mass of the head. However, the child dummy used in these tests has no neck instrumentation and because the dummy has a gap between the neck and the shoulder, the belt bunches up and is trapped in this gap.

There is also a problem in detecting the injury risk caused by poor fit of the lap section of the seatbelt. The dummy has no instrumentation to measure deflection of the abdomen, which in a real child could result in serious or fatal injuries to the abdomen or fatal, shearing type injuries of the lower spine.

Because of these limitations, it is possible to draw incorrect solutions from these test results. For example it can be seen in Figure 4.4, for the oblique +30 degrees test, that the lap belt forces are far higher for the raised seat than for the standard seat. From this result, it might be concluded that the raised seat is worse. If the video evidence is considered more carefully, it can be seen that for the standard seat the seatbelt penetrates the abdomen in a potentially injurious way, but due to this the child’s body is free to move forwards causing a longer duration low force in the lap belt. Therefore, on carefully examination, it can be concluded that the higher lap belt forces in the raised seat test are evidence of the pelvis of the child being restrained far better, in a safe fashion, by the belt acting on the upper thighs and pelvis. Similarly, retention of the upper body initially appeared to be worse in some tests with the improved raised seat. Closer examination showed that the standard seat was only performing better at the expense of unacceptable neck loading and trapping of the seatbelt webbing in the unrealistic gap between the neck and the shoulder of the dummy.

By carefully considering all the available data, TRL have come to the conclusion that the raised seat provided a considerable improvement in the fit of the seatbelt, over that obtained with the unmodified seat, and gave a satisfactory fit. However, it is possible that a further small increase in the seat height, over that used in the sled tests, may be beneficial for the smaller three year old child. Note that this has already been included in the proposed specification in Section 3.1.

Justifying this conclusion is difficult because it is based on combining a number of observations and interpretations, however, the following photographs and discussions have been included to illustrate the improvements obtained.

Figure 4.5 shows the test setup for the P3 dummy in the normal seat and in the raised and shortened seat. It can be see from the photograph of the dummy in the standard seat that the lie of the diagonal seatbelt is across the face and neck, even with the dummy angled away from the belt. Raising the child up moved the diagonal away from the neck and routed the lap section over the legs. Shortening the seat allowed the knees to bend.

The effect of the differences between the standard and raised seats can be seen in the oblique tests, see Figure 4.6, and the frontal tests, see Figure 4.7. The overhead view of the oblique tests in Figure 4.6 shows that with the standard seat the diagonal part of the seatbelt does not engage with the shoulder but instead the loads are taken through the neck (throat), with the belt bunching at this point. This effect was also present in the frontal tests, shown in Figure 4.7, but is less obvious. The figures show that in the raised seat tests the diagonal part of the seatbelt tended to stay over the shoulder, more than with the standard seat. For adults the anchorages are intentionally positioned so that the routing of the belt avoids contact with the throat as this is obviously dangerous. The improvement in the lie of the diagonal belt in the raised seat would significantly reduce the risk of a diagonal seatbelt loading injury in real life.

It can be seen in the side views of the oblique (Figure 4.6) and the frontal (Figure 4.7) tests that the angle of the initial part of the lap belt is very different for the standard and raised seat. These angles are about 10 degrees different as can be seen from the superimposed lines in Figure 4.8. Although this has only a small effect on the lie of the lap belt on the abdomen, it makes a big difference to the direction of the forces acting on the pelvis. This difference in direction of force can be deduced from the different levels of cushion compression. In the standard seat position test, the seat cushion remains largely un-deformed, indicating that the restraining force is acting on the vulnerable abdomen. Conversely, in the raised seat position the seat cushion is heavily-deformed, indicating that the force is more downwards on the less-vulnerable pelvis and thighs.
Despite the difficulty in interpreting the results of a child restraint sled test, this method is considered the best method for final approval of a universal seat for use by children, should a formal approval method be required. It should be noted that ECE Regulation 44, which is also used for assessing child restraint systems intended for cars, (Economic Commission for Europe, 1995) is also a sled based test procedure. The universal seat (including any integrated seatbelt anchorages) would also have to be approved for use by adults in the same way as a standard coach seat.

The approximate lap belt angles were measured from the test videos and are shown in Figure 4.8. For the P3 dummy on both the standard and raised seats the results (see Table 4.4) are, with one exception, within the acceptance level of Regulation 44. However, as already noted, examination of the videos and the pre and post test situation suggest that the child would have a high risk of suffering severe neck and abdominal injuries on the standard seat but would not on the raised seat. The better performance of the raised seat was due to the better fit of the seatbelt.

As already noted, there were no issues experienced with the HIII 5th percentile dummy (used to represent an 11 year old child) with regard to the fit of the belt or belt interaction during the test. Routing of the belt for both dummies at maximum excursion can be seen in Figure 4.9, showing the overhead camera view of the frontal test. It shows that the seatbelt is routed correctly over the shoulder of both dummies and is not applying any load onto the neck.

It was noted that the belt payout at the upper anchorage was about 70 mm for the P3 in the standard seat, see Figure 4.2, and also for the P3 in the raised seat and the Hybrid III in the standard seat, see Figure 4.9. The 70 mm included both the belt payout before locking (the ‘not to exceed 50 mm’ requirement), and the payout due to the remaining belt on the spool tightening and the belt run stretching. With a lightweight occupant, the extra displacement due to tightening and stretching is expected to be comparatively small. Therefore, it is possible that the payout of the seatbelts supplied as standard with the seat may have been towards the upper end of the permitted maximum. It is believed that this large payout reduced the effectiveness of the restraint and caused larger head excursions than might have been achieved had it been lower.
Figure 4.6. Comparison of the normal and raised seat in a 30° oblique test

4.2 Rollover pendulum rig

Accident data show that rollover accidents are likely to cause fatal and serious injuries, see Section 2.2.1. In-depth accident studies have shown that many of the serious and fatal injuries in rollover accidents are caused by the occupant being crushed between the vehicle and ground when they are partially or fully ejected during the accident. One of the benefits of wearing a seatbelt is that they can be very effective in preventing partial or full ejection of vehicle occupants in the event of a rollover accident.
Figure 4.7. Comparison of the normal and raised seat in a frontal test

Figure 4.8. Measurement of lap belt angle in the frontal test
The forces on the seatbelt anchorages during a rollover will be in a different direction to that of the regulatory pull test. Because the rollover forces are likely to be comparatively small, when compared with a frontal crash, this is unlikely to be a problem for cars. However, for minibuses, buses and coaches the seats are generally mounted on legs, rather than being attached directly to the floor, so they are more vulnerable to distortion and failure in this loading mode. Also, any mechanism added to move the seat cushions, to make the seatbelts fit a child, might also be vulnerable to being deformed during a rollover accident. Therefore it was decided that it would be sensible also to test a universal PSV seat with a typical rollover pulse. The ECE Regulation 66 test (Economic Commission for Europe, 1986, as amended) is the rollover test for the superstructure of large passenger carrying vehicles (PSVs) and involves testing a whole vehicle or a representation of it. A schematic of the Regulation 66 test can be seen in Figure 4.10. Although the vehicle ends up on its side, the test is primarily concerned with the effects on survival space of the roofline corner impact shown in the third position (the green vehicle). From this diagram it can be seen that the impact velocity and peak accelerations are a function of the vehicle geometry, the height of the centre of gravity, and the crumpling rate of the corner of the vehicle.

This test would be very complicated and expensive to use in order to test a vehicle component. It was concluded that a pendulum rig for rollover testing seats, that would produce similar loadings to those experienced in a typical whole vehicle subjected to a Regulation 66 test, would be more appropriate. Funding was not available at this stage of the study to make this rig and use it to test the seats. Nevertheless, if in the future it is decided that there is a need to have a legislative test of this type, then the availability of a feasible design will be of help. Therefore it was decided to produce just a design of a pendulum rig that replicated the conditions in the Regulation 66 rollover test and not the rig itself. The design process and the resulting design are described in Appendix A.

Standard seats could be tested on this rig with an adult dummy (95th or 50th percentile male) restrained by the seatbelt. Universal seats could be tested with an appropriate child dummy, with the adjusting mechanism set to the position judged to be most vulnerable, as well as being tested with an adult dummy with the mechanism in the adult position.

4.3 Modelling

The design described in Section 4.1 was used in a programme of modelling to investigate the benefits of using an integrated seat design in a bus, coach or minibus. The aim of the modelling was to find
out whether an occupant-dummy mathematical model using an industry-standard rigid-body code could be used to help design and assess any proposed universal seat designs by predicting the occupant protection that was provided, and the forces on the movable parts of the seat. It was decided to model the TRL solution in MADYMO using two dummy models, the Q3 and 5\textsuperscript{th} percentile Hybrid III (frontal dummies).

![Diagram of the ECE Regulation 66 rollover test](image)

Figure 4.10. Diagram of the ECE Regulation 66 rollover test

The concept of the integrated seat was simulated under the frontal impact conditions highlighted in Section 4. As the Regulation 80 corridor is quite wide and to provide a closer comparison with the sled testing results, the pulse used in the modelling was matched to that achieved in the sled testing. The modelling was used to run some baseline tests with the dummy unrestrained, wearing a lap belt only, and seated, wearing an adult seatbelt. The model was also run with the raised seat in order to evaluate the benefits of moving the child up and forwards and shortening the cushion. Table 4.6 below shows the modelling runs carried out.

<table>
<thead>
<tr>
<th>Dummy model</th>
<th>Seat type</th>
<th>Belted</th>
<th>Dummy mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIII 5\textsuperscript{th} pct</td>
<td>Standard seat</td>
<td>Yes</td>
<td>53</td>
</tr>
<tr>
<td>HIII 5\textsuperscript{th} pct</td>
<td>Standard seat</td>
<td>No</td>
<td>53</td>
</tr>
<tr>
<td>Q3 child</td>
<td>Standard seat</td>
<td>Yes</td>
<td>16</td>
</tr>
<tr>
<td>Q3 child</td>
<td>Standard seat</td>
<td>No</td>
<td>16</td>
</tr>
<tr>
<td>Q3 child</td>
<td>Raised seat</td>
<td>Yes</td>
<td>16</td>
</tr>
</tbody>
</table>
The outputs from the modelling gave an idea of the forces involved on the anchorages and on the seat cushion. The anchorage forces have been used to validate the model by comparing them with those measured in the sled test. The seat forces can be used to assist with designing a sufficiently robust seat lifting and locking system for a universal seat mechanism and have been included in the proposed specification, see Section 3.1.

4.3.1 Model structure

The mathematical model for this study used MADYMO as it was the most appropriate way of achieving the results. Two dummy models were used, as mentioned above, to represent the extremes of the age group for which the project is targeted (3-11 year olds). The Hybrid III 5th percentile dummy model was run using MADYMO v6.1 and for the newer Q3 model MADYMO v6.2 was used. The difference in the versions made no difference in the way the models behaved, so that the results were still comparable for the HIII and Q3 models.

The dimensions for the seat model were derived from measurements taken from the physical seats acquired for the sled testing. The dimensions were then transposed to a series of planes with the appropriate characteristics. The seat dimensions were as follows:

**Standard seat:**
- From ground = 450 mm (front end of seat cushion)
- Back length = 720 mm
- Cushion length = 460 mm
- Cushion angle = 10.8 degrees (average of overall change)
- Back angle = 24 degrees
- Seat width = 440 mm

**Raised seat:** same as above but with the following changes:

- The seat was raised by 100 mm (in Z direction)
- The cushion length was reduced by 160 mm (to 300 mm) - the prototype for the test programme was only reduced by 150 mm but the model required a greater reduction to get the child to sit in the seat realistically. The physical dummy was more malleable than the mathematical model and could therefore sit properly with the longer seat cushion.

It was noted that in the sled tests the top surface of the cushion was dragged forwards with the occupant during the crash pulse. As the mathematical cushion would only deform in a vertical direction the cushion’s coefficient of friction was reduced to 0.01 to allow the occupant to slide forward in a similar manner. Elsewhere, the coefficient of friction was set at 0.5 except in the critical chest area of Q3 where it was set to 1.0 (the reason for using this high friction coefficient is given later).

The characteristics of the belt were based on their behaviour in the sled test. The belt had a retractor underneath the seat and was modelled with both a loading and unloading function, including hysteresis.

A front seat and bus side and floor were added in order to model contacts with these surfaces. To provide deformation in the seat in front, the back of the seat was given a hinge joint with its stiffness set at 2.7 kN at 10 degrees of rotation. The distance between the seats was 720 mm and the height of the front seat base was 260 mm from the floor.

It was noted during the development of the raised seat that the seatbelt did not interact properly with the seat cushion due to the new routing of the seatbelt. In moving the seat up but not moving the anchorages, the seatbelt dug into the cushion too much during the model run, due to the interaction
properties. To prevent this from happening and to limit the effect of the seatbelt on the cushion, two cylinders were inserted under the seat plane as shown in Figure 4.11 below. The cylinders were not required on the standard seat as the seat was in a normal position relative to the anchorages.

![Figure 4.11. Raised seat model with the extra cylinders under the seat](image)

The routing of the seatbelt and anchorage positions for the two seat positions is shown in Figure 4.12 below.

![Figure 4.12. Seatbelt and anchorage positions for the normal and raised seats](image)

There was an issue in getting the seatbelt to fit the Q3 child model, due to the design of the model. The Q3 model has a ball shaped chest, as shown in Figure 4.13, and it proved difficult to get the seatbelt to route correctly over the chest and to give the appropriate fit. To get the seatbelt to sit correctly over the chest and to stop the seatbelt slipping off the chest during the test, the coefficient of friction was set to 1, effectively pinning the belt to the contact area of the chest. The dummy model was also modified by inserting an ellipsoid into the lower neck/thorax region to prevent the seatbelt from penetrating unrealistically into the dummy model. It should be noted that the Q3 model was not developed and validated for use with the adult seatbelts, as used in this project, but for child restraint systems that have a different belt arrangement.
Initially it was intended to model a number of alternative universal seat solutions. However, as described in Section 3 it was concluded that the most feasible ideas are all based around one solution, moving the child relative to the seatbelt anchorages by providing seats with adjustable geometry. It would have been interesting to model different mechanisms to move the seat, to identify potential failures and points of high stress, however, the rigid-body modelling code used could not distinguish between different mechanisms that achieve the same effect on the seat position.

4.3.2 Model validation

Figure 4.14 and Figure 4.15 show the belt time histories for the shoulder and lap belt sections of the seatbelt from the model and sled test with the 5th percentile Hybrid III. It can be seen how the model closely reproduces the seatbelt loads from the sled test, with the exception of the shoulder belt force at the buckle. However, the belt force transducers in the sled tests were positioned close to the lap belt anchorage and shoulder belt D-ring. Therefore, it is good that the model’s shoulder belt D-ring force, rather than the buckle force, is closer to the output from the sled test.

Figures 4.16 to 4.19 show similar comparisons between the belt force time histories for the Q3 sled tests and model runs. Whilst the lap belt forces from the model are close to those from the sled tests, the shoulder belt forces are not as similar. This is likely to be a product of the difficulties modelling the seatbelt interaction with the chest of the Q3. As mentioned above (see Section 4.3.1), modifications were made to the Q3 dummy model in order to prevent the seatbelt slipping off the chest. Increasing the friction was effective in keeping the seatbelt in place; however, a better solution would have been to make the shape of the chest more similar to that of the dummy (and a real child). Unfortunately, there were not sufficient resources in this project to improve the standard MADYMO Q3 dummy model in this way.

The occupant dummies in the simulation provided more outputs than in the physical sled tests. Peak values for the head and chest outputs can be found in Table 4.4 for the sled test and in Table 4.8 for the simulation runs. This comparison can only be made for the belted case as no unbelted tests were conducted in the sled test programme. From the tables, it can be seen that for both dummies the head gives similar low results. It should be noted that the chest results from the Q3 simulation runs were very ‘noisy’ and were considered unreliable and have therefore been omitted from Table 4.8. This noisy Q3 chest response was probably because, as mentioned in previously, the Q3 model was

![Modified model and Standard model](image)

**Figure 4.13. Q3 child dummy model with and without modification**

Initially it was intended to model a number of alternative universal seat solutions. However, as described in Section 3 it was concluded that the most feasible ideas are all based around one solution, moving the child relative to the seatbelt anchorages by providing seats with adjustable geometry. It would have been interesting to model different mechanisms to move the seat, to identify potential failures and points of high stress, however, the rigid-body modelling code used could not distinguish between different mechanisms that achieve the same effect on the seat position.
developed for use with child restraint systems not adult seatbelts. It can be seen from these tables that the Hybrid III simulated chest accelerations were almost identical to those of the sled test.

Figure 4.14. Fifth percentile Hybrid III in standard seat, shoulder belt forces
Figure 4.15. Fifth percentile Hybrid III in standard seat, lap belt forces

Figure 4.16. 3 year old in standard seat, shoulder belt forces (Q3 dummy in model, P3 on sled)
Figure 4.17. 3 year old in standard seat, lap belt forces (Q3 dummy in model, P3 on sled)

Figure 4.18. 3 year old in raised seat, shoulder belt forces (Q3 dummy in model, P3 on sled)
Figure 4.19. 3 year old in raised seat, lap belt forces (Q3 dummy in model, P3 on sled)

4.3.3 Modelling results

Table 4.7 shows the peak belt forces from the modelled tests with the 5th percentile Hybrid III in the standard seat and the Q3 in both the standard and raised seats.
Table 4.7: Belt load outputs from the modelling

| Dummy                  | Anchor lap belt | | D-ring shoulder belt | | Buckle lap belt | | Buckle shoulder belt |
|------------------------|-----------------|-----------------|---------------------|-----------------|-----------------|---------------------|
|                        | Load (kN) | Time (ms) | Load (kN) | Time (ms) | Load (kN) | Time (ms) | Load (kN) | Time (ms) |
| 5th pct in standard seat | 3.71     | 57.6     | 3.095    | 74.1    | 3.55     | 2.00     |
| Q3 in standard seat     | 1.665    | 50.7     | 1.585    | 83.1    | 1.36     | 1.15     |
| Q3 in raised seat       | 2.02     | 57.6     | 1.82     | 90.6    | 1.95     | 1.19     |

# Data for reference only – test belt loads taken from D-ring and anchor area

Modelling outputs for the head, neck and chest can be seen in Table 4.8 and outputs for the legs in Table 4.9. Figure 4.20 shows the standard seat cushion force time history graph for the belted Hybrid III 5th percentile adult female, used to represent an 11 year old child, and from this run the maximum force was found to be 4.7 kN.

Kinematics of the belted HIII 5th percentile female dummy on the standard seat can be seen in Figure 4.21 and the matching unbelted HIII kinematics on the standard seat are shown in Figure 4.22. Figure 4.23 shows the kinematics of the unbelted Q3 child dummy on the standard seat and the matching belted Q3 kinematics on the standard seat are shown in Figure 4.24. Kinematics of the belted Q3 child dummy on the raised seat are shown in Figure 4.25. Figure 4.26 illustrates how rotating the kinematics animations can give extra information by showing an oblique view at 150 ms, of the belted child on the standard seat.

Figure 4.20. Belted Hybrid III 5th percentile adult female on standard seat – cushion force
### Table 4.8: Modelling outputs for the head, neck and chest

<table>
<thead>
<tr>
<th></th>
<th>Head</th>
<th>Neck</th>
<th>Chest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acceleration (g)</td>
<td>Extension (Nm)</td>
<td>Tension (kN)</td>
</tr>
<tr>
<td>5th pct belted</td>
<td>24.4</td>
<td>9.7</td>
<td>0.58</td>
</tr>
<tr>
<td>5th pct unbelted</td>
<td>73.8</td>
<td>108.5</td>
<td>3.57</td>
</tr>
<tr>
<td>Q3 belted in standard seat</td>
<td>33.1</td>
<td>7.4</td>
<td>0.31</td>
</tr>
<tr>
<td>Q3 unbelted in standard seat</td>
<td>93.6</td>
<td>88.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Q3 belted in raised seat</td>
<td>47.4</td>
<td>5.0</td>
<td>0.31</td>
</tr>
</tbody>
</table>

# Not given because these outputs were ‘noisy’ and unreliable, see Section 4.3.2

### Table 4.9: Modelling outputs for the legs

|                  | Femur load (kN) | Knee slider displacement (mm) | Tibia force (kN) | Tibia index |
|------------------|-----------------|**********************************|------------------|-------------|
|                  | Left | Right | Left | Right | Upper L | Upper R | Lower L | Lower R | Upper L | Upper R | Lower L | Lower R |
| 5th pct belted   | 0.13 | 0.14  | -0.61| -0.59 | 0.79    | 0.79    | 0.93    | 0.94    | 0.62    | 0.61    | 0.64    | 0.64    |
| 5th pct unbelted | 3.99 | 4.00  | -0.49| -0.49 | 0.88    | 0.92    | 1.18    | 1.21    | 2.44    | 2.42    | 2.68    | 2.66    |
Figure 4.21. Kinematics of the belted HIII 5th percentile female dummy on the standard seat

Figure 4.22. Kinematics of the unbelted HIII 5th percentile female dummy on the standard seat
Figure 4.23. Kinematics of the unbelted Q3 child dummy on the standard seat

Figure 4.24. Kinematics of the belted Q3 child dummy on the standard seat
4.3.4 Discussion of simulation results

It has been shown that the validation of the model was very good for the Hybrid III 5\textsuperscript{th} percentile adult female, used to represent an 11 year old child. It can therefore be concluded that the model of the seat, occupant and seatbelt would be suitable for developing a universal seat mechanism for this occupant size (an 11 year old child). It can be seen from the low injury outputs found with this dummy, in both the physical sled test and the mathematical simulation, combined with the good...
seatbelt fit found with the standard seat, that there are no problems that need investigating with this model for occupants of this size. However, the fit of the diagonal seatbelt did run rather close to the neck, so some occupants of this size or slightly smaller might raise an adjustable seat cushion by one increment. As this size represents the largest occupant that might use the seat raised then the force acting on the seat in the simulations is likely to represent the maximum accident force that the locked mechanism will have to withstand. The peak force was noted in Section 4.3.3 as 4.7 kN and it is recommended that a factor of safety of about two should be used. Therefore it is recommended that the locked seat mechanism should be designed to withstand a force of 10 kN.

Unfortunately the shape of the chest of the Q3 MADYMO child occupant was found to cause the belt to slide off or get trapped. The model was modified to prevent trapping, but the complex task of developing an improved thorax was outside of the scope of this study. The simple solution of increasing the friction between the belt and the chest was found to improve the belt to chest interaction, however, the differences between the physical dummy and the mathematical model were sufficiently large that it was concluded that the results were of less value than the physical sled test. Nevertheless, it should be noted that the MADYMO Q3 model is primarily intended for assessing child harness type restraints and not three-point adult seatbelts. It can therefore be concluded that the current model of the seat, occupant and seatbelt would not be suitable for developing a universal seat mechanism for this occupant size (a 3 year old child). If it is considered beneficial to have an adequate mathematical model of a small child occupant, to help design universal seats, then an improved one could be developed. However, the option of using a physical dummy in a sled test to develop and assess a universal seat can be used instead for this age group.

One aspect that would have been worth investigating with the child model, had it worked better, would have been to examine the effects of a reclining seat back on the universal seat in child mode. In coaches it is common for the seats to be able to recline and it is very likely that reclining the seat would increase the risk of the child submarining under the lap belt with a consequently high risk of abdominal injuries. Therefore it is recommended that this be examined, or some form of interlocking be fitted so that the seat cannot be reclined when the child cushion is activated.

Alternative modelling strategies could be to use finite element (FE) software or combined rigid-body and FE code (MADYMO models can contain FE components). Rigid-body code was used in this project in order to determine whether relatively quick and easy to use software, i.e. rigid-body code, would be adequate. However, for those prepared to develop FE components or a fully FE model the results obtained should be more accurate. Also, an FE model of the seat could determine directly whether components were strong enough, whereas with a rigid-body model the components would have to be stressed separately to ensure that they could withstand the forces obtained from the model.

5 Recommendations

1) For the 0 to 3 year old age group it is recommended that car type child restraint systems (CRSs) be used in coaches and minibuses (and in buses where seatbelts are provided). These could be provided by the parents (‘universally approved’ CRS) or the coach operator (CRS approved for the vehicle / seat combination or ‘universally approved’).

Note, however, that the use in cars of CRSs with ISOFIX attachments is rapidly increasing and ISOFIX products and approval methods are currently still evolving. ‘Universally approved’ CRSs with ISOFIX attachments could not be used in PSV type vehicles unless the seats were also ISOFIX compatible. The provision of CRSs by parents would only be a realistic option if almost all parentally owned CRSs could be used.

2) If the above recommendation is considered not to be feasible then the permitted exemption from compulsory seatbelt wearing, under the EU Directive, for children of less than three years old, should be taken up.

3) It is recommended that Public Service Vehicles (PSVs) that carry children should be fitted permanently with an adequate number of seats that can be adjusted to fit any size of occupant
from about three years old up to an adult (a universal seat). The number of universal seats fitted in a specific vehicle could be decided by the operator depending on the use cycle that they anticipate.

4) If it is thought necessary to have a formal approval method for universal seats for use by children then a sled based test method is recommended, this test could be similar to that used in this study and could use the ECE Regulation 44 criteria. The universal seat (including any integrated seatbelt anchorages) would also have to be approved for use by adults in the same way as a standard coach seat.

5) Consideration should be given to introducing a rollover seat strength test for seats with integral seatbelt anchorages intended for use in minibuses, buses and coaches. The test could use a pendulum rig, similar to that described in Section 4.2 and Appendix A.

6 Conclusions

1) Examination of national accident data for children shows that, relatively, very small numbers of children are killed or seriously injured in accidents involving PSVs such as buses, coaches and minibuses.

2) When national child casualty numbers for buses and coaches are combined with estimates of the number of journeys made, it can be seen that there is a very low child casualty rate per journey with a killed or seriously injured rate of only 0.13 per million vehicle journeys for all ages of children.

3) Biomechanically, children are not simply miniature adults. From birth through childhood their needs from a restraint system change as they grow. Young children are less able to withstand local seatbelt loading to their shoulder, chest or pelvis, and infants also need support for their head (to minimise loading of their neck).

4) Although no examples of injuries induced by poorly fitting seatbelts could be found in the study of accident data, it is thought that poorly fitting adult seatbelts could increase the level of child injuries.

5) A series of fitting trials have been carried out, using seats typical of those found in PSVs and a sample of child volunteers, to evaluate the fit of the adult belt. The trial also explored what improvements to the fit were brought about by using a range of child restraint aids intended for use in cars.

- The survey found that typically an unsatisfactory seatbelt fit was observed for the majority of the children of ages ranging from 1 to 11 years old, when wearing the adult seatbelt. An unsatisfactory fit of the diagonal part of the belt was the main cause; however, there were a significant number of ‘unsatisfactory fits’ found with the lap belt.

- It was also found that the adult seatbelt will not provide a ‘good fit’ for children of three years old or less.

- The seating trials were then repeated using car-type child restraint aids (booster seats and booster cushions) intended for older children from about 4 years old up to about 11 years old and it was found that these restraint aids could provide a ‘good fit’.

- Use of car-type child restraint systems (CRSs) improved the fit of the adult belt by lifting the child or by both lifting and moving the child forward.

- Fitting a child into an adult’s seat can also be a problem for certain statures of child if the depth of the seat base is such that they cannot bend their knees. For many children their legs would be too long to fit when straight out in front of them and would clash with the back of the seat in front.

- The results of the survey showed that the shoulder height of the seated child offered the best indicator of whether a child restraint was required.
6) The fitting trial included a survey to determine whether it was feasible to fit car-type CRSs, for the 0 to 3 year old age group, in coaches and minibuses. The study concluded that it would be feasible, but not necessarily easy, to use car type CRSs in these vehicles.

7) It can be concluded from the fitting trial that if a satisfactory restraint is to be obtained then car type CRSs or similar solutions need to be used for all child passengers (from 0 up to the age of about 11 or 12 years old) carried in buses, coaches and minibuses.

   • For older children, due to the operational logistics of providing appropriate CRSs in PSVs in sufficient numbers and range of sizes, it is thought not to be practical to use car-type CRSs. It has therefore been concluded that the most practical way of providing a satisfactory restraint would be to fit the vehicles permanently with an adequate number of seats that can be adjusted to fit any size of occupant from about three years old up to an adult (a universal seat).

8) When the seatbelt wearing Directive has been implemented it will make seatbelt use compulsory for all children of three years old and over and, without some form of appropriate system to adjust the fit of the adult belt, this might, in some circumstances, increase the risk of injury for some children.

9) A design specification has been produced for a universal seat intended for occupants of three years old up to adult.

10) A universal seat design has been devised by TRL and other solutions have been found that were made by seat and restraint manufacturers.

11) Sled testing has shown that the TRL universal seat specification will achieve a ‘good fit’ of the adult belt for occupants of three years of age up to adult. Careful observation and interpretation of the results suggest that the child would have a high risk of suffering severe neck and abdominal injuries on the standard seat but not on the raised seat.

12) Despite the difficulty in interpreting the results of a child-restraint sled test, this method is considered the best method for final approval of a universal seat for use by children, should a formal approval method be required. The universal seat (including any integrated seatbelt anchorages) would also have to be approved for use by adults in the same way as a standard coach seat.

13) Mathematical modelling has been used to obtain estimates of the accident forces likely to act on the locked seat-adjusting mechanism when occupied by a large child.

14) By comparing the results of the sled tests with the mathematical modelling it has been concluded that, providing that the occupant model is satisfactory, as was the case with the larger occupant model used, additional valid information can be obtained.

15) The MADYMO three year old child dummy model used was found to be inadequate for assessing the performance of an adult seatbelt in the universal seat.

16) If it is considered beneficial to have an adequate mathematical model of a small child occupant, to help design universal seats, then an improved one could be developed. However, the option of using a physical dummy in a sled test to develop and assess a universal seat can be used instead for this age group.

Acknowledgements

The work described in this report was carried out in the Vehicle Safety and Engineering Department of TRL Limited.

The authors are grateful for the information supplied by Autoliv GmbH and Grammer AG and for permission to use their images.
The authors are grateful to Brian Hardy and Jolyon Carroll who carried out the quality review and auditing of this report.

References


Appendix A. Rollover pendulum rig – design details

As was explained in Section 4.2, it was considered desirable that the universal PSV seat should be tested in a rollover impact mode. It was decided to design a rollover rig that simulated the ECE Regulation 66 test that was shown in Figure 4.10.

A spreadsheet model of a rolling coach in a Regulation 66 test was developed to estimate the impact conditions in the roofline impact phase (see the green coach in Figure 4.10). Coach dimensions were taken from Anderson and Sadeghi (2003) and a typical roofline crush was assumed to be three-quarters of the value given in that paper for a borderline pass. Hence the impact velocity and the impact displacement during the roofline impact, both at the occupants’ centre of gravity, were estimated and the rollover pendulum was designed to replicate these values.

One of the potential problems when arresting a pendulum, used to simulate an impact, is that significant forces and loss of energy can occur in the hinge, unless the impactor is arrested on its ‘centre of percussion’. Taking all these considerations into account the targets for the pendulum design were to:

- match the impact velocity, at the seat position, of a typical Reg. 66 test;
- match the impact displacement, at the seat position, that is seen when the corner of the roof strikes the ground in a typical Reg. 66 test;
- arrest the pendulum at, or as close as is possible, to the centre of percussion;
- be safe, simple, low cost, and repeatable.

With this type of rig the centre of percussion is effectively inside the structure, as it on a line through the pivot and the centre of gravity. The ideal impact points would therefore have been at the front and rear of the structure, at the centre of percussion. However, this requires a more complex structure compared with impacting the side of the rig, which is the leading part as it falls. It was therefore decided to impact onto the side of the rig, but at a distance from the pivot that would put the line of the impact force through the centre of percussion. A small component of this force will then act radially through the bearings, but bearings can be chosen so that the load on the bearings is within their load capacity.

An iterative process was used to design the pendulum. First, a realistic but simplified design was described in the spreadsheet and the variables were adjusted to obtain the required impact velocity and the provisional location of the centre of percussion. Then a detailed pendulum design was produced in a 3D engineering design package that provided outputs of mass, centre of gravity and moments of inertia. These outputs were then fed back into the spreadsheet and minor adjustments were made to the 3D design to meet the target values.

The TRL pendulum design can be seen in Figure A.1. The safe mode can be seen in the top diagram, where the seats and test dummies can be safely fitted. The lower diagram shows the topple position. The normal release position would be just beyond this; the crane lifting hook would disengage as soon as a release is operated on the retaining cable. Note that while the target impact velocity will be obtained by releasing from just beyond the topple position, any lower velocity could be obtained by releasing when the rig is further beyond the topple position. The occupant dummies and the seat used do have a small effect on the impact velocity so minor changes could be made to the release position to give consistent impact velocities.
Figure A.1. The TRL pendulum rollover rig in 'safe' loading mode and at the topple position

In Figure A.2 the rig can be seen at the start of the arresting phase, where two blocks of aluminium honeycomb of appropriate stiffness are used to arrest the pendulum at the desired rate.
Figure A.2. The TRL rollover rig at the start of deceleration phase

In the design process it became clear that a rollover rig of this type could not simulate all aspects of the Regulation 66 test. In the Regulation 66 test only the impacting corner of the roof it brought to a halt in the first, corner impact. The rest of the coach carries on moving, so not all the impact kinetic energy is lost in the impact (about 75% is lost). The rollover rig is not designed to mimic this complex behaviour and with the rollover rig all the kinetic energy will be absorbed in the impact. This may be an advantage, as it provides a more severe test of the seats, and also the extra energy is part of the energy that would be absorbed in the second impact in the Regulation 66 test (at the blue coach position in Figure 4.10). However, it could be argued that it would be preferable to match the deceleration of the Regulation 66 test instead of the crush distance. If this were required the basic design could easily be adapted to provide the extra crush distance.