Are crashworthiness and fuel economy necessarily conflicting outcomes?

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Abstract

It has been demonstrated that larger, heavier cars generally provide more protection for their occupants, although they may be more likely to injure other road users. Smaller, lighter cars generally have better fuel economy. Some government agencies have programs that encourage consumers to purchase safer cars as measured by crashworthiness ratings; while other government agencies encourage consumers to purchase cars with good fuel economy. Consumer may find these messages contradictory. This analysis compares the Used Car Ratings calculated by Monash University Accident Research Centre with the official fuel consumption figures published by the Australian Greenhouse Office. It demonstrates that while there is a general negative correlation between crashworthiness rating and fuel economy, there is considerable scatter about the line of best fit. Particular makes and models of cars were identified as performing well on both crashworthiness and fuel economy while other makes and models of cars were shown to perform relatively poorly. The limitations of the study relate to the use of official fuel economy figures rather than in-use values and the relative variability of the published fuel economy figures compared to crashworthiness ratings. Nevertheless, further development of this type of approach of identifying cars that perform well on several dimensions may be useful.

Introduction

A car's physical construction affects both its safety and its fuel economy. The passive safety of vehicles has two components – crashworthiness and aggressivity. Crashworthiness is the ability of the vehicle to protect its occupants when a crash occurs. Aggressivity is the threat that the vehicle poses to the occupants of other cars or unprotected road users with whom it collides. A larger and/or heavier car will generally be more crashworthy but pose a larger threat in terms of aggressivity (Buzemann, 1997, IIHS, 1998). However, a smaller, lighter car is likely to be more fuel efficient than a larger, heavier car (e.g., US EPA, 2001; Van den Brink and Van Wee, 2001). Manufacturers have moved to improve fuel consumption to satisfy government requirements and consumer desires, which has resulted in a reduction in the average weight of many car types and models. This in turn generally leads to a decrease in the car's crashworthiness (although aggressivity may actually improve).

A number of organisations have developed methods for rating the crashworthiness and aggressivity of vehicles. Monash University Accident Research Centre (MUARC) has been computing vehicle crashworthiness ratings since 1994 (see Newstead, Cameron & Lee, 2000). The crashworthiness rating of a vehicle is defined as the risk of serious injury (death or hospitalisation) a vehicle poses to its driver given involvement in a crash of sufficient severity for at least one vehicle to be towed from the crash scene. The aggressivity of vehicles in two-car collisions is measured in terms of the proportion of drivers involved in crashes with that vehicle of towaway or greater severity who were injured (Newstead et al, 2000). The results are reported in technical reports and in consumer brochures. In the brochures, crashworthiness is colour-coded (ranging between green for "significantly better than average" to red for "significantly worse than average"), while aggressivity is rated as "significantly better than average", "significantly worse than average", or "indistinguishable from average". Few vehicles are shown as significantly better than average on both scales.

The Australian Greenhouse Office regularly issues guides that detail the fuel consumption of new vehicles so that vehicles of the same class can be compared according to their rate of use of fuel. These official fuel consumption figures are the results of tests carried out in accordance with Australian Standard 2877 for fuel consumption testing. The testing is carried out under identical, controlled conditions in a laboratory to allow for comparisons between vehicles.

There are two fuel consumption tests: one for city driving and one for highway driving. The city driving test simulates a 12-km, stop-and-go trip with an average speed of 32 km/h. The test includes time spent idling and cold and hot starts. The highway driving test represents 'non-city' driving over a distance of 16.48 km, at an average speed of 77 km/h. The test is run from a hot start and has little idling time and no stops (Australian Greenhouse Office, 2000). The in-service fuel consumption of vehicles is generally higher than that quoted in the official fuel consumption figures. A study of the in-service fuel consumption of the Australian passenger car fleet found that on average drivers used 15 per cent more fuel than the Guide figure in city conditions and 34 per cent more in highway driving (study cited in Australian Greenhouse Office, 2000).

Consumers are also encouraged to factor fuel efficiency into their purchasing decisions. All new cars sold in Australia must now carry a label detailing the model's fuel consumption performance.

At face value it would seem that organisations encouraging consumers to buy fuel efficient cars and therefore do their part to help the environment and save money on running costs are working at cross purposes to other (or sometimes the same) organisations promoting safety, as a lighter vehicle will generally use less fuel but be less safe from the point of view of its occupants.

The tension between crashworthiness and fuel economy is reflected in a relatively recent re-examination of the US government's push to increase the overall fuel economy of its national fleet. In 1975 the US government implemented the Energy Policy and Conservation Act to reduce the dependence of the US on imported petroleum. Part of this legislation was the Corporate Average Fuel Economy (CAFE) requirement, which stipulated that the average fuel economy for a manufacturer's fleet of new models be 27.5 miles per gallon (8.7 km/100 litres) from the 1985 model year and beyond. The principal method used by manufacturers to meet the CAFE requirement was to produce a series of smaller, lighter cars at lower selling prices with substantially better fuel economy. In this way any particular manufacturer was able to attain an average fuel economy for its new fleet within the 27.5 mpg limit. The proliferation of these smaller, lighter cars was assisted in the late 1970s and early 1980s by a consumer preference of smaller vehicles, likely driven by the oil crisis at the time.

A number of studies analysed the safety effects of the downsizing of the fleet (summarised in Committee on Fuel Economy of Automobiles and Light Trucks, 1992). Crandall and Graham (1988 in Committee on Fuel Economy of Automobiles and Light Trucks, 1992) reviewed a number of these studies and concluded that the 14% reduction in the average weight of 1985 cars caused by CAFE standards was associated with a 14 to 27% increase in occupant fatality risk.

Sport utility vehicles (SUVs) are currently not subject to the 27.5 mpg CAFE requirement (and neither are minivans). Due to their popularity in the US and Australia, requiring SUVs to meet a fuel economy limit is likely to impact a large number of vehicles and possibly see their ride height lowered to improve fuel economy through lower aerodynamic drag and the weight of the heavier models decreased – both measure will improve the fuel economy of these vehicles and improve their aggressivity, without necessarily increasing their crashworthiness substantially.

Consumers are currently provided with two separate measures to consider when purchasing a vehicle: crashworthiness (and sometimes aggressivity) and fuel economy. These measures may appear to be conflicting. This has the potential to either confuse the purchaser or press them into basing their decision on only one of the measures; in which case they may be forced to choose between costs (smaller cars are generally cheaper to buy and cheaper to run) and the safety of themselves and their families (smaller cars generally have worse crashworthiness ratings). This paper reports analyses of the extent to which the measures are conflicting and seeks to identify vehicles that perform well or badly on both measures.

Method

Crashworthiness scores for 1982-1997 model cars were sourced from real-world crash calculations (Newstead, Cameron & Le, 2000). Where it existed, the fuel economy for each four-door passenger car listed in the crashworthiness ratings was determined from the Australian Greenhouse Office website (www.ago.gov.au). Fuel economy values were selected separately for cars with manual and automatic transmissions, and for city and highway driving – both transmission type and type of driving affect fuel economy.

Each of the four sets of fuel consumption values (city manual, highway manual, city automatic and highway automatic) were graphed against crash rating in scatter plots. (Due to the available space, only the performance for manual cars is presented here, however a similar patterns were evident for automatic cars.). Higher fuel consumption values represent higher running costs in terms of more fuel used per kilometre travelled (usually expressed as number of litres per 100 kilometres traveled). Higher crash rating values signify a worse outcome for the car's occupants. R-square values (the coefficient of determination, or the percentage of variance in one set of scores related to the variance in the other set of scores) are used as an expression of the degree of correlation between the variables.

Each horizontal tick in Figures 1 and 2 represents a car model (or series of models if the crash rating and fuel consumption was consistent across models). The vertical lines signify the fuel consumption range as published by the AGO. The data indicates an often very large variation in fuel consumption for a number of cars. Both crashworthiness and fuel consumption values were available for 87 separate models (or series).

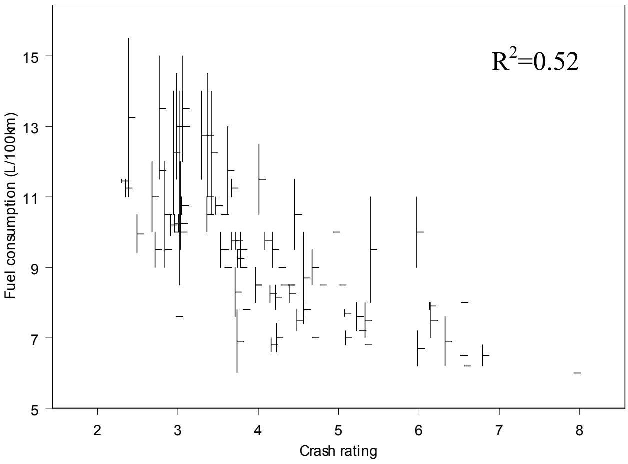

Figure 1. City fuel consumption plotted against crashworthiness score for manual cars.

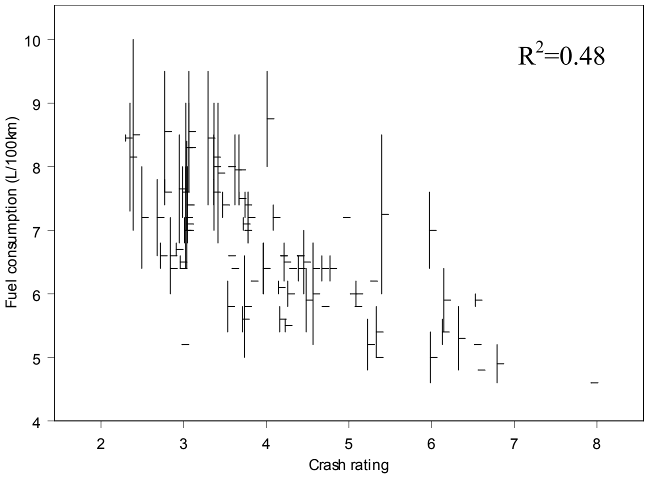

Figure 2. Highway fuel consumption plotted against crashworthiness score for manual cars.

The R-square value can be improved by removing high performance vehicles such as SS Holden Commodores and XR Ford Falcons (for example, R-square for the manual city data increases to 0.55 under these conditions). R-square is further improved by removing cars with a large degree of variability in their crashworthiness ratings (e.g. removing high performance vehicles and limiting the crash ratings to three times the confidence interval produces an R-square of 0.67 for the manual city data).

In order to potentially use these relationships to assess individual cars, the high performance cars were removed from Figures 1 and 2 (except for the Subaru Impreza due to the number of vehicles sold) and only the mean fuel consumption value used for vehicles with a variable fuel consumption value. Those cars that fell outside the 95% confidence interval from the best fit line were then identified. This is shown in Figures 3 and 4 – again only manual cars are shown. Approximately 8% of the overall number of models fell outside the confidence interval for the city cycle and 6% of the cars occupied this space for the highway cycle.

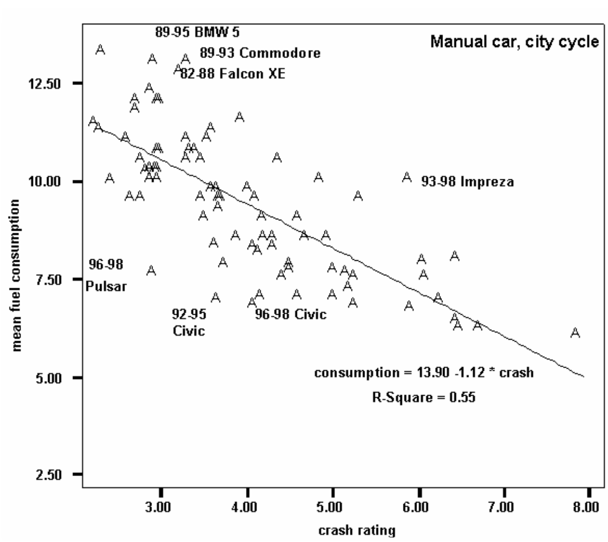

Figure 3. City fuel consumption plotted against crashworthiness score for manual cars, with outlying cars identified.

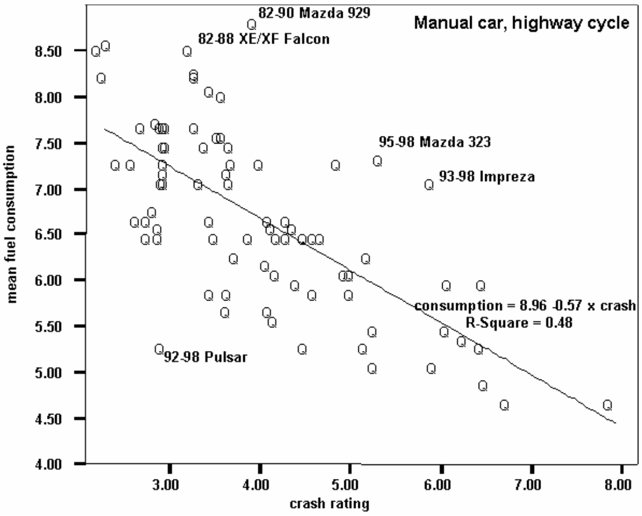

Figure 4. Highway fuel consumption plotted against crashworthiness score for manual cars with outlying cars identified.

Ideally a car will have a low fuel consumption and low (i.e. good) crash rating. Relative to the performance of other vehicles, these cars will appear towards the lower left-hand end of Figures 3 and 4. Cars below the best fit line but towards the right-hand edge of the graph represent a trade-off between fuel economy and safety (although this may not have been the manufacturer's intention) – they will be cheap to run but not overly protective of their occupants in the event of a crash. Cars towards the upper left quadrant of the graph would represent a trade-off in the other direction – safer but more expensive to run. Cars in the upper right quadrant are the worst performing – unprotective in a crash and expensive to run.

A number of points of interest are identifiable from Figures 3 and 4. Cars outside the confidence interval for the city cycle are not necessarily the same cars that appear outside the confidence interval for highway driving. Only a Ford Falcon and a Subaru Impreza fit this description – the former is relatively safe but has poor fuel economy and the latter is less safe and has lower fuel economy than expected (although not particularly well performing in terms of fuel economy).

It would be expected that smaller cars would appear in the lower right quadrant of the graph (good fuel economy but relatively unsafe). No cars appear in this area (i.e. outside the 95% confidence intervals). It might also be expected that larger cars would appear in the upper left quadrant of the graph (better performing in a crash but more expensive to run). An early model Ford Falcon, Mazda 929, Holden Commodore and a BMW all appear in this area.

The best performing cars in terms of safety and fuel usage are the mid-sized Nissan Pulsar and the Honda Civic – a small car.

Discussion

The results show that while there is a general negative correlation between rated crashworthiness and published fuel consumption figures, there is considerable scatter around the line of best fit. Some vehicles perform relatively well on both crashworthiness and fuel consumption measures. Analyses of this type have the potential to affect vehicle purchasers by consumers who are concerned about safety and the environment (or the cost of fuel).

Crashworthiness need not necessarily be traded-off against aggressivity or fuel economy – without considering next-generation technologies such as alternative fuel sources or alternative engine types, there is the potential to modify current mass-production cars to maximise safety and fuel economy. To maximise fuel economy the car must be as light as possible and as aerodynamic as possible. If light-weight alloys are used in the manufacturing process and the engine is sufficiently- rather than overly-powerful then the size of the car need not be minimised.

Design alterations can improve both crashworthiness and aggressivity, or at least improve one factor without compromising the other. In this way injuries can be minimised in any given crash (both single- and multi-vehicle crashes). For example, if the larger car's crumple zones are "weaker" than those of the lighter car (or weaker than the lighter car itself), then the larger car should absorb more of the impacting energy than it otherwise might. Alternatively, the crumple zone in the larger vehicle can be designed to crush at the same rate and degree as that of a lighter car, so that they absorb the same amount of energy. Indeed, a larger vehicle can be equipped with a larger crumple zone of a slightly lighter material so that it will absorb more energy than the lighter vehicle. In both cases the occupants of the larger vehicle are likely to be "safer" due to the extra space they have before striking any internal parts of the car, especially if the larger car is equipped with airbags. Making the crush zones stiffer for the lighter car is likely to decrease the safety levels for its occupants where a crash between two light cars may occur, or a crash between a light car and a rigid object such as a tree.

In order to achieve an overall degrease in fatalities (or injuries) in terms of crashworthiness and aggressivity, it is important to consider the frequency with which crashes between incompatible vehicles actually occurs. The IIHS (1999) points out that in the US, the percentage of crashes that actually occur between vehicles of incompatible weights and sizes is in reality relatively low. The number of crashes involving an occupant death is much higher for crashes between two cars of similar size/weight and in single-vehicle crashes. A distribution of car occupant deaths by crash type in the US indicates that around 40% occur in single-vehicle crashes, around 20% are car-car (i.e. "within" the car class rather than between classes), around 10% involve more than two vehicles, and in 4% of cases the other vehicle is not listed. This leaves around 26% of crashes where there is a crash incompatibility issue. In terms of injuries, around 30% of occupant injuries occur in single-vehicle crashes, 28-47% occur in car-car crashes (38% for all cars, 47% for light cars and 28% for heavy cars), 10-22% of these crashes involve more than two vehicles, and in around 2% of cases the other vehicle is not listed. Around 15% of crashes involve incompatible vehicle classes. However, it should be noted that this applies to crashes between classes, rather than weight mismatches within classes.

IIHS (1999) analysed five scenarios in comparison to the current situation in the US: eliminating the lightest cars from the fleet, eliminating the lightest cars and utility vehicles, eliminating the heaviest cars, eliminating the heaviest cars utilities and pickups, and eliminating the heaviest utilities and pickups. The analyses were conducted using 1997 deaths and assumed that the fleet consisted of 1990-1996 models. In each case the occupants of the removed vehicles were displaced to remaining vehicles in the same class of vehicle (for example, in the scenario where the lightest cars are removed these occupants were placed in heavier cars). In terms of overall deaths, removing the lightest vehicles is a significantly more beneficial option than removing the heavier vehicles, and "putting occupants of heavier cars into lighter cars would actually lead to more deaths" (p5). They conclude that more effort needs to be made in protecting vehicle occupants in all types of vehicles rather than focussing on vehicle incompatibility issues. This improves the outcome for occupants in most crashes, including single-vehicle crashes.

Ross and Wenzel (2002) suggest a number of measures for making vehicles lighter without reducing their size and making smaller cars a little larger without making them heavier. They suggest that this move to a narrower weight range could save more than 2,200 lives per year in two-vehicle crashes, along with an increase of 400 deaths per year due to single-vehicle crashes with stationary objects. There would also be a substantial improvement in overall fuel economy.

Conclusions

Environmental groups and safety organisations generally encourage consumers to prioritise fuel economy and safety respectively, and aiming for maximum fuel efficiency or maximum safety is likely to result in a trade-off between these factors. Enacting legislation, such as the US CAFE regulations also seems to generate a trade-off. There appears to be little encouragement of consumers to assign safety and running costs at an approximately equivalent priority. Indeed the rating scales for these measures – windscreen stickers denoting fuel economy and crash ratings demonstrating safety level – may be seen as contradictory.

The approach taken here of combining a car's fuel economy with its crashworthiness may provide a way forward. Any rating scale that combines these elements will encourage manufacturers to aim for high ratings and consumers to purchase those cars that rate highly. Likewise, CAFE-type legislation based on such a scale should not lead to the downsizing of the fleet and therefore a decrease in the overall level of safety. Any final rating formula could also factor in weight and or aggressivity, although it is not clear how weightings would be applied. Regardless of the complexity of the system, a single score (or placement in a green band for good, yellow for acceptable and red for poor) would make a consumer's purchasing decision substantially easier.

It should be noted that in these analyses the fuel economy figures used are official estimates rather than real-world values. However, as cars are being compared with each other using values from the same source it is not expected that the use of real-world values would significantly alter the above graphs – although the y-axis may be shifted up as generally official fuel use figures underestimate actual values. It should also be noted that the crashworthiness ratings used are derived from actual crashes rather than crash tests such as NCAP. Due to the small number of NCAP values available and the fact that they are mostly for relatively recent models, NCAP ratings could not be used. However, if the approach is considered sound and an overall rating equation developed, NCAP values might be used in the rating formula to score a particular car.

References

Australian Greenhouse Office (2000). Fuel consumption guide 2000-2001. (20th ed) Canberra: AGO. http://www.greenhouse.gov.au/transport/fuelguide/fcg00_01.pdf

Buzeman, D. (1997). Car-to-car and single car crash compatibility: Individual effects of mass, structure, stiffness and geometry. Thesis for the degree of Licentiate in Engineering. Chalmers Institute of Technology.

Committee on Fuel Economy of Automobiles and Light Trucks. (1992). Automotive fuel economy: How far should we go? Washington, D.C.: National Academy Press.

Insurance Institute for Highway Safety (1998). Crash compatibility: How vehicle type, weight affect outcomes. Status Report, 33(1), 1-12.

Insurance Institute for Highway Safety (1999). Putting the crash compatibility issue in perspective. Status Report, 34(9), 1-11.

Newstead, S., Cameron, M., & Le, C (2000). Vehicle crashworthiness and aggressivity ratings and crashworthiness by year of vehicle manufacture: Victoria and NSW crashes during 1987-98; Queensland crashes during 1991-98. Report 171. Melbourne: Monash University Accident Research Centre.

Ross, M., & Wenzel, T. (2002). Losing weight to save lives: A review of the role of automobile weight and size in traffic fatalities. Presentation to the Forum on Physics and Society, 1/2002. www.eps.org/aps/units/fps/jan02/a2jan02.html

US Environmental Protection Agency and US Department of Energy (2001). Fuel economy website. www.fueleconomy.gov

van den Brink, R. and Van Wee, B. (2001). Why has car-specific fuel consumption not shown any decreases since 1990? Quantitative analysis of Dutch passenger car-fleet specific fuel consumption. Transportation Research Part D: Transport and Environment, 6, 75-93.