# EVALUATION OF A METHOD FOR DETERMINING THE VELOCITY CHANGE IN TRAFFIC ACCIDENTS

Anna Nilsson-Ehle, Hans Norin
Christer Gustafsson

Automotive Safety Centre
Volvo Car Corporation

## ABSTRACT

An important parameter in the statistical evaluation of automobile accidents is the velocity change of the vehicle. The objective of this paper is to describe and evaluate a method for determining this parameter, in frontal collisions, in such a way that a reliable analysis of the Volvo accident material is achieved.

The paper begins by describing the general development from classifying accidents by the CDC-system to classification based on determination of velocity change - DV. Thereafter the early VOLVO DV calculations - based on the Campbell method - are explained and some drawbacks with this method are shown. The paper then proposes a more sophisticated method for calculating DV.

The ability of different methods to calculate correct velocity changes is compared in a few, well recorded, laboratory tests and traffic accidents. This comparison is a basis for an evaluation of the reliability of the proposed Volvo method. The influence of inaccuracy in the parameters in the model is discussed.

The paper then summarizes benefits of this method and suggests further activities in this field.

## INTRODUCTION

### The Volvo Accident Research System

To get a good knowledge of the crash behaviour of cars in the real traffic environment it is necessary to have a good traffic accident investigation system.

Volvo has a combination of multidisciplinary and statistical accident investigation (1). In this way we obtain both an overall representative picture of the whole traffic accident problem area and a deep insight into the specific vehicle behaviour and occupant injury mechanisms in a collision. This combination is illustrated in figure 1.

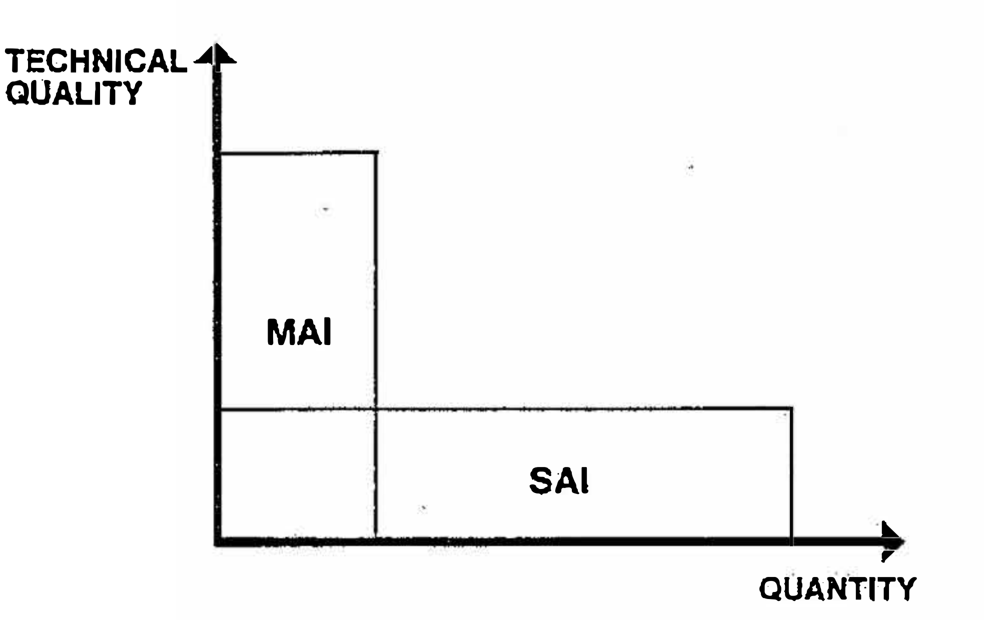


Figure 1. A schematic picture of the system for accident investigation

The multidisciplinary accident investigation includes cases where our investigation team is directly called to the scene of the accident by the police or the S.O.S. alarmcentre.

At the scene of accident all data are recorded by means of interviews, photos and measurements. This documentation is followed by a thorough analysis of the crash behaviour of the vehicle at a Volvo garage.

Through this analysis we obtain knowledge of the event of the accident, the collision object and the vehicle deformations. Together with the injury pattern of the occupants in the vehicle we can get a very good picture of the accident.

The possibility to establish different characteristics of the accident, such as impact speed, forces acting on the occupants, is relatively good for these accidents.

The accidents investigated within the multidisciplinary system represents a limited amount of accidents. Our aim is to create the necessary conditions for establishing the characteristics mentioned above also for a large accident material.

In our statistical accident investigation we record data from about 2000 of the most severe accidents each year. The selection criterion is that the deformation is large and the vehicle is relatively new.

With the aid of the damage inspectors of Volvos insurance company, VOLVIA, we get a recording of the vehicle deformation, documented through photos and certain measurements. Additional information on the accident is obtained through responses to a questionnary sent to the occupants in the car, through injury information from hospitals and through police investigation reports.

With these data as a basis the vehicle deformation is coded according to the CDC-system (2) (as described later) and the occupant injuries are coded according to the AIS-scale (3).

All information is computer stored and can be analysed with respect to all input parameters.

As of now we have more than 12.000 severe accidents, with data on about 20.000 occupants, available for analysis.

## Deformation Classification

As mentioned earlier the car deformation is classified according to the CDC-system which has been agreed on internationally (2). CDC means Collision Deformation Classification and is specified by SAE J 224B. This classification includes direction of force, area of damage, type of distribution and extent of deformation. The deformation is given as a discrete variable, VDI. An exemaple of CDC-codification is given in figure 2.

The CDC system gives a systematic recording of the remaining deformation and as long as only one car model is analysed, the extent of deformation can be the parameter used for sorting accidents according to severity. But this has to be done with great carefulness. Only cars that have experienced not only the same general accident type e.g. frontal collision but also the same distribution of damage and the same collision object may be compared.

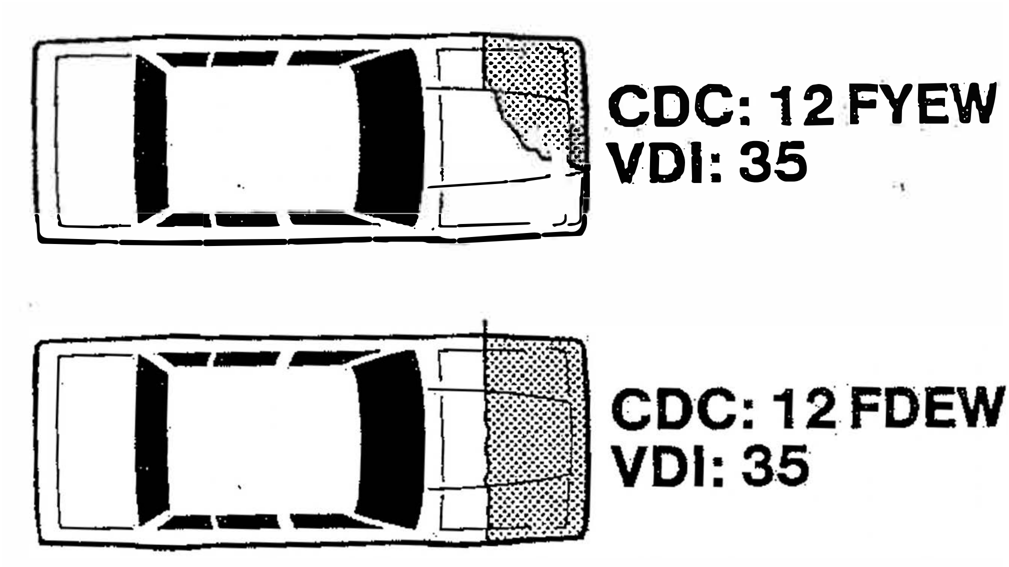


Figure 2. A typical CDC-codification of a Volvo car.

Due to the restrictions in the comparison of accidents with the extent of deformation as parameter, even a large accident material has to be broken down into several small homogenous groups suitable for analysis. This makes the statistical uncertainty of the results unnecessarily large.

It is not possible at all, to include different car models in a CDC-based analysis. For the evaluation of the accident material there is a need of a better parameter than "extent of deformation" as a measure of accident severity.

For a car manufacturer it is obvious that the consequenses for an occupant in a traffic accident depends on the whole course of deceleration of the vehicle. Thus during the engineering of a new car the restraint system is matched to the specific deceleration characteristics of the vehicle.

Also for the in depth investigation of an accident it may be important to be able to reproduce the complete deceleration history of the vehicle. Through this it is possible to obtain a good understanding of the occupant injuries and their injuries mechanisms.

Accident reconstruction can be made mathematically, experimentally or as a combination of both. Mathematically, computer programs like SMAC (4) can be used but many investigation teams have their own simulation programs. Volvo has worked somewhat with mathematical simulation of accidents but rarely with experimental accident reconstruction.

An attractive alternative for the in depth investigations is to equip cars with so called crashrecorders - accelerometers that continously records the motion of the vehicle. As of yet there are no crashrecorders cheap enough to fit as a standard equipment. There are however groups of cars, parts of research projects, that have been equipped with crashrecorders. They have then at the same time, been equipped with e.g. an experimental restraint system.

The need of data for the statistical accident analysis is different from the need for the in depth study. Where the in-depth study maps every detail and demonstrates the uniqueness of each accident, the statistical study is doing an analysis based on common characteristics for different accidents. The complex deceleration of the vehicle must be expressed in one or a few parameters. Each such parameter chosen will then have its limitations, of which the statistician must be aware.

## THE DV PARAMETER

### Theory

Due to the problems connected with CDC-based analysis, there has lately been a change, worldwide, towards the use of another parameter which measures severity. This parameter is the velocity change of the vehicle in the accident, DV.

This parameter must also be connected to a direction of force. Accidents with the same general direction of force may be analysed together. The following parts of this paper deal with frontal accidents with a direction of force not deviating more than 30° from the longitudinal axis of the vehicle.

The velocity change can by calculated for two bodies engaged in a plastic impact. The formula is

$$\Delta\vec{V}_1 = \vec{V}_1 - \frac{m_1\vec{V}_1 + m_2\vec{V}_2}{m_1 + m_2}$$

where $\Delta$ V is the velocity change of vehicle 1
$V_1$ ,$V_2$ are the involved vehicles impact speed
$M_1$ ,$M_2$ are the involved vehicle masses.

DV is thus something different from impact speed, and it depends on the impact speeds and masses of the vehicles. To be able to determine DV in accidents there must be a possibility to calculate DV from postcrash instead of precrash data.

The motive for choosing DV

The violence to the occupant can be described in terms of the change of velocity and the rate of velocitychange, the deceleration. The change of velocity is the same for both vehicle and occupant but the occupant deceleration depends on the coupling of the occupant to the compartment.

The compartment deceleration is of course dependent on the deformation characteristics of the car. Different vehicles can have different maximum deceleration and mean deceleration although they have the same DV = velocity change.

That DV is a suitable measurement of violence can be understood because the kinetic energy of the occupant during the crash is a function of DV and this energy has to be absorbed by a restraint system.

DV can be the same for a lot of different deformations. By DV, accidents with different deformation patterns can be analysed together. An example of this is given in figure 3.

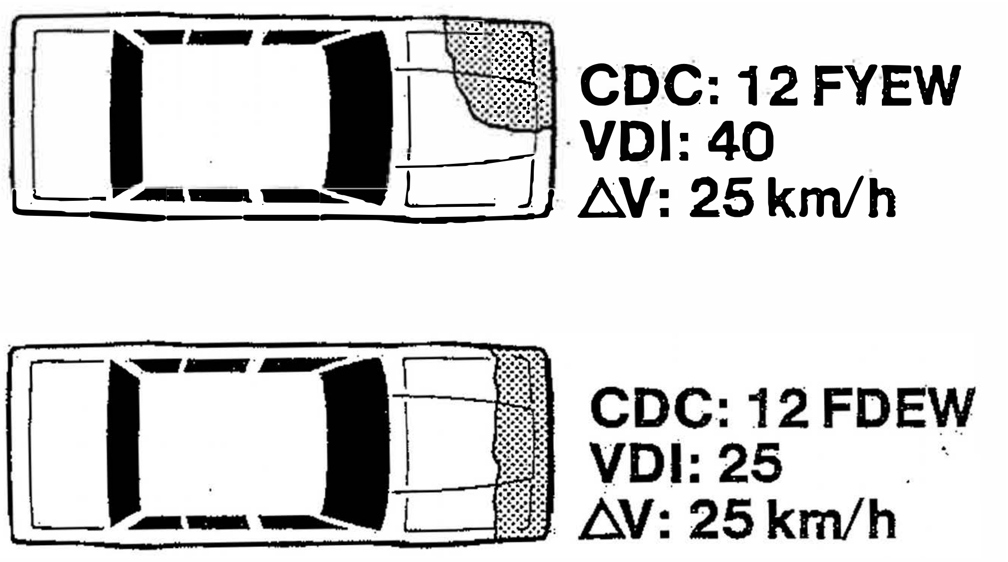


Figure 3. Example of different deformations giving the same DV.

It has been shown in different studies ( 5, 6, 11) that estimated barrier eqvivalent speed has an outstandingly high correlation to occupant injury severity. This shows that DV is highly suitable as the accident severity parameter although it is not the total answer to the problem. The mean and peak deceleration during impact is of importance (12) and should be taken into account, for instance when different car sizes are compared.

Determination of DV

DV is determined in several ways, depending on the general system of investigation chosen by a certain investigation team.

Some investigation teams make estimations of DV based on an extensive recording of post crash data, such as measurement of the involved vehicles, braking marks, skid marks, final positions, interviews with witnesses etc. This requires a great amount of data but is nevertheless a judgement whose reliability is dependent on the experience of the investigators. This type of data can also be processed by mathematical collision simulation programs.

There have been several developments of such data models. Calspan Corporation has, on contract for NHTSA, made the CRASH program, which later has been revised to CRASH II and CRASH III. (7, 8)

One way to gain experience is to perform a large amount of various collisions in the laboratory. By comparison between accident and laboratory results a barrier equivalent speed can be estimated for the accidents.

This method can be used together with reconstructions of actual collisions, thus "validating" the technique of the investigators.

Campell shows in his SAE paper of 1974 (9) that there is a linear relationship between barrier impact speed and remaining deformation. His statement is based on barrier collisions with GM fullsize cars and Chevrolet Vegas.

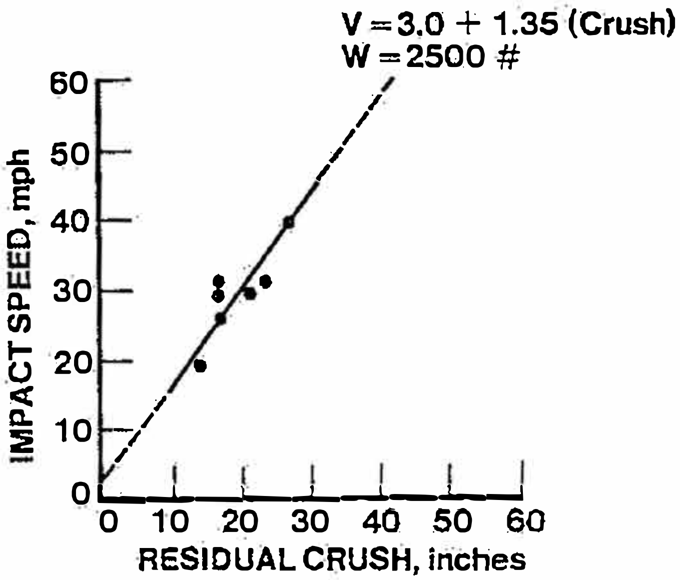


Figure 4. The crush VS impact line (from Campbell)

From this figure 4 the kinetic energy ( $\frac{mv^2}{2}$ ) required to create a certain remaining deformation can be derived.

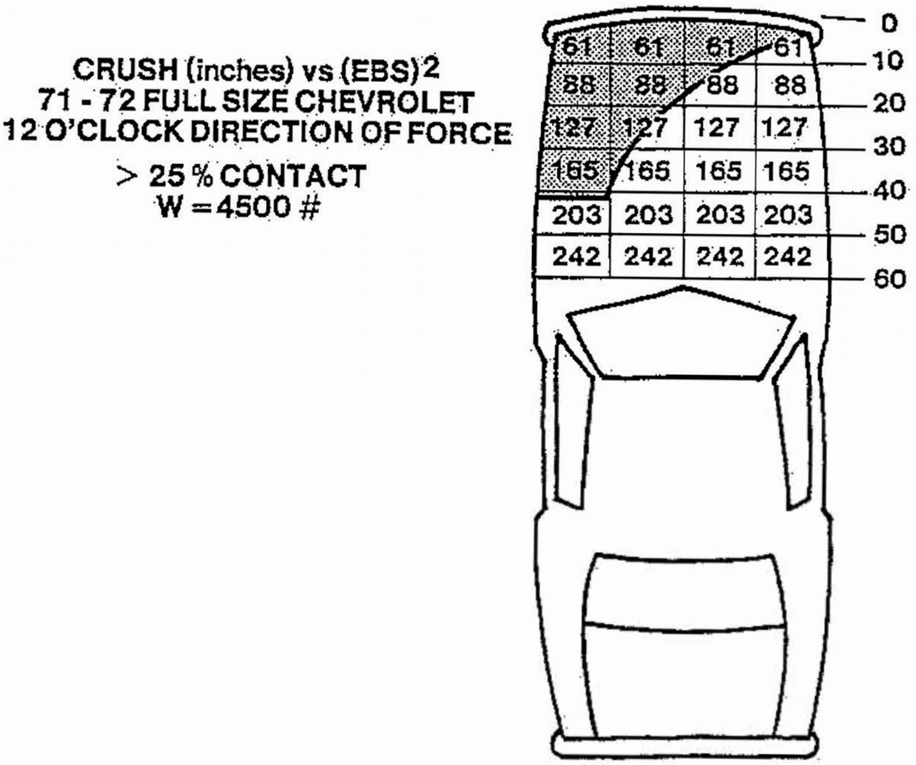
Futhermore the energy needed to create an incremental increase of crush could be determined. Campbell makes the assumption that energy absorption is the same over the entire width and height of the front, and arrives at a description of the car front, as shown in figure 5.

When the energy to create a certain deformation is known DV is calculated as

$$\Delta V_A = \frac{M_B}{M_A+M_B}\sqrt{\frac{(E_A+E_B)(M_A+M_B)}{M_A \cdot M_B}}$$

E = Absorbed energy

M = Vehicle mass



CRUSH (inches) vs (EBS)2
71 - 72 FULL SIZE CHEVROLET
12 O'CLOCK DIRECTION OF FORCE
> 25 % CONTACT
W = 4500 #

| | | | |
|---|---|---|---|
| 61 | 61 | 61 | 61 |
| 88 | 88 | 88 | 88 |
| 127 | 127 | 127 | 127 |
| 165 | 165 | 165 | 165 |
| 203 | 203 | 203 | 203 |
| 242 | 242 | 242 | 242 |

Figure 5. The energy description of a full size Chevrolet 72-73 (from Campbell)

## VOLVOS FIRST APPROACH

Volvo had some specific requirements on the DV calculation method to be the successor of, or complement to the CDC system.

- Only post-crash data should be required
- The data needed as input should be collected quickly and reliably
- The data collection should not require long experience
- The computation of DV should be quick and easy to handle
- It should not require inspection of the scene of the accident

The high emphasis on simplicity is due to the aim of using this system for all severe frontal accidents involving Volvo cars occurring in Sweden, most of which we never get the possibility to study in detail.

A survey was made of different possible DV calculation methods. We found the method described by Campbell very interesting. It seemed to suit us well because

- The only data needed from an accident is the car model, car weight and damage pattern.
- The registration of force-deflection characteristics is easily obtainable for Volvo models and hopefully possible to establish with other cars, perhaps with somewhat less accuracy.
- The model was said to work even when as little as 25% of the width of the vehicle is involved.
- The computation of DV could easily be performed by "easy to handle" computer programs.

Plots of impact speed versus residual crush from full frontal barrier tests showed that the Volvo models, 240 and 760, have linear characteristics. This statement is discussed later in the paper.

The energy absorbed per unit of crush in the front was calculated. The Campbell assumption of even distribution of energy absorption over the width and height of the car was applied, and gave for the 240 car a frontal energy absorption pattern shown in figure 6.

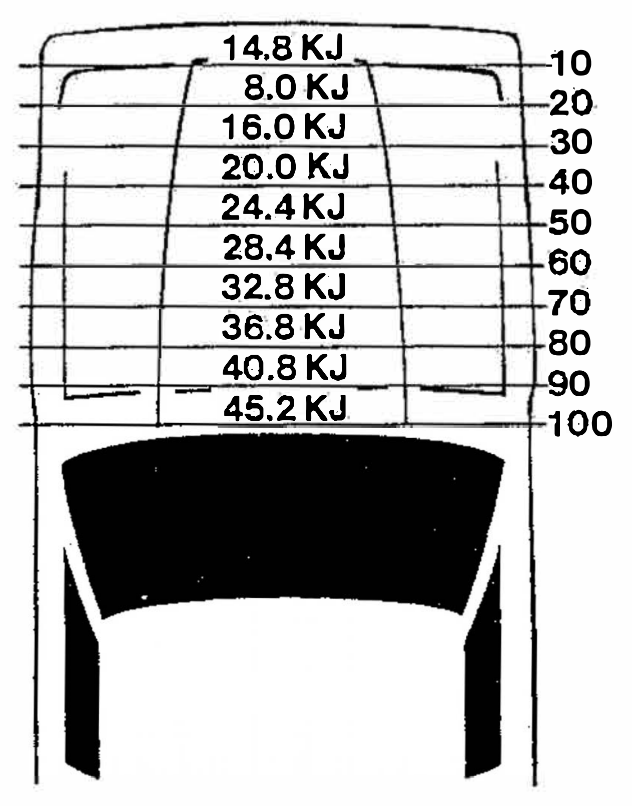


Figure 6. Energy absorption pattern for the Volvo 240

A package of computer programs was assembled to facilitate calculation of DV.

The energy matrix for any car is stored toghether with important data for that car, the length, the width, the curbweight and a few other things. The energy matrix for a car is calculated, if the equation of the line in the crush versus impact speed diagram is given.

When a DV is to be computed the program first asks for the type of car involved and fetches the stored data, including the energy matrix, for this car.

The deformation pattern is then asked for. It is given as an arbitrary number of coordinate pairs, the amount is decided by the investigator and depend on the complexity of the deformation pattern. Alternative patterns can be given. Based on the deformation pattern the absorbed energy is calculated.

To do the DV calculation according to the Campbell formula the characteristics of the various collision objects must be known.

The investigator can choose amongst three main types of collision objects.

Fixed rigid body - barrier
- rock
- pole, tree
2 Moveable rigid body - truck
3 Moveable deformable body - car

When the collision object is another car there will be a new loop of energy absorption calculation before the DV is computed.

When DV is computed and the investigator has decided on which alternative result to choose, this can be stored together with all other computer-stored information on that particular accident.

The application of this system to some selected traffic accidents soon showed that it had some major drawbacks which had to be dealt with

- The assumption that energy absorption was fairly even over the width of the car was not valid
- Accidents involving poles had to be related to the actual packing of the engine compartment
- Several of the distributed frontal collisions are partial underrides - a situation that doesn't engage the side members over the entire deformation phase.

As the existing method seemed to give good results in distributed frontal collisions where there was no underride it was decided to improve the Campbell method rather than choosing a new approach to the DV problem. Campbell himself (9) and Opel Co (10) have also written about these restrictions.

## IMPROVEMENTS AND MODIFICATIONS

Firstly, we more thoroughly penetrated the statement that there is a linear relationship between velocity and remaining deformation.

Generally, the force F as function of deformation depth X, can be written

$$F(X) = K X^{n}.$$

where K and n are constants.

For an ideal plastic impact we find that

$$\tfrac{1}{2} m V_{o}^{2} = \int_{0} F(X)\, dX = K \int_{0}^{c} X^{n}\, dX = \frac{K}{n+1} c^{n+1}$$

where

m = the weight of the vehicle
$V_o$ = the impact speed
c = crush distance

When n = 1 we have a linear relationship between $V_o$ and C $\quad V_o = \sqrt{\frac{K}{m}}\, c$

If $1 < n < \infty$ the force F (X) is described by the family of characteristics in figure7.

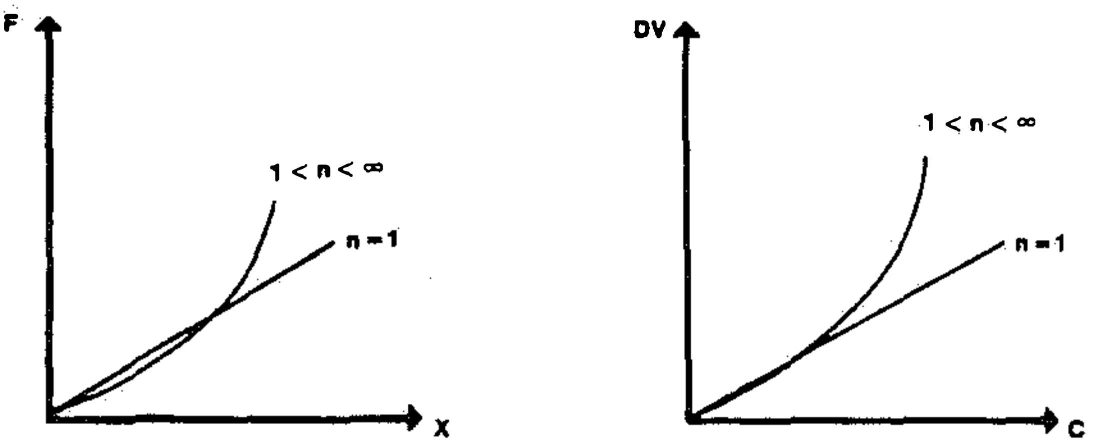


Figure 7. F (X) and DV (c) for different values of n.

All these characteristics describe processes with different degrees of deformationhardening.

Barrier forces registered during tests indicate that n slightly greater than 1 could be possible, but as not enough tests have been carried out to prove it either way, the linearity seems to be an acceptable approximation of the relationship between velocity and deformation.

From the straight line in the crush versus velocity diagram the energy needed to create a certain deformation can be calculated.

As a rule, energy as a function of deformation distance is always established in the full frontal barrier tests carried out in our laboratory. This is calculated by integration of the resultant force from the barrier.

The energy as a function of distance thus calculated (A) is in accordance with the energy versus distance curve we get from the "crush line" (B). This is shown in figure 8.

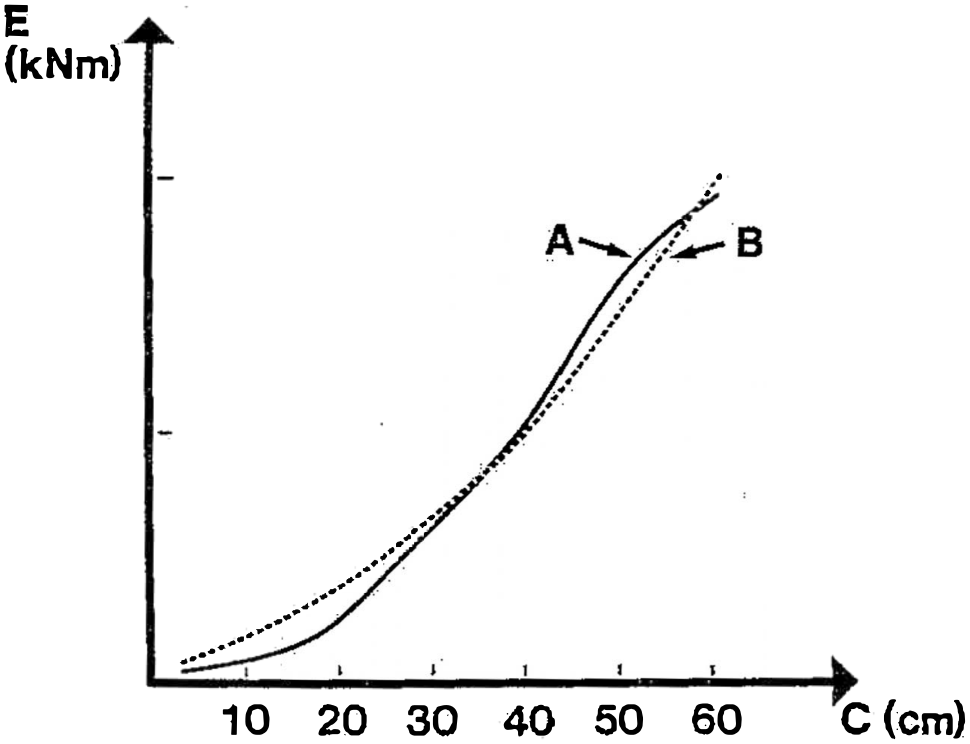


Figure 8. Comparison of energy VS crush calculated in two different ways

By this comparison we are convinced that the Campbell method is valid for distributed collisions engaging the whole front.

The improvement should thus be based on the crush versus velocity characteristics, but with a certain carefulness in the low-speed part of the diagram. Figure 9.

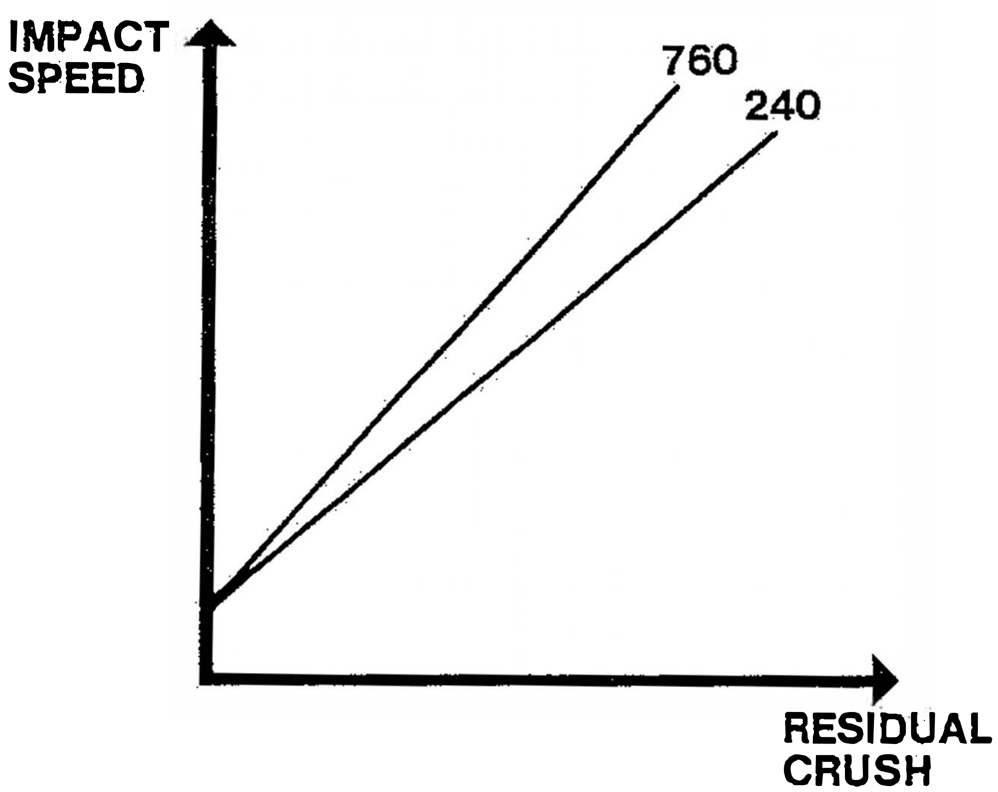


Figure 9. Crush VS impact speed for the Volvo 240, 760

The improvement was made along two parallel lines.

a) To arrive at a better representation of the energy distribution over the width of the car
b) To arrive at the energy absorption when underride occurs.

From barrier forces recorded in full barrier 0° tests, the energy distribution over the width as a function of deformation distance was calculated.

It was shown that Volvo cars, with their symmetrical side members and longitudinal engine, are well represented by three segments with the outer parts of the fenders being completely neglected.

A typical distribution, for a 240, with the energy as a percentage of the total energy absorbed in that crush increment, is illustrated in Figure 10. It can be seen how the energy distribution alters when different parts in the engine compartment are engaged.

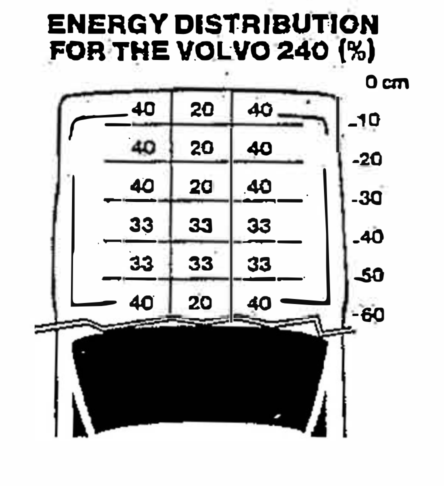


Figure 10. Energy distribution in the 240 front

A similar analysis of full barrier tests can be performed to give the distribution of energy width-wise, in a plane above the side members.

It should be observed, however, that this only gives the distribution when the whole front is engaged as by the full barrier, and it can not be used for the calculation of energy absorption when there has been a partial deformation of the front.

The next step was to analyse laboratory crashes not involving the whole front. This was done using half-barrier tests, both vertical and horizontal, and impacts with poles.

In the case both of the horizontal half barrier and impact with the pole between the side members, it can be seen that the reduction in speed is low until the engine has been pushed close to the fire wall. (Figure 11). Every collision type is "energy versus deformation" analysed, using the speed reduction as the input for the calculation of energy absorption.

The energy needed to deform a part of the front is then compared to the energy needed to achieve the same deformation distance in a full barrier crash.

In this way we find the relationship between the deformation work needed to deform a part of the front when the whole front is simultanously deformed and the deformation work needed to deform the same part of the front when this part is the only part deformed.

In the case of impact with a pole between the side members, the energy absorbed is greater than the energy absorbed by the same segment in a fullbarrier impact. This is due to the energy needed to create the separation in the border zone between deformed and undeformed areas. This energy difference we call "separation energy".

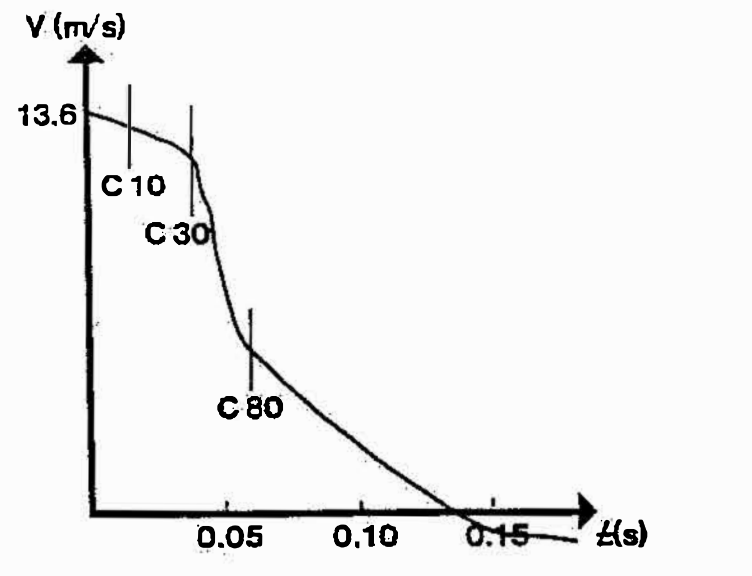
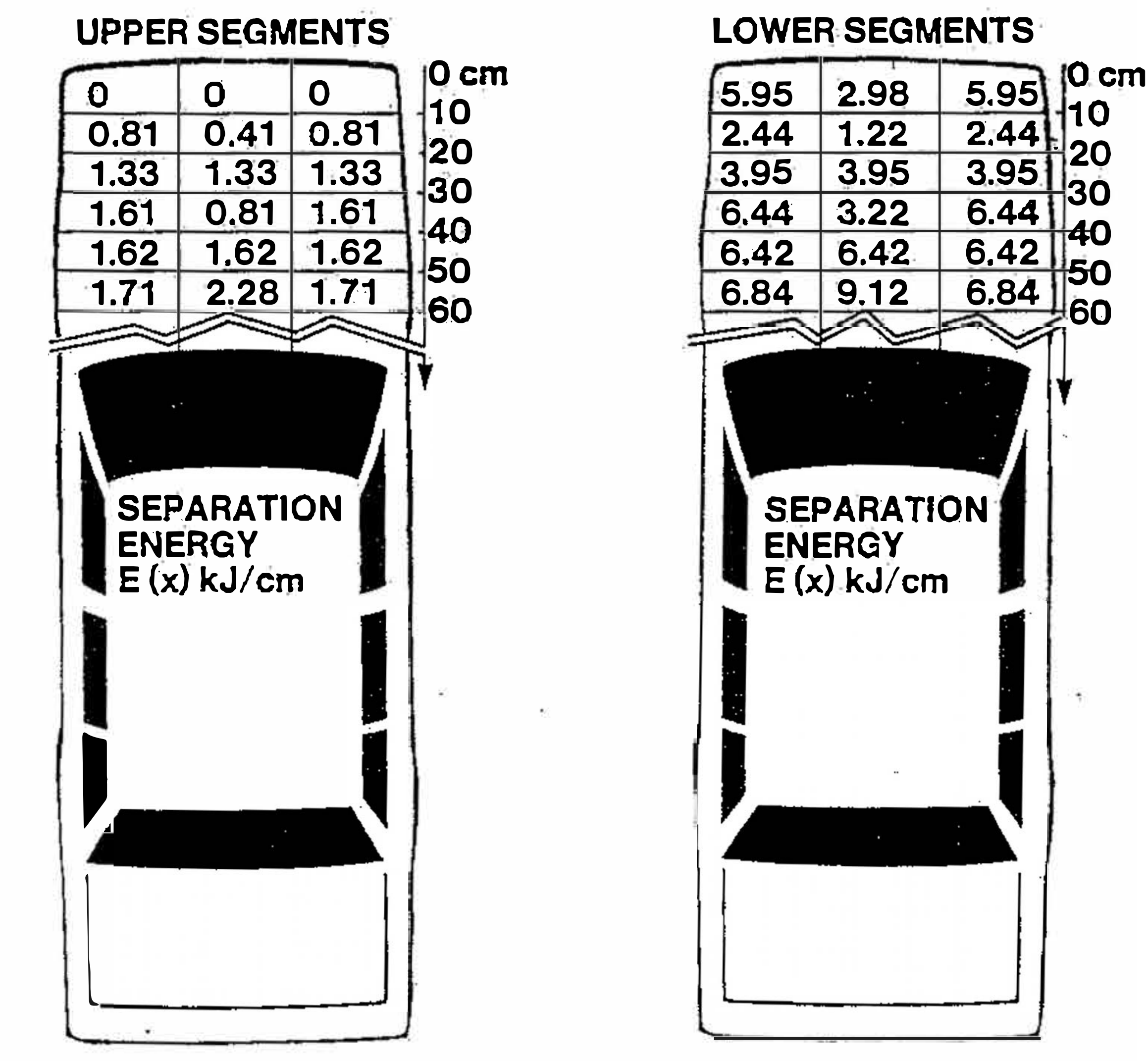


Figure 11. Typical V(t) curve for underride collision.

The separation energy is always present in a deformation with deformation borders parallel to the longitudinal axis of the car. It is a function of deformation distance, just as the energy absorption is.

There is separation taking place also in the underride case, but as we only have two situations heightwise, either underride or total front engagement, it is practical to incorporate the separation energy in the upper energy matrix.

An analysis as above can be and should be made for the deformation work in the front of every car model, including different engines. Each car will have its on characteristical matrix of the type shown in figure12.



**UPPER SEGMENTS**

| | | |
|---|---|---|
| 0 | 0 | 0 |
| 0.81 | 0.41 | 0.81 |
| 1.33 | 1.33 | 1.33 |
| 1.61 | 0.81 | 1.61 |
| 1.62 | 1.62 | 1.62 |
| 1.71 | 2.28 | 1.71 |

**LOWER SEGMENTS**

| | | |
|---|---|---|
| 5.95 | 2.98 | 5.95 |
| 2.44 | 1.22 | 2.44 |
| 3.95 | 3.95 | 3.95 |
| 6.44 | 3.22 | 6.44 |
| 6.42 | 6.42 | 6.42 |
| 6.84 | 9.12 | 6.84 |

Figure 12. Typical energy matrix

## COMPARISON OF CASES

The evaluation of actual accidents has been performed for accidents in which our investigation team has had a good opportunity to gather information other than that used for the DV calculation. In this way we try to establish reference data for our DV-results.

For some accidents we have chosen to make mathematical simulations with the CRASH III program to obtain a comparison with this. The calculations have been carried out by Prof Warner , Collision Engineering Inc. who has experience of using the CRASH III program. In Table 1. calculations of DV are presented, for each case the results for The Campbell method (A), our modified version (B) and the CRASH III (C) are shown. It is compared to the estimated velocity change or laboratory recording.

Table 1

DV calculation for some selected accidents

|  | OBSTACLE | CDC-CODE | DV km/h |  |  |  |
|---|---|---|---|---|---|---|
|  |  |  | est | A | B | C |
| 1 | FULL BARRIER 0° (LAB) |  | 48.3 | 48.8 | 47.6 | - |
| 2 | FULL BARRIER 30° (LAB) |  | 56.9 | 52.5 | 53.3 | - |
| 3 | WALL | 12 FDEW2 | 25 | 23 | 24 | 28 |
| 4 | LARGE STONE | 12 FLEW3 | - | 26 | 26 | 33 |
| 5 | HALF BARRIER 0° (LAB) |  | 48.3 | - | 48.8 | - |
| 6 | LARGE TREE | 01 FYEW3 | - | 49 | 49 | 60 |
| 7 | POLE (LAB) |  | 49.0 | 40.3 | 46.4 | - |
| 8 | POLE | 12 FCEN3 | 35 | 26 | 36 | 37 |
| 9 | UNDERRIDE (LAB) |  | 49.0 | - | 48.6 | - |
| 10 | UNDERRIDE,PARTIAL | 12 FYMW3 | 35 | 33 | 37 | 38 |
| 11 | CAR 340 (LAB) |  | 44.6 | 43.6 | 43.5 | 52.3 |
| 12 | CAR 240 (LAB) |  | 51.8 | 54.9 | 54.9 | 64.3 |
| 13 | CAR 240 | 12 FYEW3 | 35 | 34 | 30 | 38 |
| 14 | CAR 240 | 12 FYEW2 | 35 | 33 | 29 | 36 |

The table shows that our modified version (B) provides a good correlation with what we have estimated to be the true facts. In the laboratory tests the error is less than 6 % although the deformation has been measured in the same way as in the actual accidents. Other laboratory tests performed, but not shown in table 1, also give errors less than 6%.

It is shown in table 1, that for frontal distributed accidents without separation energy present, the Campbell method (A) and our modified version (B) give the same result, close to the "estimated DV". The CRASH III (C) calculation gives values which are too high.

For accidents against narrow obstacle, (A) gives a value which is too low, while CRASH III and (B) are close to each other and the "estimated DV". In the underride cases (A) and (C) give varying results depending on the interpretation the investigator has made of the damage pattern.

It is obvious that the modifications made to the Campbell method, non-uniform energy distribution width-wise and height-wise and introduction of separation-energy, should give these differences between DV calculated by (A) and (B) respectively.

To understand the differences between (B) and (C) the CRASH III calculation must be explained.

CRASH III computes DV from energy absorbed in the impact, using the formula

$$E = \int_{0}^{\ell} \left(AC_1 + B\frac{C_1^2}{2} + G\right) d\ell$$

where li is the width increment engaged
C is the deformation distance
A, B, G are constants typical for a certain vehicle

The energy absorption is thus evenly distributed across the front, width-wise.

A, B, and G can either be set by the operator of the program or found in the manual to the program, which gives a choice of 11 different stiffness classes, 5 of which are cars. This table is shown in figure 13 and you can find the Volvo in class 3. From laboratory tests we find that the A, B and G, values in class 3 are considerably higher than the actual values for the Volvo.

| PARAMETER | 3 |
|---|---|
| WHEELBASE (IN) | 101.6-110.4 |
| TRACK (IN) | 58.9 |
| LENGTH (IN) | 196.2 |
| WIDTH (IN) | 72.6 |
| a (IN) | 51.3 |
| b (IN) | 55.5 |
| $X_F$ (IN) | 89.8 |
| $X_R$ (IN) | -106.4 |
| $Y_S$ (IN) | 36.3 |
| RSQ ($IN^2$) | 3324. |
| M ($LB-SEC^2/IN$) | 9.18 |
| CURB WT (LBS) | 3247. |

Figure 13. Table of car stiffnesses used in the CRASH III program.

It is now understandable that for accidents where the force has been evenly distributed over the whole front, the higher stiffness of the CRASH III, will give a higher DV.

In accidents with narrow obstacles the higher stiffness may be balanced by the wrong assumption of an even energyabsorption width-wise, adding up to something of the right order.

Slight differences between (B) and (C) are also due to different weight calculations and damage interpretations.

The weight of the car in (A) and (B) consists of curb weight plus passenger and cargo. The weight of unbelted occupants is not added and every belted occupant is counted as 1/3 of his real weight. The gastank is assumed to be halffilled. The CRASH III includes the total weight of every occupant.

## ACCURACY

With what accuracy can DV then be determined using the modified model? The following is an attempt to estimate an overall error. This can no doubt be refined in future work. Let us assume that the DV computation of laboratory impacts will give us the maximum possible accuracy for this methods.

This gives us, as mentioned above, a minimum error in the method, amounting to ± 6 %.

The sources of errors are

A. inaccuracy in determining the speed versus crush line
B. inaccuracy in determining the deformation
   - depth wise
   - width wise
   - height wise
C. inaccuracy in determining the mass of the vehicles involved
D. inaccuracy in determining the energy-absorption characteristics of the other vehicle involved

Error B above may, in turn, be broken down into inaccuracy due to investigator inexperience, and inaccuracy due to complicated deformation patterns i.e. low quality of input data.

The Maximum Error

The maximum error can be calculated by the equation

$$DF\ max = \pm \left[ \sum_{j=1}^{k} \left| \frac{\partial F}{\partial X_j} DX_j\ max \right| \right]$$

where $F(Xj) = DV(Xj)$

Thus DV is derived with regard to all its variables Xj, and DXj is the estimated maximum error in that specific variable.

It is convenient to make the estimation of the maximum error in two steps. Step one concerns the error in the energy absorption determination of the case vehicle. This error can be estimated through an analysis of points A and B above. Step two concerns the error in the calculation of DV based on the knowledge from step one and the error contributions from points C and D above.

Thus, step one is performed as follows. The maximum error in the energy absorption depends on error sources A and B. Source A, the inaccuracy in determining the speed versus crush line, depends in its turn on the information from laboratory tests which the line is based on. A higher number of tests increases the confidence in the line being correct. We have earlier discussed the problem with determining the line, it might even be curved, and we know that the inaccuracy is higher at lower speeds. Instead of putting statistical confidence bands around our straight line we take a short-cut and assume that because the laboratory evaluation of the DV calculation method has a relative error of maximum 6%, this is also the maximum relative error arising from errors defined under point A.

Error source B, the error due to inaccurate measurements of the deformation, can also be estimated without doing the actual derivations. The maximum error arises when every measurement is errenous in the same way, too high or too low. That situation actually indicates a systematic error which should be analyzed and eliminated. However, when this is the case we can, from the speed versus crush line, determine the error in energy due to a certain error in the crush measurement. The maximum error in deformation measurements can be held below 10% in all our accident investigations thus giving a maximum relative error of 9% in the energy determination.

Step two is done by derivating the DV formula given on page 8 with respect to the variables energy and mass. The simplest case is when the collision object is a rigid obstacle.

We get $D(DV) = \frac{DV}{M} \cdot DM + \frac{DV}{2E} \quad DE$

The maximum relative error in DV can be calculated with the input from step one and the estimated maximum relative error in mass determination of 50 kg in the case vehicle. We find a maximum relative error amounting to 11%.

If the collision object is another car and not a fixed obstacle, the error in energy determination and mass estimation for that car must also be calculated. For our selected accidents the other vehicle has also been a Volvo where the errors are as discussed above. When the other vehicle is of some other make, we will have to make estimations of the energy absorption characteristics. At the best this could be done by assuming an even distribution of energy (as in the Campbell method) and base the straight line on data from a single standard complicance test. As is known from calculation in the CRASH program, this error can be quite large.

### The Plausible Error

Hopefully, the maximum errors are not always adding up to their worst combination . If the errors are not systematic but random we can instead of adding the maximum error calculate the root-mean-square-value, RMS. This would give an RMS error of 6,5% if we apply it to both step one and two and an RMS error of 8,5% if it is applied directly on step two. It must be remembered that RMS errors are "typical", and are sometimes exceeded in unfavourable cases.

## CONCLUSIONS

In accident analysis it is important to have a reliable parameter measuring the severity of the accident. The velocity change DV is such a parameter.

DV in frontal collisions can be established from postcrash data using the formula:

$$\Delta V_A = \frac{M_B}{M_A + M_B} \cdot \sqrt{\frac{(E_A + E_B)(M_A + M_B)}{M_A \cdot M_B}}$$

where EA and EB are the energies absorbed by the vehicles during the impact.

The accuracy of the DV calculation is dependent on the possibility to determine the energy absorption. It has been shown by Campbell (9) that the barrier impact speed as a function of remaining crush is a straight line. This seems to be an acceptable approximation for most cars. It is probable, though, that the straight line is curved in the extreme ends of the line.

Based on this, a simple energy absorption model can be derived, assuming even energy distribution across the whole front width wise and height wise. This model will work quite well for distributed collisions but give high errors in collisions involving narrow obstacles and underride.

By performing different laboratory tests a more complex energy absorption model of the front can be built. This model takes into consideration
- variation of energy distribution width wise
  existence of separation energy when the front is partially deformed
- special deformation characteristics when the collision is of the partial underride type.

DV-calculations based on this model for energy absorption give good accuracy for all types of frontal collisions within less than 30° from the longitudinal axis of the car and able to approximate as a plastic impact situation.

We find this model promising for our future work with our statistical accident investigation and believe that we by using this approach have sufficiently high accuracy in the DV-calculation.

The main problem, however, is still the energy absorption characteristics of the other vehicle in the car to car impact cases.

* It is undoubtdly a major need of standarization of methods for determining DV. An international cooperation on this ought to be started.

* The error in the DV calculation will always be large as long as there is lack of knowledge of different car makes and models. It is important to establish ways of exchanging vehicle data to enable reliable calculations of DV and thus create a good basis for accident analysis.

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