EUROPEAN ENHANCED VEHICLE-SAFETY COMMITTEE

EEVC WG20 Report – Document Number 167

UK Cost-benefit Analysis: Enhanced Geometric Requirements for Vehicle Head Restraints

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September 2007

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UK Cost-benefit Analysis: Enhanced Geometric Requirements for Vehicle Head Restraints

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CONTENTS

Executive Summary

No regulatory test exists in Europe to assess injury risk in rear impacts. A number of vehicle accident and occupant injury studies indicate that low-speed rear impacts can lead to neck and back injuries causing long-term disablement and discomfort. These injuries are usually classified as having a low threat to life; however, they are often associated with large societal costs. It is thought that design changes to seat systems and/or head restraints to improve their use and the occupant protection they offer could make a positive impact in mitigating injuries from rear impacts. Test procedures to assess the performance of seat and head restraint systems are being developed currently.

As a first stage in the mitigation of injuries in low-speed rear impacts a static test of head restraint geometry is being developed by the European Enhanced Vehicle-safety Committee (EEVC) Working Group 20 'Rear Impact'. It is not known whether head restraint geometry provides improved rear impact safety at a cost that is proportionate to the benefit.

There are three key factors in car seat/head restraint geometry which determine whether whiplash occurs and how serious it is:

- The head restraint height (the height of the head restraint with respect to the head of the occupant).
- The backset of the head restraint (the horizontal distance from the back of the head to the front of the head restraint).
- Whether the head restraint has the ability to remain (or lock) in its set position whilst supporting the neck.

This cost-benefit study is concerned with the first two of these key factors and has been undertaken to determine the justification for making changes to the geometrical requirements for head restraints.

The potential options for making regulatory changes considered in this study were:

1. Doing nothing
2. Increasing the current head restraint height requirement from 800 mm to somewhere in the range of 800 to 850 mm
3. Introducing a limit for head restraint backset somewhere in the range of 40 to 100 mm
4. A combination of the two options for head restraint height and backset

For each of these options the benefits were determined by evaluation of the potential casualty savings that might occur as a result of the regulatory change. A monetary value was applied to the benefit by assigning a cost to each whiplash injury with long-term symptoms. This value, which was based on the willingness to pay model, was £ 61,326. Application of this cost to the 2005 UK casualty data produced a total cost associated with the long-term whiplash injuries to front seat occupants in frontal and rear impacts of approximately three billion pounds. The potential casualty savings were calculated as a proportion of this total cost.

To evaluate the benefits from decreased backset of the head restraint an injury risk function was developed based on published injury data (see Figure S.1). This is based on relatively old data for accidents and injuries occurring in Volvo cars from the 1980s. Since then, seat back and vehicle stiffness have increased across the vehicle fleet, and both of these factors are associated with an increase in the risk of whiplash injury. Therefore, this backset risk function is considered to be conservative and suitable for use in a cost-benefit study.

The protection offered by the height of the head restraint was evaluated by assuming that if the head restraint is high enough to support the centre of gravity of the head then the protection offered is adequate, otherwise it is inadequate. The height required included an allowance for ramping-up,

whereby a person moves up the seat back during a rear impact. This assumption was combined with the height distribution of the UK population to give the proportion expected to be given adequate protection by different head restraint heights. The product of this and the backset risk function gives the injury mitigation distribution shown in Figure S.2.

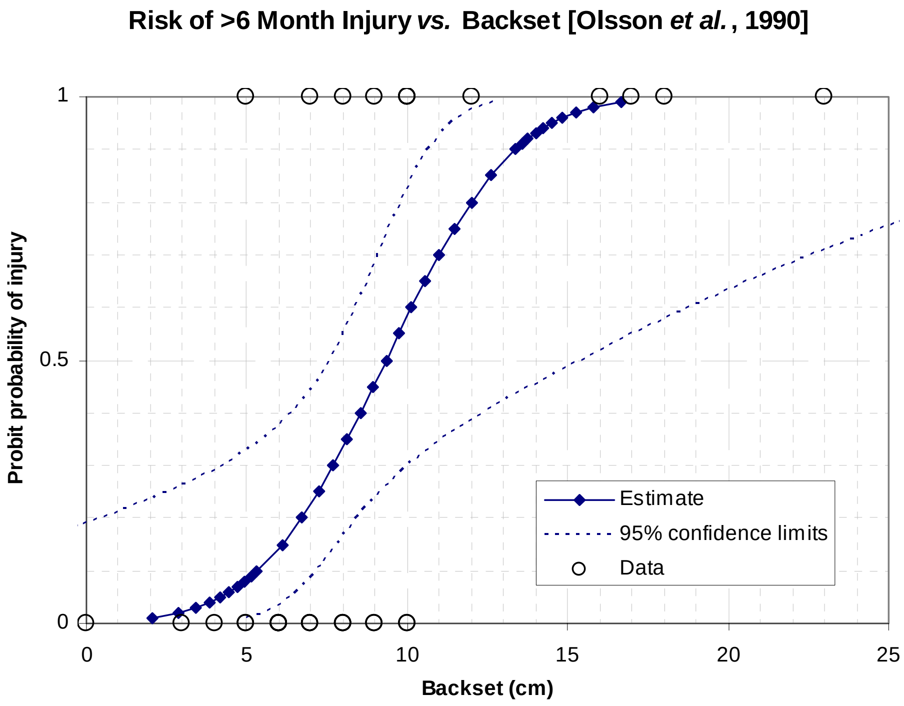

Figure S.1: Risk of long-term whiplash symptoms (> 6 months) *vs.* head restraint backset

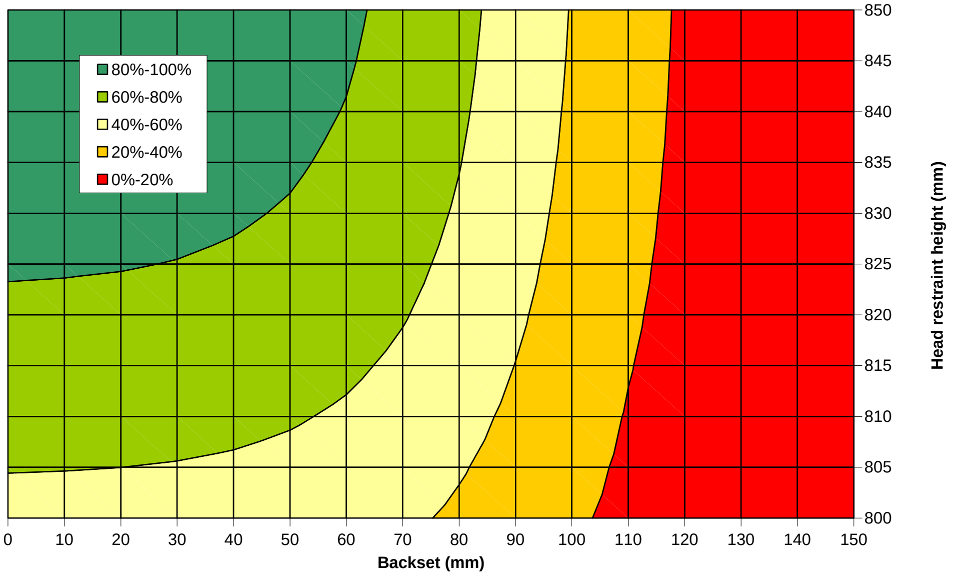

Figure S.2: Percentage probability of mitigating long-term neck injury based on head restraint height and backset for the UK male population

For each option, costs for Original Equipment Manufacturers (OEMs) to implement each of the proposed changes to the head restraint geometry were also determined. These costs were based on the increase in head restraint height. No response was forthcoming from industry for the costs associated with changing the backset of head restraints in cars, so no backset costs were used in the analysis.

The benefit minus cost value of each option was then calculated along with the benefit to cost ratio (Figure S.3). It was found that the greatest benefit after subtracting the associated cost is expected with a head restraint height of 840 mm and a backset of 40 mm. The greatest benefit to cost ratio should occur with a small change in head restraint height and a backset of 40 mm. The minimum change in regulation expected to yield a benefit to cost ratio of two would be to adopt a backset of 70 mm.

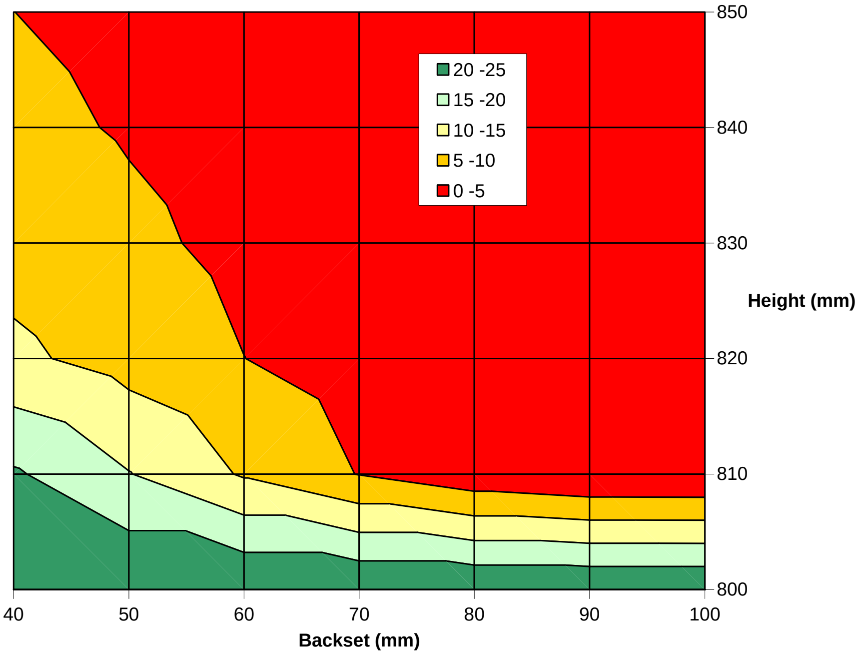

Figure S.3: Graphical representation of the benefit divided by cost for the various proposed head restraint height and backset limits

It should be noted that a static geometric head restraint requirement is a first step in mitigating low-speed rear impact injuries, and additional benefit may result from appropriate dynamic seat testing.

Purpose and Intended Effect of Measure

Objectives

The objectives of this proposal are:

- To identify possible solutions as regards improved head restraint geometry that could lead to reductions in whiplash injuries in the UK. This would be achieved by reducing the relative motion between the head and the torso.
- To identify quantitively the effect of implementing the identified solutions, in terms of how many expected injuries are likely to be saved as a result of introducing each proposal into legislation and in turn the cost saving on society that this would bring.
- To identify quantatively the cost for Original Equipment Manufacturers (OEMs) to implement each of the proposed changes to the head restraint geometry.
- To determine whether the injury cost saved on society outweighs the cost for industry to implement the recommendations.
- To determine the extent to which the outcome proposal would contribute towards the general UK government road safety target reducing the slight casualty rate.

Background

No regulatory test exists in Europe to assess injury risk in rear impacts, in particular low severity rear impacts. A number of vehicle accident and occupant injury studies indicate that low-speed rear impacts can lead to neck and back injuries causing long-term disablement and discomfort. These injuries are usually classified as having a low threat to life; however, they are often associated with large societal costs. It is thought that design changes to seat systems and/or head restraints to improve their use and occupant protection offered could make a positive impact in mitigating the injury and test procedures to assess their performance are currently being developed.

The purpose of European Enhanced Vehicle-safety Committee (EEVC) Working Group 20 ‘Rear Impact’ is to provide the EEVC Steering Committee with impartial advice, based upon scientific evidence, in order to support the development and enhancement of European safety standards and legislation. To this end, the Working Group are currently developing test procedures for rear-end collisions; with a prime focus on neck injury reduction and evaluation of the proposed test procedures in laboratory conditions.

As a first stage in the mitigation of injuries in low-speed rear impacts a static test of head restraint geometry is being developed. It is not known whether head restraint geometry provides improved rear impact safety at a cost that is proportionate to the benefit.

There are three key factors in car seat/head restraint geometry which determine whether whiplash occurs and how serious it is [EEVC WG20, 2005]:

- The head restraint height.
- The backset of the head restraint.
- Whether the head restraint has the ability to remain (or lock) in its set position whilst supporting the neck.

This cost-benefit study is concerned with the first two of these key factors. The definitions usually given for head restraint height and backset are shown, in a test situation, in Figure 0.1. These are the vertical distance from the top of the head to the top of the head restraint and the horizontal distance from the back of the head to the front of the head restraint, respectively. Alternatively, head restraint height may be measured relative to the centre of gravity of the head, or relative to the hip joint of the occupant.

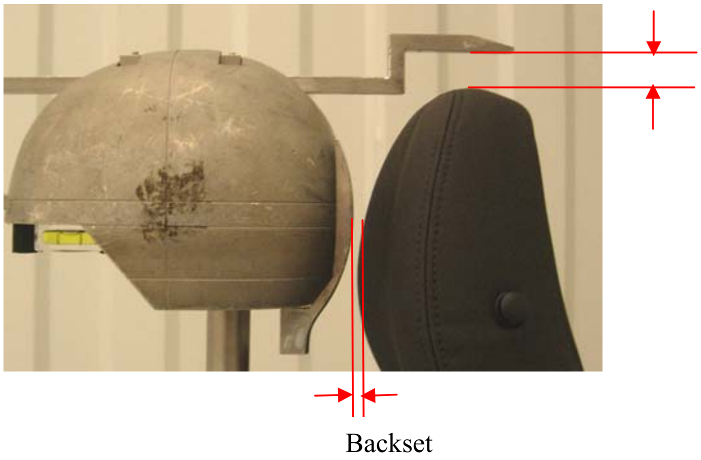

Figure 0.1: Height and backset example

The Nature of the Problem

For at least the last 40 years, vehicle safety researchers have been acquiring information on the ability of head restraints to mitigate neck injuries from rear-end collisions. Severy *et al.* [1968] produced a clear description of the ability of good seat design and head restraint position to prevent potentially injurious head and neck kinematics in rear-end collisions. They concluded that a well-designed safety seat would protect most passengers against sustaining any rear-end collision injury. Severy *et al.* also encouraged the use of head restraints commenting that,‘Head restraints are as important for the motorist involved in rear-end collisions as the safety belt is for the motorist involved in a front-end impact’.

Four years later, States *et al.* [1972] provided the first real-world accident figures for the effectiveness of head restraints. According to their report head restraints were effective for both the driver and the front seat occupant.

In 1967, Mertz and Patrick [1967] investigated the kinematics and kinetics of whiplash through tests conducted with crash test dummies, post-mortem human subject (PMHS) and volunteers. Tests were conducted on a sled with a horizontal accelerator and were designed to simulate the conditions experienced in a car-to-car rear end collision. The most severe test with the volunteer in the ‘head supported’ condition was at 23.7 km/h with a 25 cm stopping distance. It was reported that after this test the volunteer was willing to undergo higher severity runs, but because of fatigue, further tests were not conducted. Without head support, two runs were conducted at 13.5 and 14.3 km/h with a 56 and 25 cm stopping distance, respectively. Mertz and Patrick report that after the last run, the volunteer expressed the opinion that he did not care to increase the severity level at that time.

Clemens and Burow [1972] conducted 21 rear impact tests using PMHSs, with and without a head restraint. The test speed varied from 19 to 25 km/h with decelerations of the sled generally between 13 and 16 g. In the tests with a head restraint, the deceleration was as high as 20 g. However, no injuries were found when the head restraint was present and the authors’ recommended developing seats with integrated head restraints to support the head at the centre of gravity.

Most of this early work was focussed on the prevention of moderate severity neck injuries, such as AIS 3 vertebral process fractures, in rear impacts. Some of this work uses the description ‘whiplash’, which is more often used today to describe lower severity soft tissue injuries and symptoms.

In 1999, information on all rear-damage claims from 1993 to September 1996 was extracted from the electronic database of the State Farm Mutual Automobile Insurance Company by Farmer *et al.* [1999]. The analysis of the data were limited to vehicles that had been assessed in relation to the Insurance Institute for Highway Safety (IIHS) geometric evaluation and were judged to be approximately similar to each other in size, weight, and body style. Farmer *et al.* state that it was not possible for them to determine the positioning of the driver head restraint at the time of each collision. Despite this, they still assume that cars rated better in the geometric assessment would be those more likely to have head restraints in a better position during a collision.

From the logistic regression analyses performed by Farmer *et al.*, it is evident that for both male and female drivers, head restraints given a good geometric rating were associated with less likelihood of neck injury than head restraints rated as poor geometrically. However, the difference was statistically significant only among female drivers.

Apparently, the logistic regressions account for the effects of driver age, direction of impact, crash location, repair cost, and damage severity before estimating the effect of head restraint positioning. If all these factors remain the same then Farmer *et al.* report that drivers of cars with good-rated head restraints are 24% less likely than drivers of cars with poor-rated head restraints to suffer neck injuries in rear-end crashes. For female drivers, even acceptable-rated head restraints are a major improvement over poor-rated ones. The odds ratio in going from a poor restraint to a good or acceptable one is 0.63 or 0.64 for female occupants, according to Farmer *et al.*

As with the 1999 study, Farmer *et al.* [2003] again reported on head restraint and seat effectiveness with respect to whiplash injury. In this later paper, Farmer *et al.* compare the real-world performance of cars where the vehicle design has remained unchanged but the seat design has changed. Whilst the paper looks at active head restraint systems, it also reports on the effects of design changes to the Ford Taurus and Mercury Sable. In these two vehicles, the change in design is described as a significant change in the head restraint geometry according to the IIHS measurements (made using the RCAR procedure). The results show that the improved head restraint geometry in these two vehicles was associated with an 18% reduction in overall driver neck injury that was not significant, but also a statistically significant 37% reduction among female drivers.

As reported by Viano and Humer [2002], an active head restraint was developed to improve protection against whiplash even if the head restraint is not adjusted to the most favourable position while driving. The active head restraint, called SAHR (initially called the Self-Aligning Head Restraint and later the Saab Active Head Restraint) used the inertia of the occupant pressing into the seatback in a rear crash to raise and move the head restraint forward, providing earlier head-neck support and lowering loads causing neck extension. Apparently, laboratory tests of a range of real-world seating configurations showed that the active head restraint reduced whiplash loads on the neck and distributed loads on the torso and lower back. Based on the theory of operation and sled testing, Viano and Humer estimate the benefit of the SAHR to be injury prevention to the level of about 9.2% fewer minor injuries in rear crashes.

The real-world effectiveness of the SAHR was estimated by Viano and Olsen [2002]. They considered accident data for 177 front seat occupants involved in a single event rear crash in Sweden. The vehicles included the Saab 900 and 9000 that were equipped with a conventional head restraint, and the Saab 9-3 and 9-5, which included the SAHR active head restraint as standard equipment in the front seats. The accident report was obtained from Dial insurance and included information on the individual, crash, and outcome. In addition, questionnaires were used to obtain further information on the occupant's height and weight; and their injury was further classified as short-term neck pain lasting less than one week (ST), medium-term whiplash injury lasting less than ten weeks (MT), or long-term whiplash extending over 10 weeks (LT). According to the analysis conducted by Viano and Olsen, SAHR reduced MT to LT whiplash injury by 75 (± 11)% in rear crashes, from 18 (± 5)% incidence in vehicles with standard head restraints to 4 (± 3)% in vehicles with SAHR. There was also a 25 (± 29)% increase in uninjured (no pain or injury) occupants with SAHR from a 47 (± 10)% rate with the standard head restraint to 59 (± 11)% with SAHR. However, Viano and Olsen also carried out follow-up telephone calls to evaluate the nature or whiplash injury reported by the claimant. In doing so, they found that all of the MT and LT victims in the Saab 9-3 and 9-5 crashes had experienced previous rear crashes and had existing neck injury disability prior to their study. None of those occupants believed their injury to be aggravated by the current crash. When the individuals with pre-existing whiplash injury were removed from the sample, there was one MT whiplash injury in the Saab 9-5 and 9-3 group. This gave a MT-LT whiplash injury risk of 1 (± 2)% with SAHR and 15 (± 5)% in the Saab 9000 and 900, for a 92% effectiveness of SAHR in preventing new cases of whiplash.

To determine the influence of head restraint position on long-term AIS 1 neck injury risk, Eriksen [2005] simulated rear-end crashes in Madymo. Madymo models of the BioRID II and three car seats were used. A set of recorded crash pulse was selected from the Folksam database containing real-life rear-end crashes. A set of 87 crashes was chosen. For each seat, 132 head restraint positions were defined by changing the backset and the head-to-head restraint heights in steps of 1 cm. The backset ranged between 0 and 11 cm, and the head-to-head restraint height ranged from 0 to 10 cm. For every head restraint position, the mean NIC_{max} values and hence the mean risk, were calculated.

Eriksen found that for almost all crash pulses, the preferable head restraint position was that with zero backset and zero head-to-head restraint height. It was also shown that the injury risks normally rise with increased backset and with increased head-to-head restraint height. In general, Eriksen found that the NIC_{max} and the injury risk were primarily influenced by the backset and only to a small extent by the head-to-head restraint height.

The Size of the Problem

The Cost of Whiplash

A number of studies and claims statistics originating from the insurance industry indicate that low speed rear impacts are a large cause of whiplash injuries in the UK, Europe and world-wide. It is suggested that 'currently whiplash injuries cost British insurers over £1 billion annually and account for over 80% of the total cost of personal injury claims' [Thatcham, 2007a]. In other regions, whiplash injuries are also estimated to have high costs [EEVC WG20, 2005]:

• USA	$ 10 billion
• British Columbia, Canada	C$ 270 million
• European Union	€ 10 billion

In the UK, Galasko *et al.* [1996] estimated the value of the avoidance of all whiplash injuries to be approximately £2.5 billion (at 1991 costs), of which approximately 60% of the injuries were from rear impacts (£1.5 billion *pro rata* at 1991 costs).

More recently, Welsh *et al.* [2006] found that 58% of rear impacts with new cars result in an AIS 1 whiplash injury and that the cost of a whiplash injury is £42,574. They also found that the risk of whiplash injury is twice as high in rear impacts as it is in front or side impacts, although the exposure to rear impacts is relatively low.

Existing European Regulations Regarding Head Restraints

The following European regulatory requirements relate to the provision and performance of head restraints:

- UN ECE Regulation 17 - Uniform Provisions concerning the Approval of Vehicles with regard to the Seats, their Anchorages, and any Head Restraints (United Nations, 1995).

- UN ECE Regulation 25 - Uniform Provisions Concerning the Approval of Head Restraints (Head Rests), whether or not Incorporated in Vehicle Seats
- EU Directive 74/408, concerning interior fittings of motor vehicles
- EU Directive 96/037, adapting to technical progress Council Directive 74/408/EEC relating to the interior fittings of motor vehicles (strength of seats and of their anchorages)
- EU Directive 78/932/EEC, concerning head restraints of seats of motor vehicles.

Of these, the regulation most relevant to the height of head restraints is UN ECE Regulation 17; none of the regulations control the backset of head restraints. Regulation 17 defines the minimum height, measured from the R-point of the seat (the standard H-point position as stated by the vehicle manufacturer), that head restraints should be capable of reaching for both fixed and adjustable head restraints and for various seating positions. For front outboard seats, the following requirements apply:

5.1.1 Every adjustment and displacement system provided shall incorporate a locking system, which shall operate automatically.

5.5.2 Head restraints not adjustable for height shall not be less than 800 mm in the case of front seats.

5.5.3.1 For head restraints of adjustable height the height shall not be less than 800 mm in the case of the front seats and 750 mm in the case of other seats; this value shall be obtained in a position between the highest and lowest positions to which adjustment is possible.

5.5.3.2 There shall be no ‘use position’ resulting in a height of less than 750 mm.

5.5.3.4 Front seats may only have a head restraint height of less than 750 mm when the seat is not occupied and its motion is automatic. When the seat becomes occupied the head restraint should automatically return to its ‘position of use’.

5.5.4 The dimensions mentioned in paragraphs 5.5.2 and 5.5.3.1 above may be less than 800 mm in the case of front seats to leave adequate clearance between the head restraint and the interior surface of the roof, the windows or any part of the vehicle structure; however, the clearance shall not exceed 25 mm. Furthermore, in derogation to paragraph 5.5.3.2 there shall not be an ‘use position’ resulting in a height lower than 700 mm.

6.1.2 In the case of seats with adjustable head restraints, the tests shall be conducted with the head restraints placed in the most unfavourable position (generally, the highest position) allowed by its adjusting system.

VCA are the vehicle type approval authority in the UK. A discussion was held with VCA to clarify the interpretation of the above requirements. VCA test the height of the head restraint in the top-most ‘use position’, which would be the highest notch for a head restraint with a notched locking system (i.e. for most adjustable head restraints currently on the market). This represents the most unfavourable position for the strength tests required by the regulation. If no notch is present (for instance, if a friction locking device is used), they will agree a top-most position with the manufacturer. The head restraint will also undergo dynamic testing in this position, so the manufacturer must be confident that the head restraint will be retained in this top-most position and it should therefore represent a reasonable top-most use position.

These requirements were designed to reduce the danger of injury to the cervical vertebrae and the requirements were based on the anthropometry of the 50th percentile male. The height of the head restraint is measured from the R-point parallel to the seat back angle as shown in Figure 0.2.

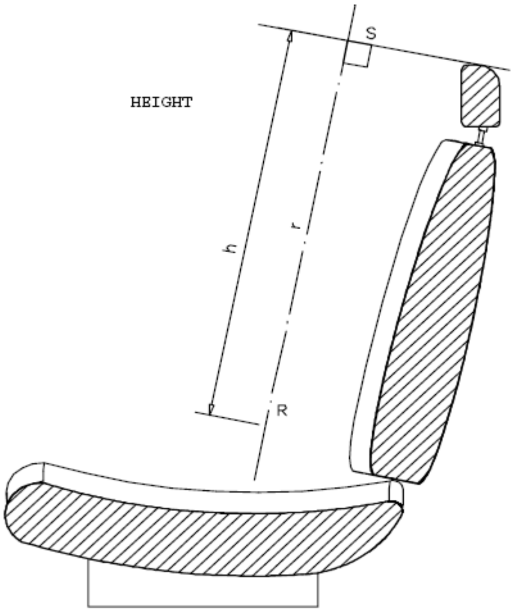

Figure 0.2: Height and backset example

Consumer Information Programmes

This section summarises the whiplash consumer information programmes currently active in Europe.

Thatcham Consumer Information Programme

Thatcham (the Motor Insurance Repair Research Centre), acting on behalf of the British insurers, has produced test information for consumers on the performance of head restraints in current vehicles protecting occupants from whiplash when subject to a rear impact. For several years they tested the height and backset of head restraints using the RCAR head restraint geomety test procedure [RCAR, 2001] and published these results on their web site (www.thatcham.org). Over the last three years, the head restraint geometry rating has been combined with a dynamic rear impact test rating to give an overall seat restraint performance rating, and again these results are published on the Thatcham web site.

The RCAR test procedure measures the height and backset of the head restraint using a 3-D H-point machine (or SAE J-826) and a head restraint measurement device (HRMD), as shown in Figure 0.3, which represent a 50th percentile male seat occupant. Backset is the horizontal distance between the back of the HRMD and the front surface of the head restraint. The height definition is somewhat different from that measured in Regulation 17 in that it is the vertical distance down from the top of the head to the top of the head restraint, as shown in Figure 0.4.

Head restraint geometry is rated by Thatcham as ‘Good’, ‘Acceptable’, ‘Marginal’ or ‘Poor’, based on a combination of height and backset measurements, as shown in Figure 0.5.

Figure 0.3: 3-D H machine (SAE J286) and HRMD

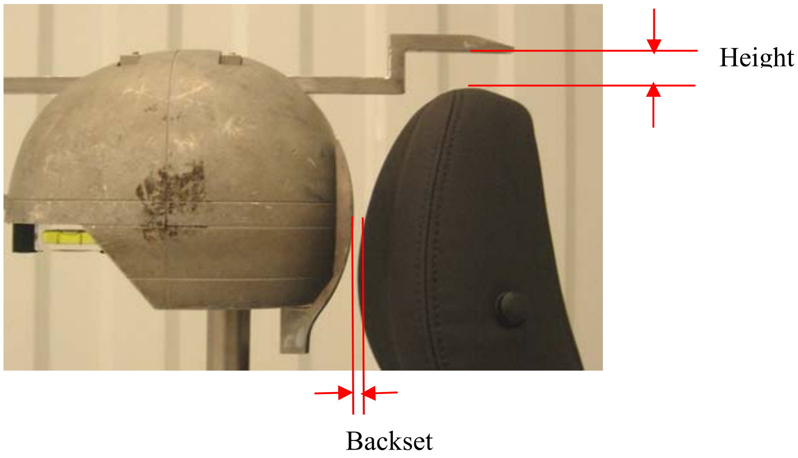

Figure 0.4: RCAR height and backset definitions, as used in Thatcham consumer information testing

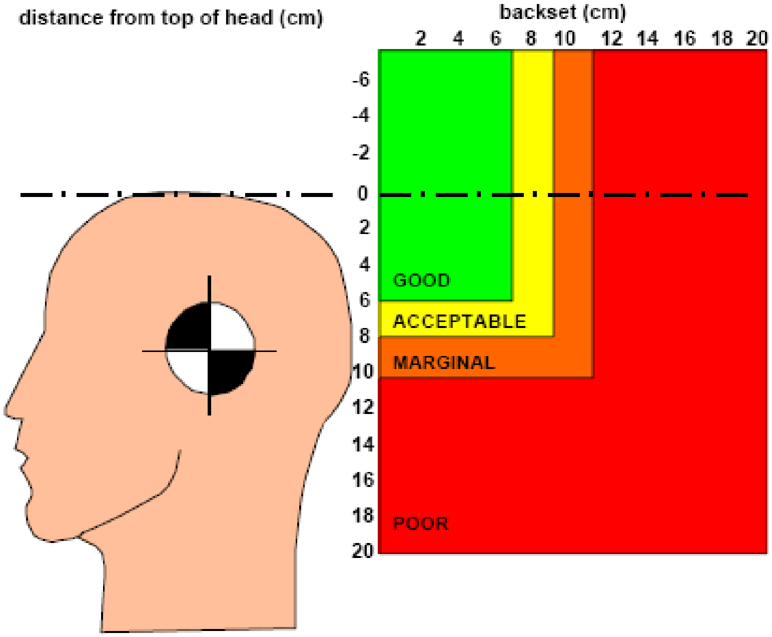

Figure 0.5: RCAR head restraint rating diagram (for adjustable head restraints) (from [RCAR, 2001])

Folksam-SRA Consumer Information Programme

The Swedish Road Administration and Folksam Insurance publish consumer information on the whiplash performance of car seats using a ‘traffic light’ rating system (green for good; yellow for adequate; and red for poor). The ratings are based on dynamic tests with each seat and head restraint system; no measurement of head restraint geometry is undertaken.

Kullgren *et al.* [2007] studied the influence of various types of car seats, whiplash consumer crash tests and real-life injury outcome. They used data from the Folksam database of accidents leading to long-term whiplash symptoms (6,383 injuries) and police files for rear-end crashes involving two cars between 1998 and 2006 (15,587 crashes). From these data Kullgren *et al.* calculated the relative risk of sustaining injury with long-term symptoms, which is defined as the product of the relative injury risk and the proportion of occupants with long-term symptoms in relation to the number of reported whiplash injuries. They found a correlation between both the IIWPG (or RCAR) and the Folksam/SRA ratings and the proportions of injuries leading to long-term symptoms as well as the relative risk of sustaining a whiplash injury leading to long-term symptoms. Kullgren *et al.* conclude that cars with seats rated as good in the consumer crash tests had a lower risk of whiplash injuries leading to long-term symptoms compared with seats with poor results.

The Situation Outside the UK

The only regulation other than UN ECE Regulation 17 that controls head restraint height is FMVSS 202 in the US (and the identical CMVSS 202 in Canada). FMVSS 202 was amended in December 2004 and will be mandatory for all vehicles after 1st September, 2008. This amendment increases the height requirement for head restraints from 700 mm to 800 mm, measured in a similar way to the Regulation 17 height requirement, and introduces a backset requirement of 55 mm, measured using a method similar to the RCAR test procedure with the 3-D H machine and HRMD.

As an alternative to the static backset measurement, a dynamic test is offered as an option (at the manufacturer's discretion), which uses the head rotation angle of the Hybrid III dummy in a rear impact test as a surrogate for the backset requirement.

This regulation is currently under discussion at GRSP, through the informal working group on head restraints, as a proposal for a possible future Global Technical Regulation.

Costs and Benefits

Each regulatory option would lead to changes: (1) in the design of the car seats and/or head restraints which would affect manufacturers’ costs and (2) in the severity of the consequences of an accident to its occupants.

In principle, each of these processes of change needs to be understood and valued. The objective is to obtain beneficial reductions in accident costs which outweigh any additional costs incurred by manufacturers. In view of the uncertainties in the estimating processes, it is normal to seek a benefit/cost ratio of at least 2 in order to justify further consideration of any option. The reductions in the number of casualties, or severity of their injuries, in road traffic accidents (RTAs) are usually valued using Department for Transport (DfT) financial values. The DfT valuations are discussed in the next section with some alternatives.

The Current Extent of Whiplash Injuries

Slight Injuries in STATS19 Data

Figure 0.1 and Figure 0.2 show, respectively, recent trends in the numbers of slight casualties occurring in cars (and taxis) involved in frontal impact and rear impact RTAs over the period 2000-2005.

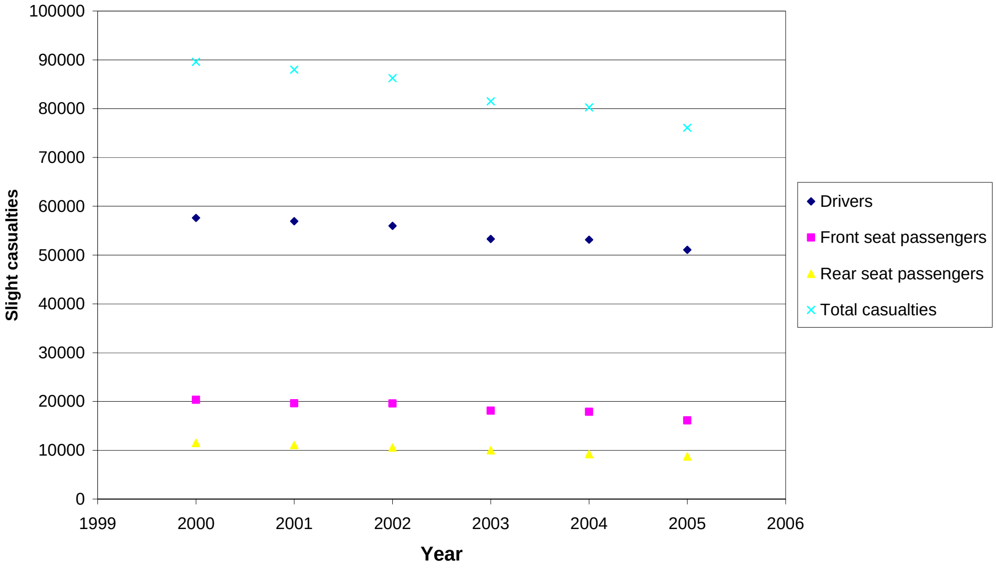

Figure 0.1: Recent trends in the numbers of frontal impact slight casualties (2000-2005)

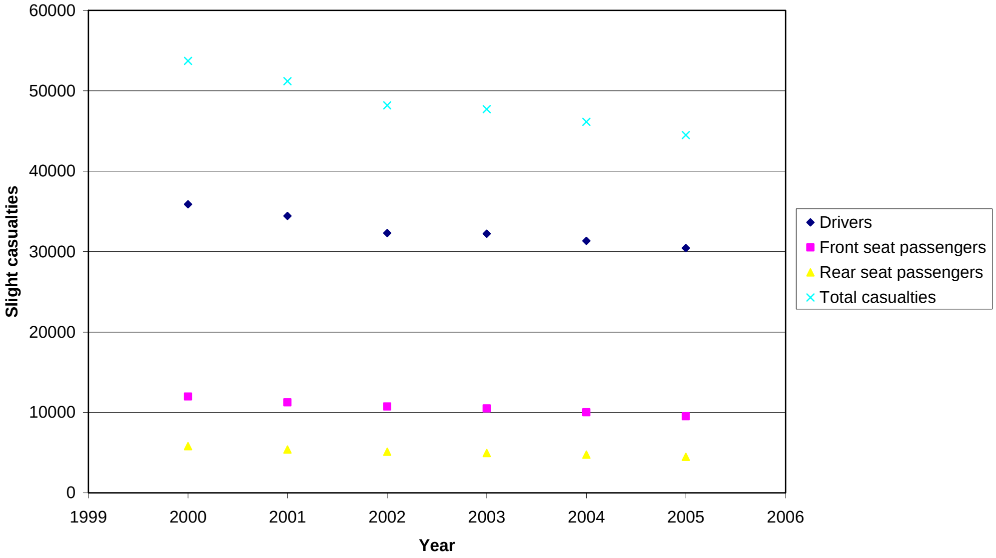

Figure 0.2: Recent trends in the numbers of rear impact slight casualties (2000-2005)

It can be seen that the numbers of the different categories of slight casualties (for all car occupants), for these directions of impact, have decreased over this period. The percentage changes are shown in Table 0.1. These reductions have occurred despite the fact that, over the same period, the numbers of cars on the road has *increased* by 9.7%. However, there is no information on whether whiplash injury follows this trend. Based on insurance costs, year-on-year, then in 2005 the UK spent £ 800 million on whiplash [EEVC WG20, 2005]. This has now risen to £ 1 billion [Thatcham, 2007a].

Table 0.1: Percentage decreases in slight casualties over the period 2000-2005

Category of casualty	Frontal impact casualties	Rear impact casualties
Drivers	11.4	15.2
Front seat passengers	20.6	20.5
Rear seat passengers	24.3	22.8
All occupants	15.1	17.2

Incidence of Whiplash Injury

Welsh *et al.* [2006] have reported that 34% of front impact and 58% of rear impact slight injury casualties involve whiplash injury. These figures broadly agree with results reported by Galasko *et al.* [1996]; they found that 247,680 (64%) of 387,331 slight RTA injuries involved Whiplash Associated Disorders (WADs). In addition, the symptoms in 59.1% of WADs lasted more than 6 months. These percentages are used in the analysis of the cost-benefit options (see Section 0). Note that side impact casualties are not considered as it is not expected that the head restraint can offer any whiplash injury protection in a side impact.

Under-reporting of Whiplash Injuries in Stats19

In Stats19, whiplash injuries are included in the ‘slight’ injury category. Galasko *et al.* [1996] matched the records of 2,670 patients seen in the accident and emergency departments of three hospitals (one a major teaching hospital, one an inner-city hospital, and one in an area that was partly urban and partly rural). They found that approximately 45% of patients with a whiplash associated disorder were unrecorded in the Stats19 database. It was calculated that there were 247,680 WAD injuries in the UK at that time, compared with 139,651 other slights.

Long-term vs. Short-term Injuries

Whiplash injuries have been classified in a number of ways, including AIS (all whiplash injuries are rated as AIS 1) and the Quebec Task Force Scale [Spitzer *et al.*, 1995] (WAD 1 to WAD 4). However, for the purposes of costing, whiplash injuries are often classified as short-term and long-term, with the majority of the cost being attributable to long-term injuries [EEVC WG20, 2005]. In the UK, the cost and prevalence of whiplash associated disorder (for all impact directions) was evaluated by Galasko *et al.* [1996], under contract to TRL and the DfT, based on a 12 year hospital study. Galasko *et al.* studied over 15,000 patients injured in road traffic accidents, of whom approximately 6,000 suffered a whiplash associated disorder.

The percentage of patients with residual disability over time is shown in Figure 0.3. This shows that 59.1% of patients had a long-term injury (greater than six months). About 40% of the total number of patients received a whiplash injury in a front or side impact, with the remaining 60% receiving a whiplash injury in a rear impact.

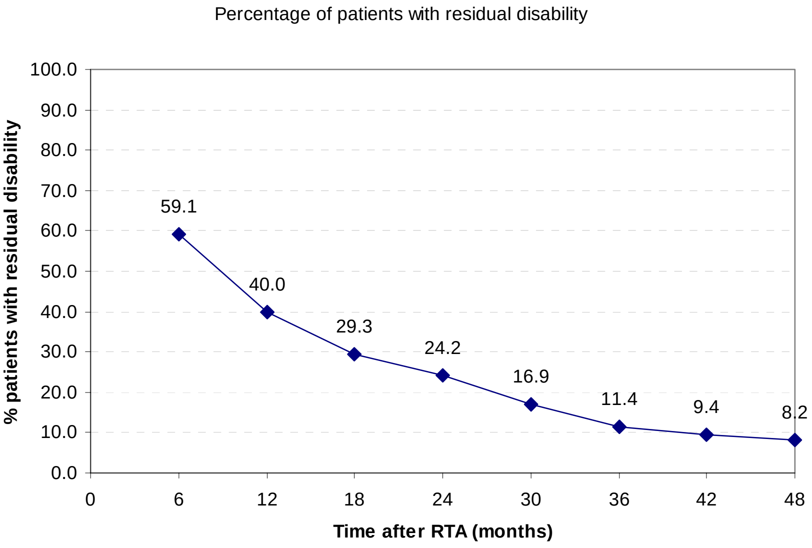

Figure 0.3: Percentage of patients with residual disability following a RTA whiplash injury (all impact directions) [Galasko *et al.*, 1996]

The cost of long-term injury has therefore been applied to 59.1% of the UK rear impact cases, with the short-term cost applied to the remaining 40.9% of rear impact whiplash cases. According to recent insurance industry data, this is a conservative assumption as the risk of long-term injury has increased since 1996. For instance, Folksam Insurance found that the risk of whiplash injuries leading to long-term disability had doubled over a period of 20 years [Folksam, 2001]. The latest UK insurance industry figures suggest that 70% of rear impact whiplash claims are longer-term, with an average recovery time of 9.1 months [Avery, 2007].

Casualty Valuations

The DfT financial values for the prevention of road accidents include the following elements of cost[1]:

- Loss of output due to injury - this is calculated as the present value of the expected loss of earnings plus any non-wage payments (national insurance contributions, etc.) paid by the employer.
- Ambulance costs and the costs of hospital treatment.
- Human costs - based on the ‘willingness to pay’ values, which represent pain, grief, and suffering to the casualty, relatives and friends, and, for fatal casualties, the intrinsic loss of enjoyment of life over and above the consumption of goods and services.
- Costs of damage to vehicles and property.
- Costs of police response and the administrative costs of accident insurance.

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[1] Source: Highways Economics Note No.1: 2005

The 2005 valuations used in this report (see Table 0.2) are taken from Road Casualties Great Britain: 2005 [Department for Transport, 2007].

Table 0.2: Casualty valuations (2005 values)

Casualty Severity	Valuation (£)
Fatal	1,428,460
Serious	160,510
Slight	12,380

Based on the frequency of occurrence of serious and slight accidents, the average cost for a non-fatal casualty is £44,930. Damage only accidents are valued at £1,710. The slight casualty cost is based on that given in Hopkin and Simpson [1995]. Within this, whiplash and other slight injuries are treated separately and then aggregated to give an average cost of slight injuries. The breakdown of the casualty costings for slight injuries are given in Table 0.3.

Table 0.3: Casualty costings for slight injuries (Hopkin and Simpson [1995])

Category	Up to 1 year (90% of slights)	1-3 years (whiplash) (10% of slights)	All slight	Whiplash cost
Lost output	£390	£8,620	£1,220	£8,620
	Recover 3-4 months	**Mild disability**		
Medical and support costs	£201	£633	£520	£520
	Minor slights (80%)	**Whiplash (20%)**		
Human costs	£120	£25,490	£5,190	£25,490
Total			**£6,920 (*sic*)**	**£34,630**

The cost of whiplash of £42,574 given in the ESRI Review of Secondary Safety Priorities [Welsh *et al.*, 2006] is the human cost of whiplash injuries from Hopkin and Simpson (£25,490 - see Table 0.3) inflated to 2003 prices; it does not include the lost output and medical and support costs. Pro-rata, the total casualty cost for a whiplash injury should be £57,840 at 2003 prices (£34,630, from Table 0.3, inflated to 2003 prices). The Welsh *et al.* and total casualty cost should be inflated by approximately 1.06 to give 2005 costs. This gives three possible casualty costs (not including accident costs) for a whiplash injury as shown in Table 0.4.

Table 0.4: Casualty costing options for whiplash injuries

DfT slight	2005	£12,380	Average of all slight injuries (underestimates whiplash cost)
RSSP whiplash	2003 2005	£42,574 £45,167	Human cost component of casualty cost using willingness to pay approach*
Whiplash casualty cost	2003 2005	£57,840 £61,362	Total casualty cost using willingness to pay approach*

* 1994 costs inflated to 2003 and 2005 prices, which assumes whiplash is the same proportion of the total number of slight cases and that the proportion of costs is the same in 2003 and 2005 as it was in 1994.

The cost of a whiplash injury in Hopkin and Simpson [1995] is based on the assumption that half of the whiplash injuries can be treated as ‘category W’ (recovery in 3-4 months, in-patient) and half in ‘category X’ (recovery in 1-3 years, in-patient). This was based on the rating given to whiplash by those who responded to the ‘willingness-to-pay’ survey on which the costings were based.

This seems an overly severe assessment as many whiplash symptoms resolve in less than three months. However, it is a reasonable assumption for long-term injuries based on the data in Galasko et al. [1996], which shows that 59.1% of whiplash victims (in all impact directions) have ongoing disability at six months post-impact. Based on the assumption that the whiplash costing in Hopkin and Simpson [1995] was appropriate and that it is still appropriate when scaled to 2005 prices, the value of £61,362 will therefore be used for long-term whiplash injuries.

In Hopkin and Simpson [1995], short-term whiplash casualties are not costed separately. The casualty cost for non-whiplash injuries includes a large number of very slight injuries. It seems reasonable that the cost for a short-term whiplash casualty (who may be injured for up to six month) would be greater than for a typical slight injury. However, in the absence of specific information in Hopkin and Simpson on short-term whiplash casualty costs, the non-long-term whiplash slight cost will be used. At 2005 prices, this gives a short-term whiplash casualty cost of £1,824.

Cost of AIS 1 Neck Injuries

From the 2005 Stats19 data it is possible to determine the number of motor vehicle occupants who sustained a slight injury as a result of a road traffic accident. The data is separated to show drivers and front seat passengers, who are either male or female. In this case, front seat occupants who received their injury from an accident with an initial point of contact to the front or rear of the vehicle are of interest. The number of slightly injured casualties in each of these groups is shown in Table 0.5. This table also shows the total number of slightly injured, front seat occupant, casualties from either frontal or rear impacts.

Table 0.5: Number of casualties who sustained a slight injury (2005 UK Stats19 data)

	Male driver	**Male FSP**	**Female driver**	**Female FSP**	**Totals**
Rear impact	15223	3047	15197	6481	
Front impact	29919	6423	21142	9711	
Total	45142	9470	36339	16192	107143

From the work of Galasko *et al.* [1996], we know that the proportion of under-reported cases in the Stats19 data is 45 %. Therefore the numbers taken from the Stats19 data need to be increased to account for under-reporting. Table 0.6 shows the adjusted Stats19 figures.

Table 0.6: Stats19 number of slightly injured casualties accounting for under-reporting

	Male driver	Male FSP	Female driver	Female FSP	Totals
Rear impact	27678	5540	27631	11784	
Front impact	54398	11678	38440	17656	
Total	82076	17218	66071	29440	194805

From the recent work of Welsh *et al.* [2006] the percentage of slightly injured occupants who sustained an AIS 1 neck injury is known for both frontal and rear impacts. In rear impacts this proportion is 58 percent and in frontal impacts it is slightly less, at 34 percent. Applying these figures to the Stats19 data provides the number of front seat occupants in frontal and rear impacts who sustained an AIS 1 neck injury. These numbers are shown in Table 0.7.

Table 0.7: Number of casualties sustaining an AIS 1 neck injury

	Male driver	Male FSP	Female driver	Female FSP	Totals
Rear impact	16053	3213	16026	6835	
Front impact	18495	3971	13070	6003	
Total	34549	7184	29096	12838	83666

Galasko *et al.* [1996] also showed that of the occupants who sustained an AIS 1 neck injury, 59.1 percent went on to display symptoms that lasted for over six months. Applying this factor to the previous table gives the number of casualties with a long-term whiplash injury. These numbers of front seat occupants are shown in Table 0.8.

Table 0.8: Numbers of casualties receiving a long-term injury (symptoms lasting > six months)

	Male driver	Male FSP	Female driver	Female FSP	Totals
Rear impact	9488	1899	9471	4039	
Front impact	10931	2347	7724	3548	

Total	20418	4246	17195	7587	49446

To transfer the number of casualties into a cost a willingness to pay figure is used, as was derived above (Table 0.4). The value associated with a long-term whiplash injury is £61,326. Therefore the cost of the long-term whiplash injuries to front seat occupants is the number of casualties multiplied by this figure. These costs, based on the UK Stats19 2005 casualty numbers, as modified above, are shown in Table 0.9.

Table 0.9: Costs of long-term whiplash injuries for front seat occupants in frontal and rear impacts

(£ millions)	Male driver	Male FSP	Female driver	Female FSP	Totals
Rear impact	582	116	581	248	
Front impact	670	144	474	218	
Total	1,252	260	1,055	465	3,032

The total cost associated with the long-term whiplash injuries to front seat occupants in frontal and rear impacts is approximately three billion pounds, based on the 2005 UK casualty data.

Options

The following four options have been considered for this cost-benefit study.

Option 1: Do Nothing

It is customary to include a ‘Do nothing’ option in cost-benefit analyses because, in some cases, such an option is a genuine possible outcome. In addition, its inclusion normally helps authors and readers alike to focus on the issues which underlie the study.

For this option, it is assumed that no change is made to the current regulatory requirements for head restraints and that the consumer testing (such as Thatcham and Folksam/SRA) continues in its current form. In this case, it would be expected that the recent trends in accidents and whiplash injury rates continue into the future. Equally there would be no costs to industry as they would be required to take no additional actions due to regulatory activity (only, at their discretion, due to consumer testing).

The recent history in slight injuries shows a downward trend (see Section 0). However, it is not known how the whiplash contribution to this is changing. For the purposes of this calculation it will be assumed that there is no change in current whiplash injury numbers. This assumes that the observed improvements in head restraint geometry due to the insurance industry tests continue across the rest of the fleet. That is that new vehicles will have similar head restraint geometry to those recently tested by Thatcham and that older vehicles, which only met the less stringent regulatory requirements, would be phased-out naturally.

An issue which would affect the ‘Do nothing’ option is whether the insurance industry consumer testing programme continues or not. If the insurance industry stops their consumer testing programme then one part of the justification for vehicle manufacturers to provide better than necessary head restraint geometry will have been removed. Whilst financial and other production constraints may cause manufacturers to consider providing vehicle seats with poorer head restraint geometry, it is thought unlikely that manufacturers will take such an option. Primarily this will be because consumers may see this as a backward step in design and also there may be a fear of litigation with a reduction in the level of safety provided. Equally, manufacturers would have little incentive to introduce a better level of protection than currently offered and it is therefore considered unlikely that they would do so. This argument is expected to be appropriate in the shorter term for manufacturers which have already undergone insurance industry testing on behalf of the consumer. However, new manufacturers of vehicles (e.g. from the emerging industries of India or China) would have no head restraint geometry baseline established previously. They would therefore have little or no incentive for providing geometry that is an improvement over that required legally (and hence is more expensive).

Because of this, the assumption that head restraint effectiveness will continue at the level of recent vehicles for all new vehicles introduced to the market is considered to be an optimistic one. By choosing this optimistic baseline, subsequent options (Options 2, 3 and 4) may have a considerably reduced benefit compared with a less optimistic baseline, such as one that assumes that consumer testing will stop and that head restraints will regress solely to meet the current regulatory requirements (a height of 800 mm and no control on backset). This optimistic assumption, and therefore conservative baseline for the benefits of the other options, is intended to balance some of the uncertainties in the data supporting the other options. Together with the target benefit-to-cost ratio of at least two, discussed in Section 0, this is considered to provide sufficient robustness for this cost-benefit study.

Option 2: Increase Head Restraint Height (within the range 800 to 850mm)

It is well documented that the head restraints in some cars, particularly older cars, are not able to give adequate support to all occupants because the centre of gravity (C of G) of some occupant’s heads is above the top of the head restraint. This option covers a change in Regulation 17 being made so that the head restraint height requirement for front-seats in passenger cars is increased from the current level of 800 mm to some other value between 800 and 850 mm (considered at 10 mm intervals). The benefit of this option will be related to the proportion of the population for whom the centre of gravity of the head is level with or below the height of the top of the head restraint during a rear impact and who would therefore expect to be adequately protected (assuming that the backset is also adequate).

Option 3: Introduce a Backset Requirement (within the range 40 to 100mm)

It is also well documented that backset is an important factor in determining whether a car occupant is likely to suffer whiplash, and how long-term any injury might be. However, there is currently no regulation applicable to the UK that governs the maximum allowable backset for a head restraint. The inclusion of the introduction of a backset regulation as an option for this study was clearly a necessity.

The benefits and costs for this option are considered alongside a backset limit set somewhere between 40 and 100 mm (at 10 mm intervals)

Option 4: Increase Head Restraint Height and Introduce a Backset Requirement (by combining Options 3 and 4)

This option considers the application of both an improved head restraint height requirement and the introduction of a limit on head restraint backset. It is expected that this would be more beneficial than either Option 2 or Option 3 on their own, but less beneficial than the sum of Option 2 and Option 3.

Comment

It is possible to consider the benefits due to a limit being introduced into regulation for either head restraint backset or height as one component of Option 4. That is, to evaluate the benefits arising from Option 4, a table will be produced comparing the benefits for each of the gradations within Options 2 and 3. By selecting the row or column which relates to the current position for height or backset, it is possible to read off the corresponding benefits due to the other variable. For this reason, Option 4 will be considered before Options 2 and 3 in the following sections.

Benefits

Identifying and Valuing the Benefits

The changes resulting from the adoption of each option would be a mixture of additional costs and benefits. In principle, these costs and benefits should be calculated or estimated, if possible, and compared in order to determine whether the benefits outweigh the costs.

The additional costs might include increased costs to be borne mainly by car manufacturers though some of them would be passed onto customers. These additional costs are discussed in Section 0.

The likely benefits are discussed in the rest of this section.

Accident Savings

Any accident savings would benefit the community as a whole.

The methodology used for estimating possible savings in casualty numbers is summarised by the theoretical steps shown by the flow charts in Appendix D. Using this methodology, estimates of the numbers of casualties saved or mitigated have been made for all proposed options.

Based on the injury risk function developed from the Volvo data [Olsson *et al.*, 1990] it was possible to derive the probability of sustaining a neck injury, with symptoms lasting longer than six months, from a rear impact accident for a given backset (see Appendix C.1). In a similar manner, through anthropometric considerations, the percentage of the population that would have a head restraint of at least appropriate height for various heights was derived. This is reported in Table A.4 in Appendix A.3. These two distributions have been combined in Table 0.1, for the male population and Table 0.2 for the female population. The result for each combination of head restraint height and backset is the probability that an occupant will not receive a neck injury with symptoms lasting longer than six months in a rear impact accident. This data is also shown in Figure 0.1 for the UK male population and Figure 0.2 for the UK female population.

Table 0.1: Matrix of percentage probability of mitigating long-term neck injury based on head restraint height and backset for the UK male population

		Backset						
		40	**50**	**60**	**70**	**80**	**90**	**100**
Height	**850**	91	88	83	75	65	52	39
	840	87	84	79	72	62	50	38
	830	82	79	74	68	58	47	35
	820	74	71	67	61	53	42	32
	810	64	61	58	53	45	37	27
	800	52	50	47	43	37	30	22

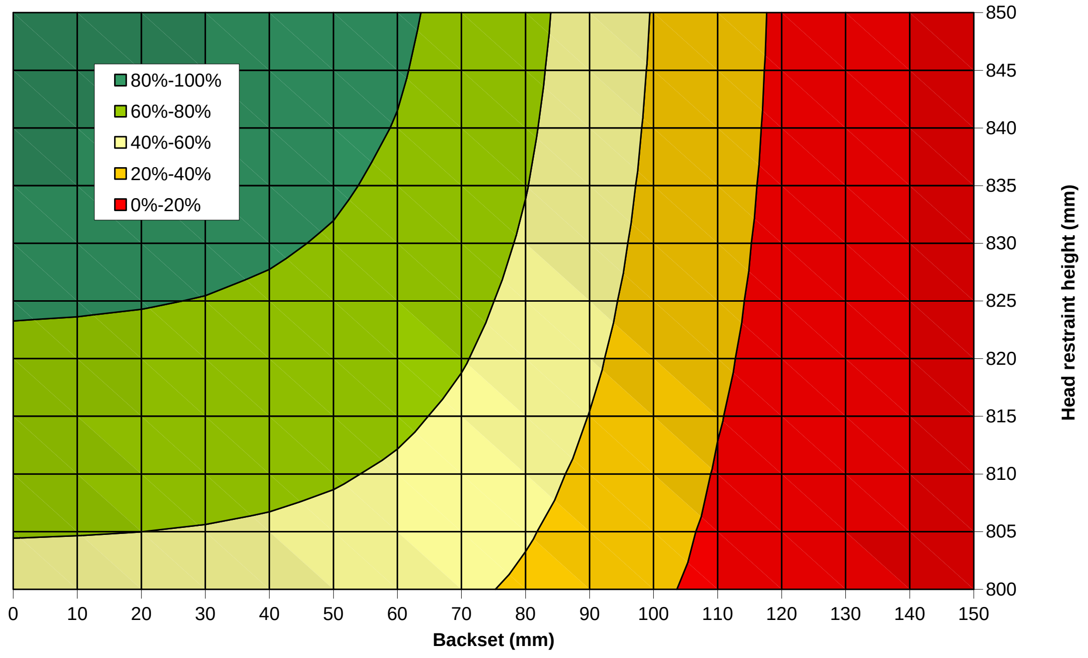

Figure 0.1: Percentage probability of mitigating long-term neck injury based on head restraint height and backset for the UK male population

Table 0.2: Matrix of percentage probability of mitigating long-term neck injury based on head restraint height and backset for the UK female population

		Backset						
		40	**50**	**60**	**70**	**80**	**90**	**100**
Height	**850**	95	92	87	79	68	55	41
	840	95	92	87	79	68	55	41
	830	95	92	86	79	68	55	41
	820	95	92	86	78	68	55	41
	810	94	91	86	78	67	54	41
	800	93	90	85	77	66	54	40

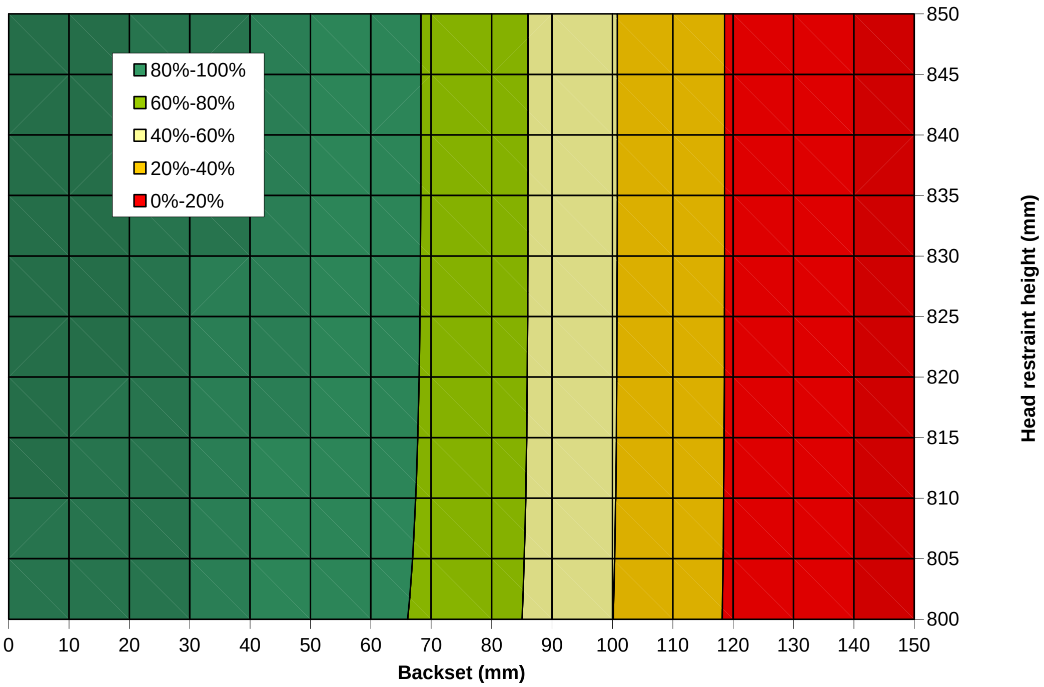

Figure 0.2: Percentage probability of mitigating long-term neck injury based on head restraint height and backset for the UK female population

To derive the benefits, in monetary terms, subsequently these savings have been given a cost using the willingness to pay casualty valuations shown in Table 0.4.

The benefits for Option 1 were considered first. As is discussed below, Option 1 is the Do nothing option and represents the zero cost and zero benefit situation. It was important to consider this option first as it defines the baseline from which the other benefits and costs are produced.

After considering the potential benefits associated with Option 1, the next option considered was Option 4 (a change in the head restraint height limit and introduction of a backset limit). As discussed in Section 0, with the background for deriving potential savings due to changes in backset and head restraint height in place (see Appendix A and Appendix B), it is most logical to draw up a matrix for the potential savings as these two parameters change. The benefits for either head restraint height or backset can then be extracted from the matrix when considered as the individual Options 2 and 3.

Option 1: Do Nothing

In Section 0, the reducing numbers of slight casualties over recent years were discussed. At the same time it is not known how the proportion of these slight injuries that are whiplash injuries is changing and additionally car volumes on the road are increasing. There is therefore some uncertainty in the number of whiplash injuries expected to occur in the future. For the purpose of the benefit calculation, the number of whiplash injuries is forecast to continue at the present level. As discussed in Section 0 this should represent quite an optimistic assumption and therefore a conservative baseline for the other options, particularly if Thatcham were to stop their consumer testing programme.

Option 4: Increase Head Restraint Height and Introduce a Backset Requirement (by combining Options 2 and 3)

The savings which are likely to result from the adoption of a specified maximum backset and increased head restraint height have been estimated from STATS19 data for 2005 using the following process:

- Derive the number of slightly injured male and female front seat occupants (drivers & front seat passengers) from a search of STATS19 database, separately for accidents involving front impact and rear impact (67224 and 39961, respectively).
- Estimate true numbers of slightly injured casualties assuming that under-reporting in the STATS19 data means that only a proportion of accidents are added to the database; this factor is thought to be 0.45, according to Galasko *et al.* [1996]
- Estimate numbers of these casualties with AIS 1 neck injuries using factors from Welsh *et al.* [2006]; these factors are 0.34 and 0.58, for frontal and rear impacts respectively.
- Estimate the number of these injuries which last longer than 6 months using a factor (0.591) from Galasko *et al.* [1996].
- Estimate the numbers of these injuries which would be saved from a reduced maximum backset and the population covered at the appropriate head restraint heights using the factors from Figure 0.1.
- Calculate their valuations using the whiplash casualty figure (£61,362) presented in Section 0.

The resulting potential savings for the proposed head restraint backset and height limits are shown in Table 0.3 and Table 0.4. These two tables show the annual benefits in terms of potential casualty savings and value of those savings in UK Sterling, respectively.

It should be borne in mind that an occupant will only obtain the full benefit of a higher head restraint if their head is sufficiently close to the seat or head restraint to be supported in an impact. An occupant in a tall seat leaning forward is not likely to benefit fully because they could be injured in the process of the head being jerked backwards in an impact. To account for occupants being out-of-position at the time of an accident, a factor has been assumed to represent that the full benefit might only be realised for 50 percent of the potential whiplash casualties identified (see below for the justification for this assumption).

In addition, head restraints would only be of benefit in preventing whiplash for those cases where neck extension (rearward head motion) was involved in the injury mechanism. It is assumed that this would be the case for 90 % of the rear impacts. A factor of 10 % has been applied for frontal impacts.

In support of these assumptions, it has been presented by Farmer *et al.* [2003] that head restraints can be effective in reducing 43 % of whiplash-based insurance claims. This is approximately consistent with the multiplicative factors for rear impacts assumed above (50% x 90% = a factor of 45% for rear impacts).

In a study by Kullgren *et al.* [2000], accidents (occurring since 1992) involving five particular car models with and without airbags and seat-belt pretensioners were investigated. Injury data was included for 158 restrained drivers in front impacts. Of these 158 drivers, 45 reported an AIS 1 neck injury. The proportion of people who sustained AIS 1 neck injuries in cars without airbags was 0.375 compared with 0.225 for cars fitted with airbags. It could be suggested that the introduction of airbags ought to have eliminated all neck injuries resulting from a mechanism involving flexion (or hyper-flexion) as the head would have been supported by the airbag. This would leave 22.5 % of the drivers undergoing some other neck injury causing mechanism and neck extension in rebound would be the most likely mechanism. However, it does not seem realistic to expect airbags to eradicate all flexion-based injuries. Similarly a whiplash causing extension mechanism is not expected to cause all other neck injuries in frontal impacts. However, these data do suggest that neck injuries caused through extension could be evident in between 0 and 22.5 % of frontal impacts. As a conservative estimate, it will be assumed that 5 % of the long-term whiplash injuries caused by frontal impacts will have been a result of a neck extension mechanism. Therefore these are the injuries that could potentially be mitigated through better head restraint geometry. For front impacts, the overall factor when combining those occupants in-position and having an injury caused by an extension-based mechanism is therefore assumed to be 50% x 10% = 5%.

Table 0.3: Maximum savings (in number of casualty terms) obtainable from limited head restraint backset and increased head restraint heights in the UK (2005 data)

Number of casualties		Backset (mm)						
		40	**50**	**60**	**70**	**80**	**90**	**100**
Height (mm)	**850**	679	500	312	158	50	2	0
	840	666	491	306	156	49	2	0
	830	647	476	297	151	47	2	0
	820	619	456	285	145	45	2	0
	810	584	430	268	136	43	2	0
	800	540	398	248	126	40	2	0

Table 0.4: Maximum savings (in monetary terms) obtainable from limited head restraint backset and increased head restraint heights in the UK (2005 data)

		Backset (mm)						
£		**40**	**50**	**60**	**70**	**80**	**90**	**100**
Height (mm)	**850**	41,636,678	30,658,498	19,142,465	9,721,168	3,050,588	121,360	0
	840	40,878,260	30,100,049	18,793,782	9,544,096	2,995,021	119,149	0
	830	39,694,163	29,228,159	18,249,393	9,267,637	2,908,266	115,698	0
	820	38,008,639	27,987,050	17,474,473	8,874,108	2,784,773	110,785	0
	810	35,806,455	26,365,508	16,462,020	8,359,951	2,623,426	104,366	0
	800	33,136,058	24,399,204	15,234,304	7,736,477	2,427,774	96,583	0

It should also be borne in mind that the table only includes the savings from mitigations of the longer term (i.e. > 6 month) injuries. In practice, these injuries are likely to be mitigated to shorter term (and lower cost) injuries. A more precise valuation, for each injury mitigated, would be to take the difference in the cost of the longer term and short term injuries (i.e. £61,362 - £1,824 = £59,538). However, higher restraint heights would also mitigate some shorter term whiplash injuries to an uninjured status. It has been assumed here that these two factors cancel. In consequence, the full saving of £61,362 has been assumed to apply to each long-term injury mitigation.

Option 2: Increase Head Restraint Height (within the range 800 to 850mm)

No direct evidence has been found in the recent literature to show a benefit of increasing the height of the head restraint. Older studies which do indicate the advantages of higher head restraints have not considered the heights being proposed here and more recent studies tend not to specifically assess head restraint height separately from good head restraint position (backset and height). However, the assumption of the importance of head restraint height may be made more pragmatically. It is suggested that for a head restraint to be effective, it needs to be of sufficient height to support the occupant's head. Either the restraint is high enough to support the head and allows a good backset to reduce the risk of injury, or it is too low to support the head and prevents good backset from helping; in the extreme, a head restraint that is too low may even increase the risk of injury compared with a head restraint that is absent [Hell *et al.*, 1998]. Ono and Kanno [1996] also showed that the bending moment experienced at the neck could be higher with a low head restraint than with no head restraint (see Section A.1). On this basis, the head restraint height should be increased to provide sufficient support for as much of the population as is possible (or can be justified on a cost basis). For this reason the percentage of the population covered by a particular head restraint height will be used to derive effective target population limits when considering the benefits arising from head restraint backset considerations.

The background and calculations used in the derivation of target population limits due to an increase in head restraint height are shown in Appendix A.3. The table of UK population coverage with increasing head restraint height is reproduced as Table 0.5.

Table 0.5: Proportion of the population with head centre of gravity at or below the top of the head restraint for incremental restraint heights

Head restraint height (mm)	**Proportion of the population (percent)**	
	UK	
	Male	Female
850	96	100
840	92	100
830	86	100
820	78	100
810	67	99
800	55	98

Using these proportions of the population that would have a head restraint of sufficient height to be of benefit, then it is possible to evaluate the potential injuries that could be prevented if the regulated head restraint height was to be increased. To do this one must assume a nominal injury risk with a head restraint of adequate height. The benefits are then the increased proportion of the population covered at a different head restraint height multiplied by the injury risk and number of casualties each year.

According to the TNO evaluation of different backset measurement methods [Cappon, 2007] the average backset using the WG20 method (with a backset probe held in position by a portal frame, with no 3-D H machine or HRMD in the seat) was 0.73 mm smaller than using the RCAR measurement method (which uses the 3-D H machine - or SAE-J826 - and HRMD). The average backset in the Thatcham database 2005-2007 is 50.65 mm, which equates to 49.92 mm in terms of the WG20 backset measurement method. If one assumes that the existing vehicle fleet has a backset of 50 mm then the casualty savings are shown by the corresponding column in Table 0.6

Table 0.6: Maximum savings (in number of casualty terms) obtainable from limited head restraint backset and increased head restraint heights in the UK (2005 data)

Number of casualties		**Backset (mm)**						
		40	**50**	**60**	**70**	**80**	**90**	**100**
Height (mm)	**850**	679	500	312	158	50	2	0
	840	666	491	306	156	49	2	0
	830	647	476	297	151	47	2	0
	820	619	456	285	145	45	2	0

810	584	430	268	136	43	2	0
800	540	398	248	126	40	2	0

These values are reproduced in Table 0.7. It can be seen from this table that the maximum benefit would be obtained if the highest head restraint limit, from the proposed range, was selected. This is not surprising as the highest head restraints would guarantee to provide a restraint of sufficient height to protect the greatest proportion of the population.

Table 0.7: Maximum savings obtainable from increased seat/head restraint heights in the UK (UK 2005 data)

Head restraint height (mm)	**Maximum additional savings (number)**		**Maximum additional savings (£)**	
	Rear impacts	Rear and front impacts	Rear impacts	Rear and front impacts
850	469	500	28,800,608	30,658,498
840	461	491	28,281,807	30,100,049
830	448	476	27,471,694	29,228,159
820	429	456	26,318,173	27,987,050
810	404	430	24,810,194	26,365,508
800	374	398	22,979,706	24,399,204

Option 3: Introduce a Backset Requirement (within the range 40 to 100mm)

The information supporting the subsequently reported potential savings resulting from defining a backset limit are shown in Appendix B. The resulting potential savings as calculated are shown in Table 0.8. This assumes that the head restraint height limit in UN-ECE Regulation 17 remains at 800 mm.

As for Options 4 and 2, injuries to rear seat passengers have been excluded. Also, the table only includes the savings from mitigations of the longer term (i.e. > 6 month) injuries.

Table 0.8: Estimated (maximum) savings following the introduction of a backset regulation (UK 2005 data)

Backset (mm)	Proportion of injuries saved	Maximum additional savings (number)		Maximum additional savings (£)	
		Rear impacts	Rear and front impacts	Rear impacts	Rear and front impacts
40	0.069	509	540	31,208,267	33,136,058
50	0.051	374	398	22,979,706	24,399,204
60	0.032	234	248	14,348,002	15,234,304
70	0.016	119	126	7,286,384	7,736,477
80	0.005	37	43	2,286,531	2,427,774
90	0.000	1	2	90,964	96,583
100	0.000	0	0	0	0

Vehicle Parc

Consideration needs to be given to the percentage of new cars that meet the proposed requirements as a proportion of the vehicle fleet. This will increase over time as more new vehicles, forced to comply with the regulation, are registered.

The number of new car registrations for the UK over the last ten years are shown in Figure 0.3. In addition three projected trends are shown for the next 20 years. Depending on which data are considered, differing forward trends can be justified. Over the last ten years, the number of annual new car registrations has been increasing in the UK. Based on these data a continuing increase could be expected. However, over the last five years, the number of new car registrations has been more consistent and has decreased for each of the last three years where data is available. Based on this trend it may be expected that the number of annual new car registrations will continue to decline. The authors are uncertain as to which trend is more likely. As an approximation between these two possibilities, a third trend of continued new car sales, at the existing level, is also plotted in Figure 0.3. This will be used as the expected future level of car sales in the later sections of the report.

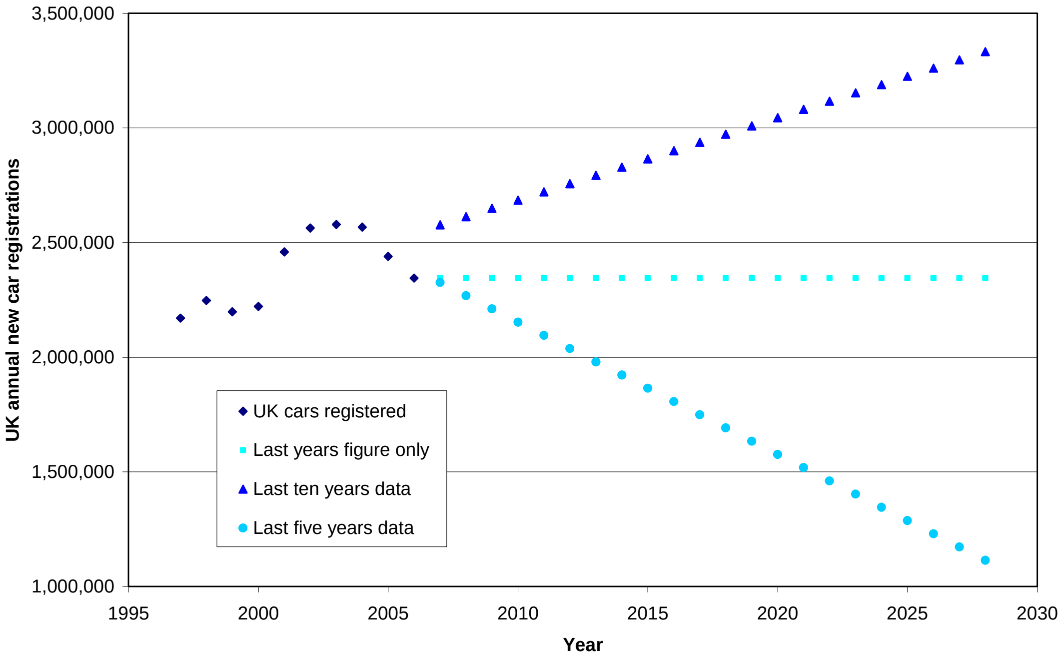

Figure 0.3: UK annual new car registrations based on previous years data and projected into the future

The continuing level of annual new car registrations is again plotted in Figure 0.4 together with data for the EU. The EU projected car registrations are based on the last five years data.

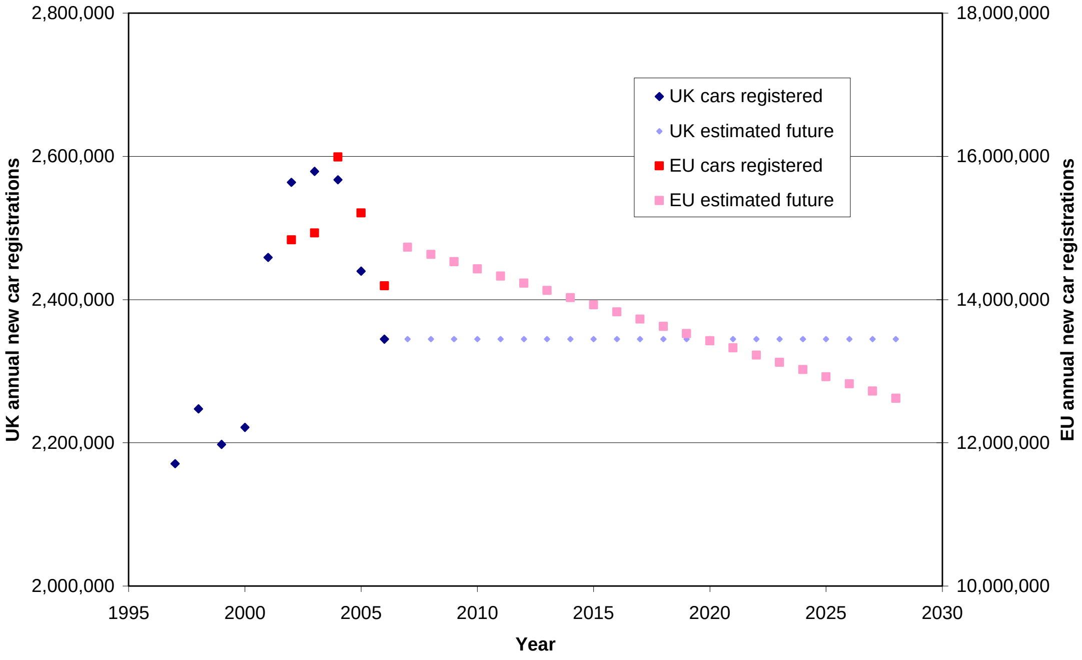

Figure 0.4: UK new car registrations in the UK and in the EU (previous years and projected data)

The previous two figures have shown the number of new cars registered in the UK and EU. This represents the new cars on the roads which will conform to any regulation that is introduced. To provide this value as a percentage of the vehicle fleet, it is also important to consider the relationship between new cars and old cars on the roads. Figure 0.5 shows the total number of cars on the UK and EU roads. Again future trends have been predicted based on the existing data that are available.

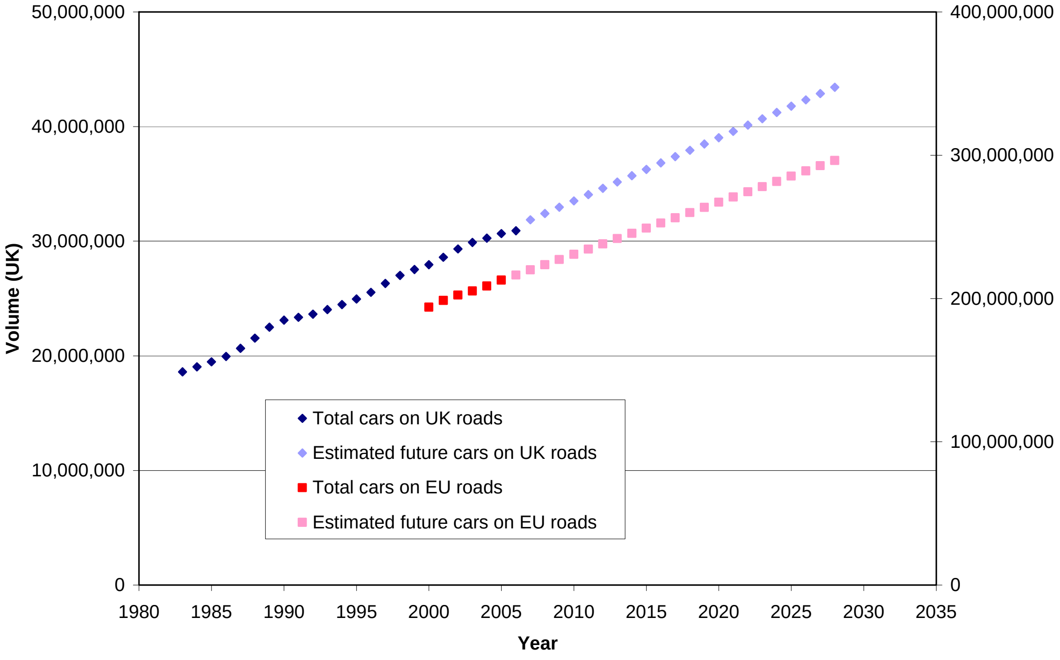

Figure 0.5: Number of cars on the roads (previous years and projected data)

From the work of Thatcham, the backset in the majority of recent new vehicles is now known. Based on the data produced by the RCAR testing conducted at Thatcham, it is possible to say the percentage of existing vehicles which would already comply with the range of backset requirements proposed. To this percentage, the annual new car sales would also be added. The trend over time of the increasing proportion of the vehicle fleet which complies with the backset requirements is shown in Figure 0.6 for the various proposed backset limits.

From Figure 0.6 it can be seen that for the proposed backset limits of 80, 90 and 100 mm it would take a year or less for all vehicles on the UK roads to comply with the requirement. However, if a limit of 40 mm was chosen, then complete compliance within the fleet would not occur until after about ten years, based on the car sales and vehicle fleet assumptions made above.

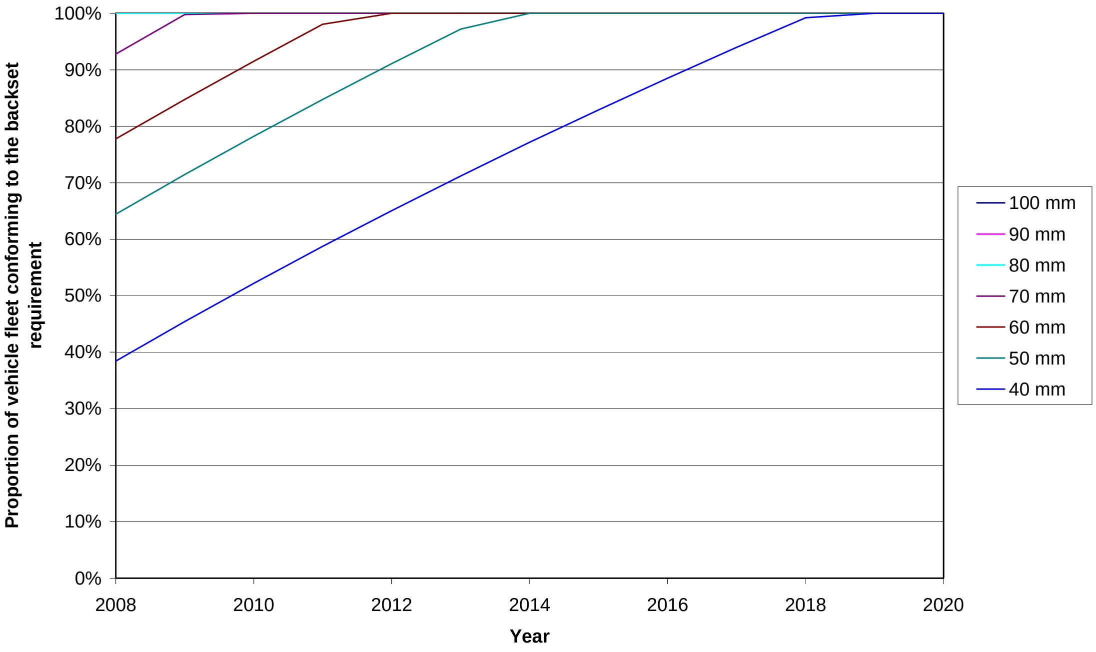

Figure 0.6: Percentage of vehicles in the UK fleet meeting the proposed requirements for backset (from 40 to 100 mm)

Costs

Introduction

In their final regulatory impact analysis for FMVSS 202, NHTSA [2004] derived cost estimates for head restraint modifications required to meet the standard (Section VI, Tables VI-1 and VI-2, page 70-73). The costs were obtained as results from tear down studies of head restraints taken from a variety of light trucks and vans, and were believed to be a good proxy for passenger cars. NHTSA found that the average consumer costs of integral and adjustable head restraints, weighted by sales estimates, were $ 32.23 and $ 31.18, respectively.

In addition to these costs for a whole head restraint, NHTSA also derived costs per inch of head restraint. The figures were produced by dividing the net cost per restraint, after subtracting adjustment hardware and assembly costs, by the height of the restraint system in each case. This assumes that the costs incurred modifying the restraints to meet the standard do not require any significant extra cost in adjustment hardware or assembly procedures over the unmodified designs. The costs per inch of head restraint, weighted by vehicles sales, for integral and adjustable head restraints were reported as $ 1.50 and $ 1.70, respectively. These costs were given in 2002 dollars. If one assumes that US inflation from 2002 to 2007 has been 16 percent[2] then in 2007 these costs would be $ 1.74 and $ 1.97 per inch of additional head restraint. With a conversion rate of 0.487[3], the costs per inch of head restraint in Sterling would be £ 0.85 and £ 0.96, respectively or £ 0.33 and £ 0.38 per cm for integral and adjustable head restraints.

Regarding a cost for decreasing the backset, NHTSA reported their belief that a backset requirement would not add cost to the vehicle. NHTSA accepted that some redesign costs would be inevitable in order to increase the height and reduce the backset. However, they thought that any design change brought about by the backset requirement could be implemented at the same time as the height increase, with no further cost. Whilst this reasoning may be appropriate for Option 4, where both a height and backset requirement are introduced, Option 3 requires a backset requirement only. In this case, there would be some cost forced by the regulation. For this reason, the SMMT (Society of Motor Manufacturers and Traders) was approached and asked to some cost estimate for such a proposed requirement. Unfortunately, no cost has been made available through this route and so a cost of zero has been assumed for backset modifications.

Option 1: Do Nothing

There would be no additional costs resulting from the ‘Do nothing’ option.

Option 4: Increase Head Restraint Height and Introduce a Backset Requirement (by combining Options 3 and 4)

Based on the costs published by NHTSA [2004], the additional costs of increasing the height of the head restraint up to 850 mm, are shown in Table 0.1. These assume that the cost of equipping the vehicle fleet with modified head restraints will be twice the cost for a single head restraint per vehicle multiplied by the number of new car registrations each year. The number of new car registrations in the UK during 2006 was 2,344,864. It has also been assumed that 20 percent of the UK vehicle fleet is equipped with fixed head restraints and 80 percent with adjustable restraints.

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[2] taken from U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Indexes: http://www.bls.gov/cpi/#data

[3] taken from www.xe.com: 20 July 2007

Table 0.1: Estimated additional cost for head restraint height increases

HR Height (mm)	HR height increase (mm)	Additional cost (£)
850	50	8,300,819
840	40	6,565,619
830	30	4,830,420
820	20	3,470,399
810	10	1,735,199
800	0	0

It should be noted that these costs for height increases assume that all recent vehicles (which are the baseline assumed in Option 1, rather than the whole vehicle fleet of old and new cars) would require a height increase of 50 mm in order to meet an increased height requirement of 850 mm. This is expected to be a large overestimate of the required costs: it has been reported to WG20 that the average height in the fleet is over 830 mm (and that some manufacturers already meet a height of 860 mm). This would mean that the costs assumed here are approximately double the real-world cost of meeting the 850 mm head restraint height.

As mentioned above, the SMMT was approached to provide a cost figure for backset modifications. However, no figure has been forthcoming. Therefore, the authors have no option but to adopt the same strategy as NHTSA and assume zero cost for changes due to the introduction of a backset limit.

Option 2: Increase Head Restraint Height (within the range 800 to 850mm)

The costs for Option 2 will be the same as shown in Table 0.1, but with the backset representative of the vehicle fleet. However, as there is no backset cost, the costs for this option become identical to those in Table 0.1.

Option 3: Introduce a Backset Requirement (within the range 40 to 100mm)

No costs were forthcoming for the introduction of a limit on head restraint backset.

Comparison of Benefits and Costs

This section summaries the estimated benefits and costs of each option, as far as this is possible.

Option 1: Do Nothing

As described in Section 0. This option represents the ‘Do nothing’ option and therefore, by default has zero cost and zero benefit associated with it.

Option 4: Increase Head Restraint Height and Introduce a Backset Requirement (by combining Options 3 and 4)

In the Sections 0 and 0 benefits and costs associated with a matrix of limits for head restraint height and backset were derived, respectively. The two tables following (Table 0.1 and Table 0.2) show the benefit minus cost and benefit divided by cost values for each 10 mm gradation of possible limits for height and backset.

Table 0.1: Benefit minus cost values associated with the change to a minimum head restraint height of 800 to 850 mm and the introduction of head restraint backset limit of 40 to 100 mm

		Backset (mm)						
£		**40**	**50**	**60**	**70**	**80**	**90**	**100**
Height (mm)	**850**	33,335,859	22,357,680	10,841,646	1,420,349	-5,250,231	-8,179,459	-8,300,819
	840	34,312,641	23,534,430	12,228,163	2,978,476	-3,570,598	-6,446,470	-6,565,619
	830	34,863,743	24,397,739	13,418,973	4,437,217	-1,922,154	-4,714,722	-4,830,420
	820	34,538,240	24,516,651	14,004,075	5,403,709	-685,626	-3,359,614	-3,470,399
	810	34,071,256	24,630,308	14,726,820	6,624,751	888,226	-1,630,833	-1,735,199
	800	33,136,058	24,399,204	15,234,304	7,736,477	2,427,774	96,583	0

Table 0.2: Benefit divided by cost values associated with the change to a minimum head restraint height of 800 to 850 mm and the introduction of head restraint backset limit of 40 to 100 mm

		Backset (mm)						
£		**40**	**50**	**60**	**70**	**80**	**90**	**100**
Height (mm)	**850**	5	4	2	1	0	0	0
	840	6	5	3	1	0	0	0
	830	8	6	4	2	1	0	0
	820	11	8	5	3	1	0	0
	810	21	15	9	5	2	0	0
	800	∞	∞	∞	∞	∞	∞	∞

A graph representing the data in Table 0.2, the value of the potential benefit divided by the cost for the various proposed head restraint height and backset limits, is shown in Figure 0.1. From this figure it can be seen that the most ideal of the proposed options would be, in theory, to increase the head restraint limit to 810 mm and introduce a limit on the allowable backset of 40 mm. This provides a ratio of benefit to cost of 21 to 1.

The line representing the option of keeping the head restraint height at 800 mm is not portrayed in a realistic manner in the subsequent figures. This is because we have no cost figures for changing the backset requirements only. Therefore the benefits for this option will be divided by zero and cannot be plotted in a continuous manner. In order to provide continuous plots, as visual aids, the points have been set to the highest value shown in each of the figures.

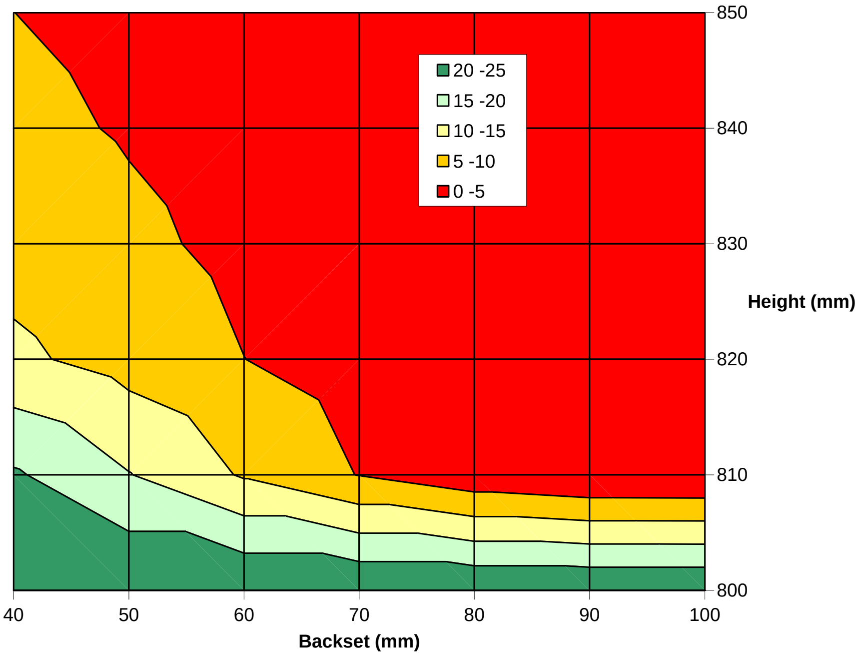

Figure 0.1: Graphical representation of the benefit divided by cost for the various proposed head restraint height and backset limits

As mentioned at the beginning of Section 0, in view of the uncertainties in the estimating processes, it is normal to seek a benefit/cost ratio of at least 2 in order to justify further consideration of any option. To enable consideration around the limit of a benefit divided by cost ratio of two, Figure 0.1 has been expanded to show this gradation (Figure 0.2). From Figure 0.2 it can be seen that to achieve such a benefit/cost ratio, any increased height limit could be selected with a backset of 60 mm. If a backset of 70 mm was more desirable, then a corresponding height limit of 820 or less would be needed.

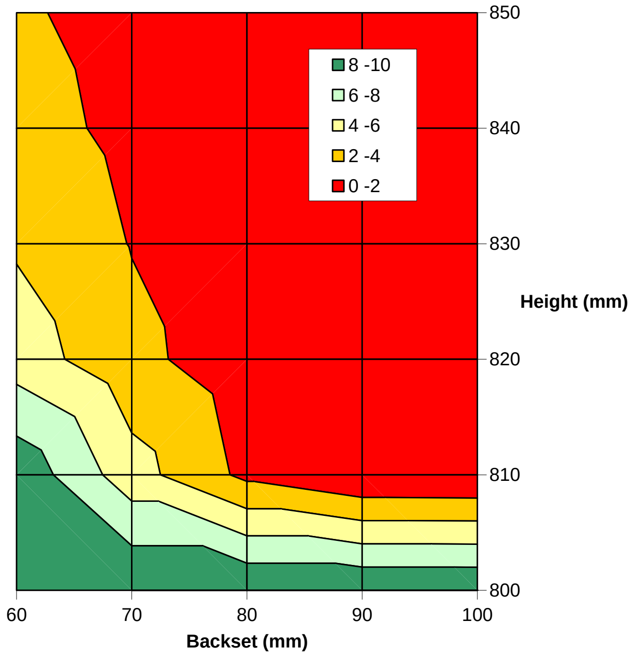

Figure 0.2: Expanded section of Figure 0.1 showing the split above and below a benefit divided by cost ratio of two

Option 2: Increase Head Restraint Height (within the range 800 to 850mm)

The comparison of benefits against costs for Option 2, where only the head restraint height limit is increased (assuming that the backset is the average of the fleet tested by Thatcham, i.e. 50 mm), are shown in Table 0.3. As was determined in previous sections, the estimated maximum benefit and additional cost both increase with increasing head restraint height. With no increase in head restraint height, there is no additional cost; therefore, it is not surprising that the benefit divided by cost values tend towards infinity at a head restraint height limit of 800 mm. Whereas, the column of benefit minus cost shows a peak value for a backset limit of 840 mm.

Table 0.3: Benefit minus, and divided by, cost values associated with the change to a minimum head restraint height in the range of 800 to 850 mm

HR height increase from 800 mm (mm)	Estimated maximum additional benefit (£) [B]	Additional cost (£) [C]	[B-C] (£)	[B/C]
0	24,399,204	0	24,399,204	∞
10	26,365,508	1,735,199	24,630,308	15
20	27,987,050	3,470,399	24,516,651	8
30	29,228,159	4,830,420	24,397,739	6
40	30,100,049	6,565,619	23,534,430	5

50	30,658,498	8,300,819	22,357,680	4

Option 3: Introduce a Backset Requirement (within the range 40 to 100mm)

The comparison of benefits and costs for Option 3 is not very meaningful. As yet, no costs have been provided for Option 3 and therefore the comparison is straightforward. The benefit minus cost values are equal to the benefit values and the benefit divided by cost values are infinite. These comparative values are shown in Table 0.4, for completeness. As would be expected, the greatest benefit is realised with the smallest backset.

Table 0.4: Benefit minus, and divided by, cost values associated with the introduction of a maximum head restraint backset limit in the range of 40 to 100 mm

Maximum backset (mm)	Estimated additional benefit (£) [B]	Additional cost (£) [C]	[B-C] (£)	[B/C]
40	33,136,058	0	33,136,058	∞
50	24,399,204	0	24,399,204	∞
60	15,234,304	0	15,234,304	∞
70	7,736,477	0	7,736,477	∞
80	2,427,774	0	2,427,774	∞
90	96,583	0	96,583	∞
100	0	0	0	∞

Summary

A conventional willingness-to-pay cost figure for whiplash injuries was inflated to provide a value appropriate for 2005. Application of this value to the number of casualties in the UK 2005 data who would be expected to receive a long-term whiplash injury provided a cost figure of £3 billion. This figure considers only front seat occupants involved in an impact with the first point of contact at the front or rear of the vehicle. In the derivation of this figure, factors have been derived to transform the number of casualties with a slight injury, from the 2005 Stats19 data to the number of casualties with a long-term whiplash injury in the UK. These factors include: under-reporting in the Stats19 dataset, the proportion of casualties with an AIS 1 neck injury and the proportion sustaining long-term whiplash injury symptoms.

To address the problem of these whiplash injuries, four options have been considered which would amend the requirements concerning the geometrical position of the head restraint with respect to the occupant. The first option considered was the option of doing nothing. This was defined as resulting in no benefit through reduction of casualties but also no cost for UK industry. The assumption behind this eventuality was that consumer testing has already given an incentive for improved head restraint geometry, over the last few years. The baseline therefore includes continued performance of vehicles with respect to the appropriateness of the head restraint geometry for reducing the incidence of whiplash injuries.

Other options included either increasing the head restraint height requirement from 800 mm to some value in the range 800 to 850 mm (Option 2), or introducing a limit on the maximum backset allowable from the rear of an occupants head in the range 40 to 100 mm (Option 3), or some combination of the two (Option 4). In each case the benefits that could be expected in the reduction of long-term whiplash injury were calculated based on the adoption of each option. The benefits were based on published information regarding the effectiveness of the head restraint in mitigating whiplash injury risk. In general terms, injury risk was expected to reduce with decreasing backset and a higher head restraint means that such benefits can be realised for a larger proportion of the population.

The injury risks and percentage of the population covered with a head restraint of adequate height were applied to the casualty data. More factors were applied to account for: the proportion of whiplash injuries that result from a neck extension mechanism, the proportion of occupants who are in position at the time of the accident and could therefore benefit from a head restraint, and the proportion of occupants who adjust their head restraint correctly if it is necessary for them to do so.

In opposition to the benefits of head restraint modifications, costs for enforcing such changes were also considered. Based on similar considerations by the US Department of Transportation, costs were obtained for increases in the height of head restraints. No costs were attributed to the changes in backset because no costs were made available.

Once benefits and costs had been derived, they were compared to show which option would result in the most overall benefit (after subtracting cost) and benefit per unit of cost. These comparisons were not at all revealing for backset because there were no direct costs associated with the changes. However, some inferences about backset could be obtained from the matrix of benefits and costs associated with the combination of options used in Option 4.

Considering the benefits of head restraint height, compared with the cost, the figures showed that the smallest change in head restraint would be expected to yield the best benefit per unit of cost incurred. However, an increase of head restraints to a height of 840 mm was expected to result in the largest benefit minus cost value.

For the combination of an increase in head restraint height and the introduction of a backset limit, then a small increase in head restraint height coupled with a small backset seemed to be the best option. This outcome is potentially misleading as the basis includes no costs for backset changes or the maintenance of the same head restraint height requirement. The minimum change required to provide an expected benefit twice that of the cost was shown to arise through a backset limit of 70 mm with some increase in the head restraint height.

The assumptions made in this cost-benefit study, and whether they are conservative or not, are summarised in Table 0.1.

Table 0.1: Summary of the assumptions used in this cost-benefit study

Parameter	Assumption	Conservative or not?	Comment
Height	Height distribution data for the UK population	Accurate for the UK	
	Erect sitting height for the UK population	Accurate for the UK	
	Assumed ramping-up factor	Slightly conservative	Based on volunteer test data, with cloth seats, rigid-backed lab seat, and downward component to occupant acceleration pulse
Backset	Backset injury risk function	Conservative	If anything, the cars in the study would be less stiff and have less stiff seat-backs than the current fleet, both of which would be expected to reduce the injury risk [EEVC WG20, 2005]
Cost - height	Full 50 mm cost applied to raising height from 800 mm to 850 mm	Conservative	Most head restraints already exceed 800 mm due to insurance industry testing
Cost - backset	No cost applied	Slightly optimistic	A proportion of seats would require a one-off tooling cost as a result of introducing a backset requirement. However, as the average backset in Thatchan testing is now 50 mm, this cost would be expected to apply only to a small proportion of seats
Cost of whiplash injuries	Front and rear impact whiplash proportions for male and female	Accurate for the UK	Data from Stats19 and Welsh et al. [2006]
	Under-reporting proportion	Accurate for the UK	From a large hospital study Galasko et al. [1996]
	Long-term symptom proportions	Accurate for the UK	From a large hospital study Galasko et al. [1996], supported by more recent UK insurance data

Parameter	Assumption	Conservative or not?	Comment
	Willingness-to-pay casualty cost for long-term whiplash injury	Accurate for the UK	From DfT willingness-to-pay costing
Proportion who could be saved by improved geometry	Proportion of rear impact occupants have an extension mechanism and are sufficiently in-position for the head restraint to be of benefit	Neutral	Consistent with insurance claims reductions with improved geometry
	Proportion of front impact occupants have an extension mechanism (from rebound) and are sufficiently in position to be saved	Little evidence, but expected to be conservative	
	Mid-range estimate of number who would correctly adjust their head restraint, including a factor for those with fixed head restraints	Neutral	
Other	Assumed long-term injuries saved to short-term are balanced by short-term injuries saved to no injury	Not known whether conservative or not	

Examining the maximum savings resulting from height changes (assuming that the average backset in the new car fleet is 50 mm as found in the Thatcham RCAR test data) in Table 0.7, it is apparent that there is a saving of approximately £24.4 million at a height requirement of 800 mm. Although dependent on the backset measurements, this can be taken to be indicative of the magnitude by which the savings are underestimated due to the assumptions used in Option 1. If it was assumed in the do-nothing option that insurance industry testing stopped and that head restraints were designed only to meet the regulatory requirement, then this value of £24 million should be added to the savings, which would have a dramatic effect on the benefit-to-cost ratio.

It should be noted that a static geometric head restraint requirement is a first step in mitigating low-speed rear impact injuries, and additional benefit may result from appropriate dynamic seat testing.

Conclusions

- A cost benefit analysis has been undertaken to determine the justification for making changes to the geometrical requirements for head restraints

- The options considered were:
    - Doing nothing
    - Increasing the current head restraint height requirement from 800 mm to somewhere in the range of 800 to 850 mm
    - Introducing a limit for head restraint backset somewhere in the range of 40 to 100 mm
    - A combination of the two options for head restraint height and backset

- For each option the benefits were determined by evaluation of the potential casualty savings that might occur as a result of the regulatory change
    - A monetary value was applied to the benefit by assigning a cost to each whiplash injury with long-term symptoms
    - This value, which was based on the willingness to pay model, was £61,326
    - The total cost associated with the long-term whiplash injuries to front seat occupants in frontal and rear impacts was found to be approximately three billion pounds, based on the 2005 UK casualty data

- For each option costs were also determined
    - Costs associated with an increase in head restraint height, as used in a similar exercise in the US, were converted to UK values
    - No response was forthcoming from industry for the costs associated with changing the backset of head restraints in cars

- The benefit minus cost value of each option was then calculated along with the benefit to cost ratio

- The greatest benefit after subtracting the associated cost is expected with a head restraint height of 840 mm and a backset of 40 mm

- The greatest benefit to cost ratio should occur with a small change in head restraint height and a backset of 40 mm

- The minimum change in regulation expected to yield a benefit to cost ratio of two would be to adopt a backset of 70 mm

- A static geometric head restraint requirement is a first step in mitigating low-speed rear impact injuries, and additional benefit may result from appropriate dynamic seat testing.

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Appendix A. Head Restraint Height

A.1 Head Restraint Height Background

An analysis of 229 rear impacts that occurred after 1970 and involved Volvo cars was reported by Carlsson *et al.* [1985]. They found that there was a statistically significant correlation between height and neck injury. The neck injury frequency increased with increasing occupant height.

Sled tests with three male human volunteers were conducted by Ono and Kanno [1996]. The tests involved three different types of head restraint; standard, low and without headrest. Ono and Kanno comment that the head rotational angle was minimised where the 'standard' headrest was used, while it becomes larger where the 'low' headrest is used, as the bending moment becomes greater. They suggest that this showed that appropriate adjustment of the headrest height is very important for the prevention of excessive rearward bending of the neck and to reduce the impact load. Further to this, they found that the highest impact response was with the low headrest, resulting in an excessive load on the neck. In the case where no headrest was installed, the load on the neck was lowest, but the head rotational angle was largest, resulting in cervical hyper-extension. In the case where the standard headrest height was used, both the bending moment and the axial force were lowest, but the shear force may have increased in proportion to the intensity of the impact.

Data from Volvo cars involved in crashes, in Sweden have been collected by Volvo's traffic accident research team for over 25 years. This is the database that was used by Lundell *et al.* [1998] and contained information from over 25,000 accidents and 45,000 occupants. In addition to technical details of the car damage, injury data is obtained from medical records and a questionnaire for each case is answered by the owner of the vehicle. In the paper by Lundell *et al.*, the authors present information of the risk of sustaining a neck injury for both genders, distributed by height (at 10 cm intervals). The data are from a subset of 2050 belted occupants of Volvo cars involved in a rear end impact, and seated in an outer seat equipped with a head restraint. For women, the neck injury risk increased from about 8% for those less than 150 cm up to about 68% for those of 185 cm. The male distribution is somewhat different in that there is no risk of injury (perhaps because there were no or few occupants) for those men less than 150 cm in height. Also, the risk of neck injury seems to plateau at around 38% which occurs for both 185 and 195 cm height groups. Lundell *et al.* comment that the differing distributions are interesting since the medium height women appear to be at the same level of risk as the tall men. They comment that this indicates that the height of the head restraint is not the only issue related to the reduction of neck injuries.

A total of 517 cases of rear-end collisions with 673 persons claiming injury, from the GDV Vehicle Safety-90 database were investigated by Hell *et al.* [1998]. The Quebec Task Force injury classification strategy was used to rank the injuries based on pathology. The injuries were rated from QTF 1 to QTF 3 which corresponded to a minor cervical spine disorder up to injuries of the neurological system. In most cases analysed retrospectively, there was no information about seat or seat back positions at the time of the impact. Nevertheless Hell *et al.* report that the position of the head restraint could be seen on the photos, which were taken shortly after the collision. For the analysis, the groups of head restraint positions (low, high and medium) were comprised of head restraints in their lowest, highest or a position in between the lowest and highest adjustments.

Hell *et al.* reported that of those persons in the group 'low head restraint' almost 74 percent suffer from QTF 2 injury and only 1.8 percent show no cervical symptoms, whereas in the 'high positioned head restraint' group the rate of QTF 2 was 60 percent and 20 percent show no cervical spine symptoms.

When analysing neck injury data, Chapline *et al.* [2000] found that women with vertical distances classified as poor, according to the RCAR assessment procedure (where the top of the head restraint is more than 10 cm below the top of the head) were at almost twice the risk or reporting neck pain as women whose vertical distances were classified as adequate (combined good, acceptable and marginal categories, where the top of the head restraint is 10 cm or less below the top of the head).

There was no benefit of increased head restraint height, from good to acceptable and acceptable to marginal. However, Chapline *et al.* show that reported neck pain increased as head restraint height further decreased among the poor head restraints. Neck pain was reported by 51 percent of those with poor head restraints no more than 7 cm below the head's centre of gravity (no more than 16 cm below the top of the head) and 69 percent for those with lower head restraints approximately below the occiput. Horizontal distance, ranging from good to poor, assessed only for those whose head restraints were high enough for backset to be relevant (vertical distance 10 cm or less), was not significantly related to neck pain. This seems to suggest that the relevant vertical distance at which the head restraint backset becomes important is lower than 10 cm. There was also an increasing trend of reported neck pain with increasing vertical restraint measurement for male drivers in the Chapline *et al.* study, but this trend was not statistically significant.

For the NHTSA Technical Report on the evaluation of head restraints, Kahane [1982] proposed percentage improvements over the then current Federal Motor Vehicle Safety Standard 202, based on the height of integral (fixed) head restraints. The potential improvements were based on an anthropometric study of the distribution of seated heights of adults together with consideration of laboratory test results and real-world effectiveness values. Kahane asserted that integral head restraints would be 12 percent less effective if they were only 24 inches high, whereas if they were 34 inches high, then they would be 10 percent more effective. These potential injury reduction percentages are shown in Figure A.1. The range of effectiveness comes from a review of Texas accident files, where the effectiveness of fixed head restraints over no head restraint was adjudged to be 23 percent (range is 22 percent). It was assumed by Kahane that between the full effectiveness and no head restraint condition, there would be an almost linear rise in effectiveness (going from low to adequate head restraint height) until a critical height was reached at which the effectiveness no longer increased. The anthropometry and laboratory studies used by Kahane were based on offering protection for the 50th percentile male occupant. Therefore the critical height was derived around a 70 inch tall occupant. Together with the decision that a head restraint would provide adequate support if it was 43 percent of the occupant's height, this leads to the critical head restraint height being set at 30 inches (762 mm). Above this point the effectiveness in Kahane's figure only rises from 8.3 to 9.6 percent.

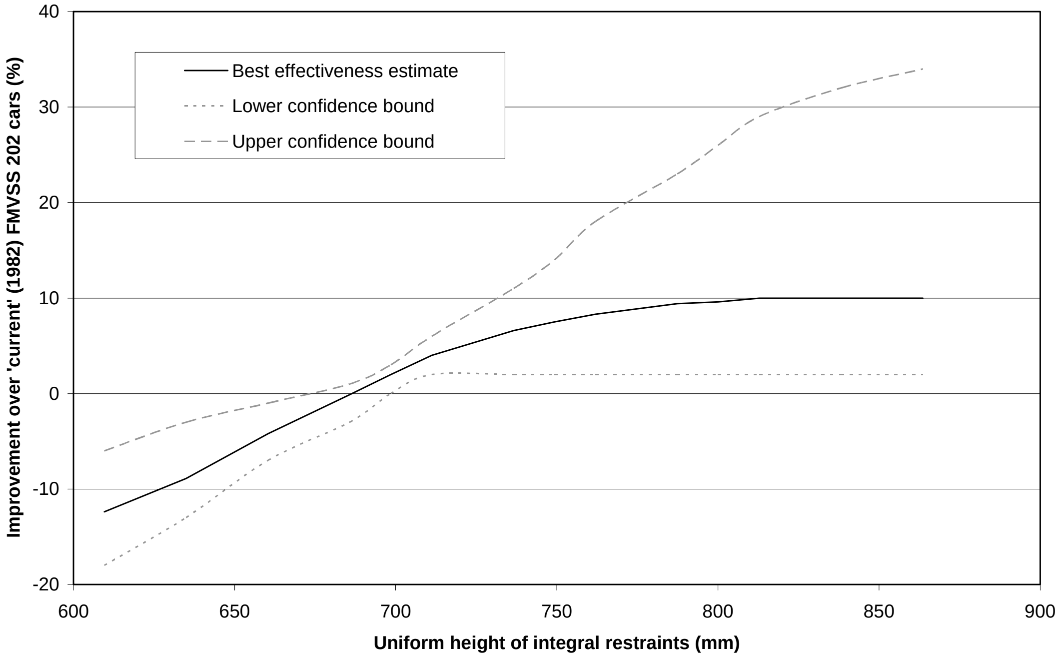


Figure A.1: Injury reduction relative to 'current' head restraints, for integral restraints by seatback height [Kahane, 1982]

In the update to the Kahane evaluation [NHTSA, 2004], the authors go on to explore the percentage of the population who would receive adequate protection from head restraints at 700, 767 and 800 mm. The first of these values is the old FMVSS 202 head restraint height requirement, the second is the height of head restraints in the vehicle fleet and the latter of these values is the head restraint height adopted in the revision to FMVSS 202 (known as 202a). The calculations are based on geometry of the seatback with respect to standard occupant seating posture and the sitting heights of 5th, 50th and 95th percentile occupants. The authors conclude that the new FMVSS No. 202 standard, of 800 mm and 55 mm backset, will cover 99.7 percent of the US male population and all females.

Note that this benefit estimate is based on the Regulation 17 height measurement method, and is therefore likely to be an overestimate of the protection offered (see Appendix B).

A.2 Head Restraint Height Potential Savings

A.2.1 Height of Current Head Restraints

As noted in Section 0, the geometry of head restraints is routinely assessed by Thatcham, using the RCAR test procedure [RCAR, 2001]) as part of its whiplash protection consumer information programme. This measures the height and backset of head restraints in their mid-locking position (or the lower of the middle two locking positions if there are an even number of locking positions) using a 3-D H point machine and a head restraint measuring device (see Figure 0.3 and Figure 0.4). If the head restraint does not lock (according to Thatcham's lock test), then the head restraint geometry is measured in the lowest adjustment position of the head restraint. This method of head restraint geometry measurement is different from that used in UN ECE Regulation 17 (see Section 0). This measures head restraint height from the R-point of the seat, parallel to the torso angle of the seat, and with the head restraint in its highest use position of adjustment. In the RCAR test procedure used by Thatcham, head restraint height is independent of backset, but in the Regulation 17 method, different backsets will affect the height measurement. However, an approximate conversion between the two measurement methods has been published by NHTSA as part of the final regulatory impact analysis for FMVSS 202 [NHTSA, 2004] (note, the NHTSA equation has been rephrased in terms of Regulation 17):

$$H = (755 - RH)\cos\theta + (254 + RB)\sin\theta \qquad \text{Equation 1}$$

where

H is the height measured by Regulation 17

θ is the torso angle (set to 25° in the RCAR procedure)

RH is the height measured using the RCAR procedure

RB is the backset measured using the RCAR procedure

755 is the vertical distance from the H-point to the top of the head of the 50th percentile male

254 is the horizontal distance from the H-point to the back of the head of the 50th percentile male

This equation assumes that the seat back is set at a torso angle of 25°. For Regulation 17, seat backs are set to the manufacturer's design angle, not a fixed angle. However, when WG20 sampled the torso angle for vehicles in the European fleet, it was found that the majority used a design angle of

25°, with most of the rest at 24° and the most extreme vehicle having a design angle of 19° (see Figure A.2).

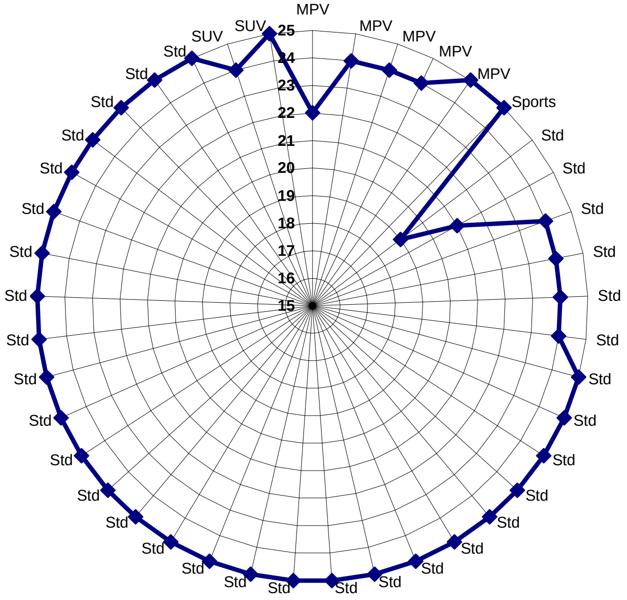


Figure A.2: Torso angle for WG20 sample of the European car fleet

This suggests that for most seats the conversion in Equation 1 will be reasonable. For more upright seats (those with a torso angle less than 25°), the backset will make less difference to the Reg17 equivalent height calculation.

The RCAR height and backset results from the last three years' of testing at Thatcham are shown in Figure A.3. Also shown are the Regulation 17 height measurement method equivalents for height requirements ranging between 800 mm (as in the current Regulation 17) and 850 mm at 10 mm intervals. Thatcham estimate that their measurements cover 80% of the market since 2004 and 95% of new car registrations, based on SMMT published figures [Avery, 2007].

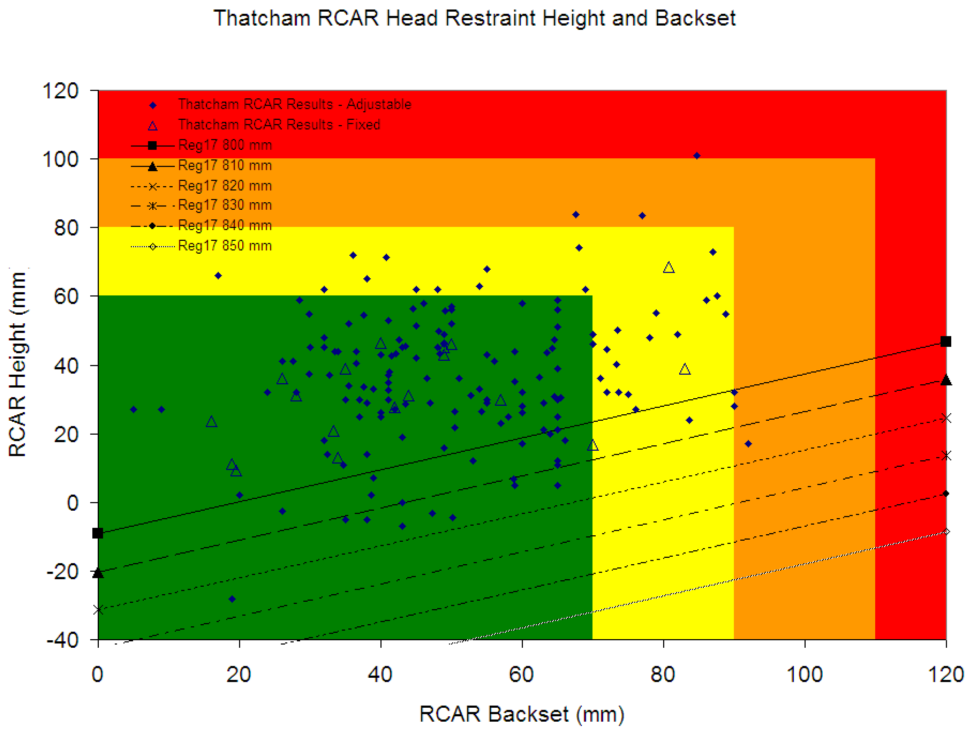


Figure A.3: Thatcham RCAR head restraint height and backset measurements, with Regulation 17 (current 800 mm requirement plus possible higher requirements) equivalent measurements shown

It is notable that most of the head restraints have a height that falls below the current 800 mm Regulation 17 requirement for fixed and adjustable front seat head restraints. This is because the RCAR procedure tests at the mid-locking position (or the lower of the middle two locking positions if there are an even number of locking positions, or at the fully down position if the locking mechanism fails the lock strength test), while the regulatory test is conducted at the highest position of adjustment of the head restraint, regardless of whether the head restraint locks in this position or not. That is, the RCAR test position for adjustable head restraints used by Thatcham will always be lower than the Regulation 17 test position, but by an amount that is different for each head restraint depending on the number and height of the locking positions relative to the maximum adjustable position of the head restraint. However, it is not immediately obvious why the majority of the fixed head restraints do not meet the Regulation 17 requirement. A further investigation of this has been undertaken and the results are shown in Appendix B. Based on the results of this investigation, it is clear that the current Regulation 17 requirement of 800 mm does not deliver a useful height of 800 mm (defined either as a height that would support the centre of gravity of the head or as a height over which the head restraint meets a given backset requirement) for the majority of seats. This means that the proportion of the population protected by the head restraint (see Section A.3) is considerably lower in reality than that used in this cost-benefit and that the benefit-cost ratio is likely to have been underestimated in this study.

A.3 Required Height of Head Restraints for the UK Population

The head restraint height that is required to protect an individual is the height of the centre of gravity of the head plus an allowance for the ramping-up that occurs in a rear impact. This is a term used to describe the increase in head height in a rear impact due to straightening of the spine and the movement of the body up the reclined seat back. This gives the equation below:

$$HRHeight = SittingHeight - \left(HeadCoG\_to\_TopOfHead\right) + Ramping - up \qquad \text{Equation 2}$$

where

HRHeight = the head restraint height required to protect an individual

SittingHeight = the sitting height for that individual

HeadCoG_to_TopOfHead = the distance between the top (crown) of the head and the centre of gravity of the head for that individual

Ramping-up = an allowance for ramping-up

The ramping-up of the centre of gravity of the head in four out of the five test conditions chosen by EEVC WG12 for the evaluation of the biofidelity of rear impact dummies is shown in Table A.1.

Table A.1: Ramping-up measured for test subjects from four of the data sets chosen for the EEVC WG12 rear impact dummy biofidelity requirements

Biofidelity test condition	**Ramping-up (mm)**	**Test subjects**	**Seat type**	**Peak acceleration (g)**	**Delta-v ($km.hr^{-1}$)**
LAB	20-60	PMHS	Lab seat	12	10
Chalmers/Allianz	20-35	Volunteers	Lab seat with stiffness designed to represent a Volvo 850 seat	3-4	7
JARI	20-40‡	Volunteers	Lab seat	3.5	7
TRL	28-40	Volunteers	Lab seat	2	7

‡ T1 vertical motion, which will typically be slightly less than the head centre of gravity motion

This shows a ramping-up of 20 to 40 mm in very low velocity rear impacts performed with volunteers (with a very low risk of short-term injury) and 20 to 60 mm in higher speed tests performed with PMHS (a pulse with some risk long-term injury). Van den Kroonenberg *et al.* [1998] reported ramping-up of the T1 of 24 to 44 mm in volunteer tests at a Δv of 6.5 and 9.5 $km.hr^{-1}$ and a peak acceleration of 3.5 and 4.5 g respectively. For the purposes of this cost-benefit, the mean ramping-up from the higher-speed PMHS tests has been used (40 mm) as this represents a test speed that is closer to that normally associated with long-term whiplash injury, although still at the low end of the long-term injury pulse range. For WAD symptoms lasting over a month, Krafft *et al.* [2002] report that the average values of crash severity are 20.0 ± 4.8 $km.h^{-1}$ at a mean acceleration of 5.3 ± 0.6 g. The value of 40 mm for ramping-up is also in the range of ramping up for very low-severity volunteer tests in which the volunteers were uninjured (no short-term or long-term injury). This therefore represents a very conservative estimate of the ramping-up that would be seen for the adult population in a rear impact with a moderate to high risk of long-term injury.

These ramping-up values include two components: head vertical motion due to spine straightening; and head vertical motion due to the pelvis moving up the slope of the seat back. Document HR-7-9 of the GRSP Global Technical Regulation Informal Group on Head Restraints indicates that only the pelvis movement part of the ramping-up should be included in the above calculation because spine straightening is already included in the erect sitting height measurements that are used (see www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/head07.html). In support of this, HR-7-9 references volunteer test data from a study by Dr. Ono. This shows spine straightening of about 30 to 40 mm and ramping-up of 10 ± 15 mm, as shown in Figure A.4 and Figure A.55.

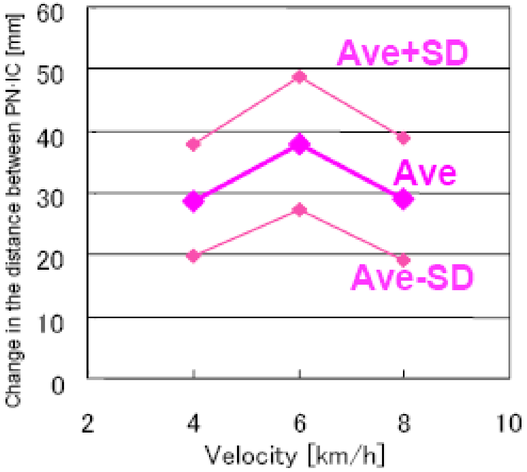


Figure A.4: Spine straightening from volunteer rear impact study

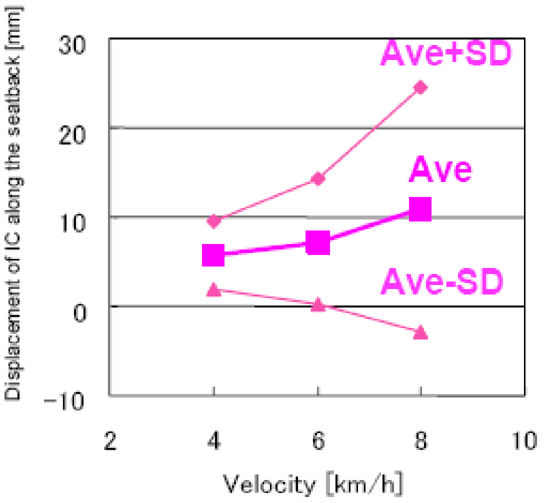


Figure A.5: Ramping-up from volunteer rear impact study

However, these tests were undertaken at a maximum Δ*v* of 8 km.hr^{-1}. If these results are extrapolated to the velocity range for long-term injury of 15 to 25 km.hr^{-1} (see Section A.3.3) then a ramping-up figure in the range of 30 to 40 mm is indicated (see Figure A.6).

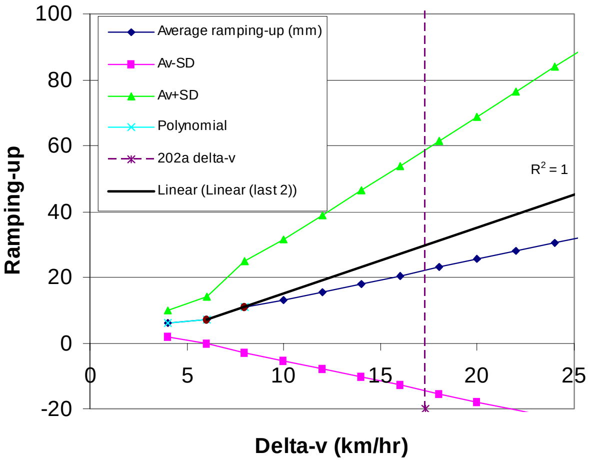


Figure A.6: Ramping-up extrapolated to 25 km.hr^{-1} (linear best fit of three volunteer average data points and linear best fit of last two volunteer average data points)

In addition, the test set-up for these volunteer tests consists of a seat mounted on a ramp at 10° to the horizontal. At impact, therefore, the volunteers would tend to be pushed down in to the base of the seat, which would considerably reduce the ramping-up effect compared with vehicle occupants impacted with a horizontal pulse. The ramping-up effect of 40 mm is therefore considered to be a reasonable estimate, more likely to be an underestimate than an overestimate.

In order to determine the proportion of the population that will be protected by a given head restraint height, the following calculation was used:

$$HRHeight\%ile = SittingHeight\%ile - 93\left(\frac{HeadHeight}{UMTRI\_HeadHeight}\right) - 71.3\left(\frac{SittingHeight}{UMTRI\_SittingHeight}\right) + RampingUp \qquad \text{Equation 3}$$

where

HRHeight%ile = the head restraint height required to protect a given percentile of the population
SittingHeight%ile = the sitting height for that percentile of the population
93 (mm) = the vertical distance between the crown (top) of the head and the centre of gravity of the head for the 50th percentile (from UMTRI)
HeadHeight = the height of the head for that percentile of the population
UMTRI_HeadHeight = the height of the head for the 50th percentile male (from UMTRI)
71.3 (mm) = the distance between the base of the buttocks and the H-point of the 50th percentile male (from UMTRI)
SittingHeight = the sitting height for that percentile of the population
UMTRI_SittingHeight = the sitting height for the 50th percentile male (from UMTRI)
Ramping-up = an allowance for ramping up (40 mm)

This equation scales the head centre of gravity position by the ratio of the head height from any population database and the head height for the 50th percentile male from the UMTRI database [Robbins, 1983a; Robbins, 1983b] This assumes that the distance from the crown to the head centre of gravity is proportional to the head height. Similarly, the equation scales the depth of the buttock (between the base of the buttocks and the H-point of the occupant) by the ratio of the sitting height from any population databases and the sitting height for the 50th percentile male from the UMTRI database. This is likely to be a less robust assumption than for head height. Buttock depth will be highly correlated to weight as well as height, and it may be expected that weight would be the dominant factor. However, in the absence of sufficient data, for the purposes of this cost-benefit the buttock depth has been assumed to be proportional to the sitting height.

The UK figures for mean, 5th percentile and 95th percentile head heights, are shown in Table A.2 [Peebles and Norris, 1998].

Table A.2: Head height for the UK population [Peebles and Norris, 1998]

Country	Gender	Mean head height	Standard deviation	5th percentile	95th percentile
UK	m	228.5	11.3	209.9	247.1
	f	196.6	11.5	177.7	215.5

The sitting heights for seven European countries are provided in Table A.3 [Peebles and Norris, 1998]. It should be noted that the anthropometric data values in Peebles and Norris are not the primary data source, in fact a variety of sources are used, some of which are several years older than this publication (up to 12 years in the case of the German data).

Table A.3: Sitting height for European populations [Peebles and Norris, 1998]

Country	Gender	Mean sitting height	Standard deviation	5th percentile	95th percentile
UK	m	920.2	36.4	860.4	980.0
	f	857.6	33.0	803.4	911.8
France	m	911		851	968
	f	861		810	912
Germany	m	907		849	962
	f	857		805	914
Italy	m	894		836	959
	f	852		794	904
Poland	m			819	955
	f			778	892
Sweden	m	900	43	830	970
	f	860	33	805	915
Netherlands	m	940	34	885	995
	f	875	33	820	930

It can be seen from Table A.3 that by choosing the height value from the UK, this should offer adequate protection for the other European countries shown, apart from the Netherlands. If the UK 95th percentile height figure was used, then it would offer a height that was appropriate for over 85 percent of the Netherlands population.

Equation 3 assumes that the head height and sitting height for an individual are always in proportion. That is, the 5th, 50th and 95th percentile head heights are given in the literature, but that is not the same as the average head height for people 5th, 50th and 95th percentile standing or sitting heights. Indeed, it seems highly unlikely that these are well correlated. This implies that a 95th percentile head height (247.1 mm in Table A.2) should be used in the calculation, rather than the 50th percentile head height of (228.5 mm), to ensure that the 95th percentile occupant is protected. This has not been undertaken in this cost benefit, and may be expected to lead to an underestimate of the required head restraint height of approximately 20 mm.

The factor of 71.3 mm for the 50th percentile male buttock depth (the distance from the H-point to the surface between the buttocks and the seat base) comes from the UMTRI database [Robbins, 1983a]. However, the test tool used in the RCAR test procedure and to locate the H-point of the seat in the Regulation 17 test has a buttock depth of 97.6 mm (see SAE Standard J826 [SAE, 1995]). This means that the H-point of the test tool (and therefore the origin for the Regulation 17 height measurement test method) is located 26.3 mm higher than the H-point of the 50th percentile male. This will lead to an underestimate of the head restraint height for tests procedures that use the H-point (or R-point) as a datum. No correction for this underestimate has been made here; it has been assumed that most of the underestimate balances out the uncertainty regarding head height proportions discussed in the paragraph above, and the rest gives a small allowance for a general increase in the weight of the population (and therefore of the average buttock depth measurement).

If sitting height within the population follows a distribution that is approximately normal, then the current head restraint height defined in ECE Regulation 17 of 800 mm above the R-point would provide a head restraint at or above the head centre of gravity for about 55% of the adult male UK population and 98% of the female population. The relative proportion of the UK and the Netherlands populations that would have a head restraint at or below the head centre of gravity for head restraint heights increasing in 10 mm increments from 800 to 850 mm are shown in Table A.4. This shows that in order to protect 95 percent of the UK male population adequately, a head restraint height of 850 mm is required; this height would also protect approximately 91% of the Dutch male population.

Table A.4: Proportion of the population with head centre of gravity at or below the top of the head restraint for incremental restraint heights

Head restraint height (mm)	**Proportion of the population (percent)**			
	UK		The Netherlands	
	Male	Female	Male	Female
800	55	98	33	94
810	67	99	47	97
820	78	100	60	99
830	86	100	73	100
840	92	100	83	100
850	96	100	91	100

A.3.1 The Proportion of Vehicle Occupants who Adjust their Head Restraint Correctly

States *et al.* [1972], reporting on the geometric positioning of the head restraint, noticed that 73 percent of the occupants did not elevate adjustable head restraints. The subsequent comment was that “Head restraint effectiveness is much less than might be anticipated because most occupants do not raise their head restraints, leaving them in the downmost position. Fixed head restraints appeared to be more effective, but whiplash injury still occurred with this type of head restraint.”

The study by Lubin and Sehmer [1993] involved two parts; firstly, a survey of vehicles in a hospital parking lot and secondly, a road survey at a busy four-way junction. The first part provided details on the vehicle type, presence or absence of a head restraint, the type of head restraint, and if adjustable, whether the restraint was in an up or down position. The second part also provided data on the type of vehicle, presence or absence of a head restraint and type of head restraint. In addition, the gender of the driver was recorded as well as whether the head restraint was properly adjusted for the driver. Proper adjustment was defined by Lubin and Sehmer as having the top of the head restraint at least as high as the vertical midpoint of the skull, and the distance from the back of the head to the head restraint being less than half of the anterior-posterior diameter of the head.

Lubin and Sehmer surveyed 708 vehicles in the hospital parking lot. Whilst all sedans had head restraints, 4 percent of the 708 vehicles did not have a head restraint. Thirteen percent had fixed restraints and 84 percent had adjustable head restraints, although 62 percent of the adjustable restraints were in the down position.

From the road survey, the results from 879 vehicles were used for analysis. Only 4.9 percent of the vehicles had no head restraint. Of all head restraints, 78.7 percent were adjustable. Whilst two thirds of fixed head restraints were properly positioned for the driver, only 40.3 percent of adjustable restraints were positioned properly. Lubin and Sehmer found that the gender of the driver seemed to make a difference. Only 30.2 percent of male drivers had correctly positioned head restraints compared with 67.6 percent of female drivers. Lubin and Sehmer comment that this is probably due to height rather than conscientiousness.

Films of drivers approaching and stopping at an intersection were obtained from the Insurance Institute for Highway Safety (IIHS) [Viano and Gargan, 1995]. Six features were recorded for each vehicle:

- Type of vehicle
- Gender of driver
- Type of headrest
- Offset: vertical distance between head and top of restraint

  The offset was determined by the relationship of the top of headrest to two obvious anatomical features. The headrest was considered high if it was above the ear (the Frankfort plane, which is about 20 mm below the head centre of gravity) and low if it was below the chin and medium if it lay between the two
- Gap: horizontal distance from head to restraint

  The gap or horizontal distance between the head and restraint was small if it was less than half of the lateral depth of the head (less than approximately four inches) and large if it was more than the head depth (more than eight inches) and medium if it was between a half and one head depths (between four and eight inches)
- Distance from head to steering wheel

The results from the investigation by Viano and Gargan are shown in the following three tables for both genders, male and female drivers, respectively. In general, only 192 (10 percent) of the sample of drivers had the most favourable combination of high headrest and small gap. Women (128, 14.8%) were more likely than men (64, 6.1%) to have a favourable headrest position.

		Gap															
		Small					Medium					Large					
Male and female		N	%	Down	Up	Fixed	N	%	Down	Up	Fixed	N	%	Down	Up	Fixed	**Total**
Head restraint height	High	192	10.0	44	47	101	298	15.6	41	71	186	73	3.8	14	16	43	563
	Medium	103	5.4	57	20	26	536	28.0	316	113	107	272	14.2	168	62	42	911
	Low						102	5.3	95	2	5	339	17.7	317	9	13	441
	Total	295	15.4				936	48.9				684	35.7				1915

		Gap															
		Small					Medium					Large					
Male		N	%	Down	Up	Fixed	N	%	Down	Up	Fixed	N	%	Down	Up	Fixed	**Total**
Head restraint height	High	64	3.3	9	13	42	162	8.5	15	32	115	48	2.5	5	7	36	274
	Medium	43	2.2	17	9	17	278	14.5	140	61	77	141	7.4	73	35	33	462
	Low						65	3.4	58	2	5	250	13.1	230	8	12	315
	Total	107	5.6				505	26.4				439	22.9				1051

		Gap															
		Small					Medium					Large					
Female		N	%	Down	Up	Fixed	N	%	Down	Up	Fixed	N	%	Down	Up	Fixed	**Total**
Head restraint height	High	128	6.7	35	34	59	136	7.1	26	39	71	25	1.3	9	9	7	289
	Medium	60	3.1	40	11	9	258	13.5	176	52	30	131	6.8	95	27	9	449
	Low						37	1.9	37			89	4.6	87	1	1	126
	Total	188	9.8				431	22.5				245	12.8				864

Five-hundred and twenty-three (27 percent) of the headrests were fixed, however, these comprised 330 (58.6 percent) of all the restraints in the high position. Only 233 (16.7%) of the adjustable headrests were high.

Of the adjustable headrests, 1052 (75.6 percent) were in the lowest possible configuration and, of these, 953 (90.6 percent) could have been adjusted to a higher position relative to the head of the driver.

Svensson [1995] reported on a field survey of the posture adopted by motor vehicle occupants. The distance between the back of the head and the headrest was estimated in terms of the units of head depth (about 20 cm). A total of 2004 observations were made. Of these, 204 had their headrest adjusted too low for it to contact the head. For the remaining sample, the head restraint clearance was reported as shown in Table A.5.

Table A.5: Posture adopted by motor vehicle occupants; head restraint clearance [Svensson, 1995]

Distance (cm)	Observed percentage
< 10	10.7
10 to 20	54.5
20 to 30	30.7
30 to 40	3.6
> 40	0.5

A study by Cullen *et al.* [1996] investigated the sitting positions of drivers in the UK. The field work took the form of three studies. The first, based in the UK, looked at head restraint positioning for front seat passengers, and the second and third studies observed drivers and front seat passengers in the US. A video camera equipped with a high speed shutter was used to film car occupants. Video footage was played back and measurements were taken from the still images.

Cullen *et al.* state that although it is recognised that the optimal position of the restraint is such that its centre is level with the centre of gravity of the head. However, due to the difficulty they had in locating this point of the head from the videotape, they redefined the ideal position as the centre of the restraint being level with the centre point of the back of the occupant's head. Cullen *et al.* found that 88 percent of UK passengers, 97 percent of US drivers and 91 percent of US passengers had the head restraint positioned below this optimum level (see Table A.6).

Table A.6: Height of the centre of the head above the centre of the head restraint [Cullen *et al.*, 1996]

Population group	Mean (mm)	Standard deviation (mm)
UK passengers	58	47
US drivers	85	47
US passengers	65	51

Occupant gender was found by Cullen *et al.* to affect vertical position significantly for UK passengers, US drivers and US passengers. In each case, male occupants had a greater separation between the head and the restraint than female occupants. Cullen *et al.* also found that occupant age was significant in affecting vertical head restraint position for passengers in the UK, such that younger (looked to be aged between 16 and 34 years) and middle aged (between 35 and 55) passengers had a greater separation than older ones (over 55 years).

A survey of head restraint use and fit was performed by random observations of drivers in vehicles stopping on a residential street by Tencer *et al.* [2000]. Two separate investigators made observations of type of vehicle, approximate age (young, middle aged, elderly), and gender of each stopped driver to ensure that the sample was representative of the driving population. Related to head restraint fit, there were four categories, from which the observer could select one:

- A well fitting head restraint, where the horizontal distance between the head and head restraint was less than 7.5 cm, and the driver's ears were below the top of the head restraint
- The driver's head to head restraint distance was greater than about 7.5 cm because the driver leaned forward or the seat was inclined backwards
- The top of the head restraint was below the level of the driver's ears
- No head restraint was present in the vehicle

A total of 719 independent observations were made. The results from these observations are shown in Table A.7. Overall, 26 percent of drivers surveyed had good head to head restraint position while 5.4% had no head restraint in their vehicle. Those with no head restraints were mostly older cars and many 1980s vintage trucks. Of the remaining drivers, 26.1% had their head restraints set too low (below ear level). These were not only taller drivers, since some older vehicles have very short and low head restraints. About 25.6% of drivers had their seats inclined backwards so that only their mid-backs were in contact with the seat, 16.8% had a kyphotic posture, so that even with the seat upright they leaned forward considerably creating a large gap between their heads and head restraints.

Table A.7: Results of head to head restraint position survey of 719 drivers in their vehicles [Tencer *et al.*, 2000]

	Good head restraint position	Seat inclined back	Head restraint too low, below ears	Driver leans forward	No head restraint
Number of samples	187	184	188	121	39
Percent of total (%)	26.0	25.6	26.1	16.8	5.4

The PRISM (Proposed Reduction of car crash Injuries through improved SMart restraint development technologies) Fifth Framework EC project undertook an observational study on how people sit in their vehicles [Bingley *et al.*, 2005]. The study was carried out in Austria, Spain and the UK. 4,774 drivers were observed in their cars in this PRISM study. They found that the gap between the driver head and the head restraint proved difficult to estimate because it was screened by the B-post for many vehicles. They report also that bulky hair was a problem in some cases. Where they could estimate a gap, they used three categories for the estimation:

- large gap (where the occupant was clearly leaning forward)
- medium gap (relatively normal in appearance)
- small gap (touching or up to approximately 50 mm)

Similarly, occupant heights were classified as either very tall, very short, or non-extreme. Of all the drivers, 17 had no head restraint, 564 had a large gap between their head and the head restraint, 3,730 had a medium gap between their head and the head restraint, 425 had a small gap between their head and the head restraint, and in 38 cases the distance between the driver's head and the head restraint was unknown. Table A.8 shows the head restraint gap (backset) and occupant height for 1719 occupants (55 occupants for whom there was no head restraint fitted in the car or for whom the head restraint gap was unknown were excluded from this table).

Table A.8: PRISM occupant height and head restraint backset data from observational studies in Austria, Spain and the UK

	Very tall			Non-extreme			Very short		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Large gap	27	7	34	362	148	510	7	13	20
Medium gap	43	7	50	2827	811	3638	18	24	42
Small gap	43	11	54	255	95	350	5	16	21

A chi-square test (which evaluates statistically significant differences between proportions for the groups in the data set) was carried out on the data in Table A.8. It was found that the gap between the driver's head and the head restraint, and height of driver were not independent variables. From the results of the test one can conclude that the taller a person is, the less likely they are to leave a large gap between their head and the head restraint. It is also apparent that the majority (81%) of occupants whose height was non-extreme had a medium backset, although medium is not precisely defined.

As part of the Whiplash 2 EC Project (Deliverable 4 – Long-term injury analysis), GDV provided data from a German insurance company who held approximately 10 percent of the market share. For the 157 front seat occupants (102 drivers and 55 FSPs) included in the data, the head restraint height adjustment was known for approximately 100, as is shown in Table A.9

Table A.9: Number of occupants with long-term injury and their head restraint adjustment

	Low	Moderate	High	Unknown
Driver	28	26	5	43
FSP	26	13	2	14

Based on the Assumption that the unknowns are evenly distributed between the low, medium and high categories, then 52 percent of drivers and 36 percent of FSPs had their head restraint adjusted to a moderate or high position. This seems to be a reasonable assumption as the assessment was based on photographs of the car and the unknown group consists of those where the photographs gave no information at all about the adjustment of the head restraint. Therefore, overall, 46 percent of front seat occupants with long-term injury had their head restraint adjusted at least to a moderate position.

Thatcham's engineers also studied head restraint use patterns on UK roads [Thatcham, 2007b]. Images of over 4,000 drivers were analysed to assess their head restraint position. They found that 72 percent of drivers failed to adjust their head restraints correctly or had head restraints that were incapable of offering any protection. Of the 28 percent who had their head restraints adjusted correctly, 11 percent of the restraints were of a fixed, one piece design.

A.3.1.1 Summary of Proportion of Population who Adjust their Head Restraint Correctly

It seems from the studies of occupant position that roughly 25 to 50 percent of the occupants with an adjustable head restraint adjust it to the correct position (with a mean estimate of 37.5 %). In most of the remaining cases the protection afforded by the head restraint would probably be improved through adjustment. Approximately 20% of the vehicle fleet have fixed head restraints (such as those used in most Volvo cars and many sports cars), which are automatically adjusted at least to a height that meets the regulatory requirement, with approximately 80 % fitted with adjustable head restraints. Overall, therefore, it is estimated that 50 % of head restraints will be correctly adjusted (37.5 % of adjustable head restraints plus 100% of fixed head restraints).

A.3.2 Injury Risk for Smaller Occupants

Generally, rear impact whiplash injury risk studies have indicated that taller occupants have a greater risk of injury than shorter occupants and that women have a greater risk of injury than men. For instance, Jakobsson *et al.* [2000] showed the risk of whiplash based on 1420 seat-belted drivers of Volvo cars, as shown in Figure A.7.

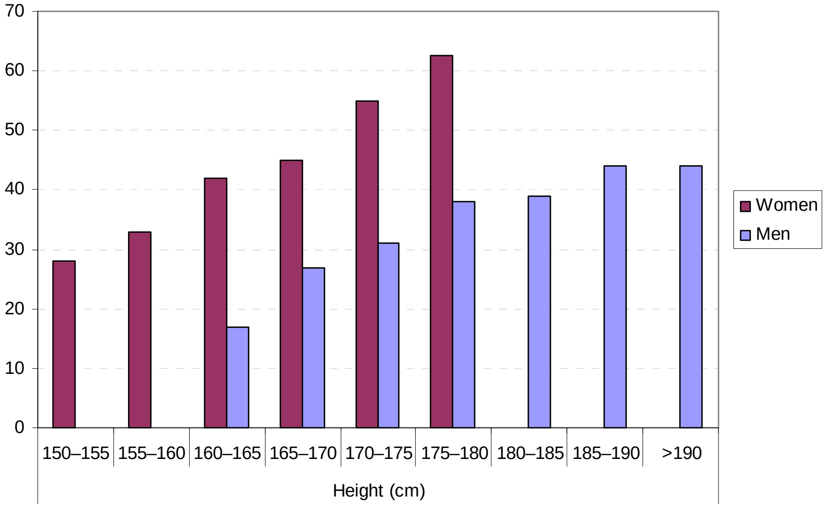


Figure A.7: Neck injury risk *vs.* gender and stature for drivers (adapted from Jakobsson *et al.* [2000])

However, more recent data from the UK Co-operative Crash Injury Study (CCIS) and the German GIDAS databases have apparently shown a higher risk for short occupants than medium and tall occupants. For example, Figure A.8 shows the soft tissue neck injury (STNI) risk for single rear impact (SRI) in CCIS where the height of the occupant was known, for belted and un-belted, male and female occupants combined. This appears to show a higher risk for the shortest group of occupants (151-163 cm). However, the small number of cases means that there are only two more cases in the 151-163 cm group than the 174-182 cm group, which could be a single accident with two front seat injured occupants. Figure A.9 shows the soft tissue neck injury risk when multiple impacts with a rear impact are considered. This does not indicate an increased risk for smaller occupants.

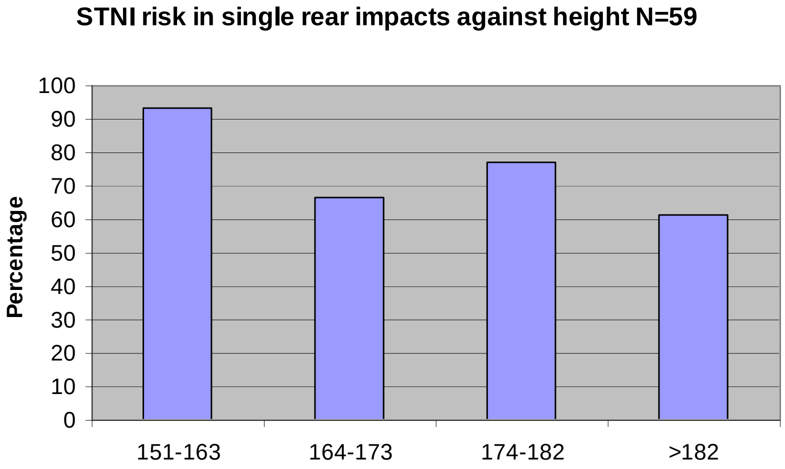


Figure A.8: Soft tissue neck injury in single rear impacts *vs.* occupant height

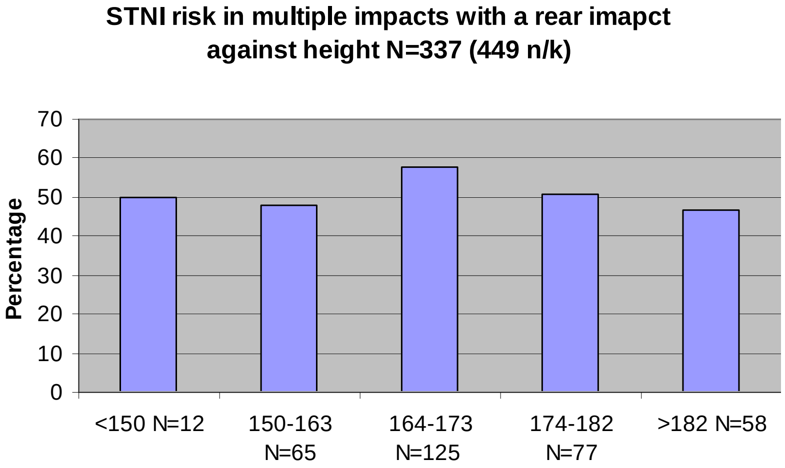


Figure A.9: Soft tissue neck injury in multiple rear impacts *vs.* occupant height

Based on the driver posture information derived in the PRISM project ([Bingley *et al.*, 2005] - see Appendix A.3.1), drivers tend not to sit in an extreme position (over 80% of occupants whose height was not classified as 'very tall' or 'very short' had a medium backset). The medium backset classification is not well defined, being greater than 50 mm and less than 'occupant clearly leaning forward'. However, the average backset in the Thatcham database 2005-2007 is 50.65 mm, measured using the RCAR test procedure that uses a test tool that is roughly 50th percentile male in stature. Therefore, most drivers have a greater backset than that indicated by the Thatcham testing. This is most likely to be related to:

- Age of vehicle - the Thatcham data relates to recent vehicles (roughly year 2000 and newer), many of which have improved head restraint geometry in response to the Thatcham test programme - Thatcham have found an increase in the number of seats rated as good from 16% in the 2005 model year to 29% in the 2007 model year). Many vehicles in the fleet would be older and would typically be expected to have greater backsets.
- Differences between normal driving posture and the idealised posture of the geometric test tool used in the RCAR procedure.

Accordingly, it is not possible to estimate accurately the average backset for drivers in the fleet, either from observational data or from seat test data.

Taking this into account it is possible to imagine how some statures of occupants may sit slightly further forward than predicted by test tool measurements. They would then be exposed to a greater level of whiplash injury risk.

As an example of this, in a recent analysis of the relationship between backset and the demographic variables age, height, and weight by gender, Jonsson *et al.* [2007] observed significant differences in backset between men and women. Women generally had lower backset values than men, particularly in the driver's and front passenger seats. Occupant height was significantly related to increased backset for men. This was not the case for women, where there was no significant relationship between occupant height and backset.

This might go some way to explaining the marginal evidence of increased injury risk for shorter occupants. Other contributory factors could be exposure based, for instance mass of the vehicle (which may not have been controlled for in previous datasets).

The latest CCIS data gives a rather larger soft tissue neck injury group (191 occupants) of front seat occupants whose height is known (see Table A.10; note that the height groups are slightly different to those in Figure A.8). This table combines male and female, front seat passengers and drivers. However, there is no indication of an increased risk for the smallest occupant group. Table A.11 and Table A.12 show the risk of soft tissue injury for male and female drivers separately (a total of 151 out of the 191 front seat occupants). These highlight the significant differences between the male and female driver population with respect to their height and the different risk for males and females. However, no clear trend can be identified to indicate that the tallest or smallest drivers are more at risk of soft tissue neck injury; statistically, there was no increased risk of soft tissue neck injury for the shortest group of occupants.

Table A.10: STNI by occupant height for SRI only

Height Group (m)	**STNI**	
	No	**Yes**
1.50 – 1.60 (n=43)	27.9%	72.1%
1.61 – 1.70 (n=52)	23.1%	76.9%
1.71 – 1.80 (n=66)	30.3%	69.7%
>1.81 (n=30)	46.7%	53.3%
Total (n=191)	30.4%	69.6%

Table A.11: STNI by occupant height for SRI only – male drivers

Height Group (m)	STNI	
	No	Yes
1.50 – 1.60 (n=2))	100.0%	.0%
1.61 – 1.70 (n=11)	36.4%	63.6%
1.71 – 1.80 (n=50)	32.0%	68.0%
>1.81 (n=27)	51.9%	48.1%
Total (n=90)	40.0%	60.0%

Table A.12: STNI by occupant height for SRI only – female drivers

Height Group (m)	STNI	
	No	Yes
1.50 – 1.60 (n=26))	11.5%	88.5%
1.61 – 1.70 (n=27)	29.6%	70.4%
1.71 – 1.80 (n=8)	12.5%	87.5%
>1.81 (n=0)	.0%	.0%
Total (n=61)	19.7%	80.3%

A.3.2.1 Summary of Injury Risk for Smaller Occupants

Overall, the data reviewed do not support an increased risk of whiplash injury for smaller occupants.

A.3.3 Delta-v for Long-term Whiplash Injuries

The EEVC WG20 *ad hoc* report update [EEVC WG20, 2005] gives the following information regarding the Δ*v* for short-term and long-term whiplash injuries:

> ‘From accident data and insurance statistics the impact severity in rear impacts is relatively well known, both when the occupants are uninjured and when they report whiplash injury. From crash recorder data at Folksam it was found that long-term WAD symptoms are rare at mean accelerations below 3g. The finding is also supported by several volunteer test studies. Based on accident statistics from several countries, the majority of whiplash injuries are reported in crashes at medium impact severity, typically at a change of velocity between 10 and 15 km/h. Women have about twice the injury risk compared to men. However, most of the reported injuries are short-term injuries where the occupants recover within a couple of weeks.

> 'Furthermore, there is knowledge regarding the impact severity when occupants sustain more long-term WAD symptoms. Based on crash recorder data from real world accidents (from a single car make), the average change of velocity and the mean acceleration are known. Those injuries leading to WAD symptoms lasting more than one month were found to occur at approximately 20km/h and 5g respectively, while those recovering within a month had approximately 10km/h and 4g respectively. The average values for occupants classified as WAD Grade 2 and 3 was approximately 16km/h and 5g. Therefore a proposed test speed and acceleration will vary, depending on whether the test is focusing on all reported whiplash injuries or on the more severe ones.'

The supporting annex from this report quotes a more precise figure of a Δv of 20 ± 4.8 km.hr^{-1} (i.e. 15 to 25 km.hr^{-1} for injuries with symptoms lasting for more than one month, based on data from Krafft *et al.* [2002]. Figure A.10 is also from the WG20 document, again based on the same source, and shows the injury risk for long-term symptoms (red bars) *vs.* Δv.

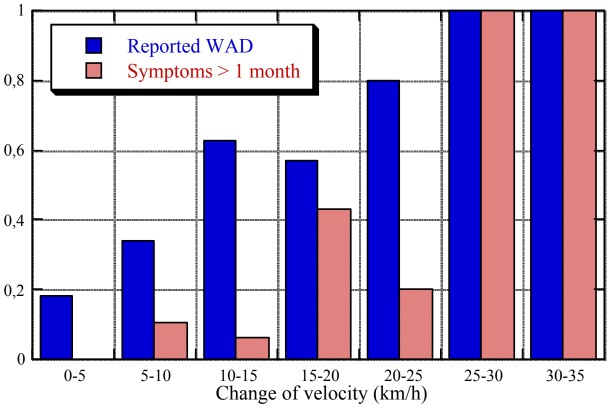


Figure A.10: Injury risk in intervals of change of velocity for occupants with WAS for less than or more than one month (quoted in [EEVC WG20, 2005])

In addition, the WG20 pulse review of pulses for low-speed rear impact testing [EEVC WG20, 2007] found that long-term injury was typically reported to occur in the Δv range of 15 to 25 km.hr^{-1} (based on an extensive critical review of the available literature) and recommended a Δv of 20 km.hr^{-1} for testing targeted at reducing long-term injury rates.

Appendix B. Regulation 17 Head Restraint Measurement Method

As mentioned previously, there are a number of reasons why the RCAR head restraint heights are not the same as those made using the UN-ECE Reg. 17 method. Fundamentally, these are potential differences in the locking position of the head restraint that is measured (uppermost in Regulation 17 and mid-locking in the RCAR procedure) and the definition of the torso angle for the seatback (the manufacturer's design angle in Regulation 17 and a fixed angle of 25° in the RCAR procedure). Also, there is likely to be a difference in the position of the R-point and H-point, which is discussed in Section B.1.

More subtle differences come about through the measurement strategies themselves. It was found that the measurement of the maximum (adjustable) height of a head restraint using the Reg. 17 method could be misleading as it includes 'height' which may not contribute to the protection of the occupant. This error is explained in the following figures.

The text describing the measurement procedure from UN-ECE Reg.17 is reproduced below and is shown by the blue lines in Figure B.1.

> 6.5. Determination of the height of the head restraint
>
> 6.5.1. All lines, including the projection of the reference line, shall be drawn in the vertical median plane of the seat or seating position concerned, the intersection of such plane with the seat determining the contour of the head restraint and of the seat-back (see figure 1 of annex 4 to this Regulation).
>
> 6.5.2. The manikin described in annex 3 to this Regulation shall be placed in a normal position on the seat.
>
> 6.5.3. The projection of the reference line of the manikin shown in annex 3 to this Regulation is then, in the seat concerned, drawn in the plane specified in paragraph 6.4.3.1 above.
>
> The tangent S to the top of the head restraint is drawn perpendicular to the reference line.
>
> 6.5.4. The distance "h" from the R point to the tangent S is the height to be taken into consideration in implementing the requirements of paragraph 5.5 above.

Figure B.1: UN-ECE Regulation 17 method for measuring head restraint height

As noted previously, NHTSA in their final regulatory impact analysis for FMVSS 202 (NHTSA [2004]) published an approximate conversion between the RCAR and Reg. 17 measurement techniques. This was an attempt to convert RCAR height measurements to the Regulation 17 height and is shown in Figure B.2. The red triangle shows the RCAR height measurement (vertical distance from the H-point to the top of the head of a 50th percentile male minus the vertical distance between the top of the head and the top of the head restraint, i.e. 755 mm - RCAR-height) and the projection of this height on to the torso angle line at 25° to the vertical (dotted red line). Similarly, the green triangle shows the backset component (the horizontal distance between the H-point and the back of the head of a 50th percentile male plus the RCAR backset measurement, i.e. 254 mm + RCAR-backset). The dotted green line shows the projection of the backset component on the torso angle line. However, the backset component is actually slightly longer than 254 mm + RCAR-backset, as shown in Figure B.3. The error that this produces along the torso angle line is shown in Figure B.4.

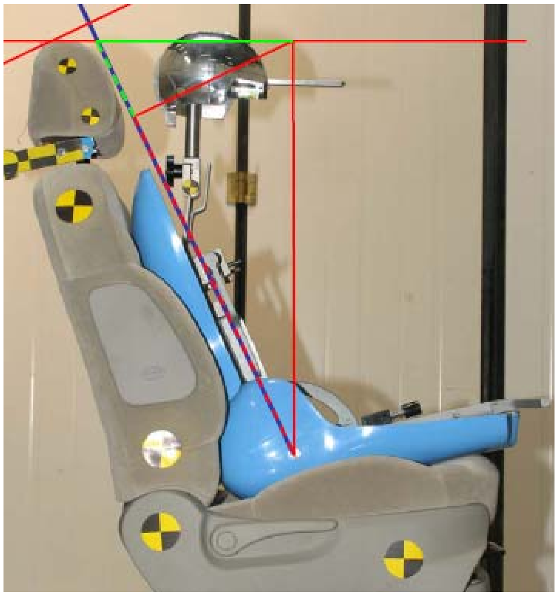


Figure B.2: NHTSA conversion between RCAR and UN-ECE Reg. 17 head restraint height measurements

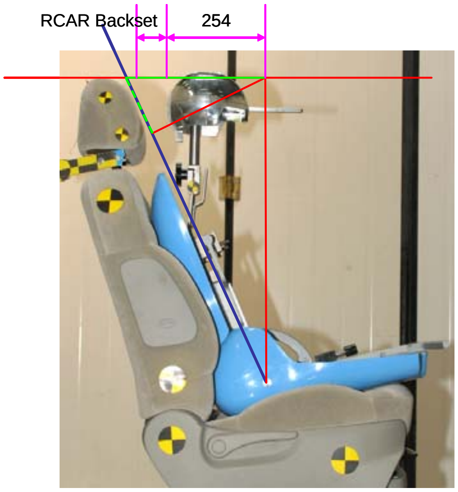


Figure B.3: Underestimation error in backset

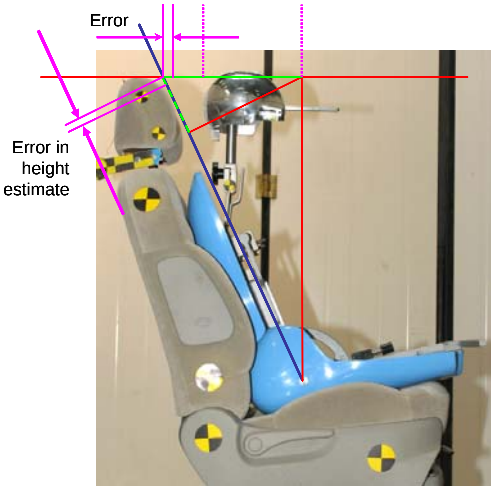


Figure B.4: Effect of backset error on height estimation

conversion

This demonstrates the (typically small) error in converting the RCAR height and backset measurements to an equivalent measurement along the torso angle of the 3-D H machine. However, there is an additional, and typically larger error, between this value and the value measured using the Regulation 17 height measurement method, as shown in Figure B.5. The pink lines show the difference between the NHTSA (over)-estimate of the RCAR-equivalent height and the Regulation 17 height measurement. The difference is due to the fact that the Regulation 17 method measures to the top, backmost corner of the head restraint (unless the top of the head restraint is sloped back at an angle at least equivalent to the torso angle, which is very unusual).

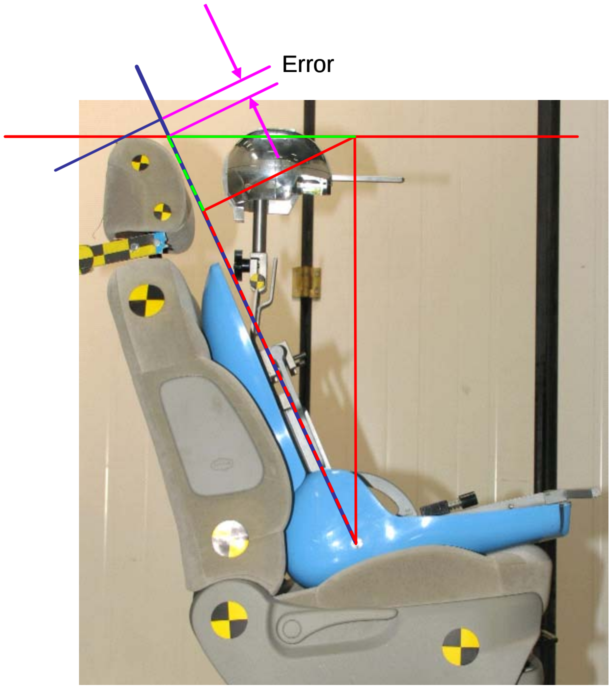


Figure B.5: Error arising through inclined line defining the top of the head restraint

For the seat shown here, the total error is approximately 48 mm. If the head restraint height was intended to protect 95 % of the UK male population, this overestimate of the effective height of the head restraint would mean that only **56 %** of the UK male population would actually be protected. The error will be greatest for head restraints with large front-to-back depth and high rear edges.

According to the calculations used in this cost-benefit study, a head restraint height of 800 mm would be expected to protect 55 % of the UK male population and 98 % of the UK female population. With an error of 48 mm in the height measurement, these proportions become **8 %** and **64 %** respectively.

This error explains why seats with fixed head restraints appear to fail the 800 mm Regulation 17 height requirement in Figure A.3. Fixed head restraints typically have a narrow front-to-back depth (which would reduce the error), but one of these head restraints has an error of approximately 40 mm. The error would be expected to be worse for adjustable head restraints than fixed head restraints due to their typically greater front-to-back depth.

This error has been documented previously in HR-02-03e from the GRSP Informal Working Group on Head Restraints. A possible solution was also proposed by the Alliance of Automobile Manufacturers in HR-03-10e, as shown in Figure B.6. This would reduce the error (except for seat where the front of the head restraint has a large radius at the top, front edge), but would still overestimate the proportion of the population that would be adequately protected by the head restraint. However, the discussion presented here quantifies the likely effect on the proportion of the population who may actually be protected compared with the expected proportion protected based on the regulatory height requirement.

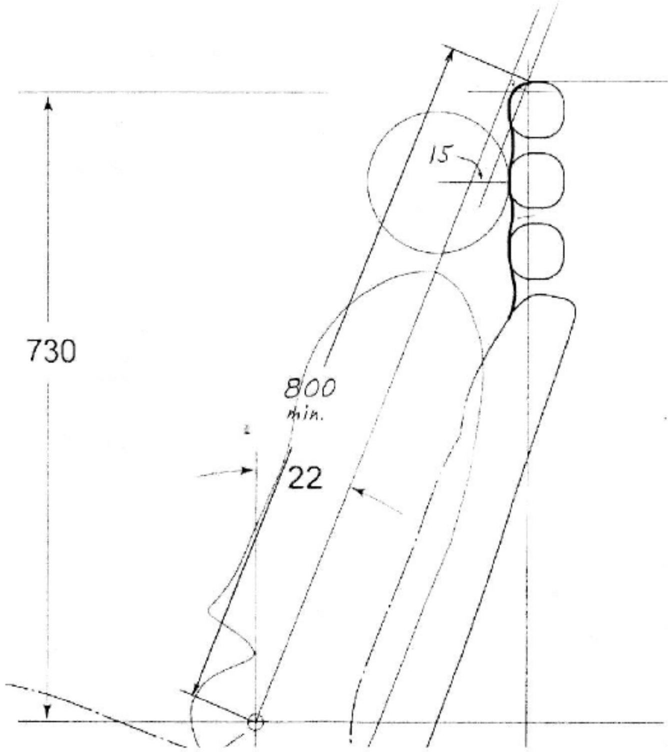


Figure B.6: Alliance 'effective' height concept (from HR-03-10e)

B.1 Head Restraint Height and Backset Measured from H-Point versus R-Point

In an analysis of Alliance and OICA car seat measurement data, NHTSA investigated the difference in height and backset measurements when using either the H-point or R-point as the basis for the measurements (GRSP document HR-07-12e). Four measurement tests starting from either the H-point or the R-point were conducted on ten car seats. The findings showed that the H-point was found to be 0.4 ± 16.2 mm further back and 3.7 ± 12.3 mm above the R-point. Of particular relevance were the further effects observed on the head restraint height and backset measurements. The average difference in backset was 14.8 ± 17.9 mm and the difference in height was on average -2.2 ± 11.2 mm. This means that when using the H-point rather than the R-point for the basis of head restraint position measurements, significant offsets were found in the recorded head restraint backset and heights. In summary, the backset tended to be about 15 mm greater using the H-point and 2 mm lower compared with measurements made from the R-point.

Appendix C. Head Restraint Backset

C.1 Head Restraint Backset Injury Risk Function

To validate statistical data from real-world impacts, Eichberger *et al.* [1996] performed 34 sled tests with nine different car seats. In the absence of a suitable rear impact dummy, Eichberger *et al.* used volunteers for the testing. When looking at the relationship between the horizontal distance and the peak value of the angular displacement between the head and torso they came to the conclusion that the risk of neck injury rises with horizontal distance, since all complaints from the volunteers occurred at high backsets. Therefore a low horizontal distance between the head and head restraint is very important for a good seat design. Even a head restraint placed high enough can only prevent neck injuries when the head is supported as soon as possible by the head restraint during a rear end collision. From the figure in the Eichberger *et al.* paper it seems that the four instances where complaints are registered occurred with 80, 100, 110 and 130 mm distances between the head and the head restraint. The other tests with a backset of 100 mm or less do not have any complaints associated with them.

To ensure that these tests were non-injurious for the volunteers, they were conducted between 8 and 11 km.h^{-1} and at 2.5 g. Therefore, whilst they provide supporting evidence for the assertion that neck injury risk increases with increasing backset, they do not provide absolute injury risk values for the range of impact pulse severities at which most injuries occur in the real-world.

Olsson *et al.* [1990] report the results of 'An In-Depth Study of Neck Injuries in Rear End Collisions'. This dataset includes a number of variables including the duration of whiplash symptoms (in specified ranges), head to head-restraint vertical distance and head to head-restraint horizontal backset distance (i.e. backset). Statistical analysis has been carried out with the duration of whiplash symptoms as dependent variable and the other variables, including vertical distance and backset, as independent variables. The conclusion was drawn that, of the variables tested, only backset appeared to be useful in predicting the duration of the whiplash injury.

Figure C.1 shows the results of a probit analysis of injury duration (more or less than 6 months) against backset. This result provides a method of estimating the benefits which are likely to result from the introduction of a regulation which specified a maximum backset.

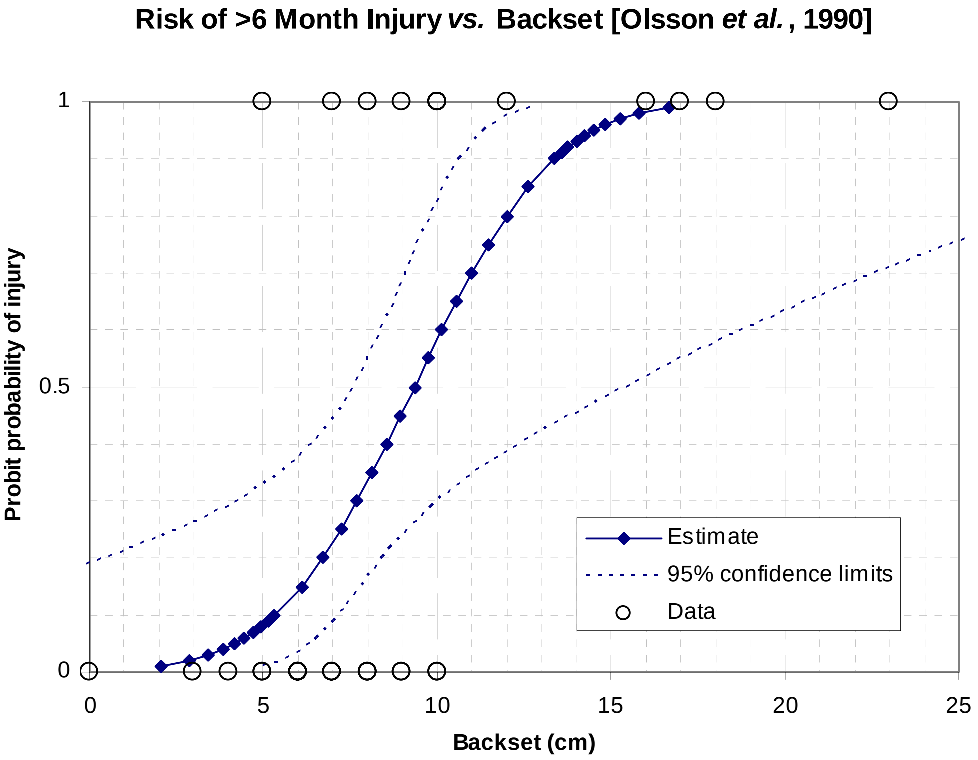


Figure C.1: Risk of long-term whiplash symptoms (> 6 months) *vs.* head restraint backset, based on data from Olsson *et al.* [1990]

According to the authors, the follow up study [Jakobsson *et al.*, 1994] supported the observations that were made in the original 1990 paper, based on a larger sample size of 163 occupants in 115 cars - although, unfortunately, detailed data are not given.

The use of this data to predict long-term whiplash injury risk for different backsets is reliant on several assumptions:

- That the rear impact pulse in 1980s Volvos struck by other 1980s cars is similar to pulses in modern fleet; and
- That the seat back stiffness of 1980s Volvos is similar to the current fleet.

It is known that the pulse is highly dependent on other factors [EEVC WG20, 2007], such as the following, and is therefore highly variable:

- Over-ride and under-ride
- Overlap of impact
- Mass ratio of impact partners
- Stiffness ratio of impact partners
- Bumper design

It is likely that the stiffness of 1980's vehicles and the Volvos comprising the vehicles in the Olsson *et al.* study compared with modern vehicles has changed. In general vehicles are likely to be stiffer now which may be commensurate with the increase in whiplash injury risk that is now evident. Avery [2001] reported on the increasing stiffness with model year of three vehicles one from each of the 1980s, 1990s and 2000s. However, it is not certain how representative each of the three vehicle models is of the fleet from each decade, so it is difficult to predict how these changes will have changed throughout the vehicle fleet at those times and how such changes will have affected the impact pulse in collisions with other vehicles from each period and therefore also the injury risk. In general it is expected that occupants in a vehicle which is less stiff and of greater mass than other vehicles in the fleet, would be at a lower risk of whiplash injury than occupants in a lighter or stiffer vehicle. Based on this general assumption, the Volvo cars from the 80s should provide relatively low risks of injury compared with other vehicles. In terms of calculating benefits due to improved geometry, the largest benefits will be produced where the underlying risk of injury is high. In such cases the geometry has the greatest potential for injury mitigation. Therefore, the Olsson *et al.* injury risk data are expected to provide a conservative estimate of the potential benefits available from changes in head restraint backset.

It is also known that Volvo had already stiffened their seat backs by this time to combat ramping-up in rear impact (e.g. Carlsson *et al.* [1985]). It is assumed, therefore, that the seat back stiffness of Volvo cars from the 1980s would be representative of the modern fleet.

C.1.1 Summary of Head Restraint Backset Injury Risk Function

The data from Olsson *et al.* [1990] provide the best available injury risk function for head restraint backset *vs*. long-term injury risk. The use of this function is reliant on the assumptions that the stiffness of the vehicles in which the occupants were injured (1980s Volvos) and the stiffness of the seat backs in those vehicles are representative of the modern vehicle fleet. It is considered that these assumptions are reasonable.

However, if these assumptions are not correct, this backset injury risk function is likely to be a conservative estimate of the long-term whiplash injury risk; both the vehicle stiffness and seat back stiffness are considered to be risk factors (with increasing risk with increasing stiffness for both) and both are considered to have got stiffer over the last few decades [EEVC WG20, 2005].

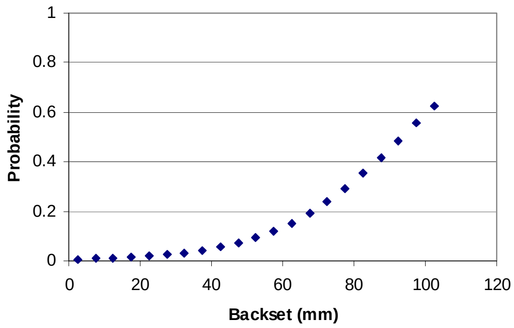
C.2 Head Restraint Backset Potential Savings

It has been noted earlier that, in the dataset reported and discussed by Olsson *et al*. [1990], whiplash injury duration was positively correlated with head restraint backset, as shown in Figure C.1 (which incorporates the results of a logit analysis of the data).

The logit equation for the curve relating injury duration probability (P) and backset (in cm) is:

$$\mathrm{P}(duration > 6mnths) = \frac{1}{e^{5.197-0.556backset}+1}$$

A second dataset has been obtained, on car seats in current use, which contains a range of variables including backset and height measurements taken from a number of current cars as part of the insurance consumer information whiplash rating programme performed by Thatcham. A spreadsheet has been built combining the frequency of occurrence of seats in given backset ranges (in 5 cm steps) with the probability of injury at each backset distance (by multiplying the two factors). Figure C.2 and Figure C.3 show, respectively, the injury probability for individual seats (from Figure C.1) and weighted for the actual population of seats.



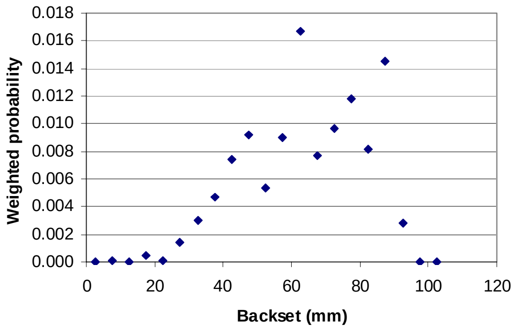


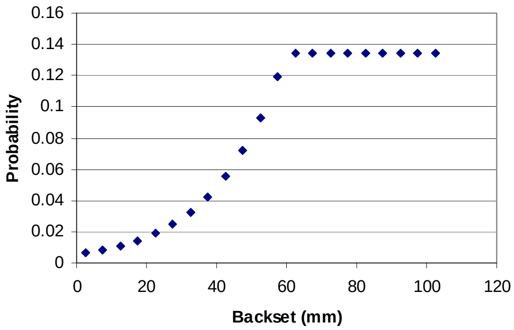
Figure C.2: Log term injury probability for individual seats

Figure C.3: Long term injury probability weighted for the proportion of seats at each backset range

The effect of the introduction of a regulation requiring seats to have a backset less than or equal to a prescribed distance has been estimated directly from the spreadsheet:

- For seats where the backset distance is less than the regulation value, the injury probability for an individual seat is unchanged and the weighted probability for all seats in that backset range is as shown in Figure C.3.
- Any seat whose backset is currently greater than the regulation distance would be modified to reduce the backset with a consequent lessening of the probability of injury.

The revised individual seat and weighted probabilities are shown in Figure C.4 and Figure C.5 (for a backset regulation of 60 mm).



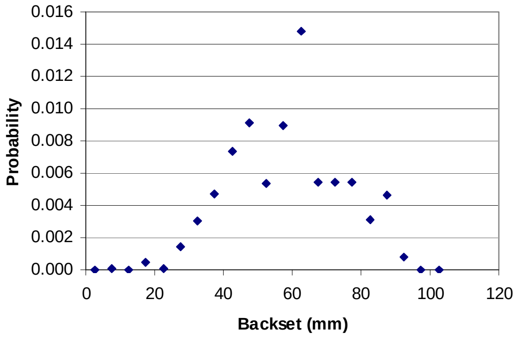


Figure C.4: Long-term injury probability distribution for 60 mm backset requirement

Figure C.5: Long-term injury probability distribution weighted for the proportion of seats at each backset range for 60 mm backset requirement

Figure C.6 shows the overall estimated savings in the probability of injury if a regulation were introduced which required backsets to be less or equal to a prescribed value (in the range 40 mm to 100 mm).

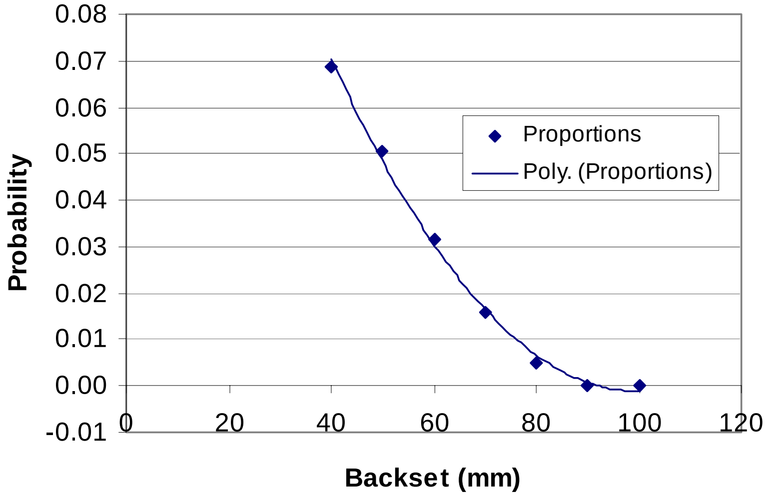


Figure C.6: Estimated savings for the probability of injury for regulation backsets in the range 40 mm to 100 mm

Appendix D. Accident Saving Calculations

The following flow charts show the procedure and calculations employed to derive the accident savings that may be expected through implementation of the suggested options.

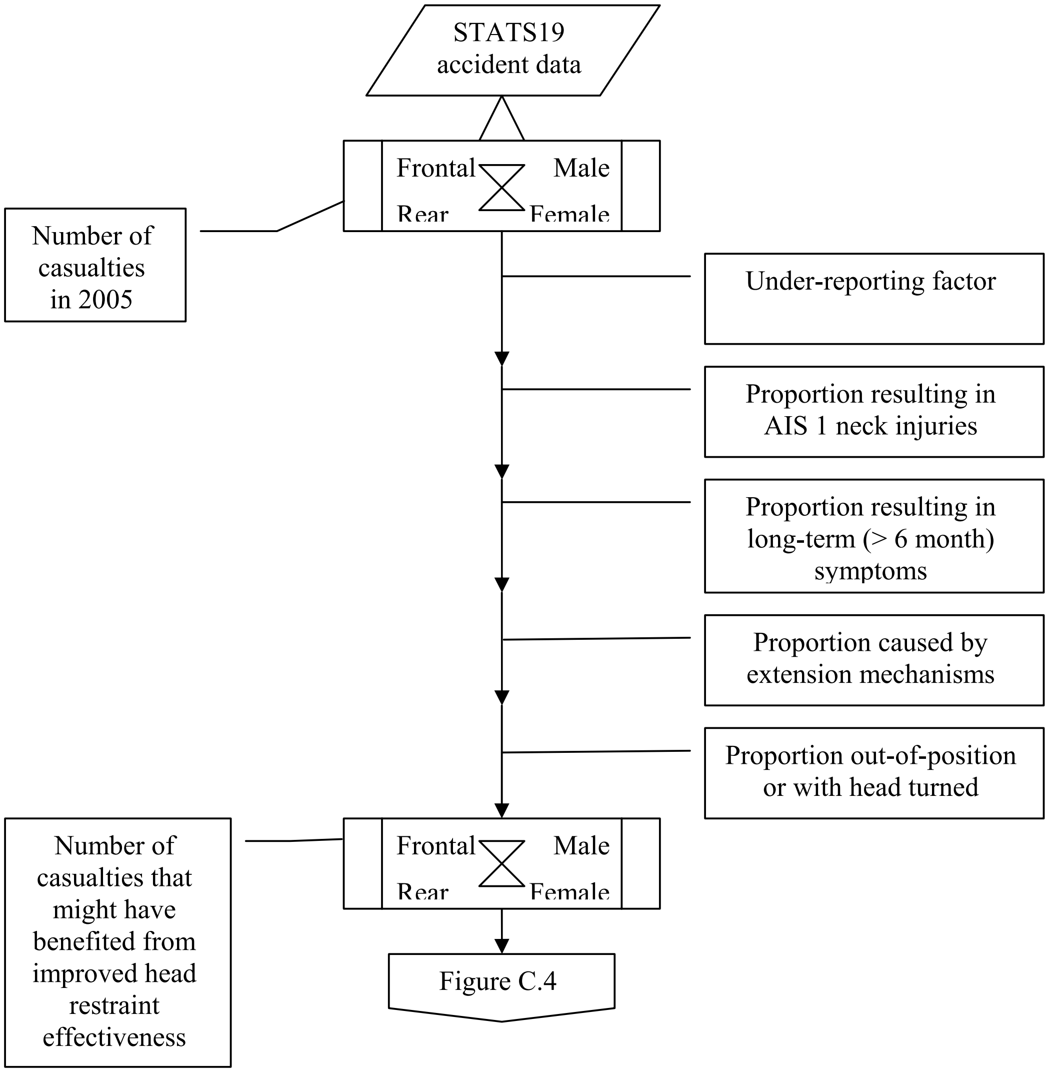


Figure D.1: Determination of the number of casualties that could be saved potentially through better head restraint positioning, or effectiveness

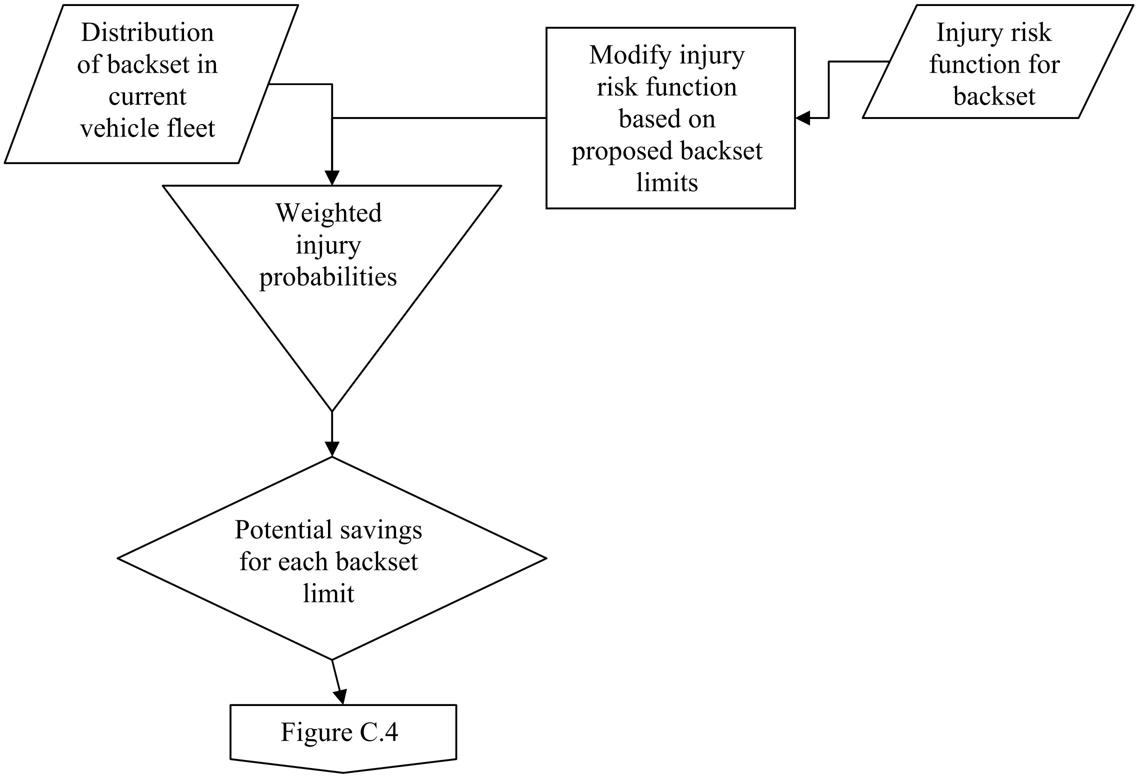


Figure D.2: Determination of the potential improvements in effectiveness resulting from decreased backset of head restraints

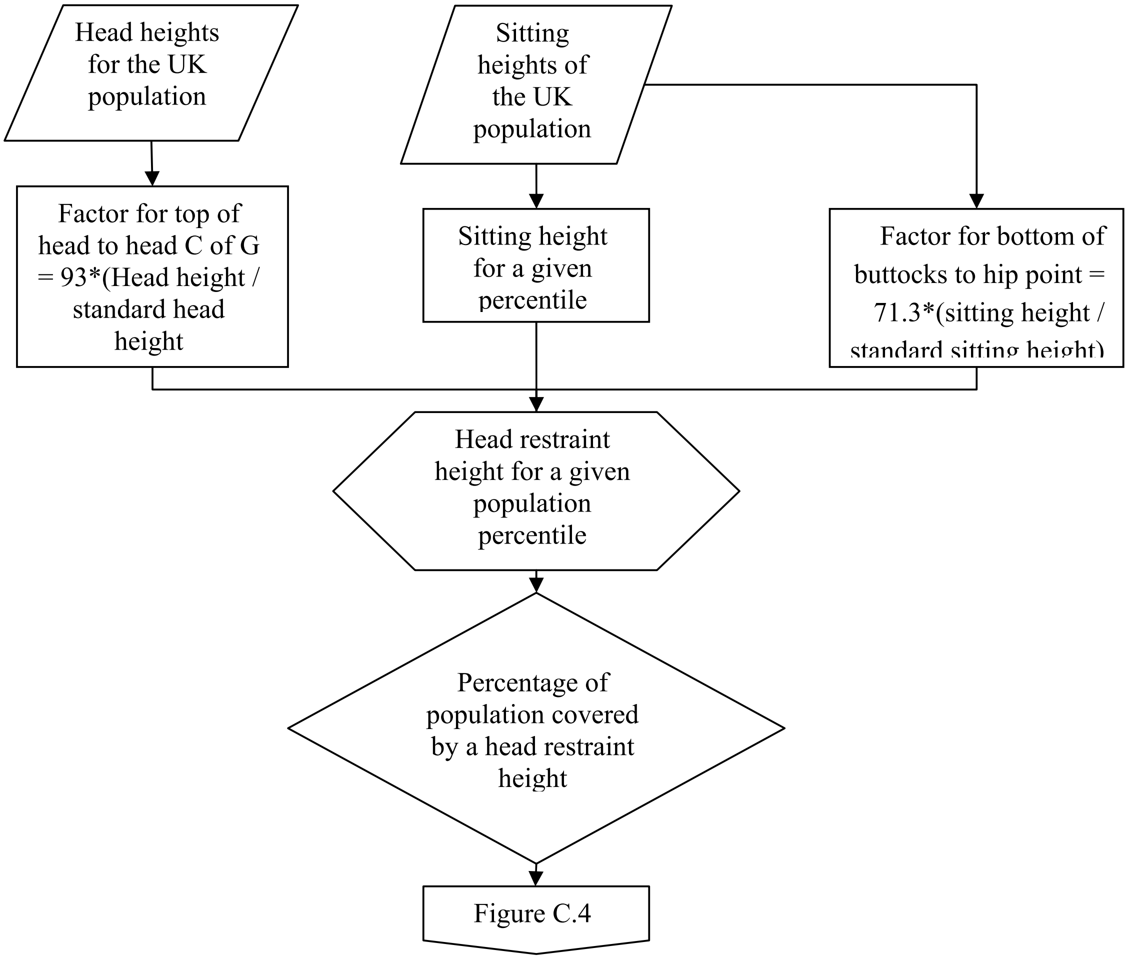


Figure D.3: Determination of the potential population coverage resulting from increased head restraint height

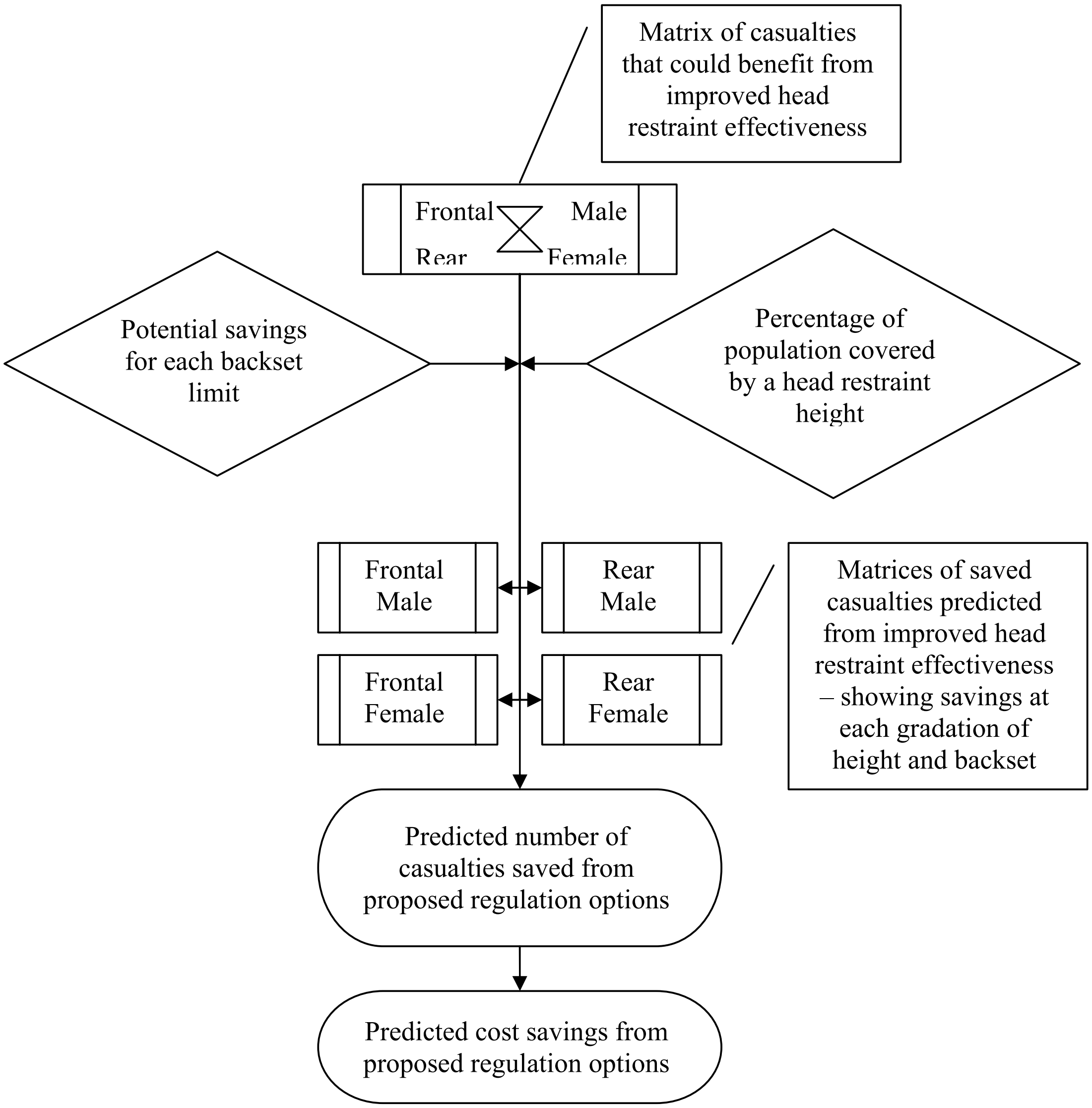


Figure D.4: Potential savings from suggested improvements in head restraint geometry and hence effectiveness