The Statistical Accuracy Of Delta-V In Systematic Field Accident Studies

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ABSTRACT

Much attention has been paid to the importance of calculating delta-V (the change of velocity during impact) and other impact severity measures accurately. However delta-V cannot be evaluated in every case sampled by a systematic study of road accidents. This can lead to statistical distortions if the subsample of cases for which delta-V is calculated is not representative of the whole sample. This problem has received less recognition than the problem of calculating delta-V accurately when it is calculated. This paper contains new results on the accuracy of CRASH3 delta-V for European passenger cars and a discussion of the problem of calculating delta-V for a representative subsample. On the data available, CRASH3 underestimates delta-V for rigid and deformable barrier impacts but not frontal car-to-car impacts. The statistical results obtained using any single method for calculating delta-V are likely to be unrepresentative of certain classes of impact type, impact severity and collision partner. A flexible approach towards using a variety of methods to evaluate delta-V is necessary to counter this difficulty.

1. INTRODUCTION

Problems with the accuracy of programs such as CRASH3, WINSMASH and EDCRASH are often thought to centre on the selection of *stiffness values*. Vehicle stiffness values link vehicle damage to energy dissipation and thus to delta-V, the change of velocity during impact. When delta-V is used for individual cases, e.g. in litigation, it may be right to focus primarily on stiffness values. However for governments, manufacturers or researchers making use of statistical results from systematic field studies such as the UK Co-operative Crash Injury Study (CCIS) or the US National Automotive Sampling System (NASS), there are other issues of comparable importance. High among these is whether the subsample of cases for which delta-V and other impact severity measures is calculated is representative of the whole sample. No method of assessing delta-V is equally applicable to all impact types, all levels of impact severity, and all collision partners. This raises the question whether any *statistical* result, such as the 50th-percentile delta-V for driver fatality in frontal impacts, is distorted by subsample bias. The method in CRASH3 for calculating delta-V from vehicle damage cannot be applied to under-run impacts for example. But frontal under-run impacts are particularly dangerous. The exclusion of this class of accident from the statistical result could mean that many fatalities at low impact speeds are not taken into account.

Improved stiffness values for individual car models have been published in the United States for a number of years. This is a worthwhile and important activity. The results discussed and summarised in section 2 are a contribution towards the development of improved stiffness values for European vehicles. The discussion in section 3 is intended to draw attention to the importance of calculating delta-V for a representative subsample of cases. This is necessary for impact severity results from systematic studies to be statistically reliable.

2. THE ACCURACY OF DELTA-V FOR CRASH TEST VEHICLES

The damage-based routines of programs such as CRASH3, WINSMASH and EDCRASH are able to provide estimates of delta-V from measurements of vehicle crush and other information about the crashed vehicles. The accuracy of this method may be checked by treating crash-tested vehicles as if they were from real accidents, and comparing the calculated value of delta-V to the known test conditions. The results in this section summarise recent findings on 137 European passenger cars. (1) (2)

Figure 1 shows the results for 91 frontal impacts. These include 22 car-to-car tests, 25 impacts into rigid barriers, and 44 impacts into deformable barriers. The cluster of frontal EuroNCAP results is clearly visible as a dense vertical line at 64 km/h. It is important to recognize that the energy dissipated by deformable barriers, as in all EuroNCAP tests, has a significant influence on the calculated delta-V but cannot be computed using CRASH3. The deformable barrier cases therefore reflect the combined effect of the accuracy of CRASH3 in modelling the passenger cars and the accuracy of the authors in estimating the energy dissipated by the barriers. The change of velocity for car-to-car impacts is on average slightly overestimated (by 2 km/h or 5%) whereas the change of velocity for rigid barrier impacts is more highly underestimated (by 10 km/h or 21%). As the stiffness values for CRASH3 were originally set by reference to rigid barrier impacts, these results are consistent with the idea that contemporary passenger cars are stiffer than they used to be. (Stiffer cars dissipate more energy than CRASH3 'realises' and consequently tend to have delta-V underestimated.) It is conceivable that the superior accuracy for car-to-car impacts is due to the penetration of stiff structures from each vehicle into soft regions of the other, in a manner that is not possible with rigid barriers. This could lead to the vehicles manifesting a lower stiffness in car-to-car impacts than rigid barrier impacts.

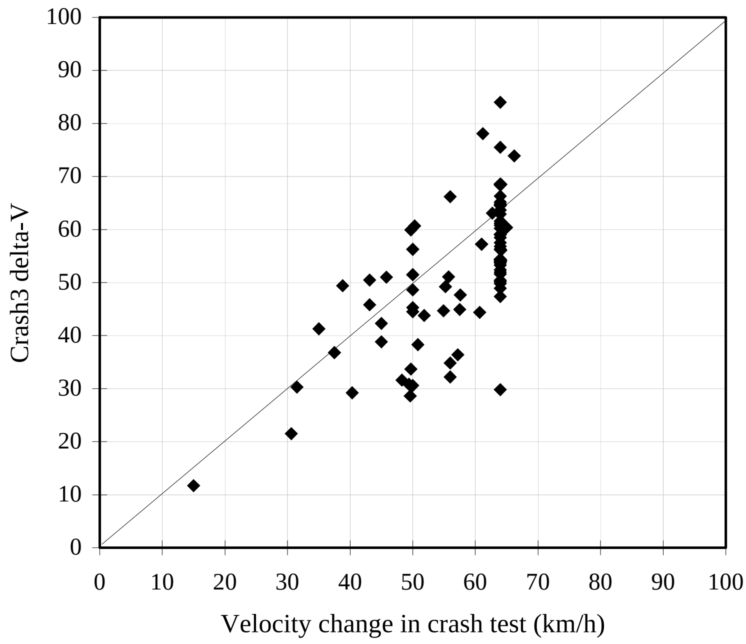

Figure 1: Actual Versus Calculated Velocity Change for Frontal Impacts

Figure 2 shows the results for 44 side impacts. These include 5 impacts into rigid barriers and 39 impacts into deformable barriers. The deformable barrier results are on average slightly underestimated (by 1 km/h or 6%) compared to the rigid barrier results (6 km/h or 27%). This resembles the results for frontal impacts, although it needs to be noted carefully that a CRASH3-independent estimation of the energy dissipated by the deformable barriers influences those calculations.

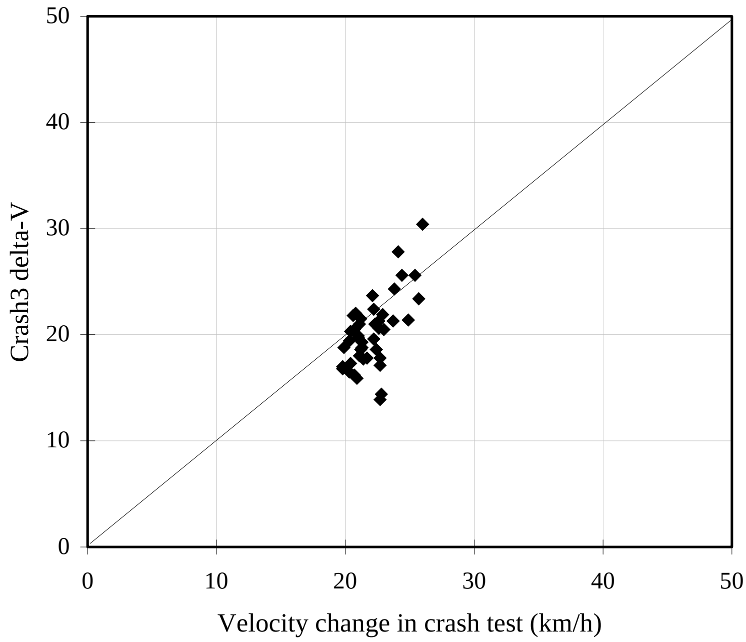

Figure 2: Actual Versus Calculated Velocity Change for Side Impacts

For all 137 vehicles, the mean absolute error was -4 km/h (an underestimate of 4 km/h) with a standard deviation of 8 km/h. This corresponds to a mean relative error of -9%, i.e. on average the change of velocity during impact was underestimated by 9%. These statistical results are summarised in table 1.

Table 1: Statistical Properties of CRASH3 Results

		Absolute error (km/h) $\Delta V_{CRASH3}-\Delta V_{test}$		Relative error (%) $(\Delta V_{CRASH3}-\Delta V_{test})/\ \Delta V_{test}$	
Impact type	Vehicles	mean	standard deviation	mean	standard deviation
Front	91	- 5	9	- 9	17
car to car	22	+ 2	7	+ 5	13
rigid barrier	25	- 10	11	- 21	19
deformable barrier	44	- 5	7	- 8	12
Side	44	- 2	3	- 9	12
rigid barrier	5	- 6	N/A	- 27	N/A
deformable barrier	39	- 1	2	- 6	9
Rear					
rigid barrier	2	- 4	N/A	- 19	N/A
Total	137	- 4	8	- 9	15

3. THE STATISTICAL ACCURACY OF DELTA-V FOR A GROUP OF CASES

In every systematic field study of road accidents, no matter which method of assessing impact severity is used, it is not possible to estimate impact velocity, energy dissipation and so on in every case. Information on what percentage of cases from a whole sample have delta-V calculated is not always readily available. Reports and publications tend to focus on describing the subset of cases for which the relevant measure of impact severity (typically delta-V, ETS or EES) *is* available. A statistical result from such data might be that 50% of occupant fatalities in frontal impacts occur below a certain impact speed; and this might be used to support crash testing at certain speeds or to demonstrate improvements in vehicle occupant protection. Yet this result may be based on perhaps only 25-60% of the whole sample. It needs to be considered whether the subsample of cases for which an estimate of impact severity is achieved is representative of the overall sample in impact severity, impact type, and collision partner. In the remaining part of this discussion, we focus on the damage-based method of CRASH3 with which we are most familiar, but exactly the same considerations apply to methods based on evidence from the scene of the accident and even to results from accident recorders.

Collision partner. When delta-V, the change of velocity during impact, is calculated from vehicle damage, it is necessary to estimate the *total* energy dissipated during the crash. For a collision involving two vehicles, this means in practice that both the case vehicle and its collision partner must be examined. If no attempt, or a lesser effort, is made to examine certain types of collision partners - such as trucks, buses, vans, minibuses, pickup utilities, four-wheel-drives, motorcycles, or ‘old’ passenger cars - then the subsample of cases for which delta-V is obtained will automatically be biased against collisions involving these types of vehicles. The same applies if CRASH3 and similar programs are thought to be inapplicable to crashes with these types of vehicles. The upshot is that the relationship between impact severity (delta-V) and the risk of fatal or serious injury may be very different for certain classes of collision partner. Systematically failing to compute delta-V for these collisions may result in a distorted view of the overall relationship between impact severity and injury outcome in the overall sample. Collisions with trucks are a likely example where the risk of fatal or serious injury is greater than for other collision partners.

Impact severity. The technique for using vehicle damage to estimate the energy dissipated in a collision, and hence also the impact velocity, is theoretically applicable to every level of impact severity. However in practice many of the lowest severity impacts leave no usable crush profile and there is some reluctance to apply the algorithm to frontal impacts that produce catastrophic collapse of the vehicle structure. This implies some bias in the sample against the extremes of impact severity. This is a problem for the database but not an intrinsic problem for the method of deducing delta-V from vehicle damage. What is required is a more flexible and widely applicable means of relating vehicle damage to energy dissipation. The relationship between vehicle damage and energy dissipated can in principle be learnt from any scientifically acceptable means: crash tests, definitive evidence from the scene of the accident, accident recorders, or even computer simulation. It would be very worthwhile to complement the focus on stiffness values with an effort to extend the scope of damage patterns for which energy dissipation can be estimated for use in damage-based reconstructions.

Under-run. Certain types of impacts are currently not suitable for programs such as CRASH3, WINSMASH and EDCRASH, because the relevant algorithm applies only to ‘vertically homogeneous’ crush. Under-run damage is a common example - and important because these impacts pose a particularly high danger to vehicle occupants. It is quite likely that the risk curve of serious or fatal injury in under-run impacts is significantly displaced towards low severity impacts compared to impacts that result in ‘vertically homogeneous’ crush (neither over-run nor under-run). However if delta-V is not calculated for these cases, these high injury/low severity cases are excluded from statistical analysis.

Swiping impacts and the “point of common velocity”. Sideswipes and other impacts in which the contacting surfaces of the colliding objects continually ‘slide’ relative to each other cannot be assessed for impact severity using the damage-based algorithms of CRASH3 and similar programs. This is because this collision type itself is not modelled by the program, not because the damage or crush profile is necessarily unsuitable. There are two separate ‘modules’ within the mathematics of programs like CRASH3: one takes vehicle damage as ‘input’ and infers energy dissipation as ‘output’; the other takes energy dissipation as ‘input’ and infers velocity change (delta-V) as ‘output’. These modules are quite independent. The problem with calculating impact severity for under-run impacts lies in the first module: inferring the energy dissipated by the crashed vehicle. The problem with calculating impact severity for side-swiping impacts, on the other hand, lies with the second module: inferring velocity change from energy dissipation. The reason there is a problem is that in order to have sufficient mathematical equations to solve for all the unknown variables, it is necessary to assume that the colliding objects reach a common velocity at their contacting surfaces (which is not true when the contacting surfaces 'slide' against each other during impact). This restriction is widely misunderstood. It is *not* the case that the *centres of mass* of the colliding objects are assumed to reach a common velocity during impact. This assumption would restrict the validity of the damage-based method to a fraction of the cases to which it is truly applicable. The relevant mathematical condition as illustrated in figure 3 is:

$$\mathbf{v}_{1P} = \mathbf{v}_{2P}$$

i.e.

$$\mathbf{u}_1 + \omega_1 \times \mathbf{r}_{1P} = \mathbf{u}_2 + \omega_2 \times \mathbf{r}_{2P}$$

where $\mathbf{v}_1$ and $\mathbf{v}_2$ are the pre-impact velocities of the colliding objects at their centres of mass; $\mathbf{u}_1$ and $\mathbf{u}_2$ are the post-impact velocities of the colliding objects at their centres of mass; $\mathbf{v}_{1P}$ and $\mathbf{v}_{2P}$ are the velocities of the colliding objects *at point P within their crush zones*; $\omega_1$and ω_2 are the rotational velocities around the centre of mass; and $\mathbf{r}_{1P}$ and $\mathbf{r}_{2P}$ are distance vectors from the centres of mass to point P. There is no equation in the mathematics that specifies that the centres of mass must attain a common velocity. Consequently no such restriction applies to the range of collision types for which delta-V can be estimated using CRASH3 and similar programs.

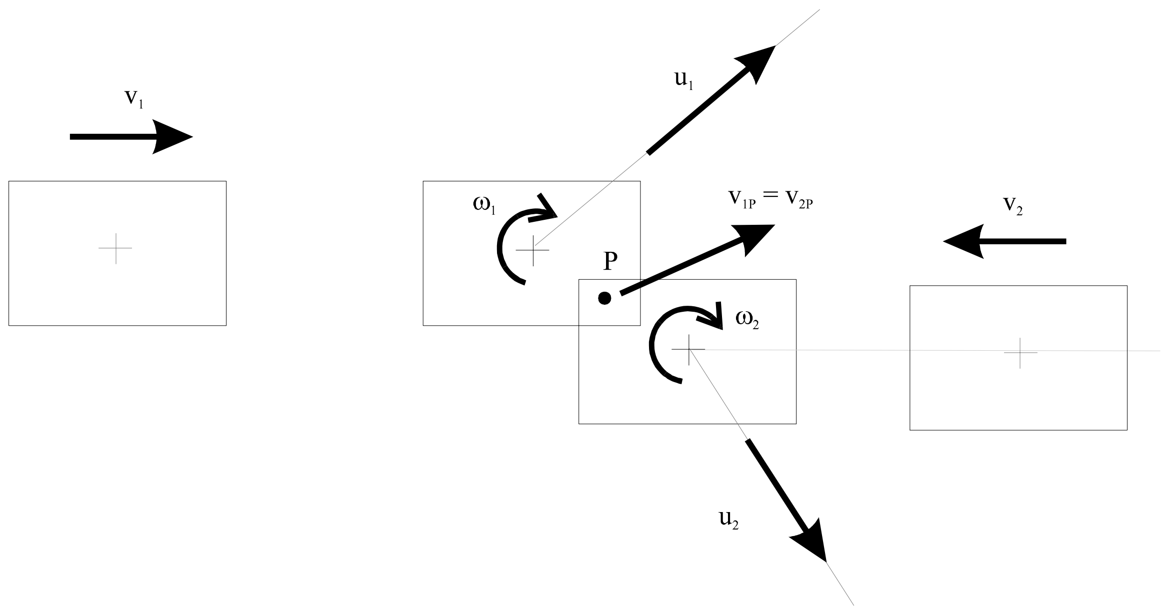

Figure 3: General representation of collision

In this section examples have been given of the ways in which the subset of cases from a systematic field study of road accidents can be biased by impact type, impact severity and collision partner. The illustrations come from the method of inferring impact speed from vehicle damage. However the same concepts certainly apply to other methods too. A widespread misunderstanding of the scope of the damage-method that affects the range of impacts to which the method is thought to be applicable has also been described. Both the bias and the misunderstanding are important for interpreting and understanding impact severity results from systematic field studies.

4. DISCUSSION

The results for the accuracy of CRASH3 in section 2 show that its default stiffness values are sufficiently well suited for modern European passenger cars in many of the crash modes studied. It is fairly clear that custom stiffness values for individual models need to be specified where possible. The crash test data required to do this is not always available. There may be a case for developing default stiffness values for European cars to achieve good overall statistical results, where it is not possible to obtain stiffness values for individual models. The problem is always to have sufficient crash tests results from which to derive stiffness values. The number of vehicle models on the public roads is very large, as is the type and severity of impacts they incur. Researchers in systematic studies such as CCIS and NASS need to deal with every combination of vehicle model and impact type. Obtaining reliable stiffness values for front, side and rear impacts for all these car models is difficult without having many crash tests results to draw upon. However much progress could be made from methodically collecting crush data from the many crash tests that are conducted on European cars.

The problem of calculating delta-V for a *representative* subsample of cases from a systematic field study of road accidents is also important. It requires an effort to evaluate delta-V for as many cases in the sample as possible and for the widest possible variety of impact severity, impact type and collision partner. How this is achieved depends on the method used in the study to obtain an estimate of delta-V. For the damage-based method of CRASH3 and similar programs it is necessary to examine all vehicles involved in an accident, even if the collision partners to the case vehicles are not otherwise of great interest. Furthermore, the greatest limitation on the damage-based method is correlating vehicle damage to energy dissipation. However there is no intrinsic reason why under-run damage and other types of impact damage beyond the scope of CRASH3 cannot be correlated with energy dissipation. This correlation could be built up from crash tests, accident recorders, reconstructions using scene-based methods, and computer simulations. This would expand the scope of the method very significantly beyond its current limitations.

5. CONCLUSIONS

On the data available for modern European passenger cars, CRASH3 appears to under-estimate delta-V for rigid (10%) and deformable (5%) barrier impacts but to marginally over-estimate delta-V for car-to-car impacts (2%). The programme under-estimates delta-V in deformable barrier side impacts by only 6%. For statistically accurate results in Europe it is therefore desirable to introduce corrected vehicle stiffness values. This implies a continued effort to collate vehicle crush data from crash tests.

The subsample of cases for which delta-V can be calculated using CRASH3 and similar programs is likely to be biased by impact severity, impact type and collision partner. This may be distorting statistical results from systematic field studies of road accidents. To overcome this problem it is necessary to calculate delta-V in as many cases as possible and in as wide a range of impacts as possible. It would be enormously helpful to compile a 'reference catalogue' of crashed cars that would provide a description of vehicle damage and energy dissipated for the types of vehicles and impacts that are commonly seen in real accidents. This 'catalogue' could be based on data from any scientifically acceptable source, such as crash tests, computer simulations, or accident recorders.

6. ACKNOWLEDGMENTS

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