

# Assessment of Passenger Safety in Local Service PSVs

## Literature Review

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## **Summary**

The aim of this literature review was to investigate and report on the main issues associated with passenger safety with regards to injury and accident causation on local service Public Service Vehicles (PSV). As a starting point, current accident statistics on buses compared with other forms of transport were reviewed with the aim of evaluating the scale of the problem.

It was clear from the literature that falls were a major cause of passenger injuries on buses. Therefore, the reasons why so many falls take place and what makes falls more likely to occur were outlined. The types of accidents and injuries sustained at each stage of bus travel were investigated with the various hazards at each stage being outlined. From this, a more extensive investigation into the designs of the many features on local service buses and their effects on casualty rates was undertaken. Features investigated included handrails and stanchions, seating, steps, doorways and gangways. In addition to the physical structure of the bus, the possibility of the surrounding visual and audible environment having an affect on the rate of accidents was also examined.

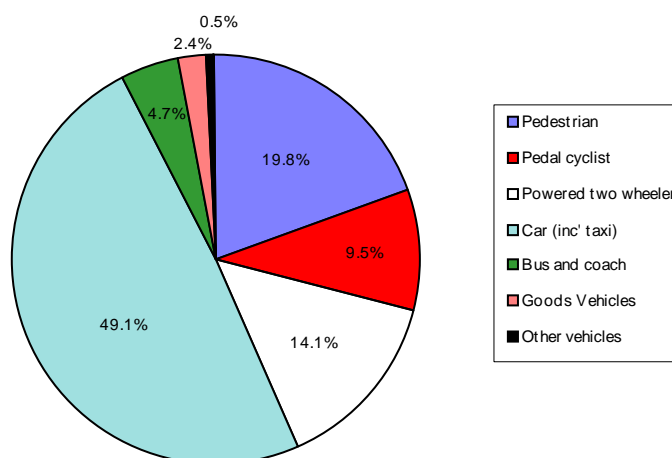
Finally, consideration was given to passenger issues with respect to how certain individuals are more susceptible to falls, such as those with ambulatory disabilities and wheelchair users, the elderly and also encumbered passengers. Methods of ensuring safer and more accessible buses for the elderly and less mobile were investigated with improved designs of conventional features and useful additional mechanisms being suggested. Gender differences in bus casualty rates were also discussed along with suggestions for these given differences.

## 1.0 Accident Statistics

### 1.1 Review of Data

With the vast number of vehicles presently on the road, the government is now aiming to reduce road traffic by encouraging people to use public transport more, such as travel by bus. However, in order to encourage people to use local bus services, the safety and comfort of the bus ride must be improved considerably.

Bus travel has been shown to be statistically a safer way to travel than car travel in terms of collision and casualty rate. For Greater London, figures for 1997 showed that there were 252 killed and seriously injured (KSI) casualties (2 fatalities) for bus and coach occupants compared to a total road user KSI rate of 6990 (276 fatalities)(Local Transport Today, 7 May 1998 - Figure 1 and Figure A.1 (Appendix A)).



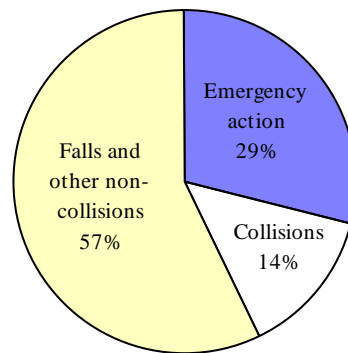
**Figure 1: Proportion of casualties recorded in Greater London for each mode of travel** (Adapted from Local Transport Today - 7 May 1998)

Between 1980 and 1991, the number of people killed and seriously injured on buses and coaches on Britain's roads decreased considerably from an annual figure of 1952 to 725 (63% decrease) (White et al., 1995). However, it is important to recognise this may be in part due to the decline in the number of passenger journeys made (Data for 1986-96 indicates a 22% reduction - Bus and Coach Statistics, 1995/96). Therefore if the government objective of encouraging more people into bus travel is achieved, this trend may reverse and casualty rates may climb. This is more likely to be the case if bus travel is adopted by a

significant proportion of vulnerable passengers, i.e. those individuals whose physical disabilities prevented them from bus travel until the advent of accessible vehicles.

Although the number of bus casualties and fatalities are less than with other road vehicles, there are still many injuries occurring which could possibly be prevented. As well as collision incidents which involve the bus impacting with other vehicles, stationary objects and pedestrians, many injuries to bus occupants occur during non-collision incidents. Non-collision accidents can occur when the bus is either stationary or moving. When stationary, a passenger could lose their balance, fall or slip either while on the bus or while boarding or alighting. When the bus is moving, an injury could occur during an accident avoidance manoeuvre, where the bus may suddenly swerve, brake or accelerate, or through poor driving where the driver takes corners badly or accelerates or brakes hard. In addition, an accident could occur if the bus driver shows little regard for people with ambulatory disabilities and those with encumbrances by not waiting for them to be seated before moving off.

It has been stated that about 57% of injuries to passengers were a result of non-collision accidents, 29% of injuries were sustained during emergency action to successfully avoid a collision and only 14% were a result of a collision. The types of accident cause and their frequency are displayed in Figure 2 (National Public Service Vehicle (PSV) Accident Survey in Fruin et al, 1994 and Leyland Vehicles Ltd. and MIRA, 1980). The National PSV Accident Survey reported that injuries due to an emergency action occurred the most often during the cruising stage of a bus journey, as did injuries sustained during a collision. Injuries sustained as a direct result of a passenger falling on a bus due to a loss of balance, a slip or a trip, occurred the most while the bus was stationary at a bus stop.



**Figure 2: Causes of passenger casualties in the National PSV Accident Survey** (adapted from Fruin et al., 1994)

White et al. (1995) found that 91% of the slight injuries reported by “Stats19” data between 1984 and 1989 occurred in accidents that involved no other degree of casualty and from this, it was concluded that many casualties do not result from major accidents but are more likely to just to involve individual passengers who experience an accident while boarding, alighting, standing or moving within the vehicle.

It was reported by Willis (1992) that 75% of fatalities and 74% of serious injury cases occur on built-up roads rather than on motorway or open roads, which suggests that there is a larger association of injuries occurring to passengers on buses than on coaches.

Dickson-Simpson (1992) stated that most personal injuries on PSVs were on ordinary service buses rather than coaches. One reason for this may be that passenger journeys on local service buses account for approximately 62 to 65% of all bus and coach journeys, based on information provided by the Department of Transport for the past 10 years (Bus and Coach Statistics Great Britain, 1995/6), so there is likely to be more accidents on local service buses. This outlines the importance of designing local service buses with passenger safety in mind.

Passenger attitudes toward modern buses compared to older design buses were investigated in a study by Mlacic et al. (1991). It was found that modern buses

(i.e. those with improved gearing and brake mechanisms, ergonomically shaped seats and air conditioning) were preferred by passengers for their micro-climate (48% compared to 5% for older buses, with 47% neutral), fatigue (47% less tired in modern buses compared to 14% in old) and comfort and safety (75% compared to 2.5% in old).

Although some progress has been made to local service buses to improve passenger safety, there is still a long way to go to enhance safety and accessibility for existing and future passengers. Particular consideration needs to be given to those with mobility difficulties and encumbered passengers, and those who are either reluctant to use buses, fearing their own safety and discomfort, or who are unable to use public service vehicles at all (e.g. wheelchair users).

## **1.2 Summary**

To conclude, bus travel appears to be a safer way to travel than by car. However, it is likely that this situation will change as the population as a whole are encouraged to use buses more often as more accessible buses are introduced on to the roads. This could lead to a rise in the number of casualties on buses, particularly among those with mobility difficulties. Many accidents, particularly those not involving collisions, could easily be prevented and can often be a result of the bus design or driver performance, when the bus is either moving or stationary. It is important that safety and accessibility requirements for present and future passengers are considered to ensure that local service buses are used more often, but the casualty rates do not increase.



## **2.0 Stability and Balance**

The likelihood of an injury occurring to a bus passenger will often depend on the quality of ride of the bus journey, for example, the driving habits of the bus driver, the quality of the road surface and the features present on the bus route, such as traffic calming measures and the severity and number of bends and stops.

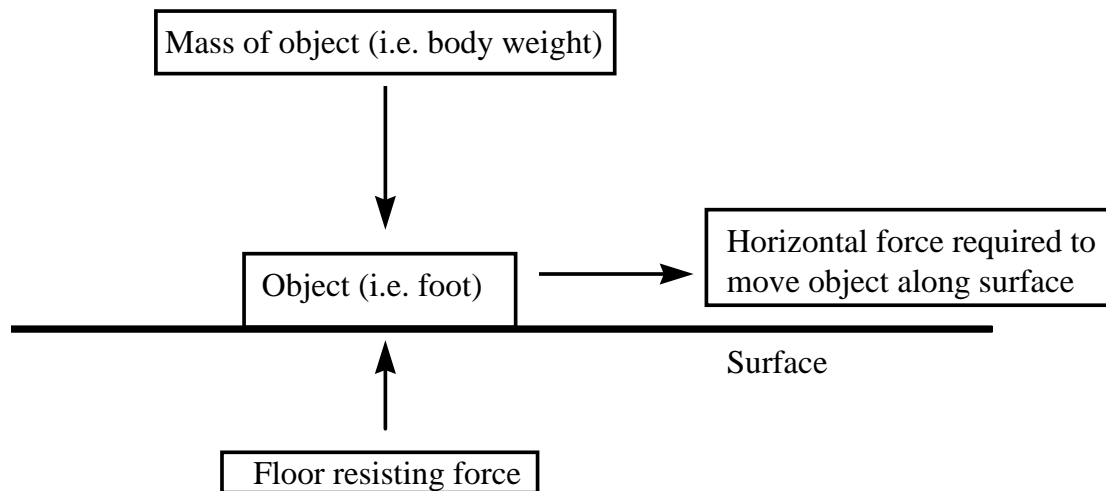
However, other factors, such as the features present within the bus interior and individual passenger attributes, also determine the likelihood of a passenger injuring themselves during an incident.

### **2.1 Motion-Related Falls**

Falls are a result of an individual losing their balance. The postural control which helps to avoid falls is maintained through the combination of sensory information from the visual, vestibular and proprioceptive systems and it is when the information from these systems are different, causing sensory conflict, that the likelihood of a fall increases (Redfern et al., 1997). A measure often used to determine levels of stability is the sway angle, the severity of the angle being determined by the level of postural control. Sway angle has been described as being “..the angle subtended at the ankle between the most posterior and most anterior positions of stability of the centre of gravity..” (Davis, 1983). As a person grows older, their postural control declines, therefore sensory conflict will have a greater effect on the sway angle of an elderly person than someone younger.

### **2.2 Slips**

As well as motion-related falls, there are falls which are a direct result of a slip or a trip. A slip will occur when there is not enough friction present between the foot and the ground to prevent the foot from sliding along the ground. Evaluation of two surfaces for their slip resistant properties is generally undertaken using a measurement called the coefficient of friction which is the ratio of the horizontal force required to move an object, in this case a foot, along a surface to the total vertical force. This is shown in Figure 3.



**Figure 3: Horizontal and vertical force components involved in measuring coefficient of friction**

The higher the coefficient of friction of the two surfaces, the less hazardous the surfaces are likely to be. An individual may be able to walk on a surface without any difficulties, but if the surface conditions suddenly change, reducing the coefficient of friction, the horizontal force required to overcome the friction could become much less than the vertical mass of the foot on the surface, therefore slipping may occur. This could happen while on board a bus as a result of stepping on discarded newspapers, spilled food or liquids or mud (Fruin et al., 1994). As well as slipping accidents on the bus gangway, slipping could occur while boarding or alighting via the steps, particularly during wet and windy weather conditions, resulting in the step treads accumulating wet mud and leaves. If the hazards of slippery surfaces are accumulated with the reduction in postural control in a moving environment, such as during a bus journey, the likelihood of a fall occurring will be considerably increased.

### 2.3 Trips

Falls due to tripping can occur while boarding a bus if the height of the step treads are misinterpreted by the passenger and while moving along the bus if obstructions on the gangway floor, such as baggage or other passengers' feet, are present. Toe clearances during normal walking (i.e. the vertical height between the toe and the object/step being stepping on to or over) can vary between 0.95 and 3.81cm, the average being approximately 1.52cm. However, it has been

suggested that standing passengers on buses could trip on lower surfaces than this (0.95cm) while adjusting their feet (Fruin et al., 1994). Again, the accumulated effect of a moving environment, such as during a bus journey, and tripping will increase the likelihood of a fall occurring.

## **2.4 Force and Levels of Acceleration**

A study by Leyland Vehicles Ltd. and MIRA, (1980) for the Transport and Road Research Laboratory (TRRL) investigated the levels and range of acceleration and jerk experienced on buses in relation to specific events and passenger reactions. The comfort threshold for fore and aft acceleration for forward facing seated passengers was found to be between 0.11 and 0.14g, as this was when mild compensatory levels in passengers were observed to start. For lateral acceleration, the threshold was found to be between 0.23 and 0.25g. An event analysis was also carried out to investigate when high acceleration and jerk events occurred. For fore and aft acceleration, gear changes produced a large number of high level events, as did deceleration into bus stops and “jerky” final stops.

To follow on from this, another study was carried out which involved investigating the ability of subjects to negotiate steps and ramps within a PSV while experiencing acceleration levels typical of those in service vehicles (Leyland Vehicles Ltd. and MIRA, 1980). The events studied were gear changing, braking, deceleration and lateral acceleration when cornering, while the conditions analysed were step height in the gangway (4 heights), ramped floor (2 ramp types, total of 5 angles) and seat location (3 locations).

It was found that subjective comfort ratings correlated better with the force applied to the stanchion rather than the vehicle acceleration level and comfort limits were defined as 0.15g for fore and aft acceleration, which is equivalent to 60 to 70% of a person’s body weight being pushed through the arms. Some subjects were required to exert forces greater than 100% of their own body weight to keep stable and it was pointed out that force exertions of this level would be result in serious implications for elderly and less able passengers in terms of keeping upright. Moving down the steeper ramp resulted in decreased comfort

and increased effort. No difference in subjective comfort and effort was found between the three seat positions, although it was noted that subjects prepared themselves for acceleration events by adopting bracing postures.

## **2.5 Summary**

The likelihood of an injury occurring to a bus passenger can depend on a number of different factors during a bus journey. However, most injuries will be similar in that they are sustained by the passenger during a fall. Falls can be a result of slips, trips or a loss of balance due to the motion of the bus and their likelihood can be influenced by the design of the bus, the ride quality and individual passenger attributes.

### 3.0 The Stages of Bus Travel

#### 3.1 Overview

This section of the report will look in more detail at the type of accidents which occur at the various stages of a bus journey and will be divided into three main sections, boarding and alighting, going to/from a seat and standing, and being seated.

The process of a bus journey has been divided into six main stages by Petzäll (Paper 1 - 1993), these being boarding the vehicle, moving within the vehicle, getting seated, sitting in the seat, rising from the seat and finally alighting. These stages have been outlined in Table 1 along with the main hazards associated with each. The second stage described by Petzäll as “moving around the vehicle” has been divided into three sub-stages in the table, which are “paying the fare”, “walking to the seat” and “walking to the exit”.

**Table 1: The various stages of bus travel and the possible hazards associated with each**

Stage of bus travel	Possible hazards
Boarding the vehicle	This is likely to involve a step or steps
Paying fare	Standing while dealing with money - no hands available to support
Walking to seat	This may involve transgressing steps or stairs
Sitting down	May have body structure around foot areas
Being seated (including calling the vehicle to stop)	Seat design Push button - may be out of reach unless you stand up - also have to locate push-button
Standing up	Seat design
Walking to exit	Down step/steps or stairs
Exiting the vehicle	Down step/steps onto differing surface heights

Passengers are susceptible to different hazards in the different stages of bus travel.

An example of the type of non-collision accidents which occur at various stages of

bus travel can be seen in Table 2, which shows the results of an accident collection database of Washington (DC) Metrobus between 1984 and 1991.

<b>Passenger injury on board stopping bus</b>	<b>1508 (100%)</b>
-Getting up/down/seated	45.4%
-General	16.6%
-Standing front door area	10.3%
-Standing front seat area	7.2%
-Walking front seat area	7.1%
-Standing rear seat area	5.6%
-Walking rear seat area	4.3%
-Other	3.4%
<b>Passenger injury alighting vehicle</b>	<b>1215 (100%)</b>
-Tripped, slipped, stumbled	33.2%
-General	15.7%
-Struck by centre/rear doors closing	13.7%
-Between street and step at front door	9.9%
-Struck by front doors closing	7.5%
-Other	20%
<b>Other passenger injury</b>	<b>1200 (100%)</b>
-Injured by defective equipment while on board	24.0%
-Injured by missile while on board	19.4%
-General	17.1%
-Bus stationary: trip, slip, or stumble	13.4%
-Injured by others on board	11.0%
-Bus moving: tripped, slipped, stumbled	7.8%
-Other	7.3%

<b>Passenger injury boarding vehicle</b>	<b>681 (100%)</b>
-Struck by front doors closing	34.9%
-Tripped, slipped, stumbled	32.9%

-General	9.0%
-Between street and step at front door	7.8%
-Other	15.4%
<b>Passenger injury on board moving bus</b>	<b>382 (100%)</b>
-Getting up/down/seated	54.7%
-General	10.2%
-Standing front door area	9.9%
-Other	25.1%
<b>Passenger injury on board starting bus</b>	<b>142 (100%)</b>
-Walking front seat area	23.2%
-Standing front door area	19.7%
-Other	57.0%

**Table 2: Washington (DC) Metrobus non-collision accident types**  
(July 1984 - January 1991)

### 3.2 Boarding and Alighting the Bus

Boarding and alighting accidents have been defined as occurring “within the stepwell or on the ground surface outside the bus” (Fruin et al, 1994). The type of accidents which occur when passengers are trying to board or alight the bus may involve a passenger losing their footing on a step, tripping up a step or losing their grip on a hand rail or stanchion. This could be a result of a loss of balance due to the passenger carrying a heavy load or as the bus starts to move off prematurely before the passenger is safely seated or off the bus. Other causes of boarding and alighting accidents may be design issues, such as high steps in relation to the pavement, poorly designed hand rails or malfunctioning automatic doors (Stahl, 1989).

It has been suggested that 37% of all fatalities and serious injury cases were associated with passengers boarding and alighting, due to either poor driver visibility (i.e. when looking to see whether all passengers have boarded/alighted), poor step or poor door design (Willis 1992). White et al. (1995) stated that half of

all killed and seriously injured cases (KSI) in built-up areas are a result of passengers boarding and alighting.

Alighting accidents appear to be more serious than accidents when boarding, due to the fall height and harder impact as a result of gravity (Fruin et al., 1994). The PSV accident survey discussed in Leyland Vehicles Ltd. and MIRA (1980) found that over 14% of casualties from the PSV accident database were boarding the bus when the accident occurred and 27% were alighting. In addition, Fruin et al (1994), reported on a study where 94% of step falls by passengers with ambulatory disabilities were downward falls.

As well as accidents involving slip, trip and loss of grip falls, another type of accident which could result in injury when boarding and alighting is being trapped in the bus automatic doors. Leyland Vehicles Ltd. and MIRA (1980) found that 3% of casualties studied from the PSV accident survey were trapped by bus doors and another study reported that of all injuries sustained on buses of 20 or more seats over a six year period, 4% involved bus doors (Injury Bulletin No.27, 1994). However, the Washington (DC) Metrobus Non-collision accident survey (previously displayed in Table 2) found a much higher rate, with passengers being trapped by bus doors found to be the most common type of injury cause when boarding (35% of casualties) and the second most common when alighting (21% of casualties). The type of injuries which were sustained from accidents with bus doors included fractures and other injuries to the limbs, cuts and bruising to the head and upper back (Injury Bulletin No.27, 1994). It appears that whatever is hit or trapped by the bus door is where the injury occurs. The Independent and Times Newspapers (13 August 1992 and 26 October 1993) reported on two very extreme cases of accidents which involved bus door entrapment. One of the incidents involved a ten year old girl who died from multiple injuries when the toggle of her coat become caught in the bus door. The bus door automatic mechanism had been switched off and an eight year old boy was operating the door, and the driver was himself unable to see anything below 4½ ft. This case brings to light a number of issues which resulted in this accident, which includes the driver not being in control or being able to see the bus doors and its surroundings, both inside and



outside, and the predicament of the young passenger not being known until it was too late. These issues will be discussed in later sections.

The final point to make about passenger injuries while boarding and alighting buses is that many bus users, namely those with ambulatory disabilities, will find this part of the bus journey particularly hazardous as it involves not just horizontal, but vertical movements. This will require a great deal of effort from passengers, with the help of steps and handrails. If these items are not of optimum design, this could result in injury to passengers, particularly those with mobility difficulties and encumbered individuals. The impact of the designs of specific bus features will be discussed in Section 4.

### **3.3 Moving to/from a seat or standing**

This section will deal with any aspect of travel on a bus which requires the passenger to stand, which includes moving to a seat after boarding, moving from a seat to alight and standing when no seats are available. The type of accidents which occur during these situations mainly involve motion falls and those due to slips and trips. Mabrook (1994) reported that just over 50% of passengers received their injuries when moving to alight the bus, while just over 20% occurred when passengers had just boarded and were moving to a seat. The type of injuries involved in these non-collision accidents included fractures of the rib, pelvis and various bones in the arm, as well as bruising.

The National PSV accident survey (in Leyland Vehicles Ltd. and MIRA, 1980) found that about 23% of casualties were involved in accidents while on the gangway while Colski (in White et al., 1995) reported that in 1990, 36% of passenger casualties over the age of 60 were standing at the time of their accident. In addition, Dickson-Simpson (1992) wrote that of the personal injuries which occurred on local service buses, 29% occurred to standing passengers. Willis (1992) outlined a figure of 28% of all serious and fatal cases involving passengers who were standing at the time of incident, compared to 27% for seated passengers. As the number of standing passengers on a bus will generally be smaller than the number who are seated, it is likely that overall, the proportion of

all standing passengers who sustain injuries will be greater than the proportion of all seated passengers. Therefore it could be argued that the case for banning standing passengers is greater than the argument for installing seat-belts into buses.

One observation of a study by Leyland Vehicles Ltd. and MIRA (1980) was that a high proportion of accidents on buses were a result of passengers moving up the gangway in accelerating vehicles, particularly with regard to elderly passengers. Similar to the stages of boarding and alighting, passengers with mobility difficulties and those with encumbrances are highly susceptible to falls and injuries while standing or moving about the bus and the likelihood of falling and injury causation is dependent on many bus features, such as the floor of the bus, availability of handrails, obstacles such as bags, other passengers and litter. This suggests that safety could be improved by limiting the amount of standing passengers within a bus, but as a report in *The Independent* (27 June 1994) suggests, this may not be simple to implement because of the efforts which would be involved in changing present driver and passenger behaviour as well as the financial implications to bus operators.

### **3.4 The process of being seated**

Accidents involving passengers who were or were about to be seated appear to be not as frequent as those who were standing. Only 29.4% of casualties included in the study by Mabrook (1994) were seated at the time the injury was sustained compared to the 70.6% who were standing. These injuries occurred when the bus braked quickly causing the passenger to hit their head on the back of the seat in front, resulting in a number of nasal fractures. Bowrey et al. (1996) reported on two injury cases of seated bus passengers which were results of the bus traversing over road humps. The first passenger received a crush fracture of a lumbar vertebrae after being jolted off her seat and the second sustained a flexion/extension injury to her neck and a soft tissue injury to her shoulder after she was thrown forward, hitting the rear of the seat in front.

A study carried out by the Parliamentary Advisory Council on Transport Safety (PACTS, 1995) investigating the trends of elderly bus and coach casualties found that of the 969 seated casualties in London between 1991 and 1993, 262 casualties fell and 41 casualties were thrown forward. The circumstances of the remaining 666 casualties were unknown.

### **3.5 Summary**

In summary, the types of accidents and injuries sustained at each stage of bus travel vary due to the different hazards passengers are exposed to. For example, while moving about or standing on the bus, passengers are more susceptible to slips, trips and loss of balance falls, resulting in impact with the floor. While seated, falls are less likely to occur, but impacts with a seat or window are more likely. Standing accidents have been found to be more frequent than those occurring while seated, which suggests that banning standing passengers may reduce a greater number of injuries than introducing seat belts. However, the most hazardous stage of a bus journey appears to be the process of boarding and alighting the bus, in particular for less mobile passengers.

## **4.0 Physical Designs of the Bus**

### **4.1 Handrails and stanchions**

Handrails and stanchions (vertical handrails) are present on buses to provide support for passengers throughout their bus journey, therefore they should provide enough grip and be available to passengers at every stage of their bus journey from boarding to alighting. They not only assist in balancing the body, but help to take some of the weight off the legs when boarding or alighting the bus.

Stanchions have been described by Shaw (1989) as being the key feature for buses in terms of safety. In order that handrails and stanchions are of an optimum use for all bus passengers including those who are elderly, those with mobility difficulties and those with encumbrances, a number of rail characteristics should be considered, including the shape, placement, positioning, texture and visual qualities.

Current regulations in Europe (including ECE regulation 36, British Disabled Persons Transport Advisory Committee (DPTAC) and Swedish and French regulations) state that, for handrails at entrances and exits, there should be a handrail fitted on each side of the doorway and for double doors, one central stanchion or handrail should be provided. They are required to be a minimum height of between 700 and 900mm above each step, depending on the regulation, and no more than 1100 and 1400mm. The clearance around the rails should be greater than about 35 to 50mm with a diameter of 30 to 35mm. For internal handrails, the regulations are the same, except that the height of the handrail from the floor should be between 800 and 1900mm from the floor, with at least one vertical stanchion for every second row of seats, the distance between them being no more than 1050mm. The shape of a handrail has been specified as either being round or oval and are normally made from stainless steel.

The main advantages and disadvantages of both round and oval handrails, as described by Byman and Hathaway (1994), are as follows. The advantage of round handrails is that they are easily available and are general standard issue. The disadvantages are that people with hand-gripping impairments such as arthritis and those with artificial hands or arms find it difficult to grip this type

and the likelihood of the hand slipping using this type is greater. The advantages of oval handrails are that this type requires less gripping ability for the passenger to keep stable and artificial arms can grip easier and also the oval shape means that much less knuckle space is required, therefore leaving wider spaces for passengers to manoeuvre, particularly in doorways. The disadvantages are that the cost will be more, as this type is not standard issue and is presently difficult to find until demand increases.

In a study by Petzäll (Paper III - 1993), the requirements of people with ambulatory disabilities were investigated in order that buses could be modified to cover these needs. From the results for participants with serious, less serious and slight ambulatory disabilities, it was concluded that handrail height should be approximately 900mm above the edge of the step with the diameter being between 25 and 35mm. These results are very similar to those suggested by the regulations. Another study by Leyland Vehicles Ltd. & MIRA (1980) for TRRL concluded that the sloping portion of a doorway handrail should be approximately 1000mm above foot level with a minimum hand clearance of 70mm.

Horizontal rails found across the front of the vehicle interior next to the driver's cabin, are also a common feature on buses and are found to assist in avoiding injury on the fare collecting devices and to provide security for passengers by leaning on it while paying their fares. These are sometimes known as grab rails (Byman and Hathaway, 1994). Overhead grab rails are another feature which are often installed in buses for standing passengers, but due to their placement height, they will often be of no use to the elderly, those with mobility difficulties, encumbered passengers or those of shorter stature. Therefore, alternative handrails which these passengers could use are the handrails positioned at the back of each seat, which are generally more stable and require less repairing and are useful for both those who are seated and standing. Petzäll (Paper I - 1993) states that handrails at seats should be between 230 and 300mm forward of the front edge of the seat behind and between 850 and 1100mm above the floor.

Handrails and stanchions should ideally have a textured surface which helps to reduce the possibility of slippage occurring. Leyland Vehicles Ltd. and MIRA (1980) found that a handrail of 25.4mm stainless steel, wrapped in white “Doverite” provided the best grip for passengers, even when under substantial force.

The visual qualities of handrails and stanchions on buses are important in determining how well they will perform when a bus passenger loses their balance, because if a passenger cannot distinguish a handrail clearly from the background, then it is less likely they will be able to grab the handrail before they fall. The issues of colour contrast and visibility will be discussed in Section 5.1.

Up to now, the use of handrails and stanchions as aids in reducing the likelihood of falls and therefore injury has been discussed. However, there may also be the risk that handrails and stanchions may be the cause of some injuries. As part of the PSV passenger accident study reported by the Leyland Vehicles Ltd. and MIRA (1980), a list of the objects reported to be struck by passenger casualties was given. There were 432 occasions reported where a passenger struck a handrail or stanchion, which was just under 11% of all occasions reported of an object being struck. The type of rail struck and the number of occasions is displayed in Table 3.

**Table 3: Number of occasions reported where a handrail or stanchion was struck by a passenger casualty**

(Adapted from Leyland Vehicles Ltd. and MIRA (1980)).

<b>Handrail or stanchion type</b>	<b>Number of occasions reported (percentage of all objects struck)</b>
Vertical stanchion	116 (2.9)
Other handrail	100 (2.5)
Seat top rail	134 (3.3)
Centre stanchion of doorway	18 (0.4)
Dashboard handrail	22 (0.5)
Staircase handrails	42 (1.0)

## 4.2 Seating

A person travelling on a bus will normally spend most of their time sitting down, therefore the design of the seat will be crucial in determining how safe and comfortable a passenger's journey is. Current regulations state that the minimum width for individual fixed seats is 430 to 500mm, with a cushion width of 400mm, cushion depth of 350 to 400mm and cushion height of 400 to 500mm. The space (leg room) in between the front of one seat squab and the back of the seat in front is required to be between 280 and 450mm. There appears to be little variation between the standards (Mitchell, 1989).

There are three different layouts of seats found in most buses, the normal front-facing seats, the paired facing seats (forward and backward) and the side facing seats. In a study by Oxley and Benwell (1985), the paired facing seats (forward and backward) were preferred by the elderly subjects as these provided them with double the normal space in which they could manoeuvre their legs.

Injuries occur to passengers while seated for a number of reasons. If a seat lacks any retention or cushioning, the passenger is more likely to move about in their seat as a result of bus motion. Injury, particularly of the back and neck, will occur when the seat is impacted by the passenger. A case study concerning this type of

accident has been discussed by Bowrey et al. (1996) which has been mentioned previously in Section 3.4. Alternatively, if the bus brakes hard or turns sharply, passengers may be thrown forward, hitting the seat in front with either their head or their legs, or thrown to the side, either hitting the window or falling into the gangway, causing injury.

PACTS (1995) reported that some bus seats have such low friction and are so cushioned that passengers are highly likely to slide off them when the bus is turning corners or slowing down. Fruin et al. (1994) describes a number of aspects of seat performance which should help to reduce passenger injury, such as the ability of the seat to absorb some of the kinetic energy during impact, particularly at head and knee height and strong seat anchorages to ensure seat retention.

From the PSV passenger accident study reported by Leyland Vehicles Ltd. and MIRA (1980), 456 occasions were reported where a passenger was involved in an accident where part of a seat was struck, which was just over 11% of all occasions reported of an object being struck. The part of the seat struck and the number of occasions is displayed in Table 4.

**Table 4: Number of occasions reported where a part of a seat was struck by a passenger casualty**

(Adapted from Leyland Vehicles Ltd. and MIRA (1980)).

<b>Part of seat</b>	<b>Number of occasions reported (percentage of all objects struck)</b>
Seat top rail	134 (3.3)
Seat back	214 (5.3)
Seat mount	108 (2.7)

Byman and Hathaway (1994) described the main advantages and disadvantages of high and low backed seats. For high backed seats, the advantages to the passenger were that it gives a better perception of comfort, provides more support for the head and neck and provides grips for passengers moving along the bus. The



disadvantages are to large sized passengers, who may find these seats less comfortable and to the bus driver, whose rear view will be limited, and to all passengers during an accident, who may hit the seat-back. The advantages of low-backed seats are that the driver will have a better rear view of passengers and it will be possible to adapt the seats with hand-grips so passengers can move down the bus much safer. The disadvantages are that there is no head or neck support and the seat in general will be less comfortable.

The process of taking a seat on a bus has been defined to be one of two ways (Brattgard and Petzäll, 1982 in Petzäll (Paper I), 1993). Either the person places themselves in front of the seat, then bends their knees to sit down or alternatively, the person sits down on the side of the seat and swivels their body round 90°. The method a passenger uses may depend on the design of the seat or may be an individual preference.

There are a number of studies which describe the benefits of placing seat-belts in coaches and buses and how this could prevent the number and severity of injuries to passengers (Dickison & Buckley 1996, Banner 1996, Kecman et al. 1997). However, the use of seat belts in local service buses would not be cost-effective, firstly because of the constructional problems of installing belts into buses and also because it would be difficult to persuade bus passengers to use them if they were installed (Krüger, 1986). This would apply particularly on short journeys, where passengers would have to spend the majority of their time fastening and unfastening the belts both for themselves and to allow other passengers to get to and from seats PACTS (1995).

Additionally, as most bus accidents involving passenger injuries are non-collision accidents and predominantly involve non-seated passengers, improving vehicle design in terms of layout of the interior, entry and exit and also driving standards could be more important than fitting seat-belts and improving “roll-over” strength. These latter aspects are more important in large collision accidents, of which there are fortunately very few (White et al., 1995).

As an alternative, some studies have suggested using the seat itself as a restraint system in both collision and non-collision accidents (Krüger, 1986, The universal coach safety seat (in IMechE Conference Transactions: Bus and Coach '96)). Krüger (1986) investigated the effects of various longitudinal distances between seat rows on the movement and force exertion of the passenger colliding with the back of the seat in front using anthropometric dummies. Typical seats used in German buses at the time were used and a minimum force exertion was achieved at a row distance of 800 - 850 mm, providing both adults and children with maximum protection. The same study also investigated the deformability of seats and dummy loads at the optimum seat row distance, at a simulated deceleration of 10g, which revealed that seat anchorages could not withstand the impact and broke loose, so had to be further reinforced to investigate dummy loads. Dummy load impacts revealed that forces on all but the head were uncritical.

### **4.3 Steps**

It has already previously been mentioned that boarding and alighting a bus is a cause of a high proportion of accidents and their resulting injuries. Not only do passengers often hit the steps when they fall but, particularly when alighting, the downward direction of the fall may result in passengers hitting the pavement as well. In order that steps can be traversed by even those with the most severe mobility difficulties or encumbrances, current regulations are enforced to ensure that step heights are no more than a maximum limit. The limits vary greatly between regulations from 250mm and 300mm suggested by the British DPTAC and London Regional Transport to 400mm suggested by ECE Regulation 36 and the French Arrêté du 2 Juillet 1982. The height of subsequent steps varies from 120 to 150mm for the minimum to a maximum from 250 to 350mm between the regulations. The minimum depth of the first step tread is established as 300mm, with subsequent steps being a minimum of between 200 and 300mm.

The number of steps on a bus entry or exit has only been defined in the regulations outlined by London Regional Transport Unit for Disabled Passengers, which states that no more than two steps should be present. However, Byman and

Hathaway (1994) propose that a four step stairwell could provide a more comfortable and safer entrance into the vehicle.

Leyland Vehicles Ltd. and MIRA (1980) compared casualty rates on buses with different gangway heights, specified by the number of steps at the bus entrance. A low floor bus was defined as having a maximum of one step riser, an intermediate floor bus having two step risers and a high floor bus having a minimum of three steps (it was noted that the definition of the number of steps does not include the first step from the ground to the vehicle). The findings were that boarding and alighting casualties accounted for 9, 15 and 11% of all accidents for low, intermediate and high floors respectively. The slightly higher rate of casualties for intermediate floor buses than those with low floors was a result of the effect of more steps present on the intermediate floor bus. The reason given for the decrease in casualty rate between intermediate floor buses and high floor buses was that there may be extra support given on either side of the passenger to help them traverse the extra steps, therefore reducing the likelihood of a fall occurring.

Other aspects such as a slip resistant surface, lighting and colour contrast have been outlined as important to step performance by the regulations mentioned in Mitchell (1989). Lighting and colour contrast issues will be discussed further in section 5.1.

Studies which have been carried out to find the ideal step height at bus entrances and exits for those passengers who have mobility difficulties include one undertaken by Petzäll (Paper I - 1993), who suggested that steps should have a height of 150 to 200mm and a depth of 250 to 300mm and that all steps should have the same dimensions. It is also suggested that the step edge is smooth, in other words, that the tread of the step does not overhang the riser, as this may increase the likelihood of tripping when boarding the bus and will result in a shorter tread depth when alighting, which could increase the likelihood of slipping if a passenger's foot is not fully on the step.

Oxley and Benwell (1985) undertook a study investigating a number of existing bus designs and looked specifically at the ease of boarding and alighting for people with ambulatory disabilities. The main conclusions were that criticisms of step height appeared to start at a height of 200mm, with a consistent step height being preferred and a depth of 350mm being suggested as a minimum. Protrusions on step edges were suggested as being avoided, as less able passengers could catch their toes on them as they lift their feet up to the next step.

Retractable steps have also been suggested in another study by the TRRL as improving the ease of entry for elderly passengers and those with mobility difficulties without necessarily increasing the wheel-stop time, or alternatively, kneeling buses can also aid the less mobile (Spencer, 1996). These issues concerning the elderly and less mobile will be discussed in Section 6.1.

Interior steps cover both steps in the gangway and stairways to upper bus floors. Little is mentioned about these type of stairways in the literature, but it is assumed that the same regulatory measures as the entrance and exit steps should apply to these steps. However, all standards tend to agree that internal steps should be grouped together in a single flight and should be avoided unless completely necessary. As stairways to upper floors of double-decker buses are very rarely used by the elderly and less mobile, it may seem that the dimensions of these stairways may not be of as much importance. However this may change in the future if more elderly passengers and those with ambulatory disabilities partake in bus travel and/or the proportion of standees to seated passengers increases on the lower deck thereby encouraging more passengers to use the upper deck. Accidents on stairways leading to upper decks are potentially very dangerous, so their design for safety for all passengers, including the elderly and encumbered passengers is highly significant.

The PSV passenger accident study by Leyland Vehicles Ltd. and MIRA (1980) reported on 580 occasions where a passenger was involved in an accident where a step was struck, which was just over 14% of all occasions reported of an object being struck. The type of step struck and the number of occasions is displayed in

Table 5. However, it must be noted that the figures for a step being struck could be higher, as many of the accidents which resulted in the saloon floor or road surface being struck may also have been caused by accidents occurring on the bus entry/exit steps.

**Table 5: Number of occasions reported where a step was struck by a passenger casualty**

(Adapted from Leyland Vehicles Ltd. and MIRA (1980)).

Step type	Number of occasions reported (percentage of all objects struck)
Platform steps	242 (6.0)
Staircase steps	338 (8.3)

#### 4.4 Doors and doorways

The main hazards concerning doorways are passengers being struck or becoming entrapped by doors opening or closing prematurely while boarding or alighting the bus. However, passengers could also strike their head on the top of a doorway while entering or leaving a bus or there may not be enough room to manoeuvre easily off the bus when loaded with shopping or children, which may lead to a loss of balance, resulting in a fall.

There is variation in different regulations regarding door width but in general a single door width should be a minimum of 600 to 800mm, a double door width should be a minimum of 1200 to 1250mm and the spacing between handrails should be a minimum of 500 and 650mm, with variations between rear and front doors (Mitchell, 1989). Suggested minimum door heights vary substantially between standards, from 1650 to 2112mm and the number of service doors vary between 2 and 4, depending on the bus passenger capacity.

Petzäll (Paper I - 1993) reported on a study previously carried out to find ideal measurements for various bus features which would suit passengers with mobility difficulties. It was suggested that the clear doorway width (single or between

handrails) should be approximately 700mm and that the door must not hinder the passenger or obstruct the handrails.

Spencer (1996) discusses the various PSV door configurations and rates each for aspects such as cost and speed of operation. Four main types of door configurations are mentioned, these being folding doors, inward gliding doors, swing plug doors and sliding plug doors. Folding doors are the earliest examples of city bus powered doors and can either be single or double doors. The disadvantages of folding doors are that clear sight is limited through the glazed portion of the door and it does not provide a good sealing, which means that rain water and debris such as leaves may enter the bus via the entrance/exit steps causing a possible slipping hazard for passengers boarding or alighting. Inward gliding doors provide a better quality of weather-sealing than folding doors, but are still rather limited.

Swing plug doors have been common in coach application for some time, but are now being used more often in city bus application. They have high quality weather-sealing, which is a simple mechanism, but due to a relatively large swept envelope outside the vehicle when the door is opening or closing, there may be some risk of contact with objects outside the vehicle in certain circumstances. Sliding plug doors are similar to swing plug doors in terms of aesthetic and sealing standards, but one advantage is that the opening and closing procedures do not involve a large swept envelope. However, the mechanism tends to be more complicated than swing plug doors and incurs more weight and cost penalties compared to other configurations.

Alternative bus doorway designs are the “Routemaster” style, where there is one open doorway at the rear, and no doors to regulate passengers. These mainly operate in Central London. The proportion of boarding and alighting casualties in London for the years 1985 to 1986 was 62% compared to only 28% in Manchester, while 64% of all boarding and alighting casualties were in London for these years (White et al., 1995). It is suggested that the high instances of

boarding and alighting casualties on buses in London is due to the use of the “Routemaster” style buses.

Another issue concerning the type of doors used on local service PSVs is the way in which the doors are controlled. In most buses the doors are controlled by the drivers from their seat. However, accidents, particularly door entrapments, could occur in circumstances where the driver’s view of the doorways is poor, which can often be the case when there is a centre exit door. One example of an incident where a door entrapment resulted in a fatality has been previously mentioned in Section 3.2. To ensure that the frequency of door entrapments are reduced, recycling mechanisms to detect passengers and objects obstructing the doorways are used. In addition, to ensure that falls from bus doorways as the bus is moving off or slowing down are prevented, interlocks can be installed to prevent the vehicle from moving when the exit door is open (Spencer, 1996).

The type of injuries which are caused by an accident involving bus doors include fractures, cuts and bruises to the limbs, upper back, head and face (Injury Bulletin No.27, 1994). However, Leyland Vehicles Ltd. and MIRA (1980) reported that leg and foot cuts, bruises and grazes were most frequent in accidents involving doorways and platforms, while fractures of all kinds were reported most often for both doorway and gangway accidents.

The PSV passenger accident study by Leyland Vehicles Ltd. and MIRA (1980) reported on 64 occasions where a passenger was involved in an accident where the bus doors were struck, which was just over 1.5% of all occasions reported of an object being struck.

#### **4.5 Gangways (including floor)**

Bus passengers are more susceptible to accidents while standing than seated as a person is more likely to lose their balance. Therefore there is a high risk of accidents occurring while standing in the gangway, particularly for the less mobile and encumbered passengers.

Current regulations for gangway dimensions state that the gangway width should be of a minimum 350 to 530mm, depending on the regulation, with the minimum height varying between regulations from 1800 to 2100mm. The draft European legislation on bus and coach construction (Lancastrian, 1997) states that for gangway height on the upper saloon of a double-decker bus, the minimum should be 1680mm. If this minimum was to be used, it could cause problems for many passengers moving along the upper deck of a bus, as they would not be able to stand up straight. The slope of the gangway is required to be no more than 8% in most standards, although the British DPTAC state that there should be no slope at all. The floor covering should be non-slip, be able to drain away water, provide a good foothold (Mitchell, 1989) and be easy to clean (Churchill, 1997).

In a physically unstable environment such as a moving bus, an increase in the amount of sway will result in an increase in the likelihood of a fall occurring, therefore the type of surface used for a bus floor should be considered carefully. A study by Redfern et al. (1997) looked at how various flooring conditions affected the balance of a number of elderly and young subjects. One of the main conclusions found was that softer floors increased the amount of sway in the older subjects.

Leyland Vehicles Ltd. and MIRA (1980) undertook a comparison of simple gangway designs with both intermediate and complex designs to investigate whether the simpler designs resulted in a smaller casualty rate. The level of complexity was determined by the number of level and gradient changes present in a gangway design. It was found that there was a proportionately greater number of gangway accidents for the simple design, but no explanation was given for why, apart from that other design or usage factors were influencing the number of accidents.

Standing passengers in gangways can also be a hazard to each other, particularly when passengers are moving about a bus which has reached its capacity for both seated and standing passengers. According to the Draft European legislation on bus and coach construction (Lancastrian, 1997), a loading of six to eight



passengers per square metre is permissible, which is much higher than currently allowed in the UK. An article in the Independent Newspaper (27 June 1994) discusses the suggestion that for safety and efficiency reasons, there should be no more than five standing passengers on a bus at one time and explains why this would be difficult to enforce.

As well as falls due to the motion of the bus which can occur in bus gangways, other circumstances include tripping over items obstructing the gangway, including fixed objects which are part of the structure of the bus (e.g. seat mountings or the base of handrails) or passengers' baggage. Slipping on floor surfaces which do not have good slip resistance, due to the floor being wet during poor weather conditions or the presence of foreign materials on the floor such as food or drink, are also hazardous (Fruin et al., 1994). Materials to be used for bus floors should be tested for their slip resistance using the procedures outlined by the American Society for Testing and Materials (ASTM) or their equivalents. For tripping hazards, the U.S. Architectural and Transportation Barriers Compliance Board (USATBC) suggests a surface height differential of 0.64cm as a threshold at which trip hazards may occur (Fruin et al., 1994). Trip hazards which are a result of the floor surface itself only occur if the surface material is worn or dislodged (Fruin et al., 1994).

Byman and Hathaway (1994) suggest that slip and fall accidents can be avoided by regular maintenance and cleaning of the vehicle surfaces and floors and warns that fine sand and dust are almost as treacherous as moisture. It has been found that head and neck injuries (cuts, bruises or grazes) were most frequently reported from accidents in the gangway and when leaving or entering seats, and that fractures of all kinds were reported most often for both gangway and doorway accidents (Leyland Vehicles Ltd. and MIRA, 1980).

The PSV passenger accident study by Leyland Vehicles Ltd. and MIRA (1980) reported that there were 1232 occasions where a passenger was involved in an accident where the floor was struck, which was just over 30% of all occasions reported of an object being struck. The type of floor struck and the number of

occasions is displayed in Table 6. However, it must be noted that the occasions where the bus floor was struck may well be over reported, as they may have been quoted for “falls from the bus” when no other injury sources are apparent (Leyland Vehicles Ltd. and MIRA, 1980).

**Table 6: A summary of the number of occasions where the floor was struck by a passenger casualty during an accident**

(Adapted from Leyland Vehicles Ltd. and MIRA (1980)).

<b>Floor type</b>	<b>Number of occasions reported (percentage of all objects struck)</b>
Platform floor	312 (7.7)
Saloon floor	886 (21.8)
Footstool for side facing seat	34 (0.8)

#### 4.6 Other Features

There are a number of other features found on the majority of local service PSVs, the designs of which may help to prevent or cause passenger injury during both collision and non-collision incidents. These include the fare paying equipment, luggage spaces, windows or windscreens and the upstairs or downstairs front dashboards/bulkheads. Table 7 displays the number of occasions where these objects were struck by passenger casualties.

**Table 7: A summary of the number of occasions where various objects were struck by a passenger casualty during an accident**

(Adapted from Leyland Vehicles Ltd. and MIRA (1980))

<b>Object</b>	<b>Number of occasions reported (percentage of all objects struck)</b>
Fare paying equipment	36 (0.9)
Overhead luggage rack	8 (0.2)
Luggage hopper	62 (1.5)
Windscreen (driver's)	4 (0.1)
Window or window frame	74 (1.8)
Windscreen	90 (2.2)
Upstairs front dashboard/bulkhead	10 (0.2)
Downstairs dashboard/bulkhead	16 (0.4)

In addition, an article by Churchill in Design Week (October 1997) has outlined a number of suggestions by London Transport Buses for improved bus design including introducing padded side walls for additional safety.

#### 4.7 Summary

The design of the various features found within all local service PSVs can often determine the number of injuries occurring during a non-collision accident by helping passengers to avoid injury or even being the cause of the injury itself. Table 8 outlines the important characteristics to be considered in the design of the various features of buses to maximise usability.

**Table 8: Prominent bus features and the characteristics important in their design when maximising usability**

<b>Bus feature</b>	<b>Handrails and stanchions</b>	<b>Seating</b>	<b>Steps</b>	<b>Doors and Doorways</b>	<b>Gangways</b>
Characteristics	-Shape -Material (texture) -Visual qualities -Positioning/availability -Placement	-Shape (dimensions) -Material -Layout	-Number -Configuration -Dimensions, -Material, -Visual qualities	-Dimensions, -Configuration -Operational control	-Dimensions -Material -Layout

## **5.0 Environmental aspects**

### **5.1 Visual issues**

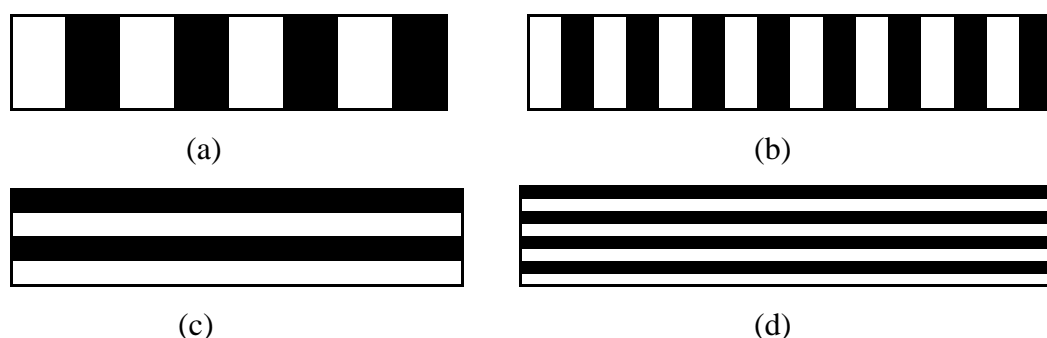
The two main visual issues to consider when investigating passenger accidents on local service PSVs are lighting and colour. A reduction in visual perception will result in an individual being more susceptible to spatial disorientation. In a moving environment, such as during a bus journey, the passengers as well as the bus will be moving, but the movements of both will be different, causing a reduced visual perception, which will result in spatial disorientation. This in turn will lead to an increased likelihood that a fall will occur (Gilmore, 1994).

The purpose of interior lighting in local service buses is to enable the gangways and the seating areas to be clearly seen by all passengers during the day or night. The lighting also needs to be sufficient to enable the driver to monitor the passengers and ensure no incidents occur, for example, a passenger being trapped in the doors of a bus.

The colours and colour combinations used for the interior of buses are important in determining the likelihood of slips and falls occurring, as some colours which have poor contrast rendering properties will result in passengers not being able to define the surroundings easily. Bright contrasting colours such as yellows and reds can improve the passengers' depth perception, while darker, harmonised colours, such as brown and blue, may blend the outlines and positioning of interior features and therefore confuse those with visual impairments. It is also important to remember that some colour combinations, such as yellow and red or blue and green will be difficult to distinguish by those with defective colour vision. Contrasting colours between seat backs and floors allow passengers to readily find a point to grab preventing or minimising falls (Byman and Hathaway, 1994). Just as important is using a colour for handrails and stanchions which will make them readily distinguishable from the background and therefore easily visible to passengers. This is why in modern buses, handrails are generally a bright colour, such as yellow or orange.

All steps on buses will often have a contrasting yellow stripe running the full width of the steps front edge. This is to aid proper foot placement while traversing the steps and so reduce incidents of tripping (Byman and Hathaway, 1994).

As well as colour rendering, the general visual surroundings during a bus journey will determine how easily passengers will find it to maintain a sense of balance and spatial orientation. Gilmore (1994) carried out a study which involved a series of experiments looking into the effects of various visual cues on spatial orientation. It was found that vertical oriented visual cues of low frequencies were most effective in decreasing the risk of falls on moving public transport, particularly for elderly passengers, since these induced a smaller postural sway angle than high frequency, horizontal surroundings. Examples of the types of visual cues used are displayed in Figures 4(a) to (d).



**Figure 4: Examples of the type of visual cues used in the study by Gilmore (1994) - (a) vertical low frequency, (b) vertical high frequency, (c) horizontal low frequency, (d) horizontal high frequency**

## 5.2 Hearing Issues

Improving the audible environment in particular can help to reduce falls on public service buses in terms of increasing the information conveyed to the passengers. Examples include audible announcements of the buses' next stop and for when the bus is slowing down (Shaw, 1989). This is particularly relevant to passengers with mobility difficulties, encumbrances and visual impairments.

Auditory information can also be used to assist the driver. For instance, if the drivers view of the passengers boarding and alighting the bus is limited, an audible warning of passengers or luggage in the doorway would be useful in reducing the likelihood of passenger entrapment in closing doors. (Spencer, 1996).

### **5.3 Summary**

By combining the use of audible and visual information, the likelihood of an accident occurring can be reduced in a number of ways. These include using contrasting colours and efficient lighting make it easier for passengers to define the surroundings on a PSV and using vertical, rather than horizontal, visual cues to improve passenger spatial orientation. Auditory information can be used to provide passengers with advanced information about the bus's movements and inform the driver of doorway or other obstructions, if the visual information is inadequate.

## **6.0 Passenger Issues**

According to current statistics, passengers who use local service PSVs are most likely to be elderly and female. For example, Leyland Vehicles Ltd. and MIRA (1980) reported from the National PSV accident survey that accident rates for females aged 60 or over were four times the rate of males over 60. The issues of passenger age and gender will be discussed in this section to determine how they could influence the likelihood of accidents occurring, as will the importance of designing buses for the most vulnerable passengers and those who are the most frequent local service bus users.

In addition, issues concerning passengers with mobility difficulties will be discussed. This includes both wheelchair users and those with ambulatory disabilities. Unlike wheelchair users, people with ambulatory disabilities can walk, but only often with difficulty, and includes those with varying degrees of illness or infirmities as well as many elderly people (Paper I - Petzäll, 1993). A study carried out in the late 1980's by the Office Population Census Surveys (OPCS) (McKee, 1996) suggested that in the UK, around 6.5 million people have some form of disability, of which 6 to 7% of these are wheelchair users, two thirds have some form of mobility difficulty (around 7.5% of the total population) and two thirds are aged 60 or over.

### **6.1 The Elderly and those with Ambulatory Disabilities**

#### **6.1.1 Accident Statistics and Review of Data**

Elderly bus users and those with ambulatory disabilities have the same type of problems using buses as they share similar physical limitations. These limitations include stiff joints and muscular weaknesses, which result in a reduced range and speed of movement. Over the years, the proportion of elderly bus passengers has increased while bus use in general has declined. This is due to some extent to a lower frequency of car ownership and lower incomes among the elderly (Oxley and Benwell, 1985), but also to a large increase in the elderly population in general, which has been predicted to rise by 7% between the years 1991 and 2011 and by 38% by 2031 (Annual Abstract of Statistics, 1990 Edition). To accommodate this class of passengers, it would be beneficial to bus manufacturers



and operators to provide a more comfortable, safe and convenient bus journey. This in turn would increase the quality of ride for the younger and more able bus passengers.

A number of studies from the 1970s, mentioned in Oxley and Benwell (1985), found that about 4 million people were unable to use, or had great difficulty using, public service buses and a further survey of the elderly in 1982 (also mentioned in Oxley and Benwell, 1985) found that 9% of over 65s were unable to use buses due to physical difficulty and 16% were able but with great difficulty. The main problems reported by less mobile bus passengers in using public service buses were the height of the steps while boarding and alighting and the fear of falling when the bus was in motion (Gilmore, 1994, Oxley and Benwell, 1985, Shaw, 1989). The most difficult stages of a bus journey for elderly passengers and those with ambulatory disabilities involved reaching a seat while the bus was moving and getting up from a seat to ring the bell and reach the exit before the bus stopped (Oxley and Benwell, 1985).

It appears that elderly passengers are over-represented in accidents, particularly in non-collision accidents (Gilmore, 1994, Leyland Vehicles Ltd. and MIRA, 1980), with the casualty rate for the over 60 age group for the years 1980 to 1984 being 56% higher than the average for all passengers (White et al., 1995). Similarly, a study by Colski (1991, in White et al., 1995) found that in 1990, 40% of bus passenger casualties were over 60. Of these, 36% were standing and 23% were boarding or alighting. As part of the National PSV Accident Survey (Leyland Vehicles Ltd. and MIRA, 1980, Fruin et al., 1994), it was found that for non-collision accidents, approximately 36% of passenger casualties were aged 60 or above compared to 48% who were under 60.

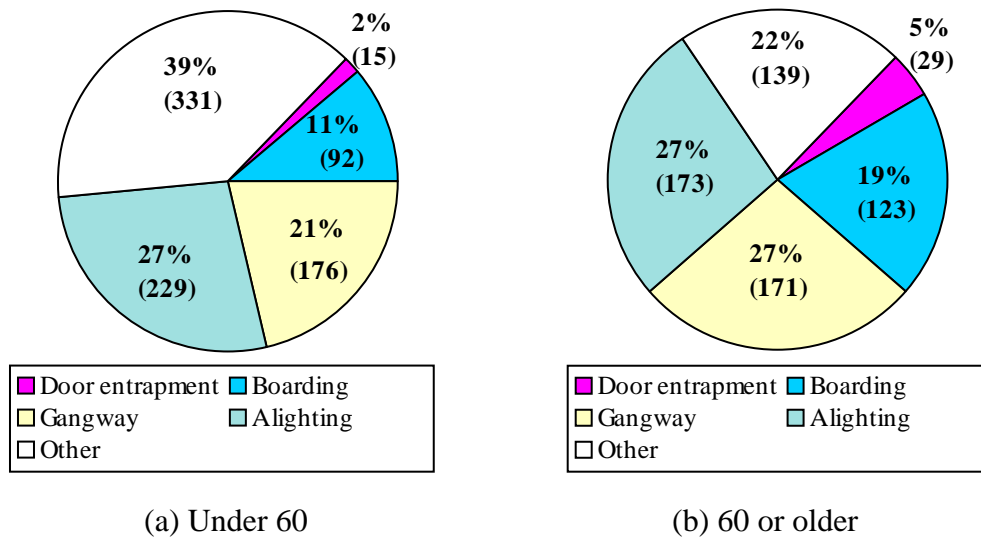
PACTS (1995) carried out a study using accident data provided by the London Accident Analysis Unit for inner and outer London areas for the years 1991 to 1993. Of the 770 accidents, there were 868 slight and 101 serious casualties aged 60 or above. The number of passenger casualties for various circumstances is displayed in Table 9 and is reproduced from PACTS (1995).

**Table 9: Casualties by age, severity of injury and by impact or other circumstances (Inner and outer London, 1991 - 1993)**

(Adapted from PACTS, 1995)

Circumstances	Severity	Passengers			Older (60+)	Younger (- 60)	All	Drive
		80s	70s	60s				
Impact	Serious	9	16	15	40	11	51	5
Impact	Slight	35	100	161	296	197	493	14
Other	Serious	10	25	26	61	16	77	0
Other	Slight	88	215	269	572	109	681	3
Impact	Both	44	116	176	336	208	544	19
Other	Both	98	240	295	633	125	758	3
All	Serious	19	41	41	101	27	128	5
All	Slight	123	315	430	868	306	1174	17
Totals		142	356	471	969	333	1302	22

The proportion of boarding and door entrapment accidents experienced by elderly passengers (60 or above) were found to be significantly greater than for the category of passengers under the age of 60 in the National PSV Accident Survey (Leyland Vehicles Ltd. and MIRA, 1980, Fruin et al., 1994). However, there appeared to be no difference between the proportion of alighting accidents (not including door entrapments) occurring to passengers aged 60 or above and passengers under 60. No significant difference was found between the two age groups for gangway accidents in general. However, when only gangway accidents which occurred while the bus was moving off are considered, a greater proportion of these accidents occurred to the over 60s. Figure 5(a) and 5(b) displays a comparison of the proportion of passenger casualties for each non-collision accident type with age.



**Figures 5(a) and (b): National PSV Accident Survey: Non-collision casualties by age** (adapted from Leyland Vehicles Ltd. and MIRA, 1980, and Fruin et al, 1994)

The study by PACTS (1995) stated that the most frequent circumstances of injuries occurring to elderly passengers was when the bus braked suddenly to avoid a collision. This accounted for 45% of the injuries which were sustained in the 770 accidents analysed in this study, with impact accidents accounting for 35% of injuries. The trends in the type of injuries suffered by elderly passengers appear to be no different to the younger passengers, except for a slightly higher incidence of cuts, grazes or bruises to the feet and legs among the over 60s (Leyland Vehicles Ltd. and MIRA, 1980).

It has been reported that falls are a leading cause of accidental deaths in the over 65s and are twelve times more likely to occur to this age group than all other age groups combined (Redfern et al., 1997). The main reason for this is because of a decline in postural control in the elderly which leads to an increased sway compared to younger adults. This will directly influence the likelihood of a fall occurring, particularly when this effect is added to the effect of being situated in a moving environment such as during a bus journey. It is often for this reason that passengers with ambulatory disabilities will also be more susceptible to falls.

### 6.1.2 The Visual Surroundings

As the adult population relies on vision for approximately 30% of the control of posture, the decreased visual performance of older bus passengers may increase their susceptibility to falls (Gilmore, 1994). The surrounding visual information could also influence the likelihood of a fall occurring, particularly in the elderly, as it has been reported that the type of visual information displayed will have a greater increased effect on sway in older individuals than younger (Redfern et al., 1997). The effect of visual cues on stability has previously been outlined in more detail in Section 5.1.

### **6.1.3 Flooring Conditions and the Ability to Stand**

There have been numerous studies undertaken which have been concerned specifically with the elderly and those with ambulatory disabilities in terms of designing buses to improve safety, physical stability and comfort for these passengers. Redfern et al. (1997) undertook a study to investigate the effects of flooring conditions on young and older subjects' balance while standing. A number of floor conditions were used ranging from soft to hard and three visual conditions were studied, which involved the subjects' eyes being open, closed and looking at a moving visual surround. The results suggest that softer floors increased the amplitude of sway in older subjects compared to younger subjects, with the moving visual surroundings increasing this effect. A study by Gilmore (1994) used subjects with ages ranging from 55 to 75 years to investigate the effects of using various visual surroundings on both objective and subjective measurements of balance maintenance with the aim of increasing bus ride comfort and safety. The study found that the use of vertical geometric patterns produced the optimum potential to reduce the rate of occurrence of falling in moving buses.

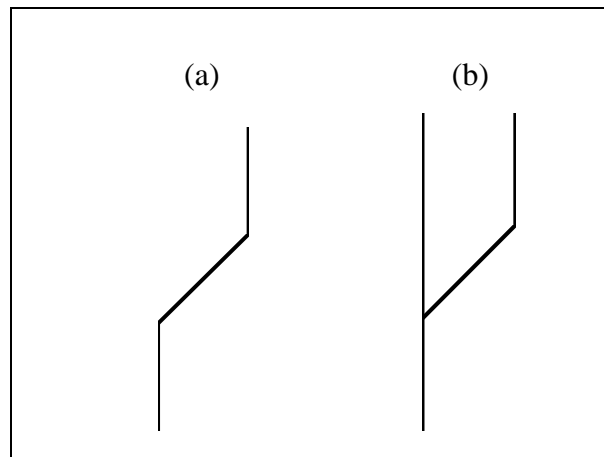
Many passengers who are have ambulatory disabilities will particularly find it difficult to stand for any period of time. Frye (1996) reported that 34% of public transport users with disabilities of could not stand up without discomfort for more than 9 minutes (20% no more than 4 minutes), while 76% of those with more severe disabilities could not stand up for more than 9 minutes (61% no more than 4 minutes). It is therefore important that some seats near bus entrances and exits

are clearly signed as being priority seats for the elderly and those with ambulatory disabilities.

#### **6.1.4 Conventional Features of Buses**

Petzäll (Paper I - 1993) describes the features of seats which are especially designed for passengers with ambulatory disabilities. Firstly, they should be located near the bus entrance, with the seat height being between 400 and 500mm above the floor. The report advises that high seats are best to use in local service buses where passengers will only be seated for short periods, as they are easier to sit down and rise up from, whereas lower seats are best to use for bus journeys which will involve passengers being seated for long periods of time, as they tend to be more comfortable. The back rest should also be slightly concave to provide stabilising support for the seated person. Armrests should be provided and they should be able to be folded out of the way to provide easier access to and from the seat.

Leyland Vehicles Ltd. and MIRA (1980) carried out a study looking specifically at requirements for handrails used to board and alight buses. Elderly subjects took part and provided their opinions on various handrail design. Hand-grip measurements were also recorded to see how much space was required to grip the various designs. The two designs which performed the best are displayed in Figure 6.



**Figure 6: Handrail designs which were ranked the best for (a) boarding and (b) alighting** (from Leyland Vehicles Ltd. and MIRA, 1980)

Petzäll (Paper III - 1993) explored the idea of adapting buses to meet the needs of the elderly and those with ambulatory disabilities by using a test bus to investigate the design of entrances and seats. It was found that low steps, of uniform height, improved boarding and alighting the bus, as did the handrails used. These consisted of two vertical stanchions on either side of the entrance, with one handrail on either side connecting the two stanchions and a further rail located from the top of the steps to the driver.

Another study which looked into bus design in terms of accessibility and safety for elderly passengers was undertaken by Oxley and Benwell (1985), where current designs were tested and evaluated by a group of elderly subjects. The issues of boarding and alighting which were reported by subjects as being important to accessibility and safety were step heights, handrail design and availability and the gap width between the bus and kerb. Subjects also commented on the seating and flooring as being important in determining levels of safety and accessibility.

Petzäll (Paper I - 1993) also reported on a study by Brooks et al. where the ability of elderly passengers and those with ambulatory disabilities to use bus steps was investigated. It was found that all subjects were capable of traversing a step with a height of 180mm when a handrail was present, while 94% could manage

270mm, with the greatest step height of 440mm being managed by 44%. When the step height managed by all subjects is compared with current regulations (see section 4.3), it can be seen that the maximum legislated step heights stated are considerably higher than 180mm. If manufacturers were to include steps on their buses which were close to the maximum height permitted, there would be many elderly passengers and those with disabilities who would find it extremely difficult to board the bus.

Split step entrances have also been highlighted in a number of studies as making it easier for less mobile passengers to enter the bus (Oxley and Benwell, 1985, Petzäll (Paper I), 1993).

### **6.1.5 New Adaptations**

The design of conventional features of buses, such as steps, handrails and seating are important in determining how safe and accessible local service buses are to all bus passengers, particularly the elderly and those with ambulatory disabilities. However, there are other features which can be implemented to particularly help improve bus accessibility for less able passengers, including kneeling and low floored buses and retractable steps.

As well as the fixed steps found at the entrance and exit of all buses, auxiliary steps are also sometimes used at bus stops to improve the safety and accessibility of buses to passengers with ambulatory disabilities (Byman and Hathaway, 1994). There are a number of different types of auxiliary steps, including manual, automatic self-storing, portable or fixed “add-on” types. Manual steps are operated fully by the bus driver and require the least maintenance while automatic steps are under minimum control by the driver, but passenger injuries may be caused during premature closure of the step or during opening if a passenger is too close to the vehicle. Self-storing auxiliary steps are kept in the undercarriage of the bus and their operation can easily be affected by poor weather conditions. The use of portable steps can avoid the possibility of any malfunctioning occurring, however, the stability of these steps must be considered in detail. Other problems which may arise when using portable auxiliary steps include

ensuring the steps are easily accessible to the driver and keeping them secure while the bus is in motion. Fixed “add-on” steps are generally very narrow, are often found on vans and it has been suggested that they increase the potential for accidents (Byman and Hathaway, 1994).

Leyland Vehicles Ltd. and MIRA (1980) undertook a study for TRRL which involved investigating the design of retractable first steps for easy entry and exit which could be stored conveniently within the structure of the bus. The study revealed that it was possible to install a mechanical retractable step to the structure of the bus and it reduced the time taken for elderly subjects to board and alight, due to easier entry and exit. However, there was a need for step height uniformity to include the retractable step as some subjects found it difficult to adjust to a higher second step. In addition, the hazards and risks of a step protruding from the side of the bus, both to passengers and the structure of the bus were outlined.

Mechanical and manual fold-out ramps are another feature which can help to improve the accessibility of local service buses for elderly passengers and those with ambulatory disabilities. Their uses and benefits will be discussed in more detail in Section 6.2.1.

To try and overcome the main fears and difficulties many elderly people and those with ambulatory disabilities may experience with boarding and alighting a bus, due to either the height of the first step or the gap between the bus step and the kerb, modifications to buses have been introduced in the form of low floored buses and “kneeling” buses (Mueller-Hellman, 1989).

Kneeling buses reduce the height from the ground to the first bus entrance step to within four to six inches therefore increasing the safety, comfort and accessibility of boarding and alighting, especially for passengers with ambulatory disabilities. However, this mechanism has a number of disadvantages which cause drivers to dislike it. It has been known to lock in the kneeling position, particularly in extreme weather conditions.



Kneeling buses are also more expensive to maintain and require more maintenance compared to other buses and using the mechanism may increase journey times (Byman and Hathaway, 1994, Fruin et al., 1994). The effect of using a kneeling mechanism on journey time can be curbed by allowing the driver to control the mechanism and decide whether it is required at a bus stop for a particular passenger (Paper I - Petzäll, 1993). Also, some European countries use a driver pre-selected automatic kneeling. However, this is prohibited in the UK due to the risks of trapping passengers feet under the step.

As part of their study investigating the use of buses by the elderly and those with disabilities, Oxley and Benwell (1985) compared a number of bus designs, including a kneeling bus, for their ease of accessibility when boarding and alighting. The kneeling bus was rated as one of the easiest vehicles to board, but was rated as the most difficult to alight from.

A low floored bus provides a permanent reduced distance between the ground and the vehicle floor. Its main advantage is that it will take a reduced amount of time for less able passengers to board and alight the bus (Fruin et al., 1994). However, due to the tyre size used on buses, the main disadvantage will be that the wheel housing will take up a substantial space inside the bus, leaving less space for seating (Petzäll (Paper I), 1993). The new European directive for bus and coach construction, as described by Lancastrian (1997) does not make the current design of low-floor buses mandatory, but does favour them.

In order that buses are at their lowest possible first step height when passengers are boarding and alighting, kneeling bus mechanisms are often used in conjunction with low-floored buses.

An article in the journal *Coach and Bus* (26 March 1998) showed how features such as low and kneeling floors are being implemented by operators on to their buses, as well as features for passengers using wheelchairs, such as ramps and lifts, which will be discussed in Section 6.2.

## **6.2 The Wheelchair User**

Up until recent years, accessibility for wheelchair users has not really been considered in the design of local service buses. However, due to changes in current European regulations (Lancastrian, 1997), passengers using wheelchairs are required to be considered in bus design so that there is at least enough space for one wheelchair user at any time on a bus. It is therefore important that safety issues concerning wheelchair using passengers travelling on local service PSVs are considered when designing new vehicles.

### **6.2.1 Mechanisms to Assist Boarding and Alighting**

Passengers using wheelchairs will experience similar stages of bus travel to most bus passengers. However, they will require some form of assistance in boarding and alighting in the form of either physical help from attendants or from a mechanical appliance and they will need to have their wheelchair restrained in the vehicle instead of taking a seat (Petzäll (Paper I), 1993). There are a number of mechanisms which can be used to assist wheelchair users when boarding and alighting buses including ramps and lifts.

Two categories of lifts have been identified (Byman and Hathaway, 1994), either passive or active. Passive lifts extend from the entrance steps to provide a platform and can perform as vehicle stairs when not in use. Active lifts consist of a platform which is fitted into the vehicle and can be operated by a number of mechanisms. Safety considerations should include the load capacity of the lift being at least 600 to 1000 pounds, while the platform surface should be free of protrusions, slip resistant, of an adequate size and have platform barriers to prevent the wheelchair from sliding off the platform (ADA in Byman and Hathaway, 1994).

The placement of the lift within the bus can have its advantages and disadvantages (Byman and Hathaway, 1994). Placement at the front of the vehicle can mean that the passenger is close to the driver, therefore it is easier for the driver to assist passengers using wheelchairs and the passenger will experience a more

comfortable ride. However, it may be extremely difficult for both wheelchair users and passengers with ambulatory disabilities to board at the same time through the same door and securing wheelchairs into position may interfere with other passengers boarding.

Lift placement at the centre of the vehicle again will mean that the passenger will be close to the driver, it will be simpler for passengers with ambulatory disabilities and wheelchair users to board simultaneously and wheelchair passengers will have the most comfortable ride travelling at the centre of the bus. The main disadvantage is that the bus has to be at least 28 feet long for a lift to be placed at the centre of the vehicle (Byman and Hathaway, 1994).

Placement of a lift at the side/rear of the bus can be the easiest location to load and secure passengers using wheelchair as it does not interfere with other passengers boarding. However, rear placement gives the roughest ride to those who are motion sensitive, increases the time it takes the driver to assist passengers with disabilities and those waiting to board or alight may have difficulty in gaining the attention of the driver. In addition, rear wheelchair lift placement may block the emergency exit and debris from the rear bus wheel may get under the lift and cause malfunctions.

One alternative to using lifts to board and alight wheelchair users is to use ramps, either manual or mechanical. The ramps should have similar safety requirements to lifts in terms of load, surface and barriers. One main disadvantage of using ramps as opposed to lifts is that there will be a greater physical demand placed on the driver or operator (Byman and Hathaway, 1994). Spencer (1986) describes three main types of access ramps. The under-floor telescopic ramp is the most common form of powered ramp and is located below the floor, where, when required, it projects outwards and hinges downwards to reach the kerb or road. In-floor telescopic ramps are located within the structure of the floor. The process of operation involves the whole unit hinging downwards followed by the extension of a further telescopic component from within the device. Both of these devices can be complex to install in the vehicle. A third device, known as the

hinged ramp, is the simplest available configuration which can be either manually or mechanically operated. When not in operation, it is kept “folded” within the entrance door structure, but when deployed, it “unfolds” until the end of the ramp makes contact with the kerb or road.

Low-floored buses can also make it possible for wheelchair users to board and alight buses by eliminating the need for entrance steps, particularly when coupled with a kneeling mechanism. This should ensure that wheelchair users will be able to board the bus with minimal help from an attendant or the driver.

### **6.2.2 Safety During the Bus Journey**

Up to now, only the process of wheelchair users boarding and alighting has been discussed. However, passenger safety during the bus journey is equally important. Mobility aids such as wheelchairs need to be secured within the bus in case of sudden braking, jerks or sharp bends during the bus journey, as do the wheelchair users themselves, so they are provided with postural support (Petzäll (Paper II), 1993). Byman and Hathaway (1994) describe two main categories of securement devices along with their advantages and disadvantages. The back wheel securement device requires little effort from the driver, as many passengers can secure themselves using this device. However, this device limits the number of wheelchairs which can be secured at one time and there is a possibility that it may fail under extreme braking or swerving. Also, this device may damage the wheelchair.

An alternative securement device is the 3-4 point securement, which allows a larger number of wheelchairs to be secured at one time and, in the event of an accident, should hold the wheelchairs much more stable. However, the process of securing the wheelchair will involve a great deal of effort from the driver, as the passenger will be unable to secure this device themselves, and will take much longer to secure than the back wheel device.

A study by Petzäll (Paper II - 1993) investigated wheelchair and occupant restraint systems and how they performed under various travel conditions. Impact

tests were also carried out. The wheelchair was restrained with four straps and the occupant restrained with a three-point seat-belt. The results included recommendations for features of both the seat belt and the wheelchair restraint system and the minimum forces they must withstand. For the seat belt, this should be 13.5kN for at least 0.2 seconds and for the wheelchair restraint system, this should be 15kN (forward facing) for at least 0.2 seconds.

The London Committee on Accessible Transport (1994) state that wheelchairs must be secured to the structure of the bus and that wheelchair users must be independently secured to the vehicle, not the wheelchair. This also stated that this area on buses where boarding aids such as lifts and ramps are used should be well lit and any spaces between the platform and the vehicle which could trap a person's limb should be protected by a safety cut-out device.

To enable space set aside on buses for wheelchairs to be used as seating space for other passengers when no passengers with disabilities are present, removable seat squabs have been designed and are currently being implemented by some bus operators into their vehicles (Coach and Bus, 26 March 1998).

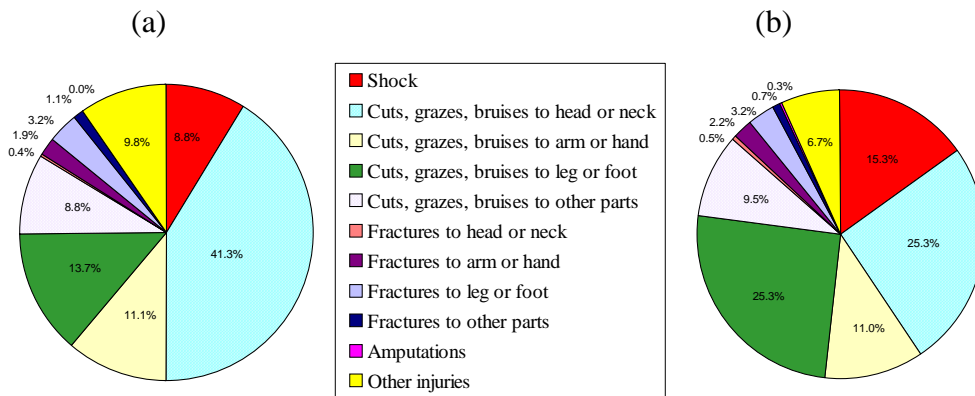
### **6.3 Gender differences**

A report by Leyland Vehicles Ltd. and MIRA (1980) on the National PSV accident survey found that more female passengers were injured than male passengers in all types of accidents (72% were female compared to 25% male). When only collision accidents are analysed, 66% were female casualties and in non-collision accidents, 73% were female. When these figures are compared with the proportion of male and female passengers using buses, it can be seen that the proportions are similar (69% female and 31 % male - figures from survey carried out by the National Bus Company in Leyland Vehicles Ltd. and MIRA, 1980). However, in most of the industrial towns surveyed, the percentage of male passengers increased to 40%, therefore suggesting that female passengers have been involved slightly more often in accidents.

Other smaller scale accident surveys include one reported by Mabrook (1994), where 21 of the 30 casualties identified in a three month period were female (70%) and another report covered in the Injury Bulletin No.27 (1994) which looked specifically at injuries involving bus doors. This report identified 17 passengers injured by bus doors within a six year period, of which 15 were female (88%). One possibility why injuries are at a higher rate for female passengers than for males could be that many women have to board the bus with heavy baggage or young children and have to cope with push chairs, all of which could reduce their stability during the bus journey (Leyland Vehicles Ltd. and MIRA, 1980).

The characteristics of accidents occurring to male and female passengers were outlined by the national PSV accident survey (in Leyland Vehicles Ltd. and MIRA, 1980). No significant differences were found for most of the accident characteristics, with the exception of accidents occurring in the gangway, where accidents to females were highly represented, and for staircase accidents where the proportion of male casualties was much higher than for female casualties.

Very few notable differences were found in the type of injuries sustained by male and female casualties using the data from the National PSV accident survey (Leyland Vehicles Ltd. and MIRA, 1980). It appeared that shock made up a larger percentage of all injuries sustained by female passengers compared to male passengers (15% compared to 9%), as did cuts, grazes and bruises to the leg or foot (25% of all injuries sustained by female passengers compared to 14% of all injuries sustained by male passengers). However, cuts, grazes and bruises to the head or neck made up a larger percentage of all injuries sustained by male passengers compared to female passengers (41% compared to 25%). Figure 7 shows how the percentages differ for all types of injuries sustained by male and female passengers.



**Figure 7: Frequency of types of injuries for (a) male and (b) female passengers casualties** (adapted from Leyland Vehicles Ltd. and MIRA, 1980).

The number of deaths from accidental falls on the same level (i.e. not involving steps) from slipping, tripping or stumbling in England and Wales in 1979 was quoted as being 205 females compared to only 83 males (Manning, 1981). There are a number of reasons why this may be the case. For example, the difference in the type of shoes men and women wear may contribute, as women more often wear shoes with higher heels, which will make them more liable to lose their balance. Another reason could be that women are more likely to report an accident than men, as they are less likely to be embarrassed about reporting a minor incident.

#### 6.4 The encumbered bus passenger

As well as the large proportion of people using buses who have to some degree ambulatory disabilities, many other passengers may have mobility difficulties when using buses, in the form of encumbrances such as luggage, heavy shopping, young children and prams, or the slightly longer term burdens of a broken limb or pregnancy (Frye, 1996). Many passengers are very reluctant to use luggage pens provided in the bus for their encumbrances such as shopping or prams as they dislike being separated from their possessions because of security reasons and, particularly on busy occasions, it may be difficult to collect baggage before alighting if other passengers are standing by the luggage pens. This therefore leaves many luggage pens under-used and passengers encumbered for the duration of their journey.

There are a number of safety issues related to passengers keeping their encumbrances with them throughout their journey. Firstly, the passenger would have greater difficulty finding a seat as they would not be able to manoeuvre around as easily, then, if a seat was found, there would be little room for encumbrances to be placed. This may lead to aisles being blocked by baggage, creating a tripping hazard for other bus users. If a seat was not found and an encumbered passenger was required to stand, their ability to stand with ease while the bus was in motion would be reduced. Standing while carrying a load may also be a hazard to other seated bus users, as when the loaded passenger attempts to move up or down the aisle, seated passengers may be struck by standing passengers' encumbrances, depending on what height the encumbrances are being carried at. Unfortunately, none of the studied literature contains any information on the frequency of accidents involving encumbrances.

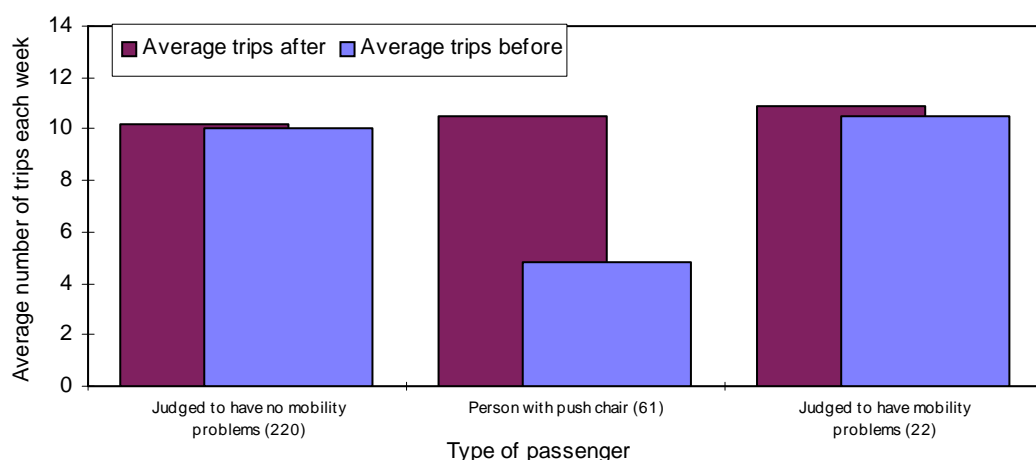
Davis (1983) investigated load carriage and found that when a person carries a load, their stability is reduced. The heavier the weight and the higher the weight is held, the greater the reduction is. Load carriage reduces stability as it moves the centre of gravity away from its normal position, this being above the ground contact area of the feet. When laden, the sway angle is increased, therefore stability is reduced. From this, it can be assumed that encumbered passengers are at more risk from falls in buses than unencumbered passengers.

The effects of load positioning as well as foot placement on an individuals' stability were investigated by Holbein and Chaffin (1997). The study found that movement was much more restricted when subjects were laden, particularly when the load was held with one hand over the shoulder. The foot placement which produced the largest stability limits was found to be when the feet were placed at shoulder width with one foot forward of the other, while feet positioned at wide stance resulted in much smaller stability limits.

Encumbered passengers had difficulty with most stages of bus travel, including boarding, alighting, paying or showing passes, moving up or down the aisle and



being seated (Field, 1993). Features on buses which are implemented to make buses safer and more accessible to elderly passengers and all those with disabilities can also increase accessibility for encumbered passengers. Features such as lifts and ramps particularly help passengers with small children in push chairs and prams, as can low-floored and kneeling buses. In fact, it was reported by Frye (1996) that the introduction of low-floor buses brought about a much higher rise in the average number of trips made by passengers with push chairs than other passengers both with and without mobility difficulties (Figure 8).



**Figure 8: Average number of trips made before and after low floor introduction**  
(adapted from Frye,1996).

A comprehensive study by Field (1993) on bus design for the encumbered passenger found that the problems experienced by encumbered passengers can be sufficient to dissuade them from bus use. It was also found that luggage pens are under-used, but when they are used, they were described as being poorly designed for the users' needs. Some passengers did not even realise that luggage pens were available. Another suggestion was that luggage pens would be more frequently used if passengers could sit close by.

The type of luggage space preferred by passengers was a lower top rail height rather than a luggage pen and a low or floor level base to the luggage pen is preferred for pushchairs and a higher base for shopping bags and suitcases. A minimum acceptable aisle for passengers to walk freely with shopping bags was

760mm and a minimum acceptable seat spacing was 880mm. Therefore, existing seat and aisle spacing would not be able to acceptably accommodate encumbered passengers, and neither would DPTAC (1988) specifications for minimum aisle and seat spacing.

There is a noticeable variation in the type of bus users throughout the day, from commuters in the morning and early evening, shopping use during the day and leisure use in the evening. It would be an advantage for both operators and bus passengers to be able to adapt buses to the change in bus users throughout the day by converting seats into luggage space or vice-versa. This would help to enhance both safety and accessibility to all bus users (Churchill, 1997).

An innovation which could ease the burden of passengers with young children in push chairs is the tip-up seat. The tip-up seat could be used as seating for all passengers, but when required, could be prioritised for use by passengers with young children to accommodate push chairs and would mean that passengers would be able to sit nearer the push chairs and children would not need to be removed from them (Coach and Bus, 26 March 1998). The ability to move seats or fold them away would also be helpful during certain times of the day to increase the amount of luggage and standing space, so that passengers could be nearer to their encumbrances without causing as much of an obstruction as they would do in the gangway (Churchill, 1997).

As this literature review shows, there are numerous issues involved in passenger safety when using Local Service PSVs, including the designs and placement of features, bus accessibility and the requirements of passengers including the elderly, those with disabilities and the encumbered. However, one issue which has not yet been discussed in any detail, which if ignored will result in the re-design of buses being of little effect to passenger safety, is driver behaviour and operational practice. If the bus was not to move off from the bus stop until all passengers were safely seated, it would be inevitable that the number of accidents on buses would be reduced. The introduction of this practice may cause some concern to bus operators who may worry that this may increase bus journey time

and therefore lose profits. However, a study by Oxley and Benwell (1985) found that, for the worst possible circumstances where each passenger boards one at a time and is allowed to get seated before the bus moves away and stays in their seats until the bus stops, only adds about 40 seconds in the hour of running time, which is approximately a 1% increase.

## **6.5 Summary**

### **6.5.1 The Elderly and those with Ambulatory Disabilities**

It appears that the over 60 age group are over-represented in bus accident casualty rates and in the bus user population as a whole, therefore their needs and the needs of those with ambulatory disabilities should be a high priority in the design of local service PSVs. Boarding, alighting and reaching or leaving a seat were found to be the most difficult actions, while nearly half of all injuries sustained by elderly passengers occurred when the bus braked suddenly. Traversing steps, grabbing on to rails and controlling posture in a moving bus were found to be the most difficult actions to accomplish. A number of modifications have been introduced to improve accessibility and safety for less able passengers, including low-floor and kneeling buses and auxiliary steps.

### **6.5.2 The Wheelchair User**

Although some mechanisms have already been introduced to assist and encourage elderly passengers and those with ambulatory disabilities to use local service PSVs more often, there is still some way to go in assisting the wheelchair user. However, new innovations are being introduced in modern PSVs to achieve this. Mechanisms to allow easier entry and exit for passengers using wheelchairs include various lift or ramp mechanisms, as well as low floor and kneeling mechanisms. When boarded, it is important that the wheelchairs and their occupants are both secured in case of sudden movements and that sufficient space is set aside for wheelchair users.

### **6.5.3 Gender Differences**

Statistics show that bus accident casualties are more often female than male. Female passengers were found to be highly represented in gangway accidents, whereas males accounted for a high proportion of staircase accidents. Head and

neck injuries were found to be associated more with male passengers while female passengers tended to suffer more from shock or leg and foot injuries.

#### **6.5.4 The Encumbered Passenger**

Encumbered bus passengers have similar problems in using local service buses to the elderly and those with ambulatory disabilities. The encumbrances they carry often reduce their postural control, increasing the likelihood of a fall occurring. In addition, encumbrances can be a safety hazard to other bus passengers, if aisles are blocked or seated passengers are struck by baggage being carried by standing passengers. To overcome this, luggage bays and spaces for children in prams should be located nearer seats. Boarding and alighting could also be made easier by introducing mechanisms similar to those which would be useful for elderly and all passengers with disabilities.

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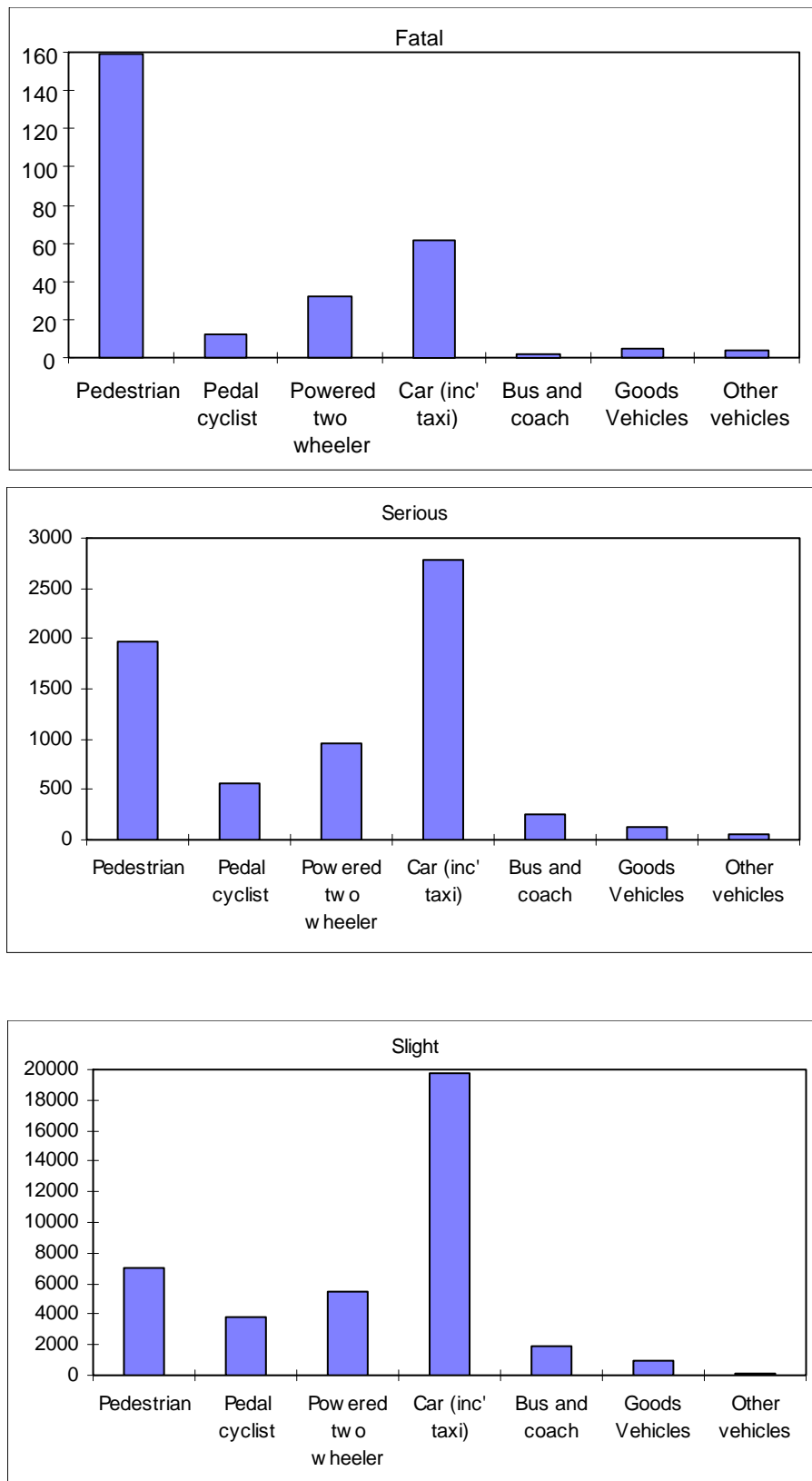
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### APPENDIX A



**Figure A.1 Fatal, serious and slight road accident casualties for various modes of transport (Adapted from Local Transport Today, 7 May 1998)**