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Relationship between Speed and Risk of Fatal Injury: Pedestrians and Car Occupants

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EXECUTIVE SUMMARY

This study explores the relationship between speed and the risk of fatal injury for three different types of traffic accident:

- pedestrians struck by the front of cars;
- car drivers following frontal impacts; and
- car drivers following side impacts.

The risk of fatality with impact speed (for pedestrians) and change of velocity (for seat-belted car drivers) has been calculated using a logistic regression method, and three current sources of accident data in the UK:

- the On the Spot (OTS) project;
- police fatal files; and
- the Co-operative Crash Injury Study (CCIS).

This same method of logistic regression has been applied to two other important sources of pedestrian accident data: data collected by Ashton and Mackay in Birmingham in the 1970s, and data from the German In-Depth Accident Study (GIDAS) used by Rosén and Sander in their 2009 paper. Using the same method on these different datasets means that the results can be directly compared. The risk of fatality was then plotted in the form of risk curves for each dataset.

Comparison of the pedestrian risk curves from the different datasets shows that the risk of pedestrian fatality is generally higher for the dataset from the 1970s, indicating that the probability of pedestrians being killed when hit by the front of a car has reduced over the last 30 years. In all of the pedestrian datasets, the risk of fatality increases slowly until impact speeds of around 30 mph. Above this speed, risk increases rapidly – the increase is between 3.5 and 5.5 times from 30 mph to 40 mph. Although the risk of pedestrians being killed at 30mph is relatively low, approximately half of pedestrian fatalities occur at this impact speed or below.

Comparing the risk of fatality for a seat-belted driver in a frontal impact with a side impact shows that the risk of fatality is much higher in a side impact than in a frontal impact with the same change of velocity.

1 INTRODUCTION

There are many variables in a road traffic accident that will affect the injury severity of the people involved. These include factors related to the casualty (age, gender, biomechanical tolerance, seat-belt wearing, etc.), factors related to the vehicle (size, shape, impact speed, effectiveness of absorbing impact energy, etc.), and factors related to the wider environment (characteristics of the object hit, effectiveness of the medical treatment, etc.). All these variables have an important relationship to the likely injury severity of the casualty.

One of the most widely studied variables is speed. For pedestrians, this is typically measured in terms of the speed of the vehicle at the point of impact with the pedestrian. For vehicle-on-vehicle impacts, the change in velocity of the vehicles involved is generally accepted as the measure of speed that is most closely linked to injury severity. The purpose of this report is to investigate the relationship between speed and the risk of fatal injury, for both pedestrians and car occupants. This investigation uses accident data currently being collected in the UK, and compares it with results from other studies around the world.

There is a particular focus on the relationship between impact speed and the risk of fatality for pedestrians in impacts with cars. Pedestrians are a particularly vulnerable road-user group, with small changes in impact speed potentially having a large effect on the risk of fatal injury. This study uses accident data collected in the UK to calculate the relationship between impact speed and the risk of fatal injury for pedestrians, and the associated confidence in this result. Using the same method as other studies, results from other studies are compared to determine how much this relationship changes in different countries and over time.

2 PEDESTRIAN INJURY RISK CURVES

A review of the literature on the relationship between impact speed and pedestrian injury found that two main sources of accident data have been used to calculate this relationship. These are data collected by Ashton and Mackay in Birmingham in the 1970s, and data collected by the German In-Depth Accident Study (GIDAS). In addition to these, recent data from the UK have been used for the pedestrian injury risk curves in this study (police fatal files and the On the Spot (OTS) project). In this section, the same method will be used on each of these datasets to calculate the relationship between impact speed and the risk of fatal injury for pedestrians. All of these datasets contain pedestrians hit by the front of cars only.

The method used to calculate the pedestrian injury risk curves is described, and then each of the data sources is investigated in turn. This begins with a review of the relevant literature, which gives details of the sample used, and the methods used to calculate the relationship between impact speed and injury severity. Following this, the same method of logistic regression is used for all three data sources in order to compare the relationship between impact speed and the risk of fatal injury. Using the same method for all three data sets enables the results to be compared directly – the differences will be due to differences in the sample alone.

2.1 Methodology overview

There are two main stages to calculating pedestrian injury risk curves. The first involves weighting the data to match national statistics, and the second is the calculation of the injury risk curves themselves and their associated confidence using logistic regression. These curves have been calculated for three sources: the Ashton and Mackay data from the 1970s; the GIDAS data from 1999–2007; and the OTS and police fatal file data from 2000–09.

It should be noted that logistic regression is not the only method which can be used for this type of analysis. Appendix 2 outlines an alternative Bayesian method, and compares it with logistic regression. The two methods give very similar results.

2.1.1 Weighting data

The data collected in the accident studies have been weighted to the total number of pedestrian casualties that occur nationally. This is to ensure that the results are representative of the national accident population in terms of severity level. In-depth accident studies tend to record a larger proportion of fatal and serious casualties than in national statistics. This could be because the sample is purposefully biased (fatalities and serious casualties may be more interesting from an injury prevention point of view), or because of the practicalities of collecting in-depth accident data (e.g. in a low-speed, low-severity collision, there will be little evidence available with which to calculate an impact speed).

The weighting procedure weights the number of fatal, serious and slightly injured casualties in the dataset so that they represent the same proportion of fatal, serious and slight casualties seen in the national data.

Table 2.1 gives details of the sample size and weighting performed on the pedestrian cases in the Ashton and Mackay data based on the information available in Ashton (1980). The Ashton and Mackay dataset included pedestrians in impacts with the front of cars. Ashton used the number of pedestrian casualties that occurred in 1976 to weight the pedestrian dataset in that paper – regardless of the type of vehicle hitting the pedestrian, or the side of the vehicle which hit them. The weighting applied to the Ashton and Mackay data in this report will be the same as used by Ashton, so that the results can be directly compared with other studies that used the Ashton and Mackay data.

Table 2.1: Sample size and weighting for Ashton and Mackay data

Pedestrian casualties in Great Britain, 1976				**Pedestrian casualties in sample**	**Weighting factors**
Age	**Injury severity**	**Number**	**Proportion (%)**		
0–14	Fatal	405	1.4	12	33.8
	Serious	7,461	25.8	72	103.6
	Slight	21,072	72.8	71	296.8
15–59	Fatal	720	2.9	35	20.6
	Serious	6,276	25.2	55	114.1
	Slight	17,873	71.9	31	576.5
60+1	Fatal	1,208	9.4	34	35.5
	Serious	4,431	34.3	38	116.6
	Slight	7,272	56.3	10	727.2
All ages	Fatal	2,333	3.5	81	28.8
	Serious	18,168	27.2	165	110.1
	Slight	46,217	69.3	112	412.7

Table 2.2 gives details of the sample size and weighting performed on the pedestrian cases in the OTS and police fatal file sample. The weighting was particularly important for this sample because of the large proportion of fatalities (many of these cases came from the police fatal files, which provided fatally injured pedestrians only). As the sample only included pedestrians hit by the front of cars, it was weighted using the number of pedestrians reported to have been hit by the front of cars nationally.

Table 2.2: Sample size and weighting for the OTS and police fatal file data				
Pedestrian casualties with the front of cars in Great Britain, 2005–07 mean			**Pedestrian casualties in sample**	**Weighting factors**
Injury severity	**Number**	**Proportion (%)**		
Fatal	347	2.4	66	5.26
Serious	3,171	21.7	74	42.9
Slight	11,116	76.0	57	195.0

It should be noted that there are some slight and serious accidents which are not reported to the police and, therefore, are not present in the national statistics (Department for Transport, 2009). This means that once the results are weighted, they are likely to give an overestimate of the risk of fatality.

Details of the weighting procedure for the GIDAS sample used in Rosén and Sander (2009) are given in that paper. The weighting procedure used was the same as that used for the other samples. The number of slight, serious and fatal pedestrian casualties in the sample were weighted to the number of slight, serious and fatal casualties in Germany from 2003 to 2007.

2.1.2 Logistic regression

The speed-injury risk curves for fatal injuries were drawn using logistic regression. This process predicts how a variable with only two possible values (in this case ‘fatal’ or ‘not fatal’) is dependent on a continuous variable (in this case ‘impact speed’; Pallant, 2005). Confidence intervals were also drawn, which show the area within which the true speed−injury curve is likely to lie. In this study, the confidence intervals given are at 95%, i.e. they show the range of values where there is a 95% chance of the true value lying.

The logistic regression and calculation of confidence intervals were performed using the statistical programming package ‘R’. Example code and output from this process can be seen in Appendix 1.

2.2 Results

2.2.1 Ashton and Mackay data

2.2.1.1 Literature

In the 1970s, Ashton and Mackay led an in-depth accident study that collected information on pedestrian accidents. This was an on-the-scene investigation by a team based at the Accident Research Unit at the University of Birmingham (Ashton and Mackay, 1979). This data were weighted to the number of pedestrian casualties occurring nationally (Ashton, 1980). The dataset included pedestrians struck by the front of cars or car derivatives, and was biased towards more severe accidents. The injury severity of the pedestrians was recorded using the police definitions of ‘fatal’, ‘serious’ and ‘slight’:

- Fatal – death within 30 days of the accident.
- Serious – includes fractures, concussion, internal injury, crushing, severe cuts and lacerations, severe shock requiring medical treatment, or any casualty who was detained as an in-patient in hospital.
- Slight – minor sprains, bruises or lacerations which are not serious.

Ashton and Mackay used this pedestrian dataset to estimate the impact speed distribution of pedestrian accidents in Great Britain. However, they did not use these data to calculate speed–injury risk curves for pedestrian impacts, although several authors have since.

Pasanen (1992) calculated a relationship between **driving speed** and the risk of pedestrian fatality. As part of this calculation, Pasanen calculated the relationship between impact speed and the risk of pedestrian fatality using the data from Ashton (1980). Pasanen applied a non-linear regression model based on the least squared method, and calculated the following relationship between impact speed in metres per second (v) and the probability of fatality (P):

$$P = \frac{1.027}{1 + 37e^{-0.017v^2}} - 0.027 \tag{2.1}$$

However, Pasanen did not weight the data collected by Ashton and Mackay to represent the national proportion of fatal, serious and slight casualties. Because the Ashton and Mackay data contained a higher proportion of fatalities than was recorded nationally, Pasenen’s results are an overestimate of the risk of pedestrian fatality.

The work of Ashton and Mackay, and Pasanen, has been widely quoted in the literature when the relationship between speed and pedestrian injury is discussed. These include studies which are often referred to as giving the risk of pedestrian injury with speed, but which in fact refer to the work by Ashton and Mackay or Pasanen, such as Pasanen and Salmivaara (1993), European Transport Safety Council (1995), World Health Organization (2004), and European Transport Safety Council (2010).

Davis (2001) also used the data collected by Ashton and Mackay to calculate the relationship between the risk of pedestrian fatality and impact speed. Davis used an ordered, discrete outcome model to calculate the relationship between impact speed and risk of pedestrian fatality, and did weight the data to the national proportion of fatal, serious and slight casualties. Davis performed these calculations separately for the three age groups included in the Ashton data: children (aged 0–14 years), adults (aged 15−59 years), and the elderly (60+ years). Davis found the following relationships between the probability of fatality (P) and impact speed (v) in kilometres per hour:

$$P_{children} = 1 - \frac{e^{8.85-0.12v}}{1 + e^{8.85-0.12v}} \quad (2.2)$$

$$P_{adults} = 1 - \frac{e^{8.87-0.13v}}{1 + e^{8.87-0.13v}} \quad (2.3)$$

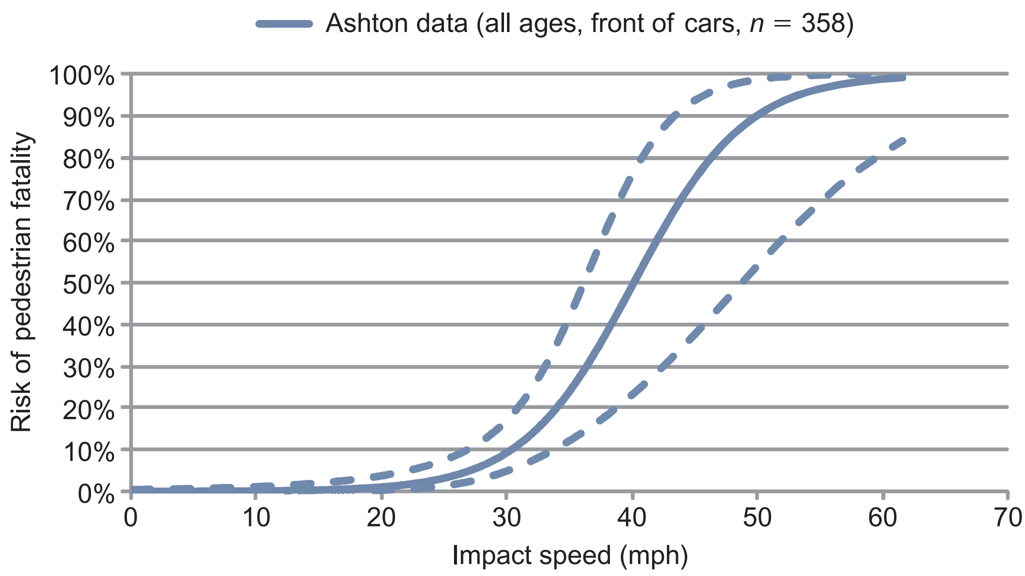
$$P_{elderly} = 1 - \frac{e^{9.73-0.20v}}{1 + e^{9.73-0.20v}} \quad (2.4)$$

The studies by Pasanen and Davis used the tables of data published in Ashton (1980). These tables gave the number of pedestrians injured by injury severity, age group and impact speed. However, the impact speed was given in groups of 10 km/h. This places a limitation on the accuracy of any risk curves based on these data. However, a good approximation used by Davis, and which is also used in this study, is to assume that the impact speeds are uniformly distributed within each impact speed group. For example, if there are 10 pedestrians with an impact speed in the range of 31−40 km/h, it is assumed that the impact speeds are 31, 32, 33, 34, 35, 36, 37, 38, 39 and 40 km/h. For the pedestrians in the uppermost speed group (71 km/h and over), it was assumed that the speeds were uniformly distributed between 71 km/h and 100 km/h − this is the same assumption used by Davis (Rosén *et al.*, 2010).

2.2.1.2 Results of logistic regression

In this report logistic regression has been used on the pedestrian dataset in Ashton (1980), weighted using the weighting factors shown in Table 2.1. The result of using this method on the total Ashton and Mackay pedestrian sample is shown in Figure 2.1. This figure shows that the estimated risk of a pedestrian being killed is approximately 9% if they are hit at a speed of 30 mph. The risk at an impact speed of 40 mph is much higher, at approximately 50%. This figure also shows that the confidence intervals (the dashed lines in the figure) get much wider as the impact speed increases. This is because there are fewer pedestrians in the sample at higher speeds, which reduces the precision of the estimated risk at these speeds.

Figure 2.1: Risk of pedestrian fatality calculated using logistic regression from Ashton and Mackay data



Figures 2.3–2.4 show the estimated relationship between impact speed and the risk of fatality for children (1–14 years), adults (15–59 years) and elderly pedestrians (60+ years), respectively. These are the age groups used in Ashton (1980), and are also the groups used by Davis (2001) when calculating the relationship between impact speed and the risk of fatality. Each of these graphs show the risk of fatal injury, the confidence intervals calculated for these data using the logistic regression method (the blue lines), and also the curves calculated by Davis (the red lines).

Figure 2.2: Risk of child pedestrian fatality calculated using logistic regression from Ashton and Mackay data compared with the Davis function

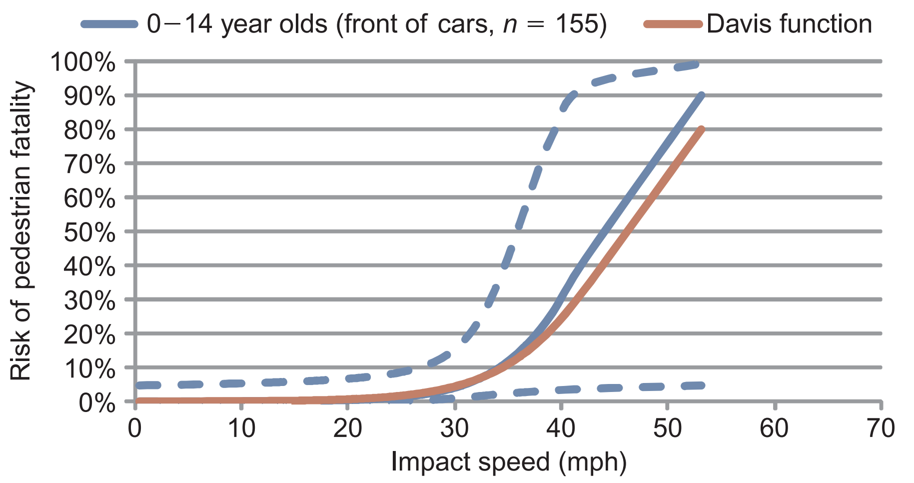


Figure 2.3: **Risk of adult pedestrian fatality calculated using logistic regression from Ashton and Mackay data compared with the Davis function**

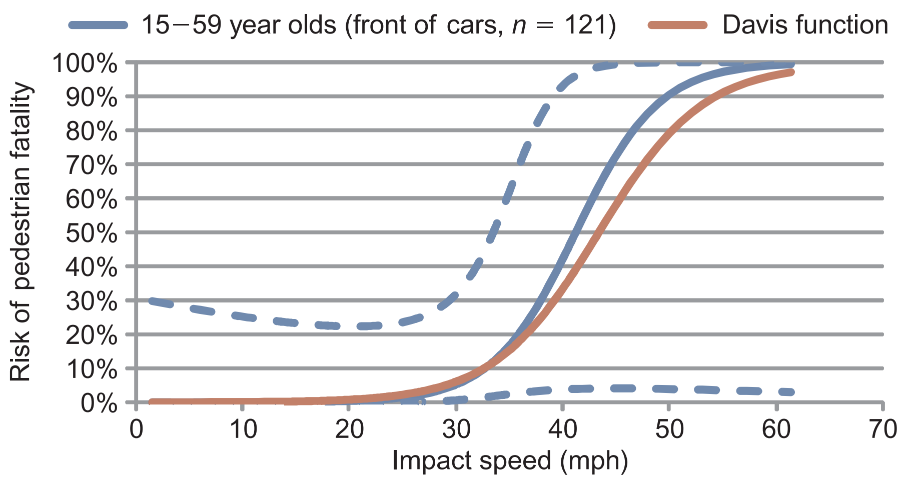
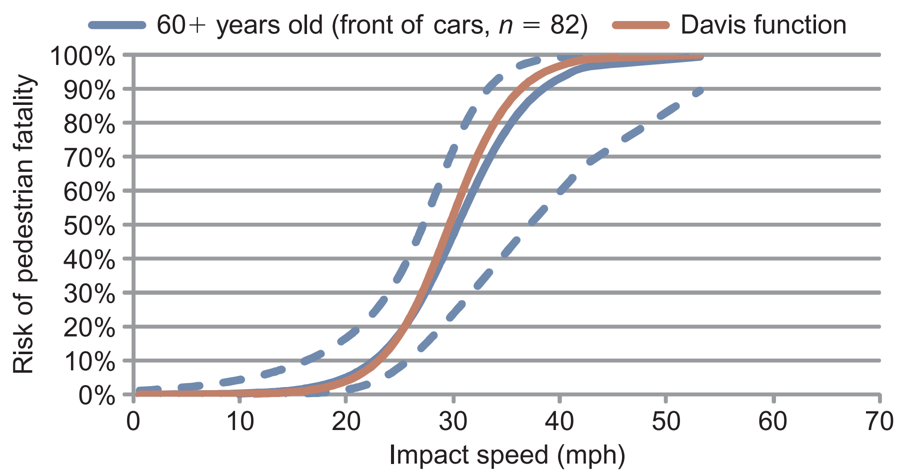


Figure 2.4: **Risk of elderly pedestrian fatality calculated using logistic regression from Ashton and Mackay data compared with the Davis function**



These three figures all show that the curves calculated using logistic regression are very similar to the curves calculated by Davis, particularly at lower speeds. As the impact speed increases, the lines start to diverge, with logistic regression giving slightly larger estimates of risk for children and adults, and lower estimates for elderly pedestrians. However, the sensitivity of the precision of these results to the sample size should be noted: the sample size has been split into three, and the confidence intervals have become much wider as a result, particularly for children and adults. For elderly pedestrians, the confidence intervals remain relatively narrow. This is because of the large proportion of fatalities in this sub-sample, which means that the estimate of fatality risk is more precise.

These figures highlight the fragility of elderly pedestrians. At an impact speed of 30 mph, the risk of fatality for elderly pedestrians is 47%, compared with 5% for adults and 4% for children.

2.2.2 GIDAS data

2.2.2.1 Literature

The German In-Depth Accident Study (GIDAS) is the largest in-depth accident study in Germany. Since mid-1999, the GIDAS project has collected on-scene accident cases in the areas of Hannover and Dresden. GIDAS collects data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and its causation. The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the German Association of the Automotive Industry (VDA).

In a study exploring the possible effectiveness of pedestrian protection measures, Hannawald and Kauer (2004) produced an injury risk function using data collected by GIDAS. This used a sample of 712 pedestrians, which were all struck by the front of cars. Hannawald and Kauer compared impact speed with the risk of being fatally injured, where 'fatal' injury was defined as pedestrians receiving a Maximum Abbreviated Injury Score (MAIS) of five or six. This is likely to have been a good approximation – all pedestrians with a MAIS of six are fatally injured by definition, and the majority of pedestrians with a MAIS of five are likely to die.

Hannawald and Kauer calculated their injury risk functions using logistic regression; however, it is not known whether they weighted the data in their sample to match the proportion of pedestrian casualties seen nationally.

A more recent study by Rosén and Sander (2009) also used GIDAS data to calculate the relationship between impact speed and the risk of pedestrian fatality. This sample included pedestrian impacts occurring between 1999 and 2007, where the pedestrian was hit by the front of the car and the impact speed was known. Pedestrians hit by sport utility vehicles, pedestrians who were lying down, and pedestrians who were 'sideswiped' were removed from the sample. The final sample that was used contained 490 pedestrians aged 15–96, including 36 fatalities. There were no children under the age of 15 in the GIDAS pedestrian dataset. The number of fatal, serious and slight casualties in this sample was weighted to the number of pedestrian casualties in Germany from 2003 to 2007. Rosén and Sander used logistic regression to calculate the relationship between impact speed v (in kilometres per hour) and the risk of pedestrian fatality P. The relationship found was:

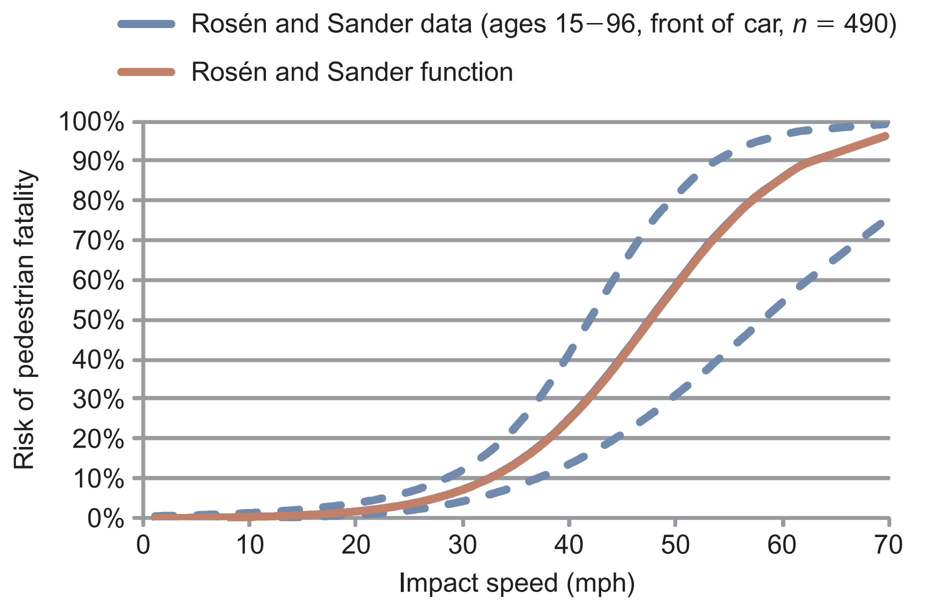
$$P = \frac{1}{1 + e^{6.9-0.090v}} \tag{2.5}$$

Rosén and Sander did not publish full details of their sample. However, through collaboration with Autoliv, it was possible to analyse the relevant dataset for use in this project.

2.2.2.2 Results of logistic regression

Figure 2.5 shows the results of using the logistic regression on the GIDAS data supplied by Rosén and Sander, and also shows the function calculated by Rosén and Sander themselves. These data contains pedestrians aged 15–96 years. Only one of these curves is visible because the results are identical: the logistic regression method matches that used by Rosen and Sander themselves. This figure shows that the risk of a pedestrian fatality at an impact speed of 30 mph is approximately 7%, and the risk of fatality at 40 mph is approximately 25%.

Figure 2.5: Risk of a pedestrian fatality calculated using logistic regression from the Rosen and Sander GIDAS dataset



2.2.3 *OTS and police fatal file data*

2.2.3.1 Overview

As part of this study, pedestrian casualties recorded in the On the Spot (OTS) study and police fatal files have been used to estimate the relationship between impact speed and pedestrian injury severity.

The OTS study began in 2000 and finished in 2010. It was funded by the Department for Transport and the Highways Agency. It aimed to establish an in-depth database that could be used to improve the understanding of the causes and consequences of road traffic collisions, and thus aid the Government in reducing road casualties.

There were two OTS teams: the Transport Research Laboratory (TRL), covering the Thames Valley area, and the Vehicle Safety Research Centre (VSRC), attached to Loughborough University and covering Nottinghamshire. Expert investigators from these teams attended the scenes of collisions, usually within 15 minutes of an accident occurring, using dedicated response vehicles and equipment. In total, the teams made in-depth investigations of about 500 collisions per year, and recorded in excess of 3,000 pieces of information about each collision. This information includes the speeds of the vehicles involved, including the speed of the vehicle at impact in a pedestrian accident. These speeds are based on evidence at the scene, witness statements and the expert judgement of experienced accident investigators.

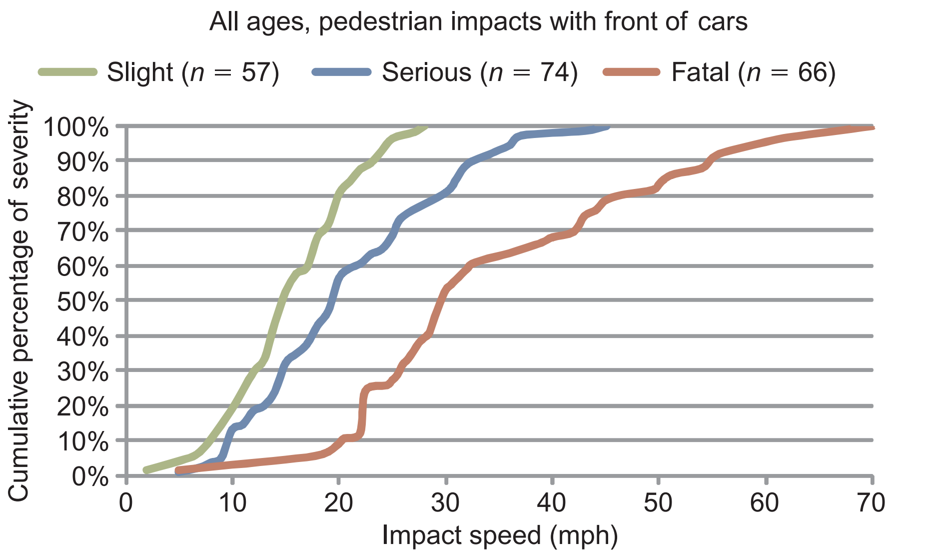
Police fatal file collision reports contain information arising from police investigations into fatal traffic collisions, and provide detailed information on the events leading up to a collision, as well as giving details of driver errors and/or vehicle defects which may have contributed to the collision and to the injuries that resulted in the fatality. They provide a unique insight into how and why fatal collisions occur.

Since 1992, TRL, on behalf of the Department for Transport, has received fatal files from police forces in England and Wales. The current archive contains over 34,000 police fatal collision reports.

From the pedestrian accidents in OTS and the police fatal files, a sample of 197 pedestrian casualties was obtained, including 66 fatalities. These pedestrians were hit by the front of cars, in accidents occurring from 2000 to 2009. Accidents where the pedestrian was lying down, or where the vehicle 'sideswiped' the pedestrian, were excluded. All ages of pedestrian casualty were included in the sample, including those of unknown age.

Figure 2.6 shows the cumulative impact speed of the pedestrians in the OTS and police fatal file dataset. This shows that approximately half of the fatally injured pedestrians in the dataset were hit at an impact speed of 30 mph or less. In order to perform the logistic regression, the number of slight, serious and fatal casualties in this dataset was weighted to match the number of pedestrian casualties in the national statistics (which was shown in Table 2.2).

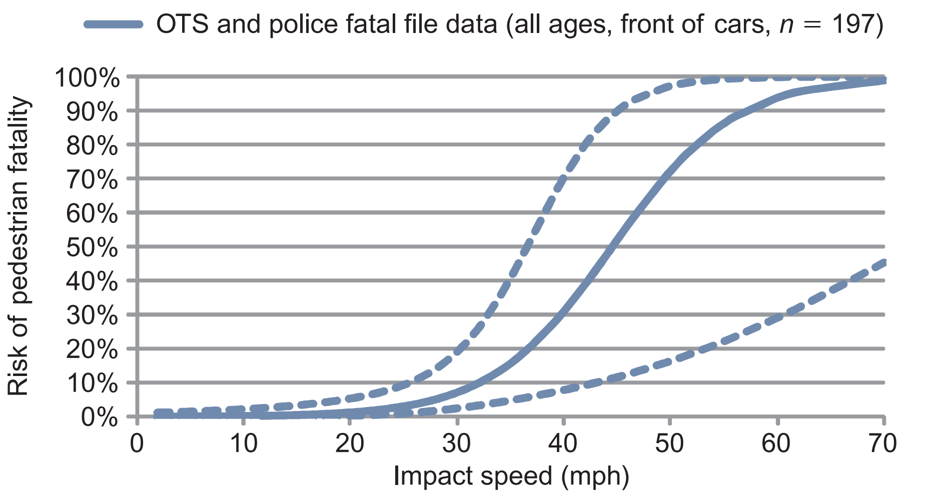
Figure 2.6: Cumulative impact speed for pedestrian casualties in the OTS and police fatal file dataset



2.2.3.2 Results of logistic regression

Figure 2.7 shows the relationship between impact speed and the risk of pedestrian fatality, calculated using the logistic regression method. This figure gives the risk of pedestrian fatality at an impact speed of 30 mph as approximately 7%, and the risk at an impact speed of 40 mph as approximately 31%. The number of cases in the sample is too small to allow the results to be broken down by age group.

Figure 2.7: Risk of pedestrian fatality calculated using logistic regression from the OTS and police fatal file dataset



2.2.4 Other sources of data

The Ashton and Mackay, GIDAS, and OTS and police fatal file datasets are the largest and most widely used datasets available for calculating the risk of pedestrian fatality with impact speed. However, in the literature there are other examples of pedestrian datasets that have been used for this purpose, which are discussed briefly here.

Anderson *et al.* (1997) investigated the relationship between reduced travel speeds and the incidence of pedestrian fatalities. As part of this, the probability of pedestrian fatality by impact speed was derived. This was based on a combination of the relationship between injury severity score (ISS) and impact speed (from Interdisciplinary Working Group for Accident Mechanics, 1986), and the relationship between ISS and the risk of being fatally injured (from Walz *et al.*, 1983). These studies were based on data collected in Switzerland in 1978 and 1981. However, this dataset was biased towards more severe injuries, and there are no details of any weighting procedure given.

Oh *et al.* (2008) developed a model for the risk of pedestrian fatality based on accident data collected in Korea from 2004 to 2005. The expression calculated for the risk of pedestrian fatality (P) with respect to impact speed (v) in kilometres per hour was as follows:

$$P = \frac{1}{1 + e^{5.433 - 0.095v}} \tag{2.6}$$

This expression was calculated using a binary logistic regression technique. However, this paper does not mention whether the sample of pedestrian accidents was representative of all pedestrian accidents in Korea, or whether it was weighted in any way.

3 CAR DRIVER INJURY RISK CURVES

In addition to exploring the relationship between impact speed and pedestrian injury, this study also looks at the relationship between speed and car driver injury severity. The process used is the same as that used for the pedestrian injury risk curves: the data in the sample are weighted to match the proportion of casualties which occur nationally, and logistic regression is used to calculate the relationship between speed and injury. The only things that differ are the source of the data and the definition of speed.

The data for the car driver injury risk curves come from accidents recorded in the On the Spot (OTS) study (described in Section 2.2.3.1), and also accidents recorded in the Co-operative Crash Injury Study (CCIS).

CCIS collected in-depth real-world accident data between 1983 and 2010. Vehicle examinations were undertaken at recovery garages several days after the collision. Car-occupant injury information was collected and questionnaires were sent to survivors. Collisions were investigated according to a stratified sampling procedure which favoured cars containing fatal or seriously injured occupants, as defined by the British Government definitions of fatal, serious and slight. The study focused on collisions involving cars which were less than eight years old at the time of the collision. More information on the data collection methods employed can be found at www.ukccis.org.

The measure of speed used to draw the speed–injury risk curves for the car drivers was the change of velocity, or delta-v, of their vehicles. In this case, delta-v is a better predictor of injury than other measures of speed, such as the impact speed or closing speed, because it takes into account the characteristics of the vehicle, such as vehicle weight and stiffness, in addition to the initial speeds of the vehicles involved. As an example of the calculation of the change in velocity, consider a front–front impact between two identical cars, both travelling at 30 mph. Conservation of momentum means that these cars will come to rest on impact, therefore they will each have a delta-v of 30 mph. If one of the cars was initially stationary, after impact they would move off at a speed of 15 mph, and the delta-v for each vehicle would be 15 mph. The delta-v is calculated in exactly the same way for a side impact; if a stationary car is hit in the side by an identical car travelling at 30 mph, both vehicles will move off at 15 mph, giving them both a delta-v of 15 mph.

Figure 3.1 shows the cumulative delta-v for the cars in frontal impacts split by the injury severity of the car drivers. This sample includes car drivers who were wearing a seat belt in a car receiving one single significant impact to the front, where this impact was with another car. Drivers in vehicles which rolled over were excluded. The cumulative data are not weighted – weighting the data would not change the form of the cumulative speed curves. This figure shows that half of drivers who were fatally injured were in an impact with a change in velocity of 34 mph or less.

Figure 3.1: Cumulative speed curves for car drivers in cars with a frontal impact

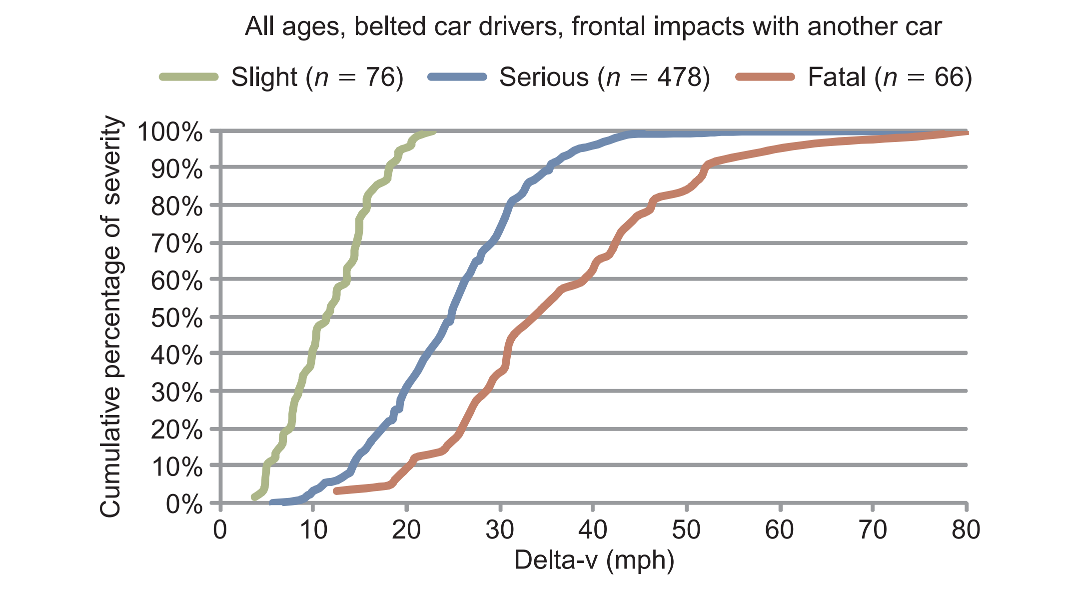
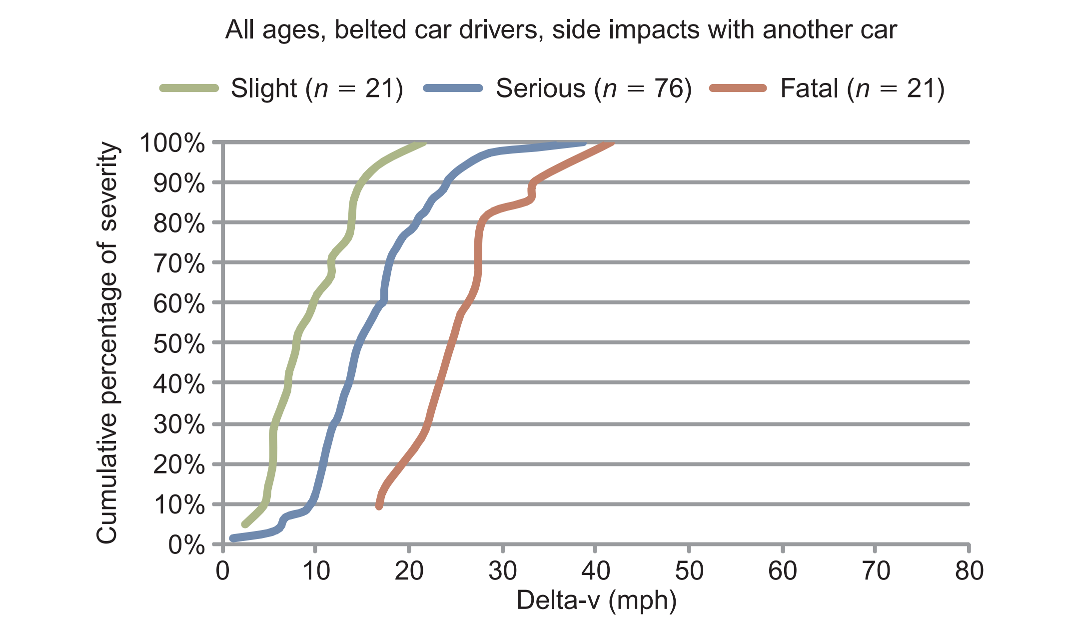


Figure 3.2 shows the cumulative delta-v of the cars in side impacts. This sample includes cars that were struck on the offside by another car and where the driver was seated on the offside of the car (i.e. the drivers are seated on the struck-side of the vehicle). Similarly to the frontal impact sample, this only includes belted drivers receiving a single significant impact to the side of the car, in impacts with another car. Drivers in cars that rolled over were excluded. This figure shows that half of the fatally injured drivers in the sample were in impacts with a change in velocity of 24 mph or less.

Figure 3.2: Cumulative speed curves for car drivers in side impacts



3.1 Weighting the data

A very similar process to that used for pedestrian casualties (in Section 2.1.1) was used to weight the data for car drivers. Table 3.1 shows details of the weighting for car drivers in frontal impacts, and Table 3.2 shows the weighting for car drivers in side impacts. As the CCIS and OTS sample excluded drivers who were not wearing a seat belt, the weighting procedure takes into account the proportion of STATS19 casualties that were wearing a seat belt, and weights to this number. Because STATS19 does not record seat-belt wearing, this proportion was estimated using the information available in CCIS.

Table 3.1: Sample size and weighting for car drivers in frontal impacts

Injury severity	Sample from CCIS/OTS	Sample in STATS19	Seat-belt wearing rates in CCIS (%)	Weighting factors
Fatal	66	479	73	5.23
Serious	478	6,744	83	11.7
Slight	76	81,642	89	956

Table 3.2: Sample size and weighting for car drivers in side impacts

Injury severity	Sample from CCIS/OTS	Sample in STATS19	Seat-belt wearing rates in CCIS (%)	Weighting factors
Fatal	21	119	80	4.53
Serious	76	1,275	91	15.3
Slight	21	24,141	94	1,081

It should be noted that there are some slight and serious accidents which are not reported to the police, and are therefore not present in the national statistics (Department for Transport, 2009). This means that, once the results are weighted, they are likely to give an overestimate of the risk of fatality.

3.2 Results of logistic regression

Figure 3.3 shows the risk of car driver fatality in frontal impacts, by the delta-v of the impact. This figure shows that the risk of car driver fatality in an impact with a delta-v of 30 mph is approximately 3%, at 40 mph the risk is approximately 17%, and at 50 mph the risk is approximately 60%.

Figure 3.3: Risk of car driver fatality calculated using logistic regression from the OTS and CCIS dataset

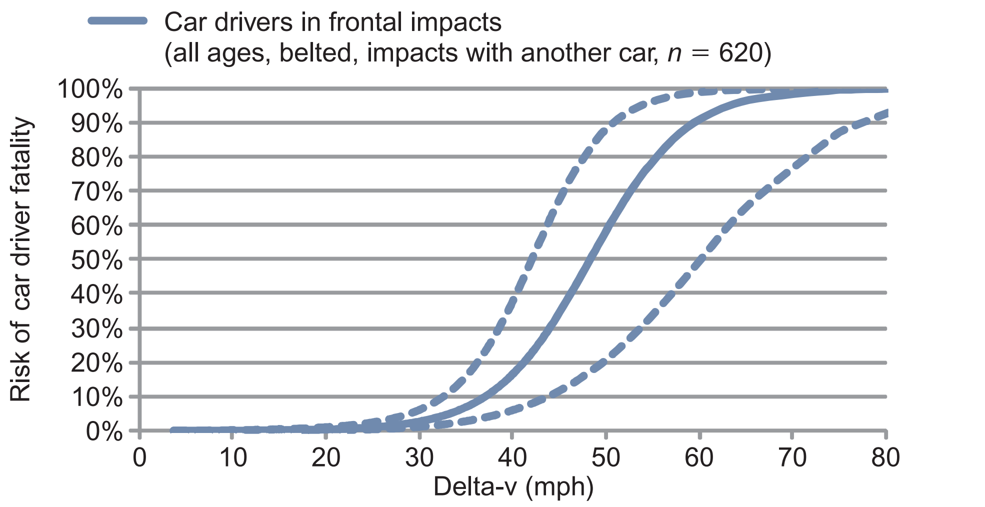
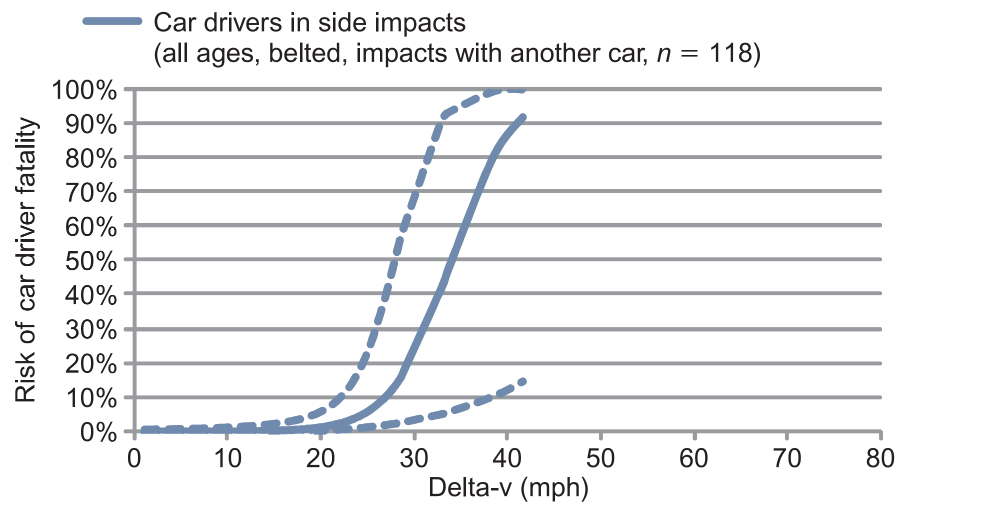


Figure 3.4 shows the risk of car driver fatality in side impacts. It is immediately apparent that the risk in side impacts is much higher than in frontal impacts. For a side impact with a delta-v of 30 mph, the risk of fatality is approximately 25%. For a delta-v of 40 mph, the risk of fatality is approximately 85%.

Figure 3.4: Risk of car driver fatality calculated using logistic regression from the OTS and CCIS dataset



4 DISCUSSION

4.1 Pedestrian injury risk curves

The same method of logistic regression has been applied to in-depth pedestrian accident data collected in Great Britain in the 1970s, in Germany from 1999 to 2007, and in Great Britain from 2000 to 2009. As the same method has been used to calculate the risk of pedestrian fatality with impact speed, the results from these datasets can be directly compared. This comparison is shown in Figure 4.1, which shows the risk of pedestrian fatality with impact speed for the three different datasets. The fatality risk at impact speeds of 30 mph and 40 mph are also shown in Table 4.1.

The comparison between the Ashton and Mackay data from the 1970s and the more recent accident data suggests that there has been a decrease in the risk of pedestrian fatality for impact speeds of 30 mph or greater. However, this should be treated with caution due to the relatively small sample sizes and confidence intervals surrounding the risk estimates. A decrease would be expected for two reasons. The first is the improvement in car design, meaning that pedestrians are less likely to be fatally injured if they are hit at the same speed by a newer car. The second reason is improvement in medical care, which means that pedestrians can survive injuries now that would have been fatal in the 1970s.

Comparison of the two new pedestrian accident datasets indicates a difference in injury risk for impacts at a speed above 35 mph. Above these speeds, the risk of fatality is greater for the On the Spot (OTS) and police fatal file dataset. Because the same method of logistic regression has been used, the differences between these results must be due to differences in the two datasets. The most apparent differences between the two datasets are that the Rosén and Sander dataset does not include any children under the age of 15, and does not include any impacts with sports utility vehicles. Either of these differences could explain why the OTS and police fatal file dataset gives slightly higher fatality risks at higher speeds compared with the Rosén and Sander dataset, although the number of children and SUVs in the dataset was small.

Figure 4.2 shows the risk of pedestrian fatality for pedestrians aged 15 years or older. This enables a better comparison with the Rosén and Sander sample. The risk of fatality at 30 mph and 40 mph is also given for these adult pedestrians in Table 4.1. Removing the children from the OTS and police fatal file dataset increases the calculated risk of pedestrian fatality slightly, meaning that the difference between the GIDAS and the OTS and fatal file datasets increases. The differences between these two datasets must be due to more than just the absence of children in the GIDAS dataset. When the child pedestrians are removed from the Ashton and Mackay dataset, the risk of fatality also increases, and by a larger amount than was seen in the OTS and police fatal file dataset.

Generally, it appears that the risk of fatality for child pedestrians is less than the risk of fatality for pedestrians aged 15 or older. This agrees with Figures 2.2–2.4, which showed that the risk of pedestrian fatality is similar for children and adults, and higher for elderly pedestrians.

Figure 4.1: Risk of pedestrian fatality calculated using logistic regression from the Ashton and Mackay, OTS and police fatal file, and Rosen and Sander datasets

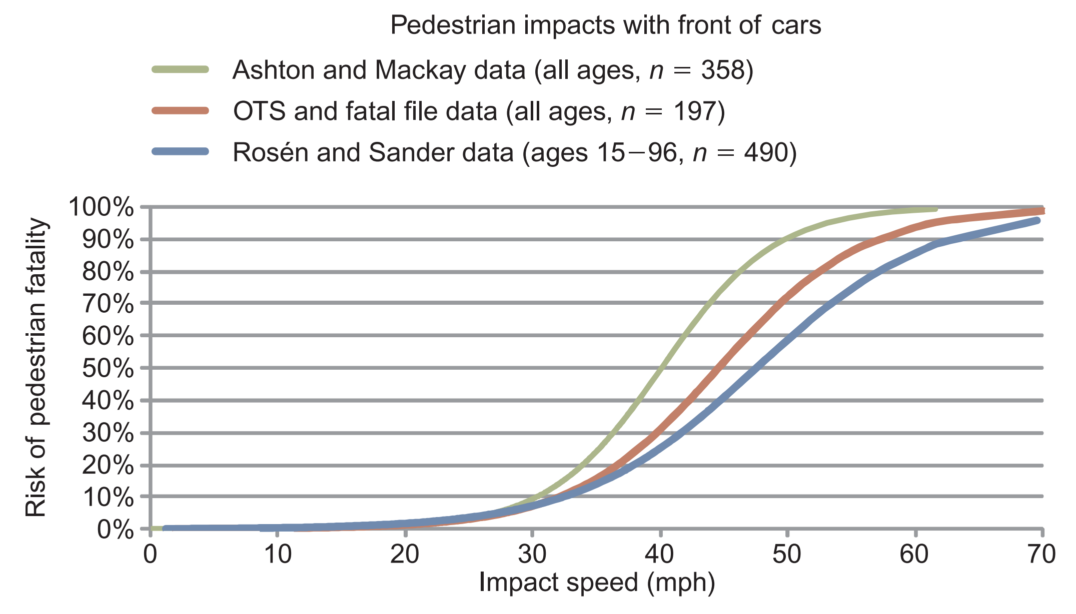


Figure 4.2: Risk of pedestrian fatality for pedestrians aged 15 years or older. Calculated using logistic regression from the Ashton and Mackay, OTS and police fatal file, and Rosen and Sander datasets

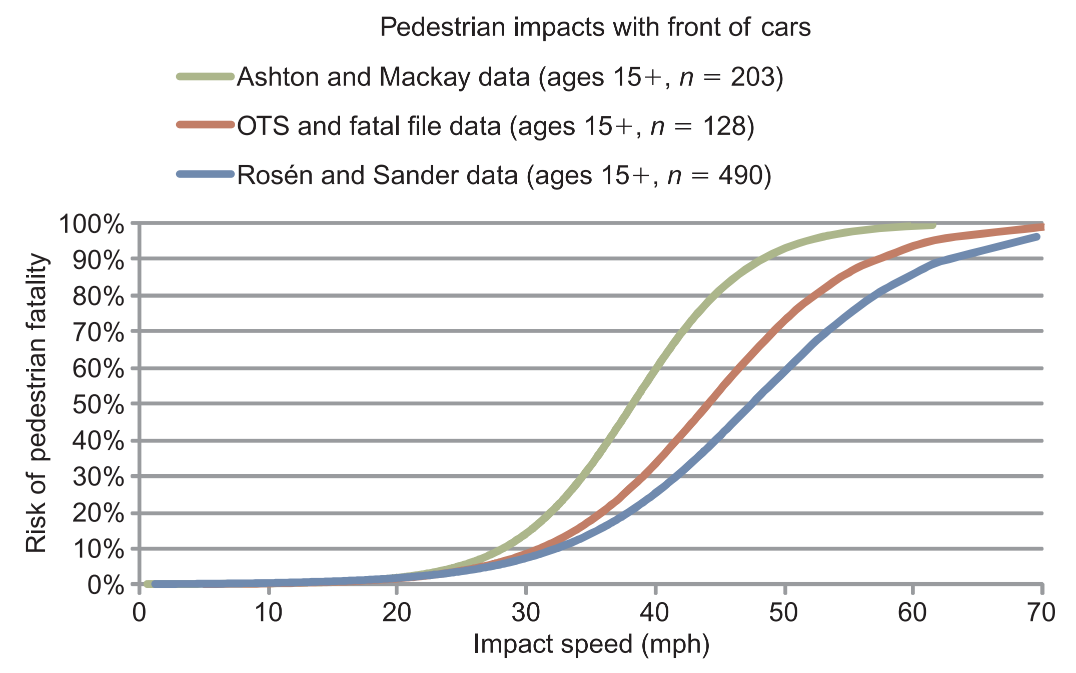


Table 4.1: Risk of pedestrian fatality at impact speeds of 30 mph and 40 mph for the three pedestrian datasets		
Dataset	**Risk of fatality for impact speed**	
	30 mph (%)	**40 mph (%)**
Ashton and Mackay (all ages)	9	50
Ashton and Mackay (ages 15+)	14	60
OTS and police fatal file (all ages)	7	31
OTS and police fatal file (ages 15+)	9	33
GIDAS (Rosén and Sander) (ages 15+)	7	25

Although Figure 4.1 shows apparent differences between the three datasets, it is clear from Figures 2.1, 2.5 and 2.7 that the confidence intervals around each curve also encloses the curves of the other two datasets. The large confidence intervals around each curve highlight the large variability of fatality risk, and that it depends on many other factors as well as impact speed. Age, gender, biomechanical tolerance, the part of the vehicle hit, and many other variables are all related to the risk of pedestrian fatality.

Although the absolute values of risk differ between the three datasets, the increase in fatality risk with impact speed follows a similar pattern in all three. There is a gradual rise of risk up to impact speeds of around 30 mph. Above 30 mph the risk of fatality increases more rapidly with respect to speed:

- in the Ashton and Mackay dataset, the risk increases 5.5 times from 30 to 40 mph;
- in the OTS and police fatal file dataset, the risk increases 4.5 times from 30 to 40 mph; and
- in the Rosén and Sander dataset, the risk increases 3.5 times.

It should be noted that these curves give the risk of fatality **provided that the pedestrian has been injured**. This is because no details have been included of any pedestrians that were hit by vehicles, but were not injured. Although OTS does record details of road users who were not injured in accidents, the national statistics do not include this information. However, it is a good assumption that the vast majority of pedestrians hit by the front of a moving car will receive at least slight injuries (which can be as minor as a bruise), therefore these curves are a good approximation of the risk of fatality which could be calculated if the number of non-injured pedestrians was known.

It is known that there are some slight and serious road traffic accidents that are not reported to the police in Great Britain (Department for Transport, 2009) and are therefore not included in the national statistics. Because the risk of pedestrian fatality was calculated by weighting the OTS and police fatal file dataset to match the proportion of fatal, serious and slight casualties nationally, this under-reporting in the national statistics will have an effect on the calculated risk. The effect will be that the risk is overestimated.

The accuracy of the curves drawn from the Ashton and Mackay data is limited by the information available in that pedestrian dataset. The results of this study, and also that of Davis (2001) and Pasanen (1992) rely on data published in tables in Ashton (1980), which groups the impact speed into categories of 10 km/h. The assumption has been made that the impact speed is uniformly distributed within these groups, but without access to the original pedestrian dataset from the 1970s it is impossible to know how good an assumption this is. However, it seems unlikely that the differences would be large enough to alter the risk curve so that there no longer appeared to be a reduction in pedestrian injury risk since the 1970s.

There have been other studies that have investigated the risk of pedestrian fatality with impact speed, most notably using data from Switzerland and Korea. However, neither of these studies appears to weight the results in any way, so they cannot be deemed representative of the risk of pedestrian fatality in Switzerland or Korea.

Although this study suggests that the **risk** of pedestrian injury at an impact speed of 30 mph is approximately 7%, the cumulative impact speed curves in Figure 2.6 show that approximately half of the fatally injured pedestrians in the OTS and police fatal file sample were hit at impact speeds of 30 mph or less. A recent study using STATS19 (Crinson *et al.*, 2009) saw that over 60% of pedestrian fatalities occurred in an area where the speed limit was 30 mph or lower. Although the risk of pedestrian fatality may seem relatively low at 30 mph, the large number of pedestrian accidents at these speeds leads to a lot of pedestrian fatalities at 30 mph or less.

4.2 Car driver injury risk curves

The car driver injury risk curves highlight the difference in risk for drivers in frontal impacts and those on the struck side in a side impact. It is much more likely that a driver will suffer a fatal injury if they are involved in a struck side impact. For a delta-v of 30 mph, the risk of fatality in a frontal impact is 3% compared with 25% in a struck side impact. At 40 mph, the risk is 17% in a frontal impact compared with 85% in a side impact. This reflects the differing mechanics of a frontal and a side impact.

In a frontal impact, there is a large crush zone in the front of the vehicle, which can absorb the energy of the impact, and which means that the change in velocity occurs over a longer timescale. Restraint systems, including seatbelts and airbags, are also at their most effective in a frontal impact. In a side impact, there is relatively little space between the outside of the door and the seating position of the driver. This explains why impacts with the same delta-v are more likely to be fatal if the car is struck on the driver side than if it is hit on the front.

Although the risk of fatality in a frontal impact at 30 mph is relatively low, the cumulative impact speed curves show that approximately 35% of fatalities occur at this delta-v or below. The large number of collisions at these speeds means that large numbers of people are killed at these speeds, even though the risk of fatality in each individual collision is low.

The sample of car drivers in frontal impacts is much larger than the sample in side impacts and the sample of pedestrians (620 in frontal impacts, 118 in side impacts, 197 pedestrians). Although this means that the confidence intervals are narrower, they still include a wide range of risk values, particularly at higher impact speeds. In the same way as for pedestrians, this highlights the large number of factors in addition to speed which affect the risk of a car driver receiving fatal injuries.

5 CONCLUSIONS

This study has explored the relationship between speed and the risk of being killed for three groups of casualties: pedestrians hit by the front of a car, belted car drivers involved in a frontal impact with another car, and belted car drivers in side impacts with another car. This relationship has been calculated in the same way for these three types of impact: first the datasets have been weighted to match the national proportion of casualties, and then logistic regression has been used to calculate the relationship between the risk of fatality and speed. Data from three pedestrian datasets (for Great Britain in the 1970s, Germany from 1999 to 2007, and Great Britain from 2000 to 2009) have been treated in the same way to allow comparison. The conclusions of this study are as follows:

- The three pedestrian datasets show a similar pattern in fatality risk. The risk increases slowly until impact speeds of around 30 mph. Above this speed, risk increases rapidly – the increase is between 3.5 and 5.5 times from 30 mph to 40 mph.
- The risk of fatality is generally higher for the dataset from the 1970s, indicating that the risk of pedestrian fatality has reduced over the last 30 years.
- Even though the risk of pedestrians being killed at 30 mph is relatively low, approximately half of pedestrian fatalities occur at this impact speed or below.
- The risk of a belted car driver being killed in an impact with another car is much higher in a side impact than in a frontal impact with the same change of velocity.

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CCIS was managed by TRL, on behalf of the United Kingdom Department for Transport who funded the project along with Autoliv, Ford Motor Company, Nissan Motor Company, Toyota Motor Europe, Daimler Chrysler, LAB, Rover Group Ltd, Visteon, Volvo Car Corporation, Daewoo Motor Company Ltd and Honda R&D Europe(UK) Ltd.

Data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham; the Vehicle Safety Research Centre (VSRC) at Loughborough University; TRL and the Vehicle and Operator Services Agency of the Department for Transport.

Further information on CCIS can be found at www.ukccis.org.

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This project uses accident data from the police fatal accident reports which are archived and stored for research purposes by a project funded by the Department for Transport.

7 REFERENCES

Anderson, R. W. G., McLean, A. J., Farmer, M. J. B., Lee, B. H. and Brooks, C. G. (1997) Vehicle travel speeds and the incidence of fatal pedestrian crashes. *Accident analysis and Prevention,* 29, 667–674

Ashton, S. J. and Mackay, G. M. (1979) Some characteristics of the population who suffer trauma as pedestrians when hit by cars and some resulting implications. *Proceedings of the 4th IRCOBI conference*.

Ashton, S. (1980) A preliminary assessment of the potential for pedestrian injury reduction through vehicle design, *Proceedings of the Twenty Fourth Stapp Car Crash Conference*, October 15–17, 1980, Troy, Michigan. SAE Technical Paper 801315 607-35. Warrendale: Society of Automotive Engineers (SAE).

Crinson, L., Cuerden, R. and Vandrevala, T. (2009) *Review of Pedestrian Fatal Road Traffic Accidents*. TRL Client Project Report CPR103. Prepared for the Department for Transport Project Record T501V. Crowthorne: TRL.

Davis, G. A. (2001) Relating severity of pedestrian injury to impact speed in vehicle pedestrian crashes. *Transportation Research Record*, 1773, 108–113.

Department for Transport (2009) *Reported Road Casualties Great Britain: 2008 – Annual Report*. London: The Stationary Office.

European Transport Safety Council (1995) *Reducing Traffic Injuries Resulting from Excess and Inappropriate Speed*. Brussels: European Transport Safety Council.

European Transport Safety Council (2010) *Speed Fact Sheet 7: Setting Appropriate, Safe, and Credible Speed Limits*. Brussels: ETSC. www.etsc.eu/documents/Speed%20Fact%20Sheet%207.pdf (accessed on 11 February 2010).

Hannawald, L. and Kauer, F. (2004) *ACEA Equal Effectiveness Study.* Technische Universität Dresden.

Interdisciplinary Working Group for Accident Mechanics (1986) *The Car–Pedestrian Collision: Injury Reduction, Accident Reconstruction, Mathematical and Experimental Simulation: Head Injuries in Two Wheeler Collisions*. University of Zürich and Swiss Federal Institute of Technology.

Oh, C., Kang, Y. and Kim, W. (2008) Assessing the safety benefits of an advanced vehicular technology for protecting pedestrians. *Accident Analysis and Prevention,* 40, 935–942.

Pallant, J. (2005) *SPSS Survival Manual*, 2nd edn. Milton Keynes: Open University Press.

Pasanen, E. (1992) *Driving Speeds and Pedestrian Safety; A Mathematical Model*. Publication 77. Helsinki University of Technology, Transport Engineering.

Pasanen, E. and Salmivaara, H. (1993) Driving speeds and pedestrian safety in the city of Helsinki. *Traffic Engineering and Control* 34(6), 308−310.

Rosén, E. and Sander, U. (2009) Pedestrian fatality risk as a function of car impact speed. *Accident Analysis and Prevention,* 41, 536−542.

Rosén, E., Stigson, H. and Sander, U. (2010) Literature review of pedestrian fatality risk as a function of car impact speed. *Accident Analysis and Prevention*, doi: 10.1016/j.aap.2010.04.003.

Walz, F. H., Hoefliger, M. and Fehlmann, W. (1983) Speed limit reduction from 60 to 50 km/h and pedestrian injuries. *Proceedings of the Twenty Seventh Stapp Car Crash Conference,* pp. 277−285.

World Health Organization (2004) *World Report on Road Traffic Injury Prevention*. Geneva: World Health Organization.

APPENDIX 1

Logistic regression input and output

A1.1 Input for logistic regression

The method of logistic regression required three variables for each pedestrian in each of the datasets used. These variables were the impact speed, a binary value for whether the pedestrian was fatally injured (0 = not fatal, 1 = fatal), and the weighting applied to that pedestrian so that the sample represents the national proportion of slight, serious and fatal pedestrian casualties.

In the German In-Depth Accident Study (GIDAS) dataset (supplied by Rosén and Sander) and the On the Spot (OTS) and police fatal file dataset, these variables were all available or easily calculated. However, the Ashton and Mackay data, published in Ashton (1980), grouped the casualties into categories of 10 km/h. In order to perform the logistic regression, the same assumption was made as that which Davis (2001) used on these data. The assumption was that, within these 10 km/h groups, the impact speeds were uniformly distributed. For example, if there were 10 pedestrians with impact speeds in the range of 31–40 km/h, it was assumed that the impact speeds were 31, 32, 33, 34, 35, 36, 37, 38, 39 and 40 km/h.

A1.2 Example R code

Below is an example of the R code that was used to calculate the speed–injury risk curves for the Ashton and Mackay sample of pedestrians:

```
#Read the data file
#Variables in the data file include:
#Impact_speed: impact speed
#Fatal: binary value, 0 = not fatal, 1 = fatal
#Weighting_by_total_sample: values used to weight data to national
statistics

pedestrians<-read.table(‘‘Ashton_Mackay_total_sample.dat’’,header=TRUE)

#Check the first four records of the data file to ensure correct file is being used

pedestrians[1:4,]
```

```
#Performs the logistic regression, and outputs a summary of the results

glmfit<-glm(Fatal~Impact_speed,data=pedestrians,
family=quasibinomial,weight=Weighting_by_total_sample)

summary(glmfit)

#Produces the values required to calculate the risk of fatality for each
impact speed in the data file. This produces two outputs – one to calculate the
risk curve, and a second output to calculate the confidence intervals

predict(glmfit,se=TRUE)
```

A1.3 Output from R

This section shows the R output produced from the above code:

```
> pedestrians<-read.table(''Ashton_Mackay_total_sample.dat'',header=TRUE)>
pedestrians[1:4,]

ID        Impact_speed      Weighting_by_total_sample   Fatal
1         0.309             412.6518                    0
2         0.927             412.6518                    0
3         1.545             412.6518                    0
4         2.163             412.6518                    0

>glmfit<-glm(Fatal~Impact_speed,data=pedestrians,
family=quasibinomial,weight=Weighting_by_total_sample)

> summary(glmfit)

Call:
glm(formula = Fatal ~ Estimated_speed_total_sample, family = quasibinomial,
data = pedestrians, weights = Weighting_by_total_sample)

Deviance Residuals:
Min 1Q Median 3Q Max
-17.4606 -2.6765 -1.3786 -0.4227 18.6874

Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) -9.02328 1.56829 -5.754 1.88e-08 ***
Impact_speed              0.13968 0.03124 4.471 1.05e-05 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for quasibinomial family taken to be 202.5878)
```

```
Null deviance: 20230 on 357 degrees of freedom
Residual deviance: 12793 on 356 degrees of freedom
AIC: NA

Number of Fisher Scoring iterations: 5

> predict(glmfit,se=TRUE)

$fit
  1 2 3 4 5 6
-8.98012348 -8.89380102 -8.80747856 -8.72115610 -8.63483364 -8.54851117
#Only first 6 values of output included. These are the x values referred to in
Section A1.4.

$se.fit
  1 2 3 4 5 6
1.5588796 1.5400672 1.5212674 1.5024803 1.4837067 1.4649470
#Only first 6 values of output included. These are the y values referred to in
Section A1.4 – the standard error of the x values.

$residual.scale
[1] 14.23333
```

A1.4 Drawing curves from the R output

The output generated by the R code ‘predict(glmfit,se=TRUE)’ formed the basis of the pedestrian injury risk curves. The output under ‘$fit’ contained the information necessary to draw the risk curve, and the output under ‘$se.fit’ provided the information necessary to draw the confidence intervals.

The risk of fatality, P, at each impact speed was calculated using:

$$P = \frac{e^x}{1 + e^x} \qquad \text{(A1.1)}$$

where x is the value given by the output of the ‘$fit’ logistic regression for each impact speed.

The lower confidence interval was calculated using the standard error given in the R output under ‘$se.fit’, using the following formula:

$$P = \frac{e^{x-1.96y}}{1 + e^{x-1.96y}} \qquad \text{(A1.2)}$$

and a similar formula for the upper confidence interval:

$$P = \frac{e^{x+1.96y}}{1 + e^{x+1.96y}} \tag{A1.3}$$

where y is the value given for the standard error by the '$se.fit' R output. The value of 1.96 times the standard error results in the confidence intervals having a 95% chance to contain the true value of risk at each impact speed.

APPENDIX 2

Comparison of the logistic and Bayesian approach

This appendix compares the results of two possible methods of calculating risk cures – logistic regression (as used in the main body of the report), and an approach using Bayes theorem. These results are compared using the On the Spot (OTS) and police fatal file dataset of pedestrian casualties.

The logistic form for the risk–speed relationship is widely used in the literature, including Rosén and Sander (2009). Pasanen (1992) used a quadratic form for the regression, however, for the OTS and police dataset a quadratic form does not explain any more of the variation in the data. This may not be the case for the other datasets.

The form for the pedestrian fatal casualty relationship with impact speed (kilometres per hour) is given by:

$$\Pr\left(\mathit{fatal\ casualty}|\mathit{impact\ speed}\right) = \frac{1}{1+e^{-z}} \qquad \text{(A2.1)}$$

where $z = -7.850 + 0.1095 * \text{Impact\_speed(km/h)}$.

Whereas the use of the logistic regression makes an assumption about the form of the 'S' shaped relationship, the Bayes approach does not. It does, however, depend on assuming that the speed distribution is Normal. The probability of pedestrian fatality using Bayes' theorem is given by the following:

$$\Pr(F|v) = \frac{f(v|F)\, p_0(F)}{f(v|F)\, p_0(F) + f(v|Se)\, p_0(Se) + f(v|Sl)\, p_0(Sl)} \qquad \text{(A2.2)}$$

where F, Se and Sl denote fatal, serious and slight injury collisions, respectively, and $f(v/F)$, etc., denote the probability density functions of speed (v) for each of the three severities of collision. The 'prior' probabilities $p_0(F)$, $p_0(Se)$ and $p_0(Sl)$ can be calculated from Table 2.2, and are given in Table A2.1. Table A2.1 summarises the characteristics of the OTS and police fatal file dataset.

There is no particular evidence of these speed distributions not being Normal, although the fatal distribution is slightly skewed. This is confirmed by the plots of the speed data, shown in Figures A2.1–A2.3.

Table A2.1: Characteristics of impact speed (mph) distribution of OTS and police fatal file dataset

Statistic	Slight	Serious	Fatal
Mean	16.45	21.61	34.38
Standard error (se)	0.81	1.06	1.73
Median	15.50	20.00	30.00
Mode	12.00	20.00	22.50
Standard deviation	6.31	9.45	14.15
Sample variance	39.77	89.36	200.27
Kurtosis	0.30	-0.62	-0.06
Skewness	0.35	0.33	0.67
Range	33.00	42.00	65.00
Minimum	2.00	3.00	5.00
Maximum	35.00	45.00	70.00
Count	60	79	67
'Prior' probability of pedestrian casualty outcome (from Table 2.2)	0.75960	0.21669	0.02371

Figure A2.1: Speed distribution of slightly injured pedestrian casualties in the OTS and police fatal file dataset

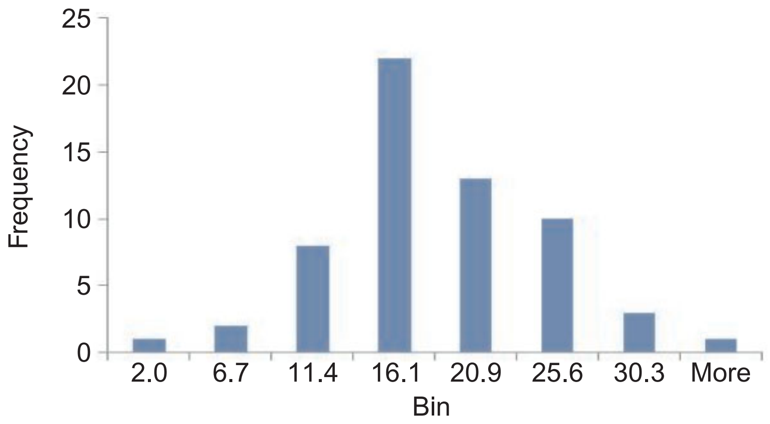


Figure A2.2: Speed distribution of seriously injured pedestrian casualties in the OTS and police fatal file dataset

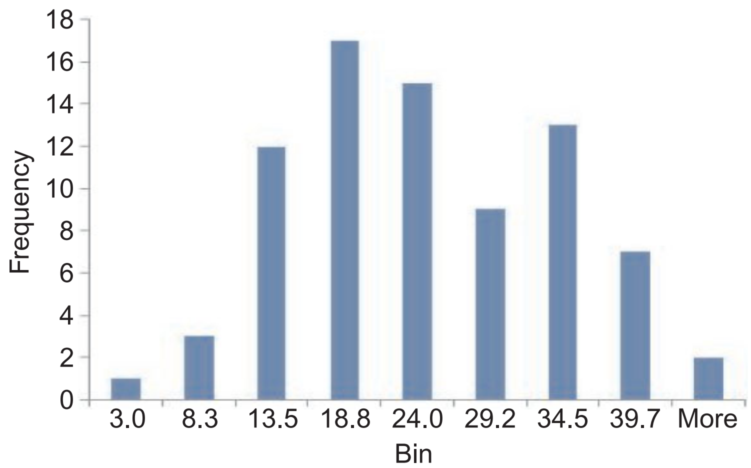
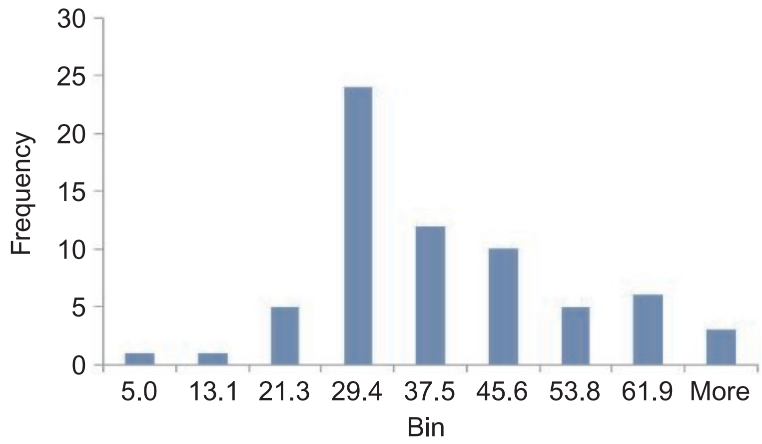


Figure A2.3: Speed distribution of fatally injured pedestrian casualties in the OTS and police fatal file dataset



Under the assumption that the speed distributions are Normally distributed and applying Bayes theory with the prior probabilities of pedestrian casualty (as given in Table A2.1), estimates of the risk of pedestrian fatality with impact speed, with 95% confidence intervals, were calculated. These are shown for fatal pedestrian casualties in Table A2.2.

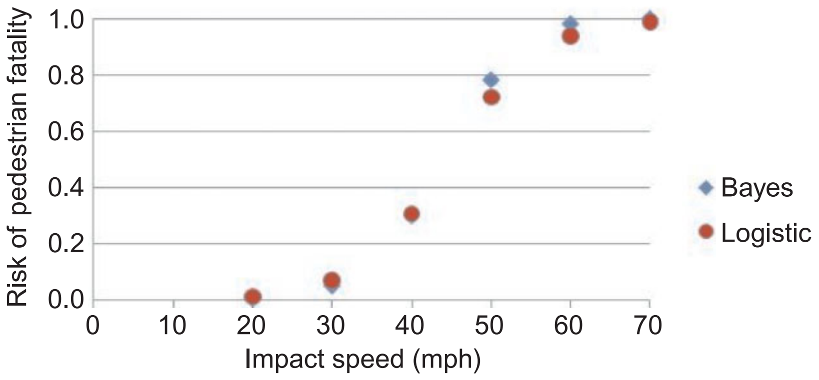
Table A2.2: Results of pedestrian fatality risk using Bayesian and logistic approaches

Impact speed (mph)	Bayesian approach	Logistic regression approach		
	Bayes estimate	Logistic	Lower*	Upper*
20	0.008	0.013	0.003	0.054
30	0.055	0.071	0.025	0.190
40	0.303	0.309	0.078	0.702
50	0.783	0.723	0.164	0.972
60	0.982	0.938	0.291	0.998
70	0.999	0.989	0.455	1.000

*95% confidence interval for the estimate as derived from the logistic regression.

The Bayesian approach tends to produce lower probabilities than the logistic regression for lower impact speeds, but higher ones for higher impact speeds – which suggests a 'steeper' slope on the risk–speed relationship. However, the Bayesian estimates were all within the 95% confidence interval surrounding the logistic regression estimates. The association between the two estimates is quite strong, as illustrated in Figure A2.4.

Figure A2.4: Risk of pedestrian fatality using Bayesian and logistic methods in the OTS and police fatal file dataset



There is some uncertainty associated with the assumption that the speed distributions are all Normal. The Bayes approach requires the probability for a specific impact speed and that a certain level of severity has occurred, i.e. the probability that speed is, say, 20 mph when a slight injury occurs. This will not change by much for small deviations from the Normality assumption. This was illustrated by using 95% confidence interval values for the mean impact speed, i.e. instead of using the mean speed when calculating the probability, the mean $\pm 1.96 * se$ was used and this resulted in only small differences in the Bayesian estimate.

It is evident from this additional analysis that using a Bayesian approach does generate slightly different probabilities than those from the weighted logistic regression, but in practice they are probably not sufficiently different to be of concern.

APPENDIX 3

Data tables

This appendix contains tables (Tables A3.1–A3.3) of the On the Spot (OTS) and police fatal file dataset of pedestrians, and the Co-operative Crash Injury Study (CCIS) and OTS dataset of car occupants. Tables of the Ashton and Mackay data can be found in Ashton (1980), and more information on the German In-Depth Accident Study (GIDAS) data can be found in Rosén and Sander (2009).

Table A3.1: Summary of pedestrian dataset from OTS and police fatal files

Age group	Injury severity	Impact speed group (mph)						Total
		0–10	11–20	21–30	31–40	41–50	50+	
0–14	Fatal	0	1	4	1	3	0	9
	Serious	5	11	5	1	0	0	22
	Slight	7	15	1	0	0	0	23
	All	12	27	10	2	3	0	54
15–59	Fatal	1	2	8	5	5	9	30
	Serious	4	13	7	9	1	0	34
	Slight	3	14	8	0	0	0	25
	All	8	29	23	14	6	9	89
60+	Fatal	1	2	16	3	3	0	25
	Serious	1	5	3	1	0	0	10
	Slight	1	2	1	0	0	0	4
	All	3	9	20	4	3	0	39
Unknown	Fatal	0	0	1	0	0	1	2
	Serious	1	2	3	1	1	0	8
	Slight	0	4	1	0	0	0	5
	All	1	6	5	1	1	1	15
Total		24	71	58	21	13	10	197

Table A3.2: Summary of frontal impact dataset for belted car drivers in impacts with another car

Injury severity	Impact speed group (mph)						Total
	0–10	11–20	21–30	31–40	41–50	50+	
Fatal	0	8	16	19	14	9	66
Serious	20	140	207	94	14	3	478
Slight	36	38	2	0	0	0	76
All	56	186	225	113	28	12	620

Table A3.3: Summary of side impact dataset for belted car drivers in impacts with another car							
Injury severity	**Impact speed group (mph)**						**Total**
	0–10	**11–20**	**21–30**	**31–40**	**41–50**	**50+**	
Fatal	0	5	12	2	2	0	21
Serious	13	47	14	2	0	0	76
Slight	13	7	1	0	0	0	21
All	26	59	27	4	2	0	118