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The likely effects of downsizing on casualties in car accidents

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Executive Summary

This report describes a series of statistical analyses of accident data that have been undertaken to examine the likely effects on road safety of reductions in the mass and size of new cars which might made to satisfy the anticipated demand for cleaner, more fuel efficient personal transport. It has sometimes been argued that reducing car mass and size (downsizing) would increase the number of casualties in car accidents. This report examines these claims using statistical evidence from the road accidents that occurred in Great Britain in 1991-94.

As the study is based on road accidents which occurred in a specific period, its results are necessarily influenced by the characteristics of the 'generation' of road vehicles in use at that time, in particular the protection that they provide to their occupants. Downsizing would require a number of years to take effect, by which time some of these characteristics may well have developed significantly. Thus, while the results give as good a guide as is possible with the evidence available, they cannot take account of future changes that are inevitably uncertain. Moreover, the results measure the association between mass and risk of injury, but cannot demonstrate that there is a causal link. This is normally the case with statistical analyses of road accident data where there is no possibility of independently varying the variable of interest - in this case car mass or size - and observing the consequences. The only way of demonstrating causality would be to carry out a major experiment, involving large numbers of downsized cars.

The approach followed has two stages. First, detailed accident data are analysed to investigate the relationship between the mass of the car or cars involved in a car accident and the risks of injury for all travellers, not just those who travel by car. (Previous research has shown that mass is the appropriate measure of 'size' for the present car fleet, although this could change in future if manufacturers were to respond in particular ways to a requirement to downsize.) These relationships are then used to simulate the changes in the number of casualties that would have been expected if the cars involved in the accidents in the data set had been 10 per cent lighter than they actually were. The figure of 10 per cent has no special significance in the context of downsizing, but is used to illustrate the implications of the relationships for downsizing.

This simulation involves two assumptions, the first referring to the total number of accidents and the second to the incidence of casualties within this total:

i that drivers will be neither more nor less likely to become involved in an accident once their cars have been downsized, so the total number of accidents (i.e. including damage-only) will remain constant and downsizing will affect the number of casualties only by changing accident severity;

ii that the *post-downsizing* risk of injury in an accident is equal to the *baseline* risk for a car of the same mass in a corresponding accident, so that the effect of mass on risk found under baseline conditions will continue to apply with downsized cars.

The first assumption is plausible, but cannot be proved. The validity of the second assumption depends upon the underlying cause of the statistical relationships that are found between mass and risk of injury, in particular whether they result from physical laws or variations of driving behaviour with size of car. The latter explanation implies that light cars and heavy cars are likely to be involved in accidents with different impact velocities, but certain results from the statistical analyses suggest that this is not true. Consequently, the second assumption is likely to be valid and the results of the simulation should be reliable. Nonetheless, as the simulation depends upon a series of statistical analyses, the explanations for its results are sometimes unclear.

The risks of injury in a car accident are influenced by the characteristics of the other vehicle or vehicles involved, so six separate types of accident are studied. The analysis is most complex for two-car accidents, since downsizing would affect the mass of both cars. The ratio of the masses of the colliding cars has much more influence on risk than the individual masses, but the ratio would be unaffected by a uniform downsizing. For simplicity, the downsizing that has been simulated consists of reducing all car masses by the same percentage. It would also be possible to simulate various other scenarios, as has been done in a recent paper (Buzeman, Viano and Lösund, 1998). It is estimated that if all cars had been 10 per cent lighter then in 1991-94 6.6 per cent fewer car drivers would have been killed and 1.5 per cent fewer would have been injured in two-car accidents.

The analysis is simpler for accidents which involve only one car, since the car is the only vehicle which would be affected by downsizing, and the sequence of analyses produces a consistent pattern of results. As the mass of the car is reduced, so the risk of injury for its occupants rises, but the risk of injury falls for others involved in accidents, such as pedestrians, motorcyclists, van drivers. Hence, downsizing would lead to increases for some categories of casualty and reductions for others. Summing the estimates over the six types of car accident, the simulation suggests that a 10 per cent downsizing might have reduced fatalities by 3.6 per cent and casualties by 0.8 per cent overall. These figures cannot be precise, given the complexity of the simulation, but the nominal standard errors from the six sets of statistical models indicate that it is highly likely that a modest reduction in fatalities and casualties would be achieved.

These results refer to the final state where the car fleet consists entirely of downsized cars, but there will be a transitional phase where current cars are progressively replaced by downsized cars. Downsized cars will coexist on the roads with older, fullsized cars during this phase, so the possibility that casualties might temporarily rise has been examined. It was assumed that downsizing would occur at a uniform rate. For those types of accident which involve only one car, there would be a linear transition to the state represented by the simulation. The transition

could be non-linear for two-car accidents, with the number of fatalities falling slightly less rapidly in the early stages. Overall, fatalities and casualties would fall throughout the transitional phase.

Thus, the results presented in this report suggest that uniform downsizing would have the effect of slightly reducing the total number of casualties in car accidents. As far as current statistical evidence from road accidents in Great Britain is able to indicate the consequences of uniform downsizing, it indicates that fears that road safety would be adversely affected are unjustified. If it appears in future that non-uniform downsizing is a more likely option, it will be possible to assess alternative downsizing scenarios to check whether these conclusions still apply.

Reference

Buzeman D G, Viano D C and Lösund P (1998). *Car occupant safety in frontal crashes: a parameter study of vehicle mass, impact speed and inherent vehicle protection*. Accident Analysis & Prevention Vol 30, No 6, pp 713-722.

1 Introduction

This report describes a series of statistical analyses of accident data that has been carried out as part of a project carried out for the Department of the Environment, Transport and the Regions. The analyses are designed to examine the likely effects on road safety of downsizing, a potential Government policy designed to reduce the size of the average car in order, principally, to reduce energy consumption and atmospheric pollution.

Opponents of downsizing have argued that it would increase the number of casualties in car accidents. Such arguments tend to be based on the extensive evidence which shows that in two-car accidents the occupants of the lighter car tend to be more severely injured than occupants of the heavier car. However, the evidence also shows that the *combined* number of casualties in these accidents is rather insensitive to the *combined* mass, so it is important to take account of all aspects of downsizing and reach an overall conclusion.

This report examines the statistical evidence from the road accidents which occurred in Great Britain in the four years 1991-94 to investigate the relationship between the size of a car and the risk of injury in an accident. An important caveat must be made about this relationship, however: it is inevitable with the results of any statistical study in which there is no control over the characteristics of the units being studied that the relationship which is found is associative and not causal. The relationship measures the association with the current fleet of cars between car mass and the risk of injury, but it is conceivable that an alternative approach to car design over the past three decades could have led to a car fleet whose different mixture of characteristics might have yielded a different relationship.

The point is especially important to an investigation of downsizing. The introduction of this policy would impose novel constraints upon car designers, and they may react by departing from current design practices. There are signs that such developments are already beginning for other reasons. Thus, detailed predictions based on the relationship that is found between mass and risk of injury must be qualified because they could be influenced by the characteristics of the current car fleet.

Detailed predictions about the future are inevitably uncertain, and qualifications like this apply to most attempts at forecasting. It is, nevertheless, valuable to study the implications of the current relationship for downsizing, so the relationship is used to simulate the number of casualties that would have been expected in 1991-94 if all cars involved in accidents had been one-tenth lighter than they actually were. Downsizing would take many years to take full effect, so caveats such as those mentioned above mean that the final results may differ from those indicated by the simulation. Naturally, this qualification would also apply to any alternative method of prediction.

Section 2 introduces the analytical framework which will be used. The risks faced by car occupants in an accident depend on the characteristics of the other vehicle or vehicles involved, and Table 1 summarises the distribution.

The relationship between risk of injury and size of car may well vary with the category of accident, so the various categories are studied separately. The safety of those who are not travelling by car, such as cyclists and lorry drivers, is also important, so the relationship between size of car and their risk of injury is investigated as well.

The various analyses of accident data and the simulated casualty effects of uniform downsizing are described in Section 3, with the technical details being presented in an appendix. The simulation results refer to the final state where all cars have been manufactured according to a downsizing regime, but the transitional effects during the period when ‘fullsized’ cars are progressively replaced by ‘downsized’ cars are also studied. Section 4 discusses the conclusions that may be drawn from the results of the modelling.

2 Analysis of accident statistics

A policy of downsizing would require many years to achieve its full effect, as the current range of cars on British roads is progressively replaced by the smaller models designed in accordance with the new regime. Many other aspects of road traffic will change over this period, so it is impossible to estimate the casualty effects in some future year when the process is expected to be complete. The only feasible approach is to simulate the consequences of an instantaneous - and totally impractical - downsizing of all current cars. Thus, the question which will be studied is: ‘If all of the cars which were involved in recent accidents in Great Britain had been smaller than they actually were, what would the likely effect have been on the number of casualties?’

Table 1 Percentage of car driver casualties by accident type, 1994

	Vehicles involved:						
Severity of driver casualty	*2 cars*	*1 car*	*1 car + 1 lighter vehicle*	*1 car + 1 heavier vehicle*	*1 car + >1 other vehicle*	*At least 1 car*	*Number of driver casualties (=100%)*
Fatal	27	30	1	21	21	100	1102
Serious	46	24	1	11	18	100	13774
Slight	57	13	1	10	19	100	106433

Lighter vehicles include pedal cycles, mopeds and motorcycles heavier vehicles include light and heavy goods vehicles, buses and coaches other vehicle can be of any type, including car

The answer will be based on analyses of recent accident data which identify the present relationship between car size and risk of injury. The results of these analyses are inevitably influenced by the characteristics of the current ‘generation’ of road vehicles, and in particular the protection that they provide to their occupants. There are already indications that the characteristics of new cars are changing, possibly influenced by consumer and regulatory pressures. Further developments may well occur before downsizing has taken full effect. Thus, while the results give as good a guide as is possible with the current evidence, they cannot take account of future changes that are inevitably uncertain.

The neutral term ‘size’ has been used, without specifying any particular measure of car size (e.g. length, wheelbase, mass). The analyses reported below all relate to mass and the consequences of having lighter cars, and there is a clear reason for this. A study of the method used by the Department of Transport to rank the secondary safety of car models (Broughton, 1994) showed that the proportion of drivers of a particular car model who are injured when involved in two-car accidents declines very regularly with increased mass of the model. Moreover, this was found to be true for most of the dozen most popular models which were studied in greater detail: the external dimensions of the variants of each model are virtually constant, yet the proportion of injured drivers still declined regularly as the mass of the variant increased. This indicates strongly that mass is at present the key variable, at least in two-car accidents.

Figure 1 provides further justification for this approach. It compares the mass and length of the 90 most popular current models and shows that the two variables are highly correlated, with a correlation coefficient of 0.892; the one clear outlier is a rather old design, the Citroen 2CV.

This correlation between mass and length may not, however, continue in future. The requirement to downsize could lead manufacturers to concentrate on smaller models within their model ranges, which would largely preserve the current correlation. They could, however, choose to preserve the external dimensions and instead build cars from lighter materials such as aluminium. Nevertheless, in view of the existing correlation, there would be little point in duplicating the analyses with another measure of size.

The accident data come from the British ‘Stats19’ national system for recording injury accidents (Department of Transport, 1995). Data for the four years 1991-94 are studied, to provide more precise results than could be achieved for a single year. There are three categories of casualty severity in the Stats19 system, and there will be analyses of the effects of downsizing upon:

a the number of people killed;

b the number who are killed or seriously injured (ksi);

c the number who are injured, i.e. all casualties.

Three sets of casualties will be investigated at each level of severity:

a car drivers;

b drivers of other vehicles;

c vulnerable road users.

Passengers are omitted because the average number of passengers per vehicle varies irregularly with type of vehicle: for example, accident data show that young car drivers tend to carry more passengers than middle-aged drivers. By contrast, in any accident there is exactly one driver per vehicle (with the trivial exception of parked vehicles), so comparisons are standardised by studying only driver casualties. The importance of this restriction in eliminating a source of bias is demonstrated in Section 3.1.1.

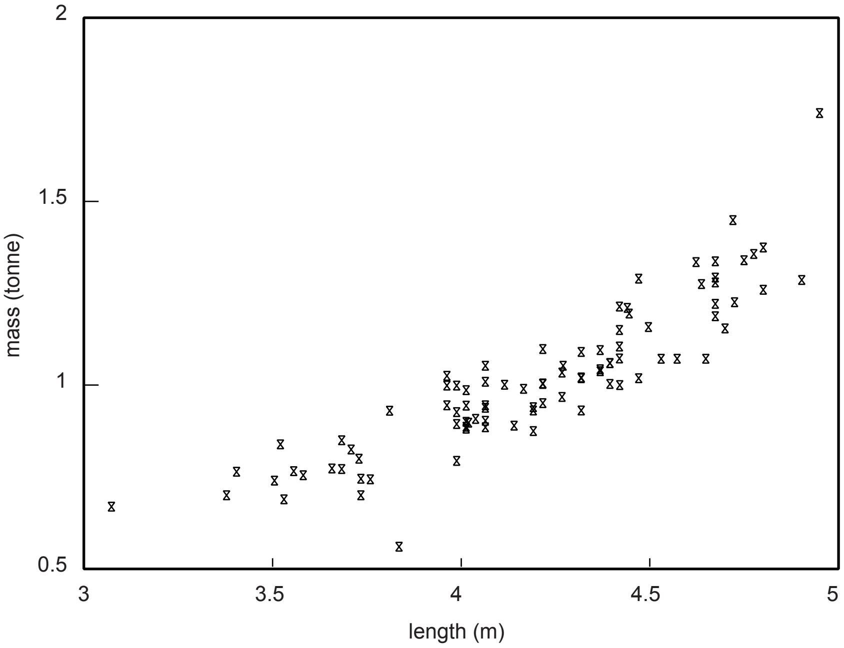

Figure 1 The relationship between mass and length for current car models

Vulnerable road users (pedestrians, pedal cyclists, motorcyclists) form an important group of casualties which could be affected by downsizing, so they are included.

Since 1989, the Stats19 accident reports include the Vehicle Registration Marks (VRM) of most accident-involved vehicles. This allows the vehicle data provided by the police to be enhanced with data from the records of the Driver and Vehicle Licensing Agency at Swansea. The information supplied does not include mass, but the mass of each of the more popular models has been established from a commercial report (Glass's Guide Service, 1995); this could only be done approximately for models such as the Ford Sierra which have variants over a wide range of masses. The mass data are for unladen vehicles, the mass of a laden vehicle at the time of an accident may be more relevant to the outcome of an accident but cannot be determined retrospectively.

2.1 The statistical methodology

The same general statistical methodology is used for all of the groups of accidents to be studied. It involves a number of statistical details which the non-specialist reader may find difficult to follow, so an overview is provided below with a full description in Appendix A. The same approach is followed for the presentation of the statistical results in Section 3.

Six groups of accident will be studied separately, for the reasons outlined in Section 1:

a two-car accidents;

b single-car accidents with no pedestrian casualty;

c single-car accidents with a pedestrian casualty;

d accidents involving one car and either a pedal cycle or a motorcycle;

e accidents involving one car and one van;

f accidents involving one car and one bus, coach or lorry.

This list includes the great majority of car accidents. The main group omitted from the list comprises accidents which involve three or more vehicles. These are difficult to analyse statistically as there are three or more masses - some of which may be unknown. However, any multi-vehicle accident begins as a two-vehicle accident and other vehicles become involved subsequently, so it should be valid to generalise the conclusions for two-vehicle accidents to multi-vehicle accidents.

For each group of accidents in turn and for each accident severity, the Stats19 database has been analysed to extract tables which show the number of people injured in 1991-94 according to the mass of the cars involved. The outcome of an accident can in addition be influenced by characteristics such as the speed limit and the age and sex of the injured people, so the tables also include these details. A statistical model is then used to establish how the risk of someone involved in a car accident being injured at a particular severity varies with the car mass, as well as the other variables of speed limit, age and sex. The *mass* coefficient (i.e. the coefficient which represents the effect of car mass) is of particular interest, the others are included principally to reduce the risk of the estimation of this coefficient being biased, e.g. by the greater vulnerability of the elderly when involved in an accident.

The model is fitted using the GLIM programme (Francis et al, 1993) to find the coefficients which best represent the variations in the probability of injury. The details of the model depend on the particular group of accidents being studied, and are discussed in Section 3.

The use of this form of model should reduce the risk of the *mass* coefficient being biased, but it appears possible that there might be one source of bias that could not be eliminated in this way. To take an extreme example, suppose that heavy cars normally collide with heavy cars and that light cars normally collide with light cars. The accident data would not then show what happens when light and heavy cars collide, so the results of any analysis of the relationship with mass would be incomplete. Similar biases might arise with the other types of accident, but Broughton (1994) showed that this is not the case in Great Britain. There is no systematic variation with mass, and the statistical model allows for the effects of random variation, so this possible source of bias can be ruled out.

It must be recognized that the results of these analyses will measure the association between mass and risk of injury, but cannot demonstrate that there is a causal link. This is normally the case with statistical analyses of road accident data since there is no possibility of independently varying the variable of interest (car size in this case) and observing the consequences. The only way of demonstrating causality would be to carry out a major experiment, involving large numbers of downsized cars.

2.2 Simulation of casualty changes

The fitted models can be used to simulate the number of casualties that would have been expected in 1991-94 if all cars involved in accidents had been downsized models. They show how the risk of injury varies with mass of car, so they can predict how the risk in any particular accident would have changed if the car or cars involved had been lighter. Based on the accident data used in the modelling, these changes can be summed to simulate the changed pattern of casualties that would be expected with downsized cars. As explained in the Introduction, it is possible that the modelling results are influenced by characteristics of the current car fleet, so this qualification applies to all the simulation results, but similar qualifications would apply to any alternative method of prediction.

The simplest downsizing scenario is of a uniform reduction, with the mass of all models reduced by a constant percentage, and all results presented below suppose a reduction of 10 per cent. The figure of 10 per cent has no special significance in the context of downsizing, but is used to illustrate the implications of the relationships for downsizing. More complex scenarios in which the percentage varied with mass range could also be assessed if necessary.

The modelling results fall into two groups: those where reduced mass is associated with *reduced* injury risk and those where it is associated with *increased* injury risk. The two groups must be considered separately. Downsizing by a limited extent would only be expected to affect those casualties whose injuries lie near the boundaries between the severity categories. A more radical downsizing cannot be simulated because the difference between current and hypothetical future conditions would be too great: information about current conditions could not be generalised to the new scenario. Thus, where the modelling results suggest that reduced mass is associated with *reduced* risk, one would expect:

- some who were killed in actual accidents would instead have been seriously injured if a downsized car had been involved;
- some who were seriously injured would have been slightly injured;
- some who were slightly injured would have escaped injury;
- those who escaped injury would still have been uninjured.

For this group of models, the total casualty *reduction* can be estimated directly from the Stats19 accident data, since all those who would have been injured with downsized vehicles appear in the Stats19 data. For the other group, where the modelling results suggest that reduced mass is associated with *increased* risk, one would expect:

- some who escaped injury in actual accidents would instead have been slightly injured if a downsized car had been involved;
- some who were slightly injured would have been seriously injured;
- some who were seriously injured would have been killed;
- all who were killed would still have been killed.

The accidents in the last three groups appear in the Stats19 data, so the *increase* in the number of people killed or seriously injured can be estimated directly. As damage-only accidents (the accidents in the first group) and uninjured people who were involved in an injury accident do not appear in the Stats19 data, the *increase* in the casualty total cannot be estimated fully; the lack of adequate information means that no adjustment can be made, but results from these incomplete simulations will be clearly identified. The potential incompleteness relates only to the post-downsizing number of slight casualties.

This method of simulation involves two assumptions. The first is that drivers will be neither more nor less likely to become involved in an accident once their cars have been downsized, so the number of accidents (i.e. including damage-only) will remain constant and downsizing will affect the number of casualties only by changing accident severity. This seems plausible, but cannot be proved.

The second assumption is that the post-downsizing risk of injury for a driver is equal to the current risk for the driver of a car of the same mass. The analysis measures the statistical relationship between risk and mass, but does not explain it. If the relationship is a consequence of physical laws (e.g. lighter cars ⇒ less energy released in accident ⇒ less risk of injury) then the assumption is probably valid. Alternatively, if it is a consequence of driver behaviour (e.g. drivers of lighter cars are more cautious ⇒ they tend to be less involved in serious accidents) then the future drivers of downsized cars of mass m may be more aggressive than the current drivers of fullsized cars of mass m. This would be manifested by different impact velocities for lighter cars, but this cannot be checked directly as impact velocity is difficult to measure and is not reported by the police. However, it may be possible to use speed limit as a proxy for mean impact velocity and derive information relating to the possible role of driver behaviour from the coefficients which represent the effects of speed limit on injury risk.

Any attempt to forecast the future requires one further assumption that has already been mentioned: that the relationships found by analysing present conditions will continue to apply in future. Thus, while the results give as good a guide as is possible with the current evidence, they cannot take account of future changes that are inevitably uncertain.

2.3 The transitional phase

The process of downsizing will take some years to complete. During the transitional phase, the car fleet will contain a mixture of fullsized and downsized cars, with the proportion of fullsized cars progressively declining until all have been scrapped. The simulation results presented in Section 3 relate to the final state where downsizing has been completed; this Section considers how casualty numbers will change in the previous years.

The transition to the final state will depend upon the type of car accident, but there are just two cases to consider. Most of the accident types shown in the list in Section 2.1 involve just one car. During the transitional phase, a declining proportion of these accidents will involve one fullsized car and the remainder will involve one downsized car, so there should be a linear transition to the final state represented by the simulation.

By contrast, the transition may be non-linear for two-car accidents, since some will involve two fullsized cars, some will involve two downsized cars and the remainder will involve one fullsized and one downsized car. This is studied in Section 3.6.

3 Analyses of car accident data

Sections 3.1-3.5 consider, for the groups of accident listed in Section 2.1, the relationship between risk of injury and car mass as represented by the coefficients from the various models. Section 3.1 deals with two-car accidents, so the models must include the mass of both vehicles as both would be affected by downsizing. The models for the other groups of accident are simpler as they include only the mass of the car and not the mass of the other vehicle, which would be unaffected by downsizing. Extraction of this information would be very difficult or, in many cases, impossible, and Appendix A demonstrates that the additional coefficients from the extended models would not contribute to the simulation. Details of the models are provided in Appendix A and the statistical results achieved with the Stats19 data are listed in Appendix B. The simulation results from the six groups of accident are presented together in Section 3.6.

3.1 Two-car accidents

These accidents involve exactly 2 cars and no other vehicle. In this group, downsizing would affect both vehicles, whereas in the other groups only the car would be downsized, so the analysis is more complex in this case as it must take account of two masses rather than one. The method used to handle two masses was first described by Klein et al (1991); the model of the risk of a driver being injured includes the ratio of the masses of the colliding cars *(ratio_mass)* in addition to the mass of the driver's car *(mass)*. Klein et al analysed data from Texas and Maryland to investigate the likely effects of downsizing, and their results are compared with the British results in Section 3.1.1.

The model has been applied to Stats19 data from two-car accidents in 1991-94 in which:

i at least one of the drivers was injured (to avoid the possibility of bias from accidents where only passengers are injured);

ii the VRM of both vehicles was reported by the police and could be matched in records held by the DVLA;

iii each car was one of those relatively popular models for which the unladen mass was known.

There are 96443 accidents in the data set, 47.4 per cent of all two-car accidents in the Stats19 database during these four years which involved a driver casualty. 591 drivers were killed, 11223 seriously injured and 103360 slightly injured. Most accidents excluded from the analysis were excluded because of the failure to match one or other vehicle, because either the police failed to report the VRM or there was a transcription error or the vehicle was unregistered (e.g. in order to evade paying the Vehicle Excise Duty). It seems highly likely that the 96443 accidents form a representative sample of the population of two-car accidents in the Stats19 database which involved a driver casualty, so that conclusions drawn can safely be generalised to the full population.

Accidents on built-up roads (with speed limits of at most 40 mph) are treated separately from those occurring on non built-up roads (speed limits of more than 40 mph), to allow for the greater severity of accidents on non built-up roads because of the higher speeds on these roads. The *mass* coefficients for built-up and non built-up roads proved to be very similar and final models were fitted for the combined data (Table A1).

The *ratio_mass* coefficients are strongly negative. This confirms what is widely known, that in a two-car accident the driver of the lighter car is more likely to be injured than the driver of the heavier car. Moreover, if two cars A and B collide and B has a fixed mass, reducing the mass of A tends to increase the risk of injury to the driver of A and to reduce the risk of injury to the driver of B.

However, *ratio_mass* would be unaffected by uniform downsizing, so the more relevant feature of the results is the fact that the *mass* coefficient is positive for all casualty severities and both road types. This shows that the risk of a driver being injured increases with car mass in two-car accidents provided that all other factors are unchanged, so it implies that uniform downsizing would lead to fewer drivers killed and injured. The modelling results could be used to assess non-uniform downsizing scenarios; the new simulations would be influenced by the *ratio_mass* coefficient, and it is possible that casualty increases could be predicted for certain scenarios.

3.1.1 Discussion

The results from Great Britain suggest that, inasmuch as past conditions provide a basis for estimating the effects of uniform downsizing in a future British car fleet, it would reduce the number of casualties in two-car accidents. However, the US study mentioned earlier (Klein et al, 1991) used a similar approach and came to the opposite conclusion: 'in car-to-car crashes, the change in injury rate associated with the reduction in vehicle fleet weight from 3700 to 2700 pounds [1680 to 1230 kg] has been estimated from the Texas data to be an additional 14 per cent. The Maryland data produced an estimated increase in the serious driver injury rate of 4 per cent....'

The statistical approach adopted by the US researchers appears to be entirely appropriate for studying the effect of car mass on the risk of driver injury. The main difference between the two approaches is that the US data included all two-car accidents where at least one occupant was injured, whereas the British analysis has been restricted to accidents where at least one car driver was injured.

This restriction was applied to avoid possible bias resulting from the inclusion of accidents where only passengers were injured. To see how this can occur, consider models A and B which have the same level of secondary safety (i.e. their drivers are protected equally well in accidents of corresponding severity). The risk of driver injury for model A is calculated by Klein et al as:

$$P(A) = \frac{\text{Number of injured drivers of model A cars}}{\text{Number of model A cars involved in two-car injury accidents}}$$

and similarly for P(B). If model A carries more passengers than model B then the denominator will contain more accidents in which a passenger was injured but the driver was not, so that $P(A)<P(B)$. This is misleading since, by hypothesis, the models have the same secondary safety and $P(A)=P(B)$. The bias arises in particular from accidents in which a car is struck on its nearside or rear, since the risk of injury is much greater for a passenger than for the driver in these accidents. This is especially important when investigating the relationship between mass and risk of injury because of the possibility that large cars carry more passengers than small cars (although, as noted in Section 2, driver characteristics are also influential).

Larger cars have greater passenger-carrying capacity than small ones, but there are no suitable survey data in Great Britain to determine whether they actually carry more passengers than small ones. If they do, the underestimate of the *true* probability is greater for heavy cars than for light and the US *mass* coefficients would be too low. The US coefficients are lower than the GB coefficients, so this is a potential explanation of the difference. It could only be verified by re-analysing the US data, omitting accidents in which only passengers were injured from the data set.

The credibility of this explanation is strengthened by a feature of the US results that is not commented upon by the authors: the effect of increasing mass on driver injury risk is strongly significant in the data from Texas but not in the Maryland data.

The consistency of the *mass* coefficients on built-up and non built-up roads has already been noted. The risk of injury rises with the speed limit, but the modelling has shown that mass influences this risk in the same way on built-up (limit ≤40 mph) and non built-up (limit >40 mph) roads. There is much greater scope for drivers of large cars to drive faster on the latter roads and experience higher impact velocities in consequence, so this provides indirect evidence that differences in driving behaviour do not influence the relationship between mass and injury risk.

3.2 Single-car accidents

The five remaining groups of accidents involve a single car, so for an accident to be included in the analysis only one VRM has to be matched instead of two for the two-car accidents. Consequently, the percentage of accidents in the Stats19 database for 1991-94 which can be included is higher: approximately 75 per cent for each group. As with the two-car accidents, it is highly likely that the accidents included form representative samples and that conclusions can safely be generalised.

The accidents studied in this Section involve just 1 car and no pedestrian or other vehicle. As with two-car accidents, only those accidents in which the driver is injured are included, in order to avoid bias resulting from passenger casualties. These accidents typically involve a car leaving the carriageway and hitting an object such as a lamp post or tree, so the risk of a driver being injured at least slightly is high and it is reasonable to assume that the number of single-car injury accidents does not vary with mass (there is no suitable source of information about damage-only accidents which would allow this assumption to be checked). The severity of drivers' injuries might vary with mass, however, so the proportion of injured drivers who are killed or seriously injured will be related to the mass of the car.

The details of the modelling are presented in Appendix A, and the results in Appendix B. Separate models were fitted for accidents on built-up and non built-up roads, but the resulting *mass* coefficients were very similar and final models were fitted for the combined data (Table A2).

The results show that in single-car accidents the proportion of injured drivers who are killed rises strongly with mass, so downsizing would reduce the number of deaths. The relationship is rather weaker for drivers killed or seriously injured. The similarity of the results for built-up and non built-up roads suggests that higher speeds among larger cars cannot explain these results, but neither is there an obvious alternative explanation.

3.3 Accidents involving vulnerable road users

These are accidents which involve just 1 car and 1 vulnerable road user (either a pedestrian, a pedal cyclist or a motorcyclist), and pedestrian accidents are considered first. Stats19 does not record the presence of uninjured pedestrians, so each of the pedestrians in the accidents recorded was killed or injured. Very few of the car drivers were injured, so the effects of downsizing will only be studied for the pedestrians. The risk of a pedestrian being injured at least slightly when struck by any car is high, so it is reasonable to expect that the number of pedestrian injury accidents would not vary with mass; however, the severity of the injuries might.

The *mass* coefficients are very similar for accidents on built-up and non built-up roads, so the final values come from models fitted to the combined data (Table A3). They indicate that downsizing would reduce the number of pedestrian fatalities but increase the number who are seriously injured. There is a possible explanation for the former result which relates to length rather than mass of car: the longer the car, the greater the risk that the pedestrian's head will strike the bonnet rather than the windscreen - impact with the bonnet is more likely to have fatal consequences.

Accidents involving 1 car and 1 two-wheeled vehicle (TWV, i.e. a pedal cycle, moped or motor cycle) are now considered. Most of the 'cyclists' are injured, but there are also risks for the car drivers: 2 per cent of the dead and seriously injured drivers and riders in these accidents are car drivers, and 5 per cent of the slightly injured. Car driver casualties are also examined, leading to parallel sets of models for driver casualties and for cyclist casualties. Once again, the *mass* coefficients for built-up and non built-up roads are very similar, so the final values come from models fitted to the combined data (Table A4).

As with two-car accidents, reducing the mass of the car increases the risk of injury for the occupants of the car and reduces the risk for the 'occupants' of the other vehicle. Thus, downsizing would be expected to *reduce* the number of cyclist casualties and *increase* the number of car occupant casualties.

As with single-car and two-car accidents, the *mass* coefficients for built-up and non built-up roads are consistent. This suggests once more that the coefficients are not the result of a systematic variation of impact velocity with mass, so the simulation should provide a reliable indication of the effects of downsizing.

3.4 Car/van accidents

These accidents involve exactly 1 car and 1 van. 'Van' is the colloquial term for the Stats19 category Light Goods Vehicle, defined as a goods vehicle not over 1.524 tonnes unladen weight (the category was redefined on the basis of gross weight from 1 January 1994). Car drivers are at greater risk than van drivers in these accidents, accounting for 91 per cent of the dead drivers in these accidents and 70 per cent of the seriously and slightly injured drivers.

Downsizing will *not* apply to the vans, with the possible exception of an indirect effect on light vans which are derived from cars, so it is only necessary for the model to investigate the relationship between the mass of the car and the risks of injury, as explained in Section 3. Preliminary analyses show very similar *mass* coefficients on built-up and non built-up roads, so the final analyses combine the two data sets with a factor to represent the greater accident severity on non built-up roads (Table A5).

The results show that the risk of injury to the van driver increases and that the risk of injury to the car driver decreases with increased car mass. This is consistent with the results for two-car accidents: reduced car mass increases the risk of injury for the occupants of the car and reduces the risk for the occupants of the other vehicle.

As vans will not be downsized, downsizing should *reduce* the number of van occupant casualties and *increase* the number of car occupant casualties: the results of the simulation are needed to determine whether the overall effect is to increase or to reduce the casualty total in these accidents.

3.5 Car/heavy vehicle accidents

Stats19 has two categories for vehicles which are much heavier than cars: ‘bus or coach’ (known as PSV) and Heavy Goods Vehicle (HGV, the heavier equivalent of the Light Goods Vehicle introduced in the previous Section). They have been grouped together because a car driver faces similarly great risks when in collision with either category of vehicle. These risks are demonstrated by the fact that car drivers account for 98 per cent of the dead drivers in these accidents, 93 and 87 per cent of the seriously and slightly injured drivers.

Once again, separate analyses for accidents on built-up and non built-up roads yield very similar *mass* coefficients, so the final analyses combine the two data sets with a factor to represent the greater accident severity on non built-up roads (Table A6).

The results follow the same pattern as for car/van accidents, so downsizing would be expected to *reduce* the number of PSV/HGV occupant casualties and *increase* the number of car occupant casualties.

3.6 Simulation results

Section 2.2 introduced the method by which the modelling results can be used to simulate the number of casualties that would have been expected in 1991-94 if all cars involved in accidents had been downsized, and discussed the underlying assumptions. The technical details are provided in Appendix A.

This section brings together the simulation results for the various groups of accidents. It also attempts to draw up an overall ‘balance-sheet’, combining the various simulated casualty increases and reductions. This is presented in Table 2, which contains the percentage changes predicted by the six sets of simulations. These percentages are then applied to the casualty numbers from the various groups of 1- and 2-vehicle accidents in 1994, to include passenger casualties (this assumes that the percentage changes found for drivers and riders will also apply for passengers). The separate changes are then summed to provide overall results for accidents involving at most 2 vehicles: those cases where the simulation of the number of slight casualties may be incomplete are indicated.

Notes discussing various details of these results follow the Table. The summary results can only be illustrative, given the qualifications that apply to the simulation process, so no confidence intervals have been estimated for the various sums. Nonetheless, as discussed in the ‘Summary’ note, the results from the individual models are sufficiently precise to be confident that the overall results are reasonably exact.

Table 2 Casualty reductions predicted for 10 per cent downsizing, based on 1994 casualty data

		killed		*ksi*		*All casualties*	
Accident involves	*Injured road users*	*% red’n*	*No.*	*% red’n*	*No.*	*% red’n*	*No.*
1 car, no pedestrian	Car occupants	8.1	42	0.6	38	-	0
1 car, ≥1 pedestrian	Others	1.2	8	-0.8	-75	-	0
1 car, 1 TWV	Car occupants	-1.5	0	-4.9	-9	-6.4	-123
	Others	1.9	5	0.4	26	0.1	22
2 cars	Car occupants	6.6	33	1.4	138	1.5	1539
1 car, 1 van	Car occupants	-2.0	-1	-7.7	-72	-3.1	-249[1]
	Others	20.6	2	17.1	61	11.2	355
1 car, 1 heavy vehicle	Car occupants	-2.9	-7	-2.5	-40	-0.4	-33[1]
	Others	33.3	1	12.2	27	11.5	380
Any	Car occupants	4.9	67	0.3	55	0.7[2]	1311[2]
	Others	1.7	16	0.2	39	1.0	758
Any	Any	3.6	83	0.3	94	0.8[2]	1889[2]

- Indicates that the change was assumed to be zero.

[1] *Indicates that the simulation of the number of slight casualties is incomplete.*

[2] *Indicates that this figure may be too large in consequence.*
A negative reduction denotes an expected casualty increase.
The % red’n figures in the last 3 rows have been calculated from the sum of the reductions, the other figures are direct modelling results.

Coverage

The table includes most of the casualties in car accidents. Table 1 showed that about one fifth of car driver casualties occurred accidents which involved three or more vehicles, and the proportion is slightly lower for passengers. Of the non-car occupant casualties in car accidents, 36 per cent of fatalities occurred in multi-vehicle accidents, and 12 and 11 per cent of the serious and slight casualties. As these multi-vehicle accidents initially involve a collision between two vehicles, the same general conclusions for two-vehicle accidents should apply to these as well.

Completeness

Section 2.1 showed that when a *mass* coefficient for ‘all casualties’ is negative then the increase in slight casualties may not be simulated fully because the increased severity would convert some damage-only accidents into accidents involving slight casualties, and the Stats19 data relate only to injury accidents. The possibility arises for car drivers when in collision with a TWV, a van or a heavy vehicle. It should not arise in the case of accidents with TWVs, however, as these ‘new’ injury accidents would involve the unusual combination of an injured car driver and an uninjured pedal cyclist or motorcyclist. The simulation is incomplete in the case of accidents with vans, so the Table slightly underestimates the increase in car occupant casualties in van accidents. The same applies in the case of accidents involving heavy vehicles, although the deficiency is probably small in view of the great risks already faced by car occupants in these collisions.

Cyclist casualties

The smallness of the reduction in the total number of cyclist casualties is noteworthy; downsizing should reduce the severity of injuries but will have little effect on the risk of a cyclist being injured to some degree when hit by a car. This provides some support for the approach adopted with pedestrians of assuming that car mass affects the severity of pedestrian casualties but not their number.

Non-linear transition in two-car accidents

It was pointed out in Section 2.2 that casualties in two-car accidents may vary non-linearly during the transition from the current to the downsized state, whereas the transition will be linear for the other groups of car accident. The reason is that there will be a mixture of fullsized and downsized cars on the roads during this period, but nevertheless the transition can be simulated using the coefficients from the regression analysis.

The method is described in Appendix C. Figure 2 shows the results, based on the assumption that downsizing will progress equally rapidly for all sizes of car (although more complex downsizing scenarios could also be evaluated). The form of the transition varies with casualty severity, as determined by the relevant set of coefficients. The number of injured drivers declines linearly as downsizing progresses, whereas the number killed or seriously injured declines slightly faster in the later stages.

Summary

Table 2 shows that the overall number of car occupants and other road users injured in car accidents would fall slightly as a result of uniform downsizing, although the reduction in slight casualties could be slightly less than shown because the simulation of car/van and car/heavy vehicle accidents is incomplete as a result of the restriction of the national accident reporting system to injury accidents. The reductions are proportionally greater for fatalities. Most of the percentage reductions are shown to be significant by the results in Appendix B, so the overall results in the final row are relatively exact. This leads to the general conclusion that the British accident data give no indication that downsizing might increase the total number of casualties.

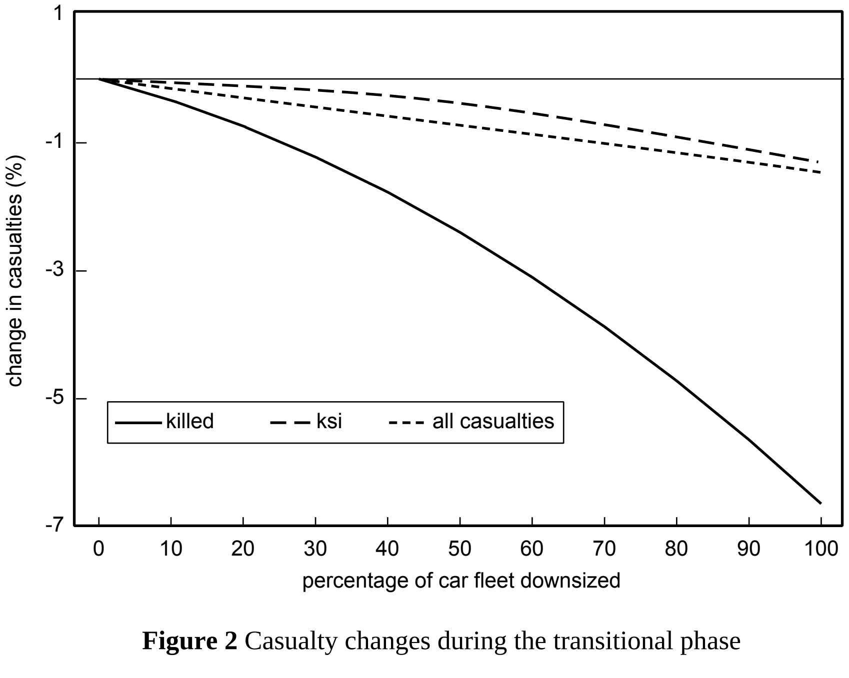

Figure 2 Casualty changes during the transitional phase

Non-uniform downsizing scenarios could be assessed using the modelling results. For accidents which involve only one car, the sign of the results would not change since mass would still reduce although not uniformly, e.g. car occupant casualties in car/van accidents would still be expected to increase, although not exactly as shown in Table 2. As explained in Section 3.1, the position is more complex for two-car accidents, and it is possible that casualties might increase with certain scenarios.

The process of downsizing would take over a decade to complete, and various other changes would affect road safety over the same period. In view of the generally small changes that are indicated, it is unlikely that these estimates could be satisfactorily checked by any future analysis of actual accident data after a policy of downsizing had been implemented.

3.7 Other studies

There have been a number of previous studies of the likely effects of downsizing, most recently a paper by Buzeman, Viano and Lösund (1998). This includes a brief review of the conclusions of these studies, which broadly fall into two groups: European studies have found that 'downsizing may improve traffic safety' while US studies have reached the opposite conclusion. This Section compares the results presented in this report with the results of the two most recent studies.

Broughton (1995)

This report developed analyses that had been carried for an earlier project which had compared alternative indices of the secondary safety of car models (see Broughton, 1994). Stats19 data were assembled for the 91 most common car models, showing their involvement in two-car accidents in 1989-92. These data showed that the probability of a driver being injured in a two-car accident tended to *fall* as the mass of the vehicle being driven rose, and to *rise* as the mass of the other vehicle rose. This raised the question of how the probability of driver injury might depend upon the *combined* mass of the two cars, with obvious implications for the question of downsizing.

The reexamination of the data from Broughton (1994) showed that combined mass had no systematic effect on the number of driver casualties, but concluded that this approach was not appropriate for studying the effects of downsizing. An alternative approach was developed, grouping the car models into mass ranges and analysing the influence of mass on various driver injury severity ratios. These analyses showed a tendency for the number of driver casualties to fall as the combined mass increases, but also a tendency for drivers to be more seriously injured in accidents which involved heavier cars.

The consequences of downsizing in two-car accidents would thus be a 'trade-off' between these two contrary tendencies, and a simple mathematical model was developed to examine this. Unfortunately, the model had of necessity to incorporate the relationship between 'p(r)', the proportion of all two-car accidents (i.e. including damage-only accidents) which involve at least one injured driver, and the combined mass of the colliding cars. As there was (and is) no suitable source of data about damage-only accidents which includes car mass, the numerical results are conditional on the relationship assumed. The sensitivity of the results to the assumed relationship was examined, but the lack of information precluded any further analysis.

The main reason for the new approach adopted in this report was to avoid the difficulties arising from the involvement of damage-only accidents. This involvement could not be avoided completely, as discussed in Section 2.2, but was greatly reduced. Only the simulation of the changes in all casualties in car/van and car/heavy vehicle accidents were affected, while two-car accidents were unaffected.

The casualty reductions predicted for two-car accidents in Broughton (1995) were greater than the predictions in Table 2: approximately four time greater for drivers KSI and twice as great for all driver casualties. This was probably caused by the assumption made about the sensitivity of p(r) to the combined mass r; the two sets of predictions can be largely reconciled by reducing the sensitivity. Thus, it appears that the methodology of the earlier report was sound, but that its dependence upon a figure which could not be estimated from available data led to exaggerated predictions (the report explained the lack of the necessary data and the consequently conditional nature of the predictions).

Buzeman, Viano and Lösund (1998)

The modelling approach followed in this paper differs considerably from the statistical approach of Broughton (1995) and of this report. Detailed models are fitted to a variety of data, using the velocity change ΔV in an accident to represent accident severity; only two-car accidents involving a frontal impact are studied. The description assumes considerable familiarity with this type of modelling and there is no account of the underlying assumptions or of their implications for simulating the effects of downsizing. This extends to the use - without comment - of relationships derived from US data to simulate possible effects on Swedish roads.

This paper could only be thoroughly reviewed by someone who is familiar with this type of modelling - and in particular with reference to the extent to which relationships derived from 'current' data can be applied to simulate the future. This issue has been considered in detail in this report but is not considered by Buzeman et al.

The effects of downsizing predicted in Table 2 in two-car accidents can compared reasonably well with certain results in the paper. This report has standardised on a uniform reduction of mass by 10 per cent, while pointing out that other scenarios could be assessed if required. Buzeman et al examine various scenarios, of which the most relevant are:

i the vehicle fleet mass is reduced by 10 per cent of the baseline average mass, i.e. the mass of each model is reduced by the same amount (which appears to be a less feasible scenario than the uniform downsizing assessed in this report);

ii the mass range about the average mass is reduced by 10 per cent.

The uniform downsizing by 10 per cent would also reduce the mass range and the average mass by 10 per cent, so results in Table 2 will be compared with the product of the results for these two scenarios.

The difference between the predictions for all casualties is slight. Table 2 estimates that a uniform reduction of car mass by 10 per cent would lead under British conditions to a 1.5 per cent decrease in driver casualties in all two-car accidents. The combination of Buzeman et al's estimates suggest that, based on Swedish conditions, the outcome would be a 0.1 per cent increase driver casualties in that subset of two-car accidents which involve frontal collisions (1.006×0.995=1.001). Given the different sets of accidents studied, the possible differences between conditions in the two countries and the likely precision of the estimates, the difference may well not be significant.

The same comparison may be made for fatalities. A 6.6 per cent reduction is predicted in Table 2, compared with an increase of 0.6 per cent predicted by Buzeman et al (1.023×0.983=1.006). This predicted increase is very modest and - if the estimate were accepted - could well be regarded as justifiable in terms of the broader benefits of downsizing.

What might account for the difference between the two predictions? Various possible explanations will be considered, a more knowledgeable review of Buzeman et al (1998) could provide others.

1. The paper selects a severe subset of two-car accidents, namely those which involve frontal collisions; it is possible that if the other subsets had also been analysed in a similar way then benefits would have been found offsetting the small disbenefit for this subset and leading to an overall benefit.
2. The impact velocity and the velocity change ΔV will normally be much greater in fatal accidents than in the typical injury accident. The fact that the two sets of results agree reasonably well for all injury accidents but disagree in the case of fatal accidents may indicate that there is a problem with the paper's treatment of high-speed accidents.
3. The modelling in the paper relies on functions representing the relationship between injury or fatality risk and ΔV, as shown in its Figure 2. The fatality data have been censored, but even so the Figure shows that the relationships do not fit the data well: the poorly-fitted points are generally for high values of ΔV. Hence, any consequences of the poor model fit for the predicted downsizing effects would be small for all injury accidents, since they are predominantly low-speed, but much greater for fatal accidents because these generally involve high ΔVs.

Both 2 and 3 suggest that the treatment of speed in the paper needs to be considered more carefully. From this perspective, the statement on p 714 that 'Vehicle mass, impact speed and injury (fatality) risk curves were assumed to be independent..' gives some cause for concern: the reasons go back to various findings of this report, in particular the conclusion from Section 3.2 that in single-car accidents the proportion of injured drivers who are killed rises strongly with mass.

It has been pointed out that a statistical model will measure the relationship between mass and injury risk, but will not explain it. One possible explanation of the greater casualty severity in accidents involving heavier cars reported by Broughton (1995) and the conclusion in Section 3.2 about single-car accidents is that, of the cars that were involved in accidents, the larger ones were being driven on the whole more aggressively or less cautiously than the smaller ones. The similarity of the Built-Up and Non Built-Up results mentioned in Sections 3.1-3.5 may be interpreted as evidence of no systematic increase in speed of impact with mass, but the results are not so clear as to rule out a limited increase.

The possibility that in the pre-accident phase larger cars tend, all things being equal, to be driven more aggressively or less cautiously than smaller cars has some credibility and cannot be dismissed easily, although it would be difficult to demonstrate empirically. Moreover, it would explain the findings summarised in the previous paragraph.

Buzeman et al assume that mass and impact speed are independent. If this is not true then their models would be biased to an extent which is difficult to assess, and the predicted consequences of downsizing would be affected. Light cars will be at less risk than shown by the modelling and heavy cars will be at more risk, so it appears that the adverse consequences of downsizing would be exaggerated. It is likely that a small variation in ΔV with mass would be sufficient to account for the difference between the fatality predictions.

Discussion

The two modelling approaches differ widely, so it is difficult to compare their strengths and weaknesses. This is accentuated by the fact that Buzeman et al make few concessions to readers who are not experienced in their specific approach, and make no attempt to consider the implicit assumptions underlying its methodology. The fact that the model is relatively detailed - much more so than the statistical model presented in this report - means that there are various parameters which have to be estimated from recent accident data, and the estimated values may not be representative of future conditions. As observed above, the crucial functions fitted to the relationship between injury or fatality risk and ΔV do not represent the data from high-speed accidents well - even for current conditions.

No model can be so complete as to be beyond criticism: the pragmatic question is whether the model captures the essential aspects of the system to be represented. The statistical model of this report adopts a high-level approach; the models are simple and effective but give little insight into the mechanisms involved. Buzeman et al take a more detailed approach and represent some of these mechanisms, but at a price: these mechanisms have to be represented mathematically, with the possibility that the parameters may change in future, and potentially important aspects such as a relationship between mass and impact velocity are omitted. It is unfortunate that the paper does not consider these broader issues, and the extent to which they might influence the results that have been obtained.

Given the differences between the technical approaches and the range of accidents studied, the predictions for all casualties agree surprisingly well. The predictions for fatalities differ to a greater extent, although these differences may result from the problems identified in the paper's modelling of high-speed accidents; a more knowledgeable review of the paper might provide other explanations.

4 Conclusions

The analyses reported above have considered the various categories of car accident in succession, examining how the mass of a car affects the risk of injury when it is involved in an accident. Previous research has indicated that mass is the appropriate measure of size, and it is highly correlated in the baseline car fleet with length, another natural measure. Although mass could well be more significant than length in certain types of accident, and length more significant in others, the existing correlation means that it is not possible to identify the separate effects statistically. Moreover, the results measure the association between mass and risk of injury, but cannot demonstrate that there is a causal link. This is normally the case with statistical analyses of road accident data where there is no possibility of independently varying the variable of interest (car size in this case) and observing the consequences. The only way of demonstrating causality would be to carry out a major experiment, involving large numbers of downsized cars.

The relationship between mass and risk of injury was then used to predict the effect on casualties of downsizing cars, specifically the effect of reducing the mass of all car models by 10 per cent (although more complex scenarios could have been assessed, this was considered to be sufficient for the purposes of this study). As with any forecast of the future, this prediction depends upon the continuation of the relationships found in the baseline car fleet. These could be affected by future development of car secondary safety through improved structural design and occupant restraint systems, as could the correlation between mass and length, and if this happened then the prediction would no longer be applicable.

The relationship found between mass and risk of driver injury for the various types of two-vehicle accidents has a consistent pattern. As the mass of a car reduces, so the risk of injury to its driver increases and the risk of injury to the driver of the other vehicle falls; because the coefficients come from a logistic regression model, it is not possible to compare results from the separate models to determine whether this effect depends upon the type of the other vehicle involved in the accident. The study of two-car accidents, where the mass of both vehicles is relevant to the simulation of downsizing, shows that a driver's risk of injury is more sensitive to the ratio of masses than to the mass of their car.

The results for two-car accidents agree largely with results from an American study, but differ in one crucial detail: the sign of the mass coefficient. It is possible that the American study was misled because it included accidents involving only injured passengers, which would tend to bias the results in favour of large cars. This could only be confirmed by reanalysing the American data.

Another common feature of the various models is the consistency of the results on built-up and non built-up roads. Accident severity is undoubtedly greater on non built-up roads, but the effect of mass on severity is the same on both types of road. This suggests that the models are measuring the effect of mass rather than of some correlation between mass and speed of impact.

These results were then used to simulate the consequences for recent accidents of an 'instantaneous downsizing', i.e. the change in casualties that would have been expected if all of the cars involved in the accidents studied had been 10 per cent lighter than they actually were. The method depends upon two assumptions. The first is that drivers will be neither more nor less likely to become involved in an accident once their cars have been downsized, so that downsizing will affect the number of casualties only by changing accident severity. This is plausible, but cannot be proved.

The second assumption is that the post-downsizing risk of injury for a driver is equal to the baseline risk for the driver of a car of the same mass. The analyses have measured the statistical relationship between risk and mass (or some aspect of car design correlated with mass), but do not explain it. The relationship might be a consequence of the laws of physics, in which case the simulation should be reliable, but alternatively it could be a consequence of driver behaviour. It has been suggested, for example, that large cars tend to be driven more aggressively than small cars, and hence to be involved in more severe accidents: this would be manifested by higher impact velocities for heavier cars. If the suggestion is true then the drivers of downsized cars would probably be more aggressive than the drivers of baseline cars of the same mass, which would cast doubt upon the assumption and the simulation results.

The possible influence of driver behaviour cannot be checked directly as impact velocity is not included in the accident data, but the consistent influence of mass on built-up and non built-up roads suggests that the relationships demonstrated between car mass and risk of injury are not explained by substantial differences in driver behaviour. There is much greater scope for drivers of large cars to drive faster on non built-up roads and experience higher impact velocities in consequence, so this consistency provides indirect evidence that differences in driver behaviour do not contribute significantly to the relationship between mass and injury risk. Hence, the second assumption appears plausible, and the simulations should reproduce the effects of downsizing reasonably accurately.

In one-car accidents, the simulation suggests that downsizing would reduce the number of deaths but have little effect on the number of serious casualties. In two-car accidents, where both vehicles would be downsized, casualties of all severities would be reduced. In other two-vehicle accidents, where only the cars would be downsized, there would be more driver casualties in the downsized cars but fewer in the other vehicles. Combining together the results from the various groups of car accidents, there should be a reduction of less than 1 per cent in the total number of casualties; the reduction in the fatality total is expected to be greater, about 3½ per cent.

It is not possible to simulate the effects of downsizing for car accidents involving three or more vehicles because of the complexity of the interactions involved. These accidents initially involve a collision between two vehicles, however, so the general conclusions for two-vehicle accidents should apply to these as well.

These results refer to the final state where the car fleet consists entirely of downsized cars, but there will be a transitional phase where current cars are progressively replaced by downsized cars. Downsized cars will coexist on the roads with older, fullsized cars during this phase, so the possibility that casualties might temporarily rise has been examined. It was assumed that downsizing would occur at a uniform rate. For those types of accident which involve one car, but possibly another vehicle which is not a car, there would be a linear transition to the state represented by the simulation. The transition could be non-linear for two-car accidents, with the number of fatalities falling less rapidly in the early stages. Overall, fatalities and casualties would fall throughout the transitional phase.

To summarise, these analyses of British accident data indicate that uniform downsizing - reducing all car masses by the same percentage - would lead to slightly fewer casualties in car accidents of all severities, with proportionately greater reductions among fatalities. Thus, as far as the evidence available from road accidents in Great Britain can predict, fears that downsizing would adversely affect road safety appear to be unjustified. If it appears in future that downsizing is more likely involve non-uniform mass reduction, it would be possible to assess alternative downsizing scenarios to check whether these conclusions still apply.

5 References

Broughton J (1994). *The theoretical basis for comparing the accident record of car models*. Project Report PR70. Transport Research Laboratory, Crowthorne.

Broughton J (1995). *The likely effect of downsizing on driver casualties in two-car accidents*. TRL Report TRL171. Transport Research Laboratory, Crowthorne.

Buzeman D G, Viano D C and Lösund P (1998). *Car occupant safety in frontal crashes: a parameter study of vehicle mass, impact speed and inherent vehicle protection*. Accident Analysis & Prevention Vol 30, No 6, pp 713-722.

Department of Transport (1995). *Road Accidents Great Britain 1994*. Stationery Office.

Francis B, Green M and Payne C (eds) (1993). *The GLIM System, Release 4 Manual*. Clarendon Press, Oxford.

Glass's Guide Service (1995). *Glass's Car Check Book 1995*.

Klein T M, Hertz E and Borener S A (1991). *Collection of recent analyses of vehicle weight and safety*. Paper presented at the 13th International Technical Conference on Experimental Safety Vehicles.

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Appendix A: Statistical details of models

A statistical model is fitted to the accident data to establish how P, the probability of someone involved in a car accident being injured at a particular severity, varies with the mass of the car or cars involved. The probability lies between 0.0 and 1.0 so logistic regression is the appropriate statistical model. The exact details depend on the particular data set, but the general model can be written:

$$\log [P/(1-P)] = A + B.\text{mass} + \Sigma D_i.\delta_i \qquad (1)$$

where $\{\delta_i\}$ are factors such as age and sex of casualty which may influence the injury probability P. These factors are included to minimise the risk of bias in the estimate of B e.g. women tend to drive smaller cars than men and are more likely to be injured once involved in an accident, so an analysis which failed to make allowance for this would misrepresent the relationship between mass and risk of injury. The coefficients $\{D_i\}$ do not contribute directly to the simulation of the effects of downsizing. The model is fitted by using the GLIM programme (Francis et al, 1993) to find the coefficients A, B and $\{D_i\}$ which best represent the probabilities P that are calculated from the accident data.

Although the use of logistic regression in (1) is necessary for technical reasons, it has one unfortunate consequence. In linear regression, a unit change in an independent variable has a constant effect on the dependent variable, so that linear regression coefficients can be readily interpreted. This is not true with logistic regression, and coefficients for different data sets cannot be compared directly. When coefficients are presented in Appendix B, the sign and significance of the coefficient (as shown by the t-statistic) are more important than the magnitude. The importance of the magnitude is as a parameter for the subsequent simulation.

Model (1) is used for all sets of accidents except two-car accidents, where the analysis must take account of two masses rather than one. The method used to handle two masses was first described by Klein et al (1991), who added one variable: *ratio_mass*, expressed as the mass of the driver's car divided by the mass of the other car. The expanded model can be written:

$$\log [P/(1-P)] = A + B.\text{mass} + C.\text{ratio\_mass} + \Sigma D_i.\delta_i \qquad (2)$$

Klein et al (1991) do not discuss the validity of using the simple ratio of the masses of the two cars, but a simple example will show that it is an unsatisfactory choice. Suppose that cars with masses of 1000 and 1500 kg collide; in modelling the risk faced by the driver of the lighter car, *ratio_mass*=1000/1500=0.667, whereas when the risk faced by the other driver is modelled, *ratio_mass*=1500/1000=1.500. Because the fitting of a Generalised Linear Model such as the logistic regression model requires that the factors act linearly, the two values should be equidistant from the central value of 1.000, which indicates that the logarithm of the ratio should be used. Tests using Stats19 data confirm that this is a better choice, but the values of B and C are little changed.

A.1 Simulation of casualty changes

The effects of downsizing for the groups of accident which involve only one car are simulated by using (1) to estimate the probability of injury that would be expected if the car mass were *mass'* rather than *mass* as a result of downsizing. To calculate the change in risk in the existing set of injury accidents, suppose that mass is reduced by a fraction θ so *mass* reduces to *mass*.(1-θ) for each model of car. If the new probability of injury is P(θ) then

$$\log [P(\theta)/(1-P(\theta))] = \log [P/(1-P)] - B.\text{mass}.\theta$$

and $$P(\theta) = 1/\{1 + 1/\exp[\log(P/(1-P)) - B.\text{mass}.\theta]\} \quad (3)$$

Thus, the relation between P and P(θ) is slightly complicated, but the overall casualty change can be assessed by summing the changes predicted by (3) over the ranges of *mass*. Note that if $B<0$ then $P(\theta)>P$ and more driver casualties would be expected; conversely, if $B>0$ there should be fewer driver casualties.

The simplest downsizing scenario is of a uniform reduction, with q constant, and all of the results presented in Section 3.6 have supposed a uniform reduction with θ=0.10. More complex scenarios in which θ varies with mass range could also be assessed if necessary.

In the case of two-car accidents, where model (2) applies, with uniform downsizing *ratio_mass* would be unchanged in all collisions but *mass* would fall for all cars. Thus, B is fundamental to the assessment of downsizing; C would only be important for assessing non-uniform downsizing, where the ratios would be affected. To calculate the change in risk more precisely, if mass is reduced by a fraction θ then

$$\log [P(\theta)/(1-P(\theta))] = A + B.\text{mass}.(1-\theta) + C.\text{ratio\_mass} + \Sigma D_i.\delta_i$$

so $$\log [P(\theta)/(1-P(\theta))] = \log [P/(1-P)] - B.\text{mass}.\theta$$

Thus, (3) is also valid for two-car accidents with uniform downsizing because the *ratio_mass* term cancels out. It is also possible to simulate non-uniform downsizing; this would require a slightly more elaborate equation including the altered mass ratios.

To see that it is unnecessary to include the mass of the other vehicle when that vehicle is of a type which will not be affected by downsizing, as argued in Section 3, consider the extension of (1) to include the mass of the other vehicle:

$$\log [P/(1-P)] = A + B.\text{mass} + E.\text{other\_mass} + \Sigma D_i.\delta_i$$

so $$\log [P(\theta)/(1-P(\theta))] = A + B.\text{mass}.(1-\theta) + E.\text{other\_mass} + \Sigma D_i.\delta_i$$

and once again

$$\log [P(\theta)/(1-P(\theta))] = \log [P/(1-P)] - B.\text{mass}.\theta$$

i.e. E does not influence P(θ).

Appendix B: Modelling results

The key statistical results from the models described in Sections 3.1-3.5 are brought together in this Appendix. The estimated coefficients and t-values are presented in Tables A1-A6, together with results measuring the overall fit of the models. The simulated casualty changes have been shown in Table 2 (the columns headed '% red'n') and are not repeated here; the statistical significance of each estimated reduction is shown by the t-value of the corresponding *mass* coefficient.

The overall fit of a logistic regression model is assessed from its scaled deviance and the number of degrees of freedom (Francis et al, 1993). The scaled deviance is distributed as χ^2, so it is possible to calculate P_{inc}, the probability that the model is incomplete, i.e. that elements not included in the model (other variables, or interactions between variables that are included) influence significantly the dependent variable - the probability of injury. Thus, if P_{inc}=0.0 then the model fully represents the factors influencing the dependent variable. At the other extreme, if P_{inc}=1.0 then influential factors are omitted from the model.

Note that the statistical significance of the coefficient increases as the number of driver casualties increases with the broadening of the injury severity. This suggests that the lower precision of the killed and ksi results for built-up and non built-up roads is caused by the relatively small number of casualties, rather than the absence of any genuine influence of *mass* on the risk of injury.

There is no generally-accepted level of P_{inc} which separates 'complete' from 'incomplete' models, but note that 20 of the 31 models $P_{inc} \leq 0.90$, for example. Ideally, P_{inc} would be as low or lower in all cases, but this could only be achieved at considerable cost, collecting additional data and developing more elaborate models. Indeed, it is quite possible that the 'missing' influences cannot be represented by available data and that no real improvement would be feasible.

There would only be cause for concern in the present study if there are models:

- which are clearly incomplete; and
- where it is likely that the missing influences bias the estimation of the *mass* coefficients and consequently provide a misleading simulation of the effects of downsizing.

In the case of two-car accidents, the fatality models are complete and indicate that downsizing would lead to fewer casualties. The other models may be incomplete; they also indicate that downsizing would reduce casualties, but to a

Table B1 Mass-related coefficients and deviance statistics, two-car accidents (Section 3.1)

	Ratio_mass	*t*	*Mass*	*t*	*Scaled deviance*	*Degrees of freedom*	P_{inc}
Built-up roads							
Drivers killed	-3.252	-6.09	.8793	1.06	176	380	0.00
Drivers ksi	-1.345	-17.4	.1521	1.29	413	380	0.88
Drivers injured	-2.043	-59.3	.3257	6.66	540	380	1.00
Non built-up roads							
Drivers killed	-1.927	-7.80	.7164	1.93	316	371	0.02
Drivers ksi	-1.123	-15.6	.1624	1.51	420	371	0.96
Drivers injured	-2.218	-42.3	.4072	5.56	460	371	1.00
All roads							
Drivers killed	-2.162	-9.63	.7490	2.21	507	758	0.00
Drivers ksi	-1.228	-23.3	.1615	2.03	873	758	1.00
Drivers injured	-2.097	-72.9	.3511	8.64	1050	758	1.00

Table B2 Mass-related coefficients and deviance statistics, single-car accidents (Section 3.2)

	Coefficient				
	Mass	*t*	*Scaled deviance*	*Degrees of freedom*	P_{inc}
Drivers killed	0.892	4.67	122	110	0.788
Drivers ksi	0.085	1.26	131	110	0.920

Table B3 Mass-related coefficients and deviance statistics, pedestrian accidents (Section 3.3)

	Coefficient				
	Mass	*t*	*Scaled deviance*	*Degrees of freedom*	P_{inc}
Pedestrians killed	0.125	1.04	220	147	0.999
Pedestrians ksi	-0.112	-2.76	159	147	0.768

Table B4 Mass-related coefficients and deviance statistics, car/cycle accidents (Section 3.3)

	Mass	*t*	*Scaled deviance*	*Degrees of freedom*	P_{inc}
Car drivers killed	-3.017	-2.01	37	108	0.000
Car drivers ksi	-0.521	-1.65	103	108	0.385
Car drivers injured	-0.712	-7.22	155	108	0.998
Cyclists killed	0.202	0.99	157	149	0.694
Cyclists ksi	0.053	1.12	183	149	0.969
Cyclists injured	1.120	4.67	104	149	0.002

Table B5 Mass-related coefficients and deviance statistics, car/van accidents (Section 3.4)

	Mass	*t*	*Scaled deviance*	*Degrees of freedom*	P_{inc}
Car drivers killed	-0.219	-0.43	99	107	0.312
Car drivers ksi	-0.918	-6.04	117	107	0.766
Car drivers injured	-1.930	-16.43	141	107	0.998
Van drivers killed	2.132	1.74	39	102	0.850
Van drivers ksi	1.996	9.61	97	102	0.366
Van drivers injured	2.022	21.50	115	102	0.815

Table B6 Mass-related coefficients and deviance statistics, car/heavy vehicle accidents (Section 3.5)

	Mass	*t*	*Scaled deviance*	*Degrees of freedom*	P_{inc}
Car drivers killed	-0.317	-1.21	122	107	0.847
Car drivers ksi	-0.331	-2.84	112	107	0.650
Car drivers injured	-0.904	-4.51	112	107	0.637
PSV/HGV drivers killed	3.826	2.58	18	89	0.000
PSV/HGV drivers ksi	1.354	3.86	86	89	0.440
PSV/HGV drivers injured	1.452	11.81	108	89	0.916

lesser extent. Thus, if the estimation of the *mass* coefficient has been biased in these cases, it would have led to an *underestimation* of the benefits of downsizing.

The other sets of models can also be assessed in the same light, comparing the results from models which are probably complete to those which are clearly incomplete. This suggests that the conclusions presented in Section 4 about the effects of downsizing are probably reliable, although there may be room for doubt in isolated instances such as pedestrian fatalities.

Appendix C: Transitional effects in two-car accidents

This section describes the method used to simulate the transitional effects for two-car accidents, the results of which were presented in Section 3.6. Suppose that the models in each mass range m are succeeded by downsized cars in mass range m^D and, for any pair of (fullsized) ranges m_1 and m_2, consider the accidents which involve:

i 1 car which is either a fullsized car from mass range m_1 or a downsized car from the corresponding mass range m_1^D,

ii 1 car which is either a fullsized car from mass range m_2 or a downsized car from the corresponding mass range m_2^D,

At a time when the proportion of downsized cars has risen to t, the expected proportions of fullsized and downsized cars in this type of accident are as follows:

		Mass range m_1 or m_1^D	
		Fullsized	*Downsized*
Mass range	Fullsized	$(1-t)^2$	t(1-t)
m_2 or m_2^D	Downsized	t(1-t)	t^2

Clearly, when t=0 then all cars are fullsized, when t=1 all are downsized and for intermediate values a certain proportion of accidents involve one fullsized and one downsized car. In order to calculate the expected number of driver casualties, let:

$R(m_i,m_j)$ = risk of injury for the driver of a car of mass m_i when in collision with a car of mass m_j, as calculated by the appropriate logistic regression model,

$N(m_i,m_j)$ = number of two-car accidents in the Stats19 accident data which involve fullsized cars of mass m_i and m_j,

so the expected number of casualties is

$$N(m_1,m_2).\{(1-t)^2[R(m_1,m_2)+R(m_2,m_1)]+ \\ t^2[R(m_1^D,m_2^D)+R(m_2^D,m_1^D)]+ \\ t(1-t)[R(m_1,m_2^D)+R(m_2^D,m_1)+R(m_1^D,m_2)+R(m_2,m_1^D)]\}$$

The calculation is repeated for each pair of mass ranges, and the results summed.

This description has assumed that downsizing will progress equally rapidly for all sizes of car. It could be elaborated to include differential rates of progress.

Abstract

The principal aim of downsizing - reducing the mass and/or size of cars - is to improve fuel efficiency and reduce atmospheric pollution, but it has been argued that this would increase the number of casualties in car accidents. This report studies the relationship between car mass and risk of injury using British accident data for 1991-94, and the results are used to predict the effects of downsizing upon the number of casualties among car occupants and other road users involved in car accidents. It is recognised, however, that future development of car secondary safety through improved structural design and occupant restraint systems may significantly affect the relationship and hence the validity of the predictions.

The report concludes that uniform downsizing - reducing all car masses by the same percentage - would lead to slightly fewer injured car occupants and non-car occupants, with the number of fatalities falling rather more (proportionately) than the total number of casualties. As far as the evidence examined in this study is able to indicate, fears that downsizing would adversely affect road safety appear to be unjustified.

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