A Review and Investigation of Better Crash Severity Measures: An Annotated Bibliography

June 15, 1977 UM-HSRI-77-22

UM Project Account 361122
under MVMA Project 4.28

Analysts:
Joseph C. Marsh IV
Kenneth L. Campbell
Upendra Shah

Systems Analysis Division
Highway Safety Research Institute
The University of Michigan
Ann Arbor, Michigan 48109

Technical Report Documentation Page

1. Report No. UM-HSRI-77-22	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
A REVIEW AND INVESTIGATION OF BETTER CRASH
SEVERITY MEASURES: AN ANNOTATED BIBLIOGRAPHY

5. Report Date
June 15, 1977

6. Performing Organization Code

7. Author(s)
J. C. Marsh IV, K. L. Campbell, U. Shah

8. Performing Organization Report No.
UM-HSRI-77-22

9. Performing Organization Name and Address
Highway Safety Research Institute
The University of Michigan
Huron Parkway & Baxter Road
Ann Arbor, Michigan 48109

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
361122

12. Sponsoring Agency Name and Address
Motor Vehicle Manufacturers Association
320 New Center Building
Detroit, Michigan 48202

13. Type of Report and Period Covered
Final Report, Phase I
3/77-6/77

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Over the last ten years, dozens of crash severity measures have been proposed, discussed, and used. This annotated bibliography reviews the extensive amount of "crash severity" literature—both American and European. The 245 references are grouped according to four subject categories: crash severity, accidents, crashworthiness, and biomechanics. Within each category the references are arranged by author and publication date. Exhaustive coverage has not been provided, but representative examples of literature on peripheral subjects have been included.

17. Key Words
accident data, crash severity, speed, injury, crashworthiness, biomechanics, impact, testing, accident investigation

18. Distribution Statement
UNLIMITED

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

PREFACE

Over the last ten years, dozens of crash severity measures have been proposed, discussed, and used. The confusion that can result from conflicting crash severity definitions and interpretations--from barrier-equivalent speed to traveling speed, and from crash recorders to field evidence--has been demonstrated by the reporting and evaluation of the ACRS field experience (Appendix A). There is an extensive amount of "crash severity" literature--both American and European. This annotated bibliography is Phase I of a program to review and investigate better crash severity measures. Phase II involves a cohesive state-of-the-art review of the divergent requirements, definitions, and applications documented in Phase I, and an investigation into the potential for the further evolution of existing engineering and statistical crash severity measures.

This bibliography of crash severity literature contains 245 annotated references grouped according to four subject categories. Within each category the references are arranged by author (or organization if no personal author) and publication date. A glossary of abbreviations and the availability of documents are also provided. A total of 438 documents were retrieved from the HSRI Information Center collection and screened for relevance. No attempt has been made to provide exhaustive coverage of each topic. Representative examples of literature on peripheral subjects (e.g., human tolerance) have been included. The authors would appreciate receiving notification of any significant omissions.

Annotations of the relevant portion(s) of each document were prepared in order to portray the current state of knowledge. An introduction to each section provides an overview of that section's contents.

TABLE OF CONTENTS

GLOSSARY OF ABBREVIATIONS

AAAM	American Association of Automotive Medicine
ACIR	Automobile Crash Injury Research (CALSPAN Program)
ACRS	Air Cushion Restraint System
AEC	Automotive Engineering Congress
AIS	Abbreviated Injury Scale
AMA	Automobile Manufacturer's Association (now MVMA)
AMF	American Machines and Foundry (now AMF, Inc.)
ASME	American Society of Mechanical Engineers
BCL	Battelle Columbus Laboratories
BEIV	Barrier Equivalent Impact Velocity
BES	Barrier Equivalent Speed
BEV	Barrier Equivalent Velocity
CAL	Cornell Aeronautical Laboratory (now CALSPAN)
CDC	Collision Deformation Classification (SAE J224a)
CPIR	Collision Performance and Injury Report - Revision 3
CRASH	Calspan Reconstruction of Accident Speeds on Highways
CRASH	Simulation of Nonlinear Transient Response of Vehicle Frame (Philco-Ford)
CRUSH	Derives Vehicle Damage Parameters for CRASH from Crash Tests (Calspan)
CRUSH	General Structural Analysis Program for Interconnected Beam Structures (Chrysler)
Delta-E	Loss of Translatory Kinetic Energy Resulting from Impact
Delta-S	Equivalent Stopping Distance or Second Integral of Acceleration
Delta-V	ΔV, Change in Velocity
DOT	U.S. Department of Transportation
EBS	Equivalent Barrier Speed
EDI	Effective Displacement Index
ELR	Emergency Locking Retractor
ESV	Experimental Safety Vehicle
ETS	Equivalent Test Speed
FARS	Fatal Accident Reporting System (NHTSA)
FMCCM	Four Mass Per Car Collinear Collision Model
FMVSS	Federal Motor Vehicle Safety Standard

GLOSSARY OF ABBREVIATIONS (Cont.)

GADD SI	GADD Severity Index
GM	General Motors Corporation
GPO	Government Printing Office (see Availability of Documents)
g-t	Acceleration-Time History Measured in Gravitational Units
HIC	Head Injury Criterion
HSRI	Highway Safety Research Institute
HVOSM	Highway Vehicle-Object Simulation Model (Calspan)
ICAS	International Congress on Automotive Safety
IIHS	Insurance Institute for Highway Safety
IRCOBI	International Research Committee on Biokinetics of Impacts
ISS	Injury Severity Score
MDAI	Multidisciplinary Accident Investigation (Level III)
MEAN γ	Mean Acceleration
MSC	Maximum Strain Criterion
MVMA	Motor Vehicle Manufacturers Association (formerly AMA)
NHTSA	National Highway Traffic Safety Administration, DOT
NTIS	National Technical Information Service
OAIS	Overall Abbreviated Injury Scale
OPAT	Occupant Protection Assessment Test (dummy)
PCV	Peak Contact Velocity
PIC	Police Injury Code
RCS	Relative Collision Speed
RD	Residual Deformation (index)
RSES	Restraint System Evaluation Study
RSV	Research Safety Vehicle
SAE	Society of Automotive Engineers
SI	Severity Index
SMAC	Simulation Model on Automobile Collision (Calspan)
SPAD	Speedy Access to Data (HSRI)
SwRI	Southwest Research Institute
TAD	Traffic Accident Data Project
TELSAP	Computer Program for Processing Vehicle Structure Mass Matrices (Chrysler)
TRRL	Transportation and Road Research Laboratory, UK

GLOSSARY OF ABBREVIATIONS (Cont.)

UCLA	University of California, Los Angeles
UMF	University MicroFilm
VDI	Vehicle Deformation Index (now CDC)
VW	Volkswagen
WHAM	Wayne Horizontal Acceleration Mechanism

AVAILABILITY OF DOCUMENTS

Documents may be obtained from the original author (organization), publisher, or through the journal reference cited. Although all of the documents cited are in the HSRI Information Center collection or the personal collections of the authors, locally available technical document services should be contacted for locating the documents in this bibliography. Abbreviations have been used for many of the organizations from which documents are available. Their full names and addresses are given below.

Documents cited with SAE numbers (e.g., SAE-720243 or P-29) are available from SAE. Documents cited with AD or PB numbers (e.g., PB-632894) are available from NTIS. Documents with DOT/HS numbers (e.g., DOT/HS 801 692) are also available from NTIS.

AAAM	American Association of Automotive Medicine P. O. Box 222 Morton Grove, Illinois 60053
ASME	American Society of Mechanical Engineers 29 West 39th Street New York, New York 10018
GPO	Superintendent of Documents U.S. Government Printing Office Washington, D.C. 20402
NTIS	National Technical Information Service 5285 Port Royal Springfield, Virginia 22161
SAE	Society of Automotive Engineers, Inc. 400 Commonwealth Drive Warrendale, Pennsylvania 15096
UMF	University Microfilms 300 North Zeeb Road Ann Arbor, Michigan 48104

SECTION 1

CRASH SEVERITY

This section covers literature that deals explicitly with crash severity and/or general safety literature that covers more than one of the other three topics (e.g., Research Safety Vehicle contract reports). Only those portions dealing with crash severity have been annotated. Each report fits into one or more of four categories, depending on whether it: (1) notes need for crash severity measure; (2) proposes crash severity measures; (3) relates crash severity to frequency and/or severity of injury; or (4) projects results of countermeasure effectiveness to a national basis, and/or into the future. Consequently, the reports in this section will tend to overlap the other three sections. These citations have been included in Section 1 because of their significant relationship to crash severity.

The 81 citations in this section cover a number of specific crash severity measures ranging from vehicle damage classification schemes (e.g., TAD, CDC) to derived measures (e.g., EBS, delta-V) and direct measures (e.g., four-level crash recorder in GM ACRS vehicles). The derived measures use either an engineering approach (e.g., Campbell) or statistical approach (e.g., Watson). There also are a number of reports that discuss the relationship between field and laboratory results, and the need for crash severity measures as a basis for countermeasure evaluation.

Aldman, B. "The Character and Severity of Lesions in Regard to Velocity Changes." In *Proceedings, Traffic and Speed Casualties*. Odense University Press, Denmark, pp. 58-62. 1975. (33062)

Emphasizes that research should be carried out in two areas: biomechanics and engineering. Several problem areas are noted: The different responses of biological material to static and transient dynamic loading is not clearly understood. Human body can be used in experimental work on a sub-injurious level only. In experiments likely to produce injury, human substitutes must be used, and results from such experiments are difficult to apply on human beings. Output from an accelerometer is very difficult to interpret. Use of terms like Equivalent Speed is very confusing.

Andon, J., et al. *U.S. Research Safety Vehicle (RSV). Phase I Program. Volume II. Program Definition Foundation. Final Report.* DOT/HS 801 597. 427 p. June, 1975. (32398)

Contains AMF projections of vehicle accidents and usage for the mid-1980's. CPIR/MDAI data are stratified by impact speed (4 levels), urban/rural, primary damage area, and vehicle weight (2 levels).

Ashton, S.J., Hardy, J.L.G., and Mackay, G.M. "The Use of the Vehicle Deformation Index and Collision Speed Assessments." In *Proceedings, International Accident Investigation Workshop. Pilot Study on Road Safety.* NHTSA. pp. 85-102. 1974. (29399)

Lists various methods of assessing vehicle damage such as Moreland's Damage Index, Equivalent Test Speed (ETS), and Change in Velocity (delta-V). (1) *Moreland's DI*—The vehicle is divided into three sections: chassis, superstructure, and passenger compartment. The mass deformation of each section is multiplied by a weighting factor to allow for the relative importance and stiffness of each section. The sum of these three figures divided by the weight of the vehicle is the Damage Index. (2) *ETS*—Accident Severity is assessed by relating the damage sustained by the vehicle to the damage sustained in experimental impact tests. The vehicle damage is expressed in terms of the type of test impact speed necessary to most closely reproduce the case vehicle damage. (3) *Delta-V*—The criterion that should be used for describing occupant accident severity is the change in velocity experienced by the vehicle. This can be calculated from the masses and deformations of the vehicle involved, using the force-deformation relationship for each vehicle. Although delta-V requires more effort, it is a more powerful method than ETS (since it takes into account relative masses and stiffness of the vehicles). When the vehicles involved in the accident have similar deformation characteristics, both the models, ETS and delta-V, give similar assessments. Otherwise ETS assessment would be in error. Delta-V is concerned with change in velocity only. This, although important, is not the sole factor. Deceleration of the vehicle is more important for restrained occupants than change in velocity. Hence, effectiveness of delta-V will become less as usage of restraint system becomes more common. Variations in the VDI assessments arise due to problems of interpretation. Therefore, before assessment can become more consistent, an agreement must be reached as to conventions about damage interpretation.

Brach, R.M. An Impact Moment Coefficient for Vehicle Collision Analysis. SAE 770014. 8 p. March, 1977. (36556)

Introduces a new coefficient "The impact moment coefficient." While using impulse-momentum-energy approaches, classical coefficient of restitution is generally used to measure energy loss. But in real collisions, contact is over a surface; in many collisions, momentary or permanent interlocking of deformed parts occurs over this surface. Unlike coefficient of restitution, newly introduced "Impact moment coefficient" takes this phenomenon into account. It differs in two respects: (1) Its range is between -1 and +1. It represents the extent to which a moment has developed across the surface of deformation. (2) No a priori knowledge of its value is required. If other information regarding the impact is known, it may be treated as an unknown.

Brooks, S.H., Nahum, A.M., and Siegel, A.W. "Causes of Injury in Motor Vehicle Accidents." Surgery, Gynecology and Obstetrics. Vol. 131, No. 2. pp. 185-197. August, 1970. (16145)

Provides plots of injury versus vehicle impact speed by occupant age, sex, height, and weight, and by vehicle model and weight.

Campbell, B.J., Rouse, W., and Gendre, F. "The Traffic Accident Data Project Scale." In Proceedings, The Collision Investigation Methodology Symposium. CAL. pp. 675-681. 1970 (14379)

Points out the usefulness of the TAD scale. The TAD (Traffic Accident Data Project) scale enables the officer at the scene to produce a usable indication of car deformation. A manual has been developed which depicts automobiles struck in various places and with various degrees of resulting deformation. By comparing the damaged vehicle with the photographs in the manual, one can classify the damage on a 7-point scale. Efforts are also being made to evolve a 10-point scale (instead of 7-point); to have sharply defined intervals with equal properties; and generally to validate the scale.

Campbell, E. O'F. Human Body Injury and Vehicle Crash Damage. Traffic Injury Research Foundation. Ottawa (Canada). 14 p. May, 1971. (28219)

Analysis of police and medical reports on 542 occupants coded by the 7-point TAD for vehicle damage and by the author's own 9-point injury scale for tissue damage. There was an increased number of injuries per occupant and greater tissue involvement with increased vehicle damage. Tables of injury severity versus vehicle damage are provided for all cases, for fatals, for cranial injuries, for rollover injuries, and for combinations of these factors.

Campbell, K.L. Energy as a Basis for Accident Severity - A Preliminary Study. Wisconsin University, Madison. UMF Order Number: 72-23, 303. 197 p. 1972. (28307)

Argues that a collision severity measure should be based on, or related to, the physical laws that describe the dynamics of the collision. Such a relationship will provide the basis for appropriate use of the variable in subsequent analyses. The particular measure described is based on the energy absorbed by the vehicle in plastic deformation. A simplified force-deflection model of the vehicle front-structure is used to estimate this quantity. A regression analysis using a small group of MDAI cases is presented to illustrate usage of the developed measure of collision severity.

Campbell, K.L. "Energy Basis for Collision Severity." In Proceedings, Third International Conference on Occupant Protection. Society of Automotive Engineers. pp. 1-13. 1974. (30029)

Presents data relating front crush to barrier impact speed for 1971-1974 GM cars. These data, in conjunction with a simplified force-deflection model of the vehicle front-structure, are used to estimate the energy absorbed by the vehicle. The use of energy as a measure of collision severity is described.

Carlson, W.L. "Crash Injury Loss: The Effect of Speed, Weight, and Crash Configuration." Accident Analysis and Prevention. Vol. 9, No. 1. pp. 55-68. March, 1977. (53355)

Develops crash injury prediction models for major crash configurations using data from in-depth investigations. Analysis of these models demonstrates the positive contribution of higher impact velocity to crash injury, especially for head-on and side impacts. Squared velocities are added for head-on impacts, and average velocity effect is used for side impacts and velocity differences are used for rear impacts. Other predictor variables included car size, crash configuration, occupant age, seating position, and restraint usage.

Carter, R.L. *Passive Protection at 50 Miles Per Hour.* DOT/HS 810 197. 50 p. May, 1972. (19587)

Examines the feasibility of inflatable restraint systems to achieve passive protection for occupants in frontal collisions of 50 mph equivalent barrier speed. Costs and benefits are examined, and NHTSA concludes that cost-effective occupant protection at 50 mph can be achieved. Of particular interest are the cumulative distributions of equivalent test speed which are presented for injured and fatal occupants. These curves were developed from Cooke's analysis. These distributions were referred to as "cumulative risk" and "probability of death (injury)." This choice of terms is misleading, since the "equivalent test speed" was equal to or less than a particular value, *given that a fatality occurred*.

Cesari, D. and Ramet, M. "Comparison Between In-The-Field Accidents and Reconstructed Accidents with Dummies and with Cadavers." In *Proceedings, Nineteenth Stapp Car Crash Conference*. Society of Automotive Engineers. pp. 167-194. 1975. (33279)

Reconstruction of two in-the-field accidents permitted association of forces and accelerations with injuries. Vehicle damage and occupant injuries were compared. Head and chest results differed, while lower-extremity responses were similar.

Cooke, C.H. *Safety Benefits of the Occupant Crash Protection Standard*. NHTSA. 96 p. January, 1971. (15834)

Presents an analysis to transform distributions of traveling speed to distributions of equivalent test speed. The purpose of this transformation was to estimate the benefit to be obtained from any particular set of test speed requirements. In the methodology used, eight collision modes (head-on, fixed object, etc.) are analyzed in 102 separate steps. The objective was to determine a test speed in which the same amount of energy would be absorbed by the vehicle in the test and in the real accident. In making this estimation, consideration was given to the possible range of weights and stiffnesses of the impacted objects. The Cornell data used by Cooke are described by Wolf in a 1969 report.

Cromack, J.R. Multidisciplinary Accident Investigation, Volume 5, Supplementary Report. DOT/HS 801 283. 29 p. November, 1974. (30925)

Defines and compares TAD vehicle damage scale and CDC/VDI using 3415 vehicles rated jointly by Texas police and Southwest Research Institute. TAD and CDC damage extent is compared with inches of crush for frontal impacts.

Danforth, J.P., Lin, Kuang-Huei. Limitations of the Barrier Equivalent Speed Concept for Estimation of Crash Severity. General Motors Research Laboratories. Report Number: GMR-1953. 26 p. November, 1975. (33981)

Examines the question of whether crashes of equal barrier equivalent speed, as determined from residual vehicle front crush, represent crashes of equal severity for the occupant. The analysis utilizes computer simulations of the vehicle impact and occupant dynamics. Comparisons are made using crash severity indices such as the Head Injury Criterion. The authors conclude that other parameters of the collision, such as time duration, also influence the crash severity. In the closing sentence of the "Conclusions" the authors state:

> "This requirement for extensive information to describe the pre-impact parameters serves to illustrate the complexity of the crash analysis problem and precludes, at this time, use of the models in routine studies of vehicle crashes."

The paper lacks any examination of the limitations of the computer simulations and indices of crash severity utilized.

Danner, M. "Interior Safety of Automobiles." Fourth International Conference on Experimental Safety Vehicles. Kyoto, Japan. 7 p. March, 1973. (29313)

Describes an alternative to the use of vehicle damage as a starting point. Here the starting point is an estimate of the relative collision speed (relative velocity prior to impact). The technique presented is one in which test data are used to relate the relative collision speed to the energy absorbed, and, in turn, to a test speed in which the same energy would be absorbed. Cases studied by the German Association of Motor Traffic Insurers were limited to cases where insurance liability was involved. All of these were two-vehicle accidents. The case vehicle was taken to be the vehicle judged to be not at fault. Uninjured occupants are included. A total of 29,000 accidents have been studied. Danner presents distributions of "Equivalent Test Speed" of various injury levels for 2,400 head-on collisions. Also shown are frequency plots which show the number of occupants receiving various levels of injuries as a function of ETS.

Danner, M. and Langweider, K. Car/Vehicle Side Impacts - A Study of Accident Characteristics and Occupant Injuries. HUK-Verband, Munich. 40 p. October, 1976. (36388)

Presents analysis of injury severity in side impacts in terms of collision parameters, mass ratio, impact area, direction of impact, resultant damage, and intrusion. It is noted that the degree and direction of the impact impulse changes during the crash phase. Hence description of relative speed vector prior to impact is not sufficient. The problem of speed specification in side collisions has not yet been satisfactorily solved. Damage is not equivalent to crash tests, so Equivalent Test Speed (ETS) cannot be determined and delta-V is frequently computed from ETS. Consequently, a cross-tabulation of striking and struck speeds is used, which results in 100 cells (10 x 10). Vehicle damage is coded with the HUK Overall Damage Index into five categories (like CDC/VDI, see HUK-75).

DeLorean, John Z., Corporation. Automotive Occupant Protective Safety Air Cushion Expenditure/Benefit Study. Bloomfield Hills, Michigan. 228 p. August, 1975. (33078)

Evaluates the total benefits and expenditures associated with various restraint systems that might be installed during the next eleven years (1975-1985). Four restraint systems considered were: lap belt, present three-point lap-torso system, and the air cushion restraint system (ACRS) with and without the use of lap belts. The benefits and expenditures for each system were evaluated using an accident projection model. Effectiveness for injury reduction and for severity reduction was estimated for each crash mode as a function of crash intensity. It was seen that for all modes (e.g., front, side, rollover, etc.) the air-cushion lap-belt system was most effective of all four systems. A table gives the predicted costs and savings of five alternative restraint implementation assumptions. The primary analysis sub-divisions were vehicle weight class, accident mode, occupied seat position, and barrier equivalent velocity (BEV). Injury and fatality distributions as a function of velocity (BEV) were identified for each accident mode. BEV was calculated from the CPIR/MDAI data file variables: traveling speed, impact angle, vehicle mass, and principal damage area. BEV was defined as the "impact velocity of a vehicle in the center of mass reference range."

Economics and Science Planning, Inc. Automobile Collision Data; an Assessment of Needs and Methods of Acquisition. Washington, D.C. 250 p. February 17, 1975. (32144)

The 1800 installed crash recorders provide a 3-axis acceleration time history which would probably be adequate to determine crash severity had a severity index been explicitly defined. Fundamental to the statistics of accidents are the cumulative probability distribution functions of severity for all accidents, injury accidents, and fatal accidents. It is recommended that the NHTSA Fatal Accident Reporting System (FARS) include vehicle crush measurements that could be converted to Equivalent Barrier Impact Speed (EBS) using K.L. Campbell's method in order to construct a cumulative distribution function of EBS for fatality accidents. A measure of intrinsic crash severity rather than outcome severity is needed so data can be stratified by intrinsic severity levels that would permit inferences to be drawn about countermeasures as a function of severity. Without the severity measure, the levels of exposure of uninjured occupants cannot be determined and the basis for finding and comparing injury incidence is lacking. What constitutes a proper intrinsic vehicle crash severity index (VCSI) both as regards occupant injury and vehicle damage? The speed of unrestrained occupant impact is correlated with injury severity and is determined by average car acceleration in the direction from the object to the occupant and the distance between the two. The Head Injury Criterion (HIC) can then be computed from delta-V and delta-t. The forces experienced by the tightly restrained occupant are proportional to the passenger compartment acceleration and his own weight. Since "jerk" inflicts only minor punishment, the restrained occupant's injury is related to the average level of acceleration he is subjected to in the impact. Average deceleration is proportional to EBS and vehicle stiffness. K.L. Campbell has related crush distance and EBS by modeling the energy absorbed in plastic deformation of the vehicle. Volvo obtained crush characteristics from 11 full-scale impact tests. Average accelerations could be obtained from crash recorder histories, vehicle damage (use vehicle as its crash recorder), and computer reconstructions (e.g., SMAC). Use of vehicle damage is flawed if vehicle exteriors become softer or more resilient. Other current field-determined crash severity measures (e.g., CDC) are not adequate.

Edwards, J.J. "Research Safety Vehicle Crash Effectiveness Methodology." Fifth International Technical Conference on Experimental Safety Vehicles. GPO. pp. 937-945. 1975. (32385)

A modeling approach that focuses on the conversion of dynamic response into probability of survival ("lethal dosage"). HSRI survival curves for head and chest deceleration levels were used. Probability of survival can also be related to barrier equivalent speed for a particular system. Effectiveness must also take into account the probability of being exposed to a crash of any given speed. Overall effectiveness is determined by multiplying relative effectiveness with severity exposure and integrating across the whole severity (speed spectrum).

Ford Motor Company. Research Safety Vehicle (RSV). Phase I. Final Report. Volume II. Automobile Usage Trends, Accident Factors. DOT/HS 801 599. 109 p. June, 1975. (32394)

Determines vehicle and occupant dynamics by exercising mathematical models for a set of representative collision types over the complete spectrum of accident severity. The resulting occupant dynamics are transformed into injury levels through a biomechanical model, and numbers of fatalities and injuries are calculated by forming a probability-weighted average of those injury levels, weighted over collision type and severity. Collision types are classified by mode and struck object. Accident severity is defined by relative speed and the weight and "stiffness" of the object impacted. Accident severity is determined for four collision types and for "direct" (high injury potential) and "indirect/offset" (superficial, low injury/impacts). Barrier equivalent speed or "equal energy" was not used because of significantly different vehicle and occupant dynamics resulting from "equal energy" impacts. BES is also not independent of vehicle structure, hence is not a true crash severity exposure measure. Consequently, relative speed is used as the severity measure. Cumulative closing speeds are developed from CPIR/MDAI data for front-to-front, front-to-side, etc. Normal probability distributions were fit between the 20 percent and 80 percent cumulative distribution points. Closing speed, CPIR impact speed, and delta-V distributions are similar, if not identical. Barrier speeds are identical to delta-V if the "stiffness to weight ratio" is equal for both vehicles. As a check, the barrier impact speed as estimated from 75 CDC/VDI codes assigned to crash test data. The barrier speeds were converted to closing speed and resulted in a similar cumulative distribution.

Ford Motor Company. Occupant Crash Protection. Supplemental submission of Ford Motor Company on OST Docket No. 44; Notice 76-8, presented to the Department of Transportation. MVSS208. 171 p. September 17, 1976. (35698)

Tabulates societal costs and benefits as a function of ACRS sensor threshold speed (mph). Campbell's equations were used to compute Barrier Equivalent Speed (BES) for RSES (SWRI, Calspan, HSRI) frontal damage cases. A cumulative annual injury distribution by BES and AIS was calculated using the minicars estimate of 1,128,200 annual passenger car frontal injuries as a base. Due to an insufficient number of RSES fatalities, Carter's fatality distribution was used for AIS-6 (fatal) injuries.

General Electric Company. Development of Vehicle Rating Systems for the Automobile Consumer Information Study. Final Report. Information Systems Programs, Arlington, Va. 22 p. March, 1976. (33958)

Develops a Vehicle Rating System for comparative rating of makes and models of automobiles according to three criteria: Damage-Susceptibility, Crashworthiness, and Maintainability. In order to compare the various makes and models, indices of damage, injury, and maintenance are employed. These measures are numerical quantities determined for each make/model and are used to rank each make/model within a group of make/models, typically a market class.

General Motors Corporation. Comments of General Motors Corporation with Respect to Advance Notice of Proposed Rule Making; Higher Speed Protection Requirements. Docket No. 74-15; Notice 1. MVSS208. 19 September 1974. (35922)

General Motors takes issue with the NHTSA analysis in the areas of restraint system costs, number and costs of injuries, projected restraint effectiveness, and the incremental benefit/cost computed. Of particular interest is Appendix C, in which GM points out that the NHTSA cumulative curve of EBS for fatal accidents is not the probability of a fatal accident as a function of EBS, but rather the probability that the EBS was of a particular value, given that a fatality occurred. GM goes on to say that the NHTSA curve may be thought of as the product of two curves, one showing the probability of an accident's occurring at a given severity level, and the other showing the probability of death, given the severity of the collision. It is that latter curve which is relevant to vehicle design considerations. GM also presents its own estimates of restraint system benefits and costs.

Griffiths, D.K., et al. "Car Occupant Fatalities and the Effects of Future Safety Legislation." In Proceedings, Twentieth Stapp Car Crash Conference. SAE. pp. 335-388. 1976. (35834)

Describes the analysis of 342 fatalities. Injuries are described by AIS and ISS. Crash vehicle mass ratios are displayed by impact type. Equivalent Test Speed (ETS) was determined by matching damage to whole vehicle crash test results. Delta-V was computed from ETS's and vehicle masses. Of the ETS values, 76.8 percent were within ± 10 percent of the delta-V estimates. A distribution of 97 ETS values is plotted for fatalities. Mean deceleration was computed from ETS's, vehicle masses, and vehicle maximum crush using Ventre's method. ISS values for the fatalities and the survivors in these vehicles were plotted by mortality. Intrusion is a common factor in fatalities. Intrusion was judged according to the percentage reduction of "ride down" distance in the header, dash, footwell, and seat areas. Ejection and door openings were also considered.

Grime, G. and Jones, I.S. "Car Collisions - The Movements of Cars and Their Occupants in Accidents." In Proceedings, Institution of Mechanical Engineers. Vol. 184, Part 2A. 50 p. 1970. (50230)

Illustrates a theoretical study of collision dynamics with examples from road accidents. Head-on, rear-end, and side impacts are considered from the standpoint of both vehicle and occupant movement. Both symmetrical and asymmetrical collisions are addressed. The authors show that the relative velocity of the two vehicles determines the motion during impact. The total energy dissipated is shown to be independent of the deformation characteristics of the vehicles. However, the manner in which this energy is distributed between the two vehicles is influenced by their force-deflection characteristics. The influence of rotational motions is found to be small.

Grime, G. "Injuries to Car Occupants - Theoretical Considerations." Proceedings, Institute of Mechanical Engineers, Automobile Division. Vol. 189. pp. 405-416. 1975. (34146)

For head-on collisions, computes the percentage of occupants at each injury level from (1) a distribution showing the percentage of collisions within successive equal intervals of relative velocity at impact and (2) information on the probability of occurrence of each injury level as a function of velocity change. Various vehicle mass ratios were included, and satisfactory agreement was found with results derived from the national accident statistics. Included is a discussion of the errors involved in using the ratio of deaths to all injuries as a measure of severity. This error arises when the ratio of injured to uninjured occupants changes also. In this situation, use of number injured as the denominator in the ratio underestimates the effect.

Grime, G. "Probabilities of Injury in Road Accidents." Accident Analysis and Prevention. Vol. 9. pp. 125-142. June, 1977. (00000)

Describes a method for calculating the percentages of the various levels of injury in head-on collisions. The whole subject is studied from the viewpoint of probability. Also presents a diagram giving the probabilities of the four injury levels versus velocity change of the vehicle, and a distribution diagram of the percentages of head-on collisions within successive equal intervals of relative velocity at impact. Reasons for expecting the probability curves in all types to be similar are also explained. Finally, it is suggested that studies of the uninjured or slightly injured in severe frontal impacts may be as rewarding as studies of those injured more seriously. This paper is update of Grime, 1975.

Grush, E.S., Henson, S.E., and Ritterling, O.R. Restraint System Effectiveness. Ford Motor Company. Report Number: 5-71-40. 109 p. September, 1971. (31861)

Describes a comprehensive effort to estimate the effectiveness in terms of lives saved for various restraint systems. Computer simulations and occupant severity indices are used to determine restraint effectiveness as a function of crash severity. Accident data from the Automotive Crash Injury Research (ACIR) project were provided by Calspan to determine distributions of fatalities by type of accident and seating position. Distributions of barrier equivalent speed (BES) were developed from ACIR investigator-reported speeds by adjusting four factors: relative closing speed between fatality vehicle and object struck, the weight differential, a center of gravity adjustment, and accident location (e.g., rural/urban). The center of gravity adjustment was used to remove the energy lost in rotation/spin-out. A second method of BES determination is based on matching photographs of vehicle crash damage with known crash test results. A cumulative plot of the adjusted BES is provided. The two results were widely divergent, particularly at higher speeds, even though derived from the same data base. The data suggest that state troopers grossly overestimate at higher speeds. The use of BES as the crash severity measure assumes that the hazard to the occupant is related to the amount of energy absorbed by the vehicle (i.e., BES). There is no one common crash severity scale, since collisions which are equivalent in one dynamic parameter are seldom equivalent in others. For example, if we base collision severity on speed change (delta-V), we find that peak vehicle accelerations and absorbed energy vary considerably. Conversely, collisions with the same BES (energy dissipation) do not have the same delta-V. The actual velocity changes of vehicles may be slightly higher than the BES; however, the maximum vehicle deceleration will be the same. Increasing the delta-V at a fixed peak vehicle deceleration may decrease occupant loading. It is felt that the difference between delta-V and BES is small compared to other uncertainties.

Haddon, W., Jr. "Approaching the Reduction of Road Losses - Replacing Guesswork with Logic, Specificity and Scientifically Determined Fact." National Road Safety Symposium, Canberra (Australia). pp. 21-41. 1972. (28017)

Provides injury severity (AIS) distributions versus speed at impact for 1967 UCLA data on occupants striking the windshield and steering wheel. Maximum human tolerance limits to transverse acceleration are given as a function of acceleration and acceleration duration. The relationship between stopping distance, velocity change, and injury is also plotted.

Hardy, J.L., et al. "Field Accident Damage as a Basis for Crash Tests." In Proceedings, International Conference on the Biokinetics of Impacts. National de Securite Routiere, Laboratoire des Chocs, Lyon-Bron. pp. 213-223. May 25, 1973. (28048)

Asserts that current and proposed crash testing do not reflect the pattern of impact types found in the real world. It is suggested that one-quarter overlap offset frontal barrier be adopted in conjunction with the central pole and the front distributed barrier as appropriate crash tests for frontal impacts; and that in order to establish appropriate test speeds (ETS), proposed tests should be carried out on a number of vehicles.

Hartemann, F. and Tarriere, C. "Synthesis of Statistical Data on Traffic Accidents in France, West Germany, Italy, and United Kingdom." Fifth International Technical Conference on Experimental Safety Vehicles. GPO. pp. 405-413. 1975. (32385)

Provides cumulative plots of delta-V in all crashes and severe + fatal crashes for frontal and lateral impacts.

Hartemann, F., Henry, C., and Tarriere, C. Compared Influences of ΔV, Mean γ, and Intrusion Upon the Overall Severity of Injuries in Frontal Impacts. Peugeot-Renault Association, Physiology and Biomechanics Laboratory, Garenne-Colombes (France). 12 p. September 20, 1976. (36387)

Evaluates the effects of speed variation, mean acceleration, and intrusion upon the severity of lesions. Of primary interest is the interaction of the independent variables. A regression of these three variables is also performed. The influence of delta-V and mean acceleration was 6 to 8 times greater than intrusion in predicting an OAIS of 3 or more.

Hofferberth, J.E. "User Data Needs." In Proceedings, Motor Vehicle Collision Investigation Symposium. Volume I. DOT/HS 801 979. pp. 143-148. August, 1976. (35846)

Develops a computerized benefits analysis model which consists of an exposure matrix that contains the relative frequency of various crash situations, and an effectiveness matrix that states the likelihood of various levels of injury severity for each crash situation. Multiplication of the two matrices yields the number of various levels of injury in the population. No indication is provided of the crash parameters used in the exposure matrix. The need for significant crash severity descriptors is emphasized.

Hromi, J.D. "Collision Data Needs." In Proceedings, Motor Vehicle Collision Investigation Symposium. Volume I. DOT/HS 801 979. pp. 171-177. August, 1976. (35846)

Reviews four methods of crash speed estimations: (1) impact speed distributions as developed from the accident investigators' speed estimates by adjusting for known biases; (2) impact speed as related to crush by using linear force-deflection model; (3) impact speed as provided by computer models; (4) impact speed as determined from crash vehicle crash recorders.

HUK-Verband. "Interior Safety of Automobiles." Road Traffic Accidents and Their Consequences. A Study by German Motor Traffic Insurers on 28,936 Car Crashes with Passenger Injury. Hamburg (Germany). 127 p. 1975. (36020)

Presents 26 figures and 42 tables of descriptive statistics drawn from 28,936 third-party liability insurance. Both driving and collision speeds are reported. Cumulative distributions of relative collision speeds are plotted for rear, front, and side impacts by AIS levels. An appendix defines the HUK "Degrees of Damage" for vehicles into five zones similar to the CDC/VDI. There are three zones on the hood/trunk, with zone 4 being the windshield/backlight and zone 5 being anything inside of the headers. For side impacts zone 3 begins at the header and anything beyond the centerline is zone 5.

Ivey, D.L. "Predicting the Probability of Injury During Highway Collisions, Sub-Compacts Versus Standard Size Vehicles." In Proceedings, Third International Congress on Automotive Safety. Vol. II. pp. 41.1-41.35. 1974. (30080)

Develops a relationship between probability of injury and acceleration (lateral and longitudinal). TAD damage was related to deceleration versus photographs of test vehicles. Cornell and Weaver maximum tolerable occupant decelerations (Gx and Gy) are used. A severity index is defined as the ratio of the vector sum of the collision accelerations to the vector sum of the "tolerable" accelerations. The severity index was then converted into a probability of injury, using the earlier injury/acceleration relationship.

Joksch, H.C. "An Empirical Relation Between Fatal Accident Involvement Per Accident Involvement and Speed." Accident Analysis and Prevention. Vol. 7, No. 2. pp. 129-132. 1975. (52464)

Provides an analysis of the data from five states giving fatal involvements relative to all involvement by speed ranges and multiplied by a factor. There is a higher injury involvement risk for speeds for each range above 40-50 mph. Overall assessment between data from several states is surprisingly good up to 70 mph, but there are large discrepancies below 40 mph.

Klove, E.H., Jr. and Oglesby, R.N. Special Problems and Considerations in the Development of Air Cushion Restraint Systems. SAE 720411. 8 p. 1972. (19910)

Presents data on four impact threshold levels measured by crash recorder in General Motors ACRS cars: (1) crash severity below 12 mph barrier equivalent; (2) 12 mph barrier-equivalent low-level deployment; (3) 18 mph barrier-equivalent high-level deployment; and (4) greater than a 30 mph barrier collision.

Langweider, K. Car Crash Types and Passenger Injuries in Dependency Upon Car Construction (Field Studies of the German Automobile Insurance Companies). SAE 770968. 34 p. 1972. (19862)

Provides information on 10,271 injury accidents for cases where insurance liability was involved. All of these are two-vehicle collisions. The case vehicle is the vehicle judged to be not at fault. Distributions of type of accident and impact speed are presented. The author reports that 90% of all oncoming traffic accidents occur at impact speeds less than 60 km/h (36 mph), and 95% of all intersection accidents occur at impact speeds less than 60 km/h (36 mph). Distributions of body area injured are also presented by seated position. Various injury types are then related to the severity of vehicle damage. The authors report that in 50% of all accidents with fatal injuries, the fatality cannot be ascribed to extreme damage. In these cases the fatality is ascribed to "unfortunate circumstances" or "insufficient use of available safety measures."

Langwider, K. Passenger Injuries and Their Relation to General Speed Scale. SAE 730963. 34 p. November, 1973. (28770)

Presents distributions of relative collision speed for several different collision configurations. These are further broken down by seated location of the occupant. For example, 120 accidents involved the front of the striking vehicle impacting the left door area of the struck vehicle. Both front seats were occupied in the struck vehicle in all cases. Results are shown separately for the driver and right front occupant seated position. Distributions or relative collision speed (RCS) (in increments of 20 km/h) are shown for five different levels of injury severity ranging from "no injury" to "life-threatening and fatal." RCS is obtained by vectorial addition of the speeds of the vehicles involved. Also presented is a distribution of "equivalent test speed" for 94 fatal occupants involved in frontal collisions. Equivalent test speed is determined by using test data to relate the amount of energy absorbed by each vehicle to the collision configuration and relative velocity at impact. The equivalent test speed is determined to result in the same amount of energy absorbed by the vehicle.

Lincke, W. and Langner, W. "Cost-Benefit Considerations for Determining Priorities in Safety Standards." In Proceedings, Fourth International Congress on Automotive Safety. NHTSA. pp. 359-382. 1975. (32949)

Points out that benefits of safety measures are significantly affected by any changes in the frequency distribution of accidents. An optimization procedure was applied to several sets of varying effectiveness ratings resulting from shifts of cumulative frequency of impact speed. The measures of safety benefits are more sensitive to estimates of cost figures and effectiveness ratings than to variations in the distribution of accident types.

Lutkefedder, N.W. and Teel, S.S. "Automotive Recorder Research and Its Effects on Future Vehicle Safety." Vehicle Safety Research Integration Symposium. NHTSA. pp. 353-373. 1973. (29031)

Presents significant difference in results which compare accident severity with occupant injuries and fatalities including (1) curves of fatalities versus estimated barrier equivalent speed diverge significantly above 30 mph depending on source of data and (2) curves of cumulative frequency of fatalities versus estimated traveling speed also show considerable divergence. This difference can be attributed to several factors, including lack of quantitative pre-crash and crash data. An important indicator of vehicle crash severity is Barrier Equivalent Impact Velocity (BEIV). It can be computed by estimating the vehicle velocity at the time of impact, the change in velocity during impact, and the amount of energy absorbed by the object struck. But these estimates are rough approximations, since accidents are complex events from which reliable quantitative data are difficult to obtain. The task of determining BEIV will be greatly simplified in case of recorder-equipped vehicles, since accurate dynamic data will be available from the accident. Then a question arises: Now that accurate records of acceleration versus time from real-world accidents are available, can a more meaningful vehicle crash severity index be developed? People in the field of biomechanics have already taken a stop forward by defining a more meaningful measure of crash severity, the "Head Injury Criterion" (HIC). It defines head injury severity as a function of acceleration and time. The fact that an injury severity index can be defined for human heads is no guarantee that a crash severity index can be developed for vehicles. A vehicle severity index may have to take into account internal geometry, structural size, mass and crush characteristics, aggressiveness of one car against the other, etc. However, as a first step, a weighted average of acceleration versus time (somewhat similar to HIC) may be appropriate.

Mackay, G.M. "Injury and Collision Severity." In Proceedings, Twelfth Stapp Car Crash Conference. Society of Automotive Engineers. pp. 207-219. 1968. (06742)

Considers vehicle damage as the starting point for estimating collision severity. Test data are used to estimate an "equivalent barrier speed" which would produce the same deformation.

An adjustment to these estimates is made based on the mass of the struck object. Results are presented for a sample of British accidents relating collision severity and injury severity for various crash configurations. The benefit of seat belts is also illustrated.

Mackay, G.M. "Field Studies of Traffic Accidents in Europe." Fourth International Technical Conference on Experimental Safety Vehicles. Report. NHTSA. pp. 601-606. 1973. (29313)

Five European accident teams investigated 986 cars in collisions producing injury to at least one person. Each damage type was classed into the closest equivalent crash test category (e.g., front angle). Equivalent Test Speed (ETS) was determined by matching damage to crash test results. Such an assessment is therefore a comparison based on collision energy. (Future analysis will be based upon delta-V of each vehicle.) Cumulative curves of speed are plotted for AIS-1, AIS-2 and 3, AIS-4 and 5, and AIS-6+ for frontal collisions. The European and USA-Carter injury-speed distribution curves are shown to differ. Since the Carter analysis of ACRI data used 20 mph increments, the curve is largely defined on the basis of three points only. Injuries from side and rear impacts are also plotted by speed.

Marquardt, J.F. Vehicle and Occupant Factors That Determine Occupant Injury. SAE 740303. 17 p. February 1974. (29784)

Describes a method for computing change in vehicle velocity, using the Campbell method to estimate the energy absorbed by each vehicle. Knowing the total energy absorbed and the masses of the vehicles, the change in their relative velocity may be computed if changes in rotational kinetic energy are not significant. Velocity changes for each vehicle are computed from the change in relative velocity. A discussion is presented on the relationship of vehicle mass and stiffness, energy absorbed, and velocity change. This paper also examines occupant-related factors which influence occupant injury. A computer simulation is used to illustrate the effects of initial occupant position, time duration, and ride-down.

Marsh, J.C., Campbell, K.L., and Kingman, B.C. An Assessment of the Relationship Between Frontal Impact Severity and Injury Level. SAE 770156. 12 p. 1977. (36622)

Looks at the relationship between crash severity and injury level. Emphasizes that the probability of injury is a function of both (1) the risk of injury, given a set of crash factors (severity, etc.) and (2) the crash exposure, or chance of those factors occurring. This approach is illustrated using the Restraint

System Evaluation Study (RSES) data and Texas police-reported data. Changes in crash exposure with time are illustrated, as well as the role of crash factors other than the traditional speed-related measures.

Martin, D.E. and Yanik, A.J. "Occupant Protection Research Needs." In Proceedings, Automotive Safety Engineering Seminar. General Motors Corporation, Environmental Activities Staff, Milford, Michigan. pp. 181-185. 1973. (28833)

Plots fatalities in 1968 GM cars by estimated barrier speed.

McHenry, R.R. Notes on Interpretation of Collision Damage. Calspan Corporation, Buffalo, N.Y. 15 p. March 29, 1976. (34162)

Proves that structural damage produced by a given speed change of a vehicle in a non-sideswipe collision is independent of the speed range in which it occurs. Therefore, interpretation of damage in terms of the severity of the occupant exposure can be made without knowledge of the final speed of the striking vehicle. The extent of damage does, however, depend on the mass and stiffness of the struck obstacle.

Michalski, C.S. "Model Vehicle Damage Scale: A Performance Test." Traffic Safety Research Review. Vol. 12, No. 2. pp. 34-39. June, 1968. (06389)

Describes Traffic Accident Data Project (TAD) damage scale for policemen and a 565-accident Oregon field trial. A parabolic relationship between damage ratings and the incidence of injury was plotted along with a probability integral curve for front-end damage.

Miller, P.M., et al. Research Safety Vehicle Program (Phase I) - Volume II. RSV Characterization and Performance Specification. Final Technical Report. DOT/HS 801 608. 444 p. June, 1975 (32548)

Plots ACIR data on police-estimated impact speeds for pedestrian, single-vehicle, and vehicle-to-vehicle collisions by area of impact, injury severity, and vehicle weight. The policemen were trained by Calspan beforehand. The speed data have not "been adjusted in any fashion to reflect some sort of barrier equivalence." Real cars do not hit ideal flat barriers.

Moore, J.O. "A Study of Speed in Injury-Producing Accidents." American Journal of Public Health. Vol. 48, No. 11, pp. 1516-1525. November, 1958. (03018)

Studies each of 3203 automobiles involved in injury accidents during the period 1953-1956 to determine the association of injury and speed. Dangerous and fatal injury increases were relatively small in speed ranges up to 50 mph. Above 50 mph the frequency rises sharply. It was pointed out that other causes, concommitant with speed, may be the real factors of serious injuries occurring at high speeds.

National Highway Traffic Safety Administration. Analysis of Effects of Proposed Changes to Passenger Car Requirements of MVSS 208. 59 p. August, 1974.

and

National Highway Traffic Safety Administration. Amendement to Analysis of Effects of Proposed Changes to Passenger Car Requirements of MVSS 208. DOT/HS 801 328. 51 p. December, 1974. (30276)

Projects benefit/cost ratios, cost and effectiveness for three restraint options. Most of the data are from earlier work by Cooke. Plots of "cumulative percent of deaths or injuries" by barrier test speed were provided and then updated in the amendment.

Organisme National de Securite Routiere. "Voice les Proportions dans Lesquelles la Gravite des Collisions Augmente Avec les Vitesse des Vehicules." [Here are the proportions in which the severity of collisions increase with vehicle speed.] ONSER Activities. Vol. II. pp. 6-8. 1964. (13431)

Early graph of speed and consequences is provided in this French language paper.

Patrick, L.M. and Andersson, A. "Three-Point Harness Accident and Laboratory Data Comparison." In Proceedings, Eighteenth Stapp Car Crash Conference. pp. 201-302. 1974. (30826)

Compares the data from 128 accidents involving 169 occupants of BEV 2 to 53 mph with 11 staged and 72 simulated collisions. Then presents from real-life data: (1) the injury data as a function of BEV, showing maximum injury level for three body areas (head, neck, and chest), (2) distribution of single most severe occupant injury versus BEV, and (3) most severe injury for all occupant versus BEV from staged and simulated accidents.

Also presents velocity versus: (1) chest peak "G," (2) total belt load, (3) head HIC, and (4) crush (in inches). A common base for comparing the severity of the accident data and staged and simulated collisions was achieved by referring them to a Barrier Equivalent Velocity. Permanent front-end crush of the case vehicle was compared to permanent crush of vehicles in staged collisions to arrive at a collision severity based on BEV.

Prost-Dame, C. "The French Technical Presentation - Rating Accident Severities of Occupants." In *Report, Fourth International Technical Conference on Experimental Safety Vehicles*. NHTSA. pp. 197-200. 1973. (29313)

Criticizes the assignment of collision severity based on vehicle deformation. Velocity change of the vehicle is advanced as a more appropriate measure of collision severity. Differences between speeds based on vehicle damage and the actual velocity change arise from the combination of differences in mass and structural stiffness of the vehicles involved. In this approach, vehicle damage is used to estimate the total energy absorbed in the collision. This quantity can then be related to the closing speed (relative velocity of the vehicles prior to impact) and, finally, to the velocity changes of each vehicle during the impact. A cumulative distribution of change in velocity is plotted for 410 Peugot-Renault head-on cases, and compared to the NHTSA curve. See also Ventre (73).

Ruter, G. and Hontschik, H. "Determination of Injury Threshold Levels by Reconstruction of Real Road Accidents." In *Proceedings, Second International Conference, Biomechanics of Serious Trauma*. Bron. IRCOBI. pp. 279-287. 1975. (32768)

Determines biomechanical tolerance levels by road accident reconstruction. Vehicle damage and occupant injury are investigated. The interior damage is simulated in the laboratory, so that loads can be measured. Results are compared with data determined by other methods.

Ryder, M.O., Jr. *Development and Evaluation of Automobile Crash Sensors - Executive Summary. Summary Final Report*. DOT/HS 801 262. 33 p. November, 1974. (30722)

Compares various sensors manufactured by different firms with respect to their actuation time. The report also concludes that a sensor's crash acceleration environment is highly dependent upon its location on the vehicle and environmental factors, e.g., temperature, radiation, vibration. A velocity-displacement-sensitive bumper was also developed, which reacted to a variety of frontal impact conditions.

Ryder, M.O., Jr. Development and Evaluation of Automobile Crash Sensors. Final Technical Report. DOT/HS 801 263. 230 p. November, 1974. (30809)

Notes the importance of a crash sensor which can make a crash/non-crash discrimination in the shortest possible time. There are two fundamentally different approaches to crash detection: (1) predictive or anticipatory (makes crash/non-crash discrimination prior to the impact) and (2) active or post-contact (makes the determination during impact).

Schmidt, R. "Accident Investigation in the Evaluation of Safety Standards - A Survey of Methodology and Applicability." In Proceedings, Fourth International Congress on Automotive Safety. NHTSA. pp. 605-665. 1975. (32949)

Determines the absolute national numbers of injuries versus accident type, seat position, impact location; projects accident situation into mid-1980's; and determines injuries as a function of vehicle velocities. Regressions are performed on TAD versus crash test results to determine an empirical relationship with impact speed. It was noted that TAD7 only means "more than TAD6." North Carolina rural police-reported TAD data for unrestrained occupants in frontal impacts are converted into cumulative speed plots for various classes of accidents.

Smith, R.A. "Use of Measurement Data." In Proceedings, Motor Vehicle Collision Investigation Symposium. Volume I. DOT/HS 801 979. pp. 411-415. August, 1976. (35846)

Points out that the divergence of opinion as to the potential benefits of safety features is largely the result of the absence of any substantive definition of the severity of crashes and their role. (1) Severity could be measured by accelerometers placed at the vehicle center of mass. Cost has precluded their use. (2) the SMAC simulator could provide severity but is precluded due to cost and limited application. (3) A cheap crash pulse recorder that provides a measure of delta-V uses a small mass in a tube of viscous fluid. (4) The CRASH computer program is its software counterpart. The important characteristics of the acceleration-time history include: peak acceleration, pulse width, velocity change, and curve shape (e.g., initial rise). Analogous crash data include: object struck, vehicle masses, and collision configuration. Peak acceleration and pulse width are related to collision configuration and the ability of struck object to yield. The relative vehicle masses will also influence peak acceleration.

Society of Automotive Engineers. "Collision Deformation Classification." In SAE Handbook 1977. SAE-J-224a. pp. 34.110-34.114. 1977. (00857)

Describes a system of classification which can categorize most deformations of a given vehicle, model, year, and body style within narrow but practical boundaries. Classification is based on impact severity in terms of direction, location, and extent of vehicle damage in seven data columns. Deformation of different vehicles in the same exposure may yield differences in the damage index due to design changes. It is therefore important to limit the use of the deformation index as an indicator of accident severity to vehicles of the same make, model, year, and body style. To make comparisons using collision deformation on vehicles of varied vintages, makes, and models will require development of calibration factors which can be used to adjust the deformation index for vehicle structure, weight, and size differences.

Struble, D. and Bradley, G. Research Safety Vehicle. Phase I. Volume II. Program Definition Foundation. Final Report. DOT/HS 801 604. 195 p. June, 1975. (32391)

Projects accident situation into 1980's. Accidents are classified as vehicle-vehicle, vehicle-object, and rollover. Crash severity is defined as Barrier Equivalent Velocity (BEV) to place all crashes on a common base. BEV accounts for unequal-mass collisions; i.e., it is a function of both masses and both velocities. The Calspan Level II data are used to adjust for MDAI/CPIR file biases. Data are subdivided by vehicle size, impact angle, BEV range, and injury level (AIS) before costs are applied. These were combined to produce a BEV versus societal cost curve. For car-car collisions, relative velocity is the vector difference corrected for eccentricity. The Law of Cosines is used to compute closing velocity by assuming [incorrectly] that the CDC clock direction is about the vehicle center of mass. Finally, the BEV is computed by considering vehicle masses. Claims costs per velocity arb developed from insurance data. Using the frequency distribution of claim costs, a probability distribution of BEV is developed.

Tarriere, C. "Efficiency of the 3-Point Belt in Real Accidents." Fourth International Technical Conference on Experimental Safety Vehicles. NHTSA. pp. 607-619. 1973. (29313)

Measures collision severity using the Prost-Dame method of computing change in velocity during the period of vehicle deformation (delta-V). Velocity distributions were plotted for belted and unbelted occupants. Results are presented for 160 belted occupants and 782 unbelted occupants. No fatalities were observed for belted occupants at velocity changes less than 55 km/hr (33 mph). The probability of being killed or seriously injured was found to be six times lower for the belted occupants for velocity changes less than 55 km/hr (33 mph).

Tarriere, C., et al. "The Contribution of Physical Analysis of Accidents Towards Interpretation of Severe Traffic Trauma." In Proceedings, Nineteenth Stapp Car Crash Conference. SAE. pp. 965-993. 1975. (33279)

Stresses that the Equivalent Test Speed method of crash severity assessment be discarded, to be replaced by the Speed Variation Method (delta-V) and more recently by two parameters, namely, the speed variation and mean deceleration of the undistorted part of the vehicle. An understanding of the distribution of actual violence of impacts in accidents is essential to sound safety policy. Valid and unbiased severity measurements are needed. The conventional method of estimating equivalent test speed is a source of considerable error and only applies for rigid-obstacle impacts. Delta-V is the critical measure for unrestrained occupants. Delta-V can be computed from the masses and energy dissipated by each vehicle or structure. Either the stress deformation or energy/deformation relationship must be known for each structure. The same delta-V can produce widely differing deformations. Speed variation and mean deceleration are the needed parameters for restrained occupants because of the importance of time during which the delta-V occurs. Both parameters were plotted for 330 frontal collisions in France and 21 U.S.A. crash recorder outputs. A 2 to 1 difference in crash recorder and field team speed results is noted.

Tartaglia, P.E. "Multi-Purpose Collision Trajectory Sensing." American Society of Safety Engineers Journal. Vol. 18, No. 12. pp. 14-19. December, 1973. (51709)

Discusses use of a radar with electronic logic systems to warn the driver of impending collision and allow him time to decelerate. According to the information compiled by Automotive Crash Injury Research (ACIR) of Cornell Aeronautical Laboratory, there is a direct correlation between the most severe injury occurring and the speed at which the accident occurred. When speed reduction attainable (by use of radar) was correlated with severity index-speed graph, it was found that there was an average reduction in the severity index of about 20%.

Teel, S.S., Pierce, S.J., and Lutkefedder, N.W. "Automotive Recorder Research - A Summary of Accident Data and Test Results." In Proceedings, Third International Conference on Occupant Protection. SAE 740566. pp. 14-70. 1974. (30029)

NHTSA developed a recorder that measures crash triaxial acceleration/time history during vehicle collisions. Based on that, velocity/time history and velocity change, during impact, can be derived to provide measures of vehicle crash severity. Since these recorders can provide accurate records of vehicle acceleration/time histories from actual accidents, and in-depth injury data can be made available, we can try to: (1) determine relationship between vehicle crash severity and occupant injury severity; (2) compare different accidents on the basis of vehicle-crash severity index; (3) compare actual highway accidents with laboratory results; (4) relate actual accident severity to crash survivability standard; and (5) establish the criteria for future crash survivability standards to provide optimum benefit/cost payoff.

Timpner, F.F. Vehicle Impact Analysis. General Motors Corporation, Pontiac Motor Division. 5 p. November 6, 1969. (16119)

Describes an expression for computing the relative velocity at impact from the vehicle masses and energy absorbed. The vehicles are treated as point masses and the coefficient of restitution is assumed to be 0 (a completely plastic collision). The expression was developed to relate relative speeds at impact to test speeds using rigid barriers and pendulums which would produce the same damage. Defines delta-V as the "relative striking velocity" of two masses to achieve the same degree of crush as single-car impact into a wall.

Trenka, A.R. Basic Research in Crashworthiness II - Comparison of Teledyne-Geotech Crash Recorder Data and Accelerometer Data. Capspan. DOT/HS 800 873. 111 p. April, 1974. (29610)

Compares accelerations measured by conventional strain gauge accelerometers and new self-contained crash recorder in vehicle-to-pole and vehicle-to-vehicle impacts. A NHTSA addendum corrects crash recorder data reduction errors. Calspan found poor velocity agreement between the recorder and accelerometer data. NHTSA developed a new and improved method for crash recorder data reduction and obtained reasonably close results.

Van Kirk, D.J., Hirsch, J., and Sato, T.B. Effective Impact Velocity From Vehicle Deformation - A Preliminary Study. SAE 680477. 6 p. May, 1968. (05586)

One of the earliest papers to suggest an energy basis or equivalent barrier speed basis as a uniform basis for measuring crash severity. Speed at impact is shown to produce a wide variation in deformation (inches of crush). Vehicle damage is suggested as a measure of crash severity as it relates to deformation energy, and it can be compared with barrier results. Equivalent barrier impact velocity will always be equal to or less than the real velocity. A plot of kinetic energy (ft-lbs) versus volume of deformation (cubic inches) is provided.

Ventre, P. and Provensal, J. "Proposal for Method of Analyzing Collision Speeds in Real Accidents." In Report, Fourth International Technical Conference on Experimental Safety Vehicles. NHTSA. pp. 549-559. 1973. (29313)

Provides experimental force-deflection curves and techniques for using curves to estimate a constant force level which, when multiplied by the mutual crush (summation of crush measurements for the two vehicles), an estimate of the total energy absorbed is obtained. See Prost-Dame (73) for further discussion.

Ventre, P. "Compatibility Between Vehicles in Frontal and Semi-Frontal Collisions." In Report, Fifth International Technical Conference on Experimental Safety Vehicles. GPO. pp. 670-673. 1975. (32385)

Asserts that the effects of a collision on the occupants depends on: delta-V, deceleration level, and intrusion. Delta-V depends on vehicle masses and closing speed at moment of impact. Vehicle registration provides data for cumulative plots of car masses and hence the ratio of car masses. A hypothetical of vehicle speed distribution before impact is plotted. Accident data on delta-V are plotted for belted and unbelted occupants and by three injury severity levels.

Villardo, F.J. "Vehicle Damage Scale for Traffic Accident Investigators: An Investigation of Its Use and Potential for Predicting Driver Injury." Journal of Safety Research. Vol. 5, No. 4. pp. 229-237. December, 1973. (51551)

Attempts to show the relationship between driver injuries and TAD severity level. To the degree that crash severity is defined in terms of driver injuries, a strong relationship between TAD rating and injury was found, indicating that TAD is a good estimate of crash severity.

Wall, J.G. and Lowne, R.W. "Human Injury Tolerance Level Determination from Accident Data Using the OPAT Dummy." In Report, Fifth International Technical Conference on Experimental Safety Vehicles. GPO. pp. 501-507. 1975. (32385)

Calibrates OPAT dummy for injury tolerance levels through use of field accident data on vehicle damage and injury to restrained occupants. Equivalent barrier speed was estimated by matching damage from vehicle crash tests. Equivalent barrier speed is plotted versus belt tension, chest deflection, peak head acceleration, and peak chest acceleration. These measured forces parameters were then correlated with specific injury types, e.g., rib fracture versus shoulder belt tension.

Warner, C.Y., et al. An Assessment of the Performance of Belt Restraint Systems in Automobile Crashes. NHTSA. Report No.: ASME-73-ICT-107. 70 p. 1973. (28143)

Discusses crash severity measures that determine injury severity: vehicle velocity change, stopping distance, deceleration profile, and structural interactions of the vehicle and the object struck. Crash survival also depends upon the occupant/vehicle interface. In many situations the occupant experiences deceleration levels exceeding the vehicle levels. A single, easily understood crash severity measure is needed. Two candidates include velocity change and deceleration level—realizing that they are directly related only under ideal conditions. Equivalent Barrier Speed (EBS) has been assigned by matching experimental crash damage results, by engineering estimates, and by consideration of crash dynamics and structural characteristics. Several EBS cumulative curves are compared. Restraint effectiveness is considered as a function of severity (CDC/VDI extent and speed). It is noted that stopping distance varies independently of EBS.

Warner, C.Y., et al. "An Inexpensive Automobile Crash Recorder." In Proceedings, Third International Conference on Occupant Protection. SAE 740567. pp. 71-79. 1974. (30029)

Emphasizes that velocity change and/or vehicle crush are not a sufficient measure of crash intensity. But vectoral velocity change and stopping distance combined with minimal data on occupant compartment intrusion, collision partner characteristic, could provide a sufficient measure of intensity. The current NHTSA recorder program has the following deficiencies: (1) large number of recorders are needed to provide even a small amount of statistically useful data, and (2) both Teledyne-Geotech recorder and AVCO device are useful but are very expensive. Hence, a scaled-down recorder that measures one or two essentials of crash intensity at modest cost may be more valuable. Authors suggest and are working on a model that will: (1) be inexpensive (less than $10.00 per car); (2) record velocity changes in crashes with a minimum of OAIS-5; (3) have trigger level of 10g frontal and/or 7g lateral; and (4) identify crash velocity change with at least 10 mph resolution.

Watson, L.G. and Shiels, A.C. "Injury Predictions for Frontal Collisions." In Proceedings, Nineteenth Stapp Car Crash Conference. SAE. pp. 849-868. 1975. (33279)

Discusses the development and application of empirical equations relating frontal damage as expressed by the CDC to mean AIS injury severity. Different equations are developed for unrestrained, lap-belted, and fully-belted occupants and for ten CDC/VDI damage types (e.g., FREW, FCEW, FLEE, FZEW, FCEN, FREN). Three age groups were used. Actual and predicted air cushion AIS levels are compared for 13 cases.

Watson, L.G. and Shiels, A.C. Evaluating Crashworthiness with AIS and CDC. SAE 750918. 6 p. 1975. (32935)

Discusses the use of linear and nonlinear curve fitting programs for the development of injury prediction equations for automobile side and rear collisions. Separate equations are developed for unrestrained, lap-belted, and fully-belted front seat occupants. Three injury mechanisms are noted: acceleration/striking, crushing, and ejection (or combinations of these). AIS was predicted solely on the basis of CDC extent code.

Wolf, R.A., et al. Vehicle Speed and Rural Automotive Crash Injury, Part I: Estimated Traveling Speed and Fatalities. DOT/HS 800 285. 44 p. January, 1969. (13093)

Served as basic reference data used by Cooke, Grush (71) and others in estimating impact speeds. The data were collected under the Cornell Aeronautical Laboratory ACIR program during the period 1953-1968. The information was collected by state police officers in 31 states on rural injury-producing accidents involving U.S. passenger cars. Only unrestrained occupants who were at least 15 years old were included. Only cases in which the investigatory officer reported an estimate of traveling speed were included.

SECTION 2

ACCIDENTS

This section covers both data analysis and accident reconstruction. Emphasis in the data analysis annotations is on injury prediction techniques, and on crash severity control variables or stratification techniques. Reconstruction includes field techniques, impacy dynamics, and computer simulation applications. Accident studies which did not control for or discuss crash severity are not included. Accident studies whose central topic was primarily crash severity are included under Crash Severity, Section 1.

The 79 citations include many suggestions for crash severity measures. While most are directly related to acceleration, velocity, or distance/time, several indirect measures have been used, e.g., impact configuration, vehicle size, percent of vehicle overlap, and windshield bond separation. The various acceleration-velocity-distance (crush) measures are of two types: actual and barrier equivalent (i.e., what barrier crash would produce the severity measure?). There is a wide range of methods of deriving these crash severity measures: crash evidence, a simple monogram of skid length, friction coefficient, minimum velocity, and sophisticated SMAC computer simulation.

Auter, J.H., Webb, D.G. The Crash-Speed Calculator. Charles C. Thomas, Publisher, Springfield, Ill. 19p. 1972. (27628)

Includes a plastic crash-speed nomograph calculator based upon sliding distance and coefficient of friction. A coefficient of friction estimator for rubber tires is also included.

Baker, J.S. "Reconstruction of Accidents." Traffic Digest and Review. Vol. 17, No. 3. pp. 9-16. March, 1969. (12973)

Outlines methods for speed reconstruction from field accident evidence, including skidmarks, yaw marks, horizontal and vertical distances traveled while airborne, vehicle damage, and vehicle momentums.

Baker, J.S. "Traffic Accident Analysis." Traffic Engineering Handbook. Prentice-Hall. pp. 377-403. 1976. (33194)

Suggests a way to reduce accidents at specific locations. The method usually involves: (1) Selecting locations to study, (2) Determining what can be done to improve each location studied, (3) Comparing cost of the improvement and value of the harm that could be prevented by it, (4) Selecting locations to be improved, (5) Determining the success of the improvement after it has been made.

Bartz, J.A., Segal, D.J., McHenry, R.R. Mathematical Reconstruction of Accidents - Analytical and Physical Reconstruction of Ten Selected Highway Accidents. Interim. Calspan Corporation. Report No. CAL ZQ-5341-V-1, DOT-HS-801 150. 282p. March 1974. (30231)

Mathematical reconstructions of ten actual highway accidents. SMAC was used to reconstruct vehicle trajectories from scene evidence. The Calspan 3-D crash victim simulator was used to reconstruct the responses of the right front occupants from observed internal vehicle damage, passenger injuries, and the SMAC-predicted vehicle crash history. Results were generally comparable for the majority of cases, but the injury indicators (e.g., HIC) did not correlate significantly with observed injuries. Occupant responses were also physically reconstructed on an impact sled with anthropometric crash test dummies. Again, results generally agreed, but head severity indexes were not correlated with observed injury. Observed injury did correlate with predicted speed change.

Beatty, R.L. "Speed Analysis of Accidents on Interstate Highways." Public Roads, Volume 37, Number 3, pp. 89-102. December, 1972. (51055)

Presents various tasks and graphs showing speed before accident versus (1) average number of injuries per 100 accidents in rural area, (2) average number of injuries per 100 accidents in urban area and tilted regression line, (3) average reported fatalities per 100 accidents, both rural and urban, (4) average reported injuries per 100 accidents by type of collision, and (5) average reported injuries per 100 accidents by time of day. The study partly substantiates the conclusion that a direct relationship exists between the speed of a vehicle before an accident and the severity of the accident and number of injuries per accident for all times of day, manners of collision, and area types. A statistically significant linear relationship between injuries per single-vehicle accident and speed before the accident existed in all cases.

Bhushan, B. Analysis of Automobile Collisions. SAE 750895. 12p. 1975. (32920)

Presents an expert investigator's approach to accident reconstruction. The approach covers transient analysis of automobile collision, including relative sliding, rotation, and plastic deformation. Analysis is based on energy loss in sliding and plastic deformation. It uses post-accident information (e.g., skid marks, distance traveled after impact, etc.) and automobile parameters (e.g., center of gravity, moment of inertia). Experimental methods to determine automobile parameters are also described.

Burgett, A.L., and Monk, M.W. "Car-to-Car Side Impacts: Computerized Crash Reconstruction." In Proceedings, Nineteenth Stapp Car Crash Conference, SAE, pp. 405-427. 1975. (33279)

Describes relationship between injury severity and crash severity by SMAC (Simulation Model of Automobile Collisions) reconstruction of 49 CPIR/MDAI side impacts. Plots of striking vs. struck velocities are provided for fatals, life-threatening injury, and low-level injury. Car size and mass ratios are also considered. It is suggested that a single parameter, relative velocity, is sufficient for separating injury levels. Striking velocity also works but not as well as relative velocity. Accident mode, impact location, seating position, and vehicle weights should also be considered.

California Highway Patrol, Sacramento. Accident Investigation. Revised. 51p. April 1970. (14970)

The formula for calculating speed from skid marks is:

$$S = \frac{V^2}{30\ f}$$

where
S = skid distance in feet,
V = speed in miles per hour, and
f = coefficient of friction.

The simplest way of estimating the minimum initial speed of a vehicle traveling on a dry, level, hard-surfaced pavement is to arbitrarily assign a coefficient of friction of 60%. The percentage of grade is added to this figure if uphill and subtracted if downhill. Skids from all skidding wheels should be averaged and results used to calculate the minimum vehicle speed.

Campbell, K.L., Scott, R.E., and Tolkin, S.E. Highway Safety Effects of the Energy Crisis on U.S. Toll Roads. Final Report. Highway Safety Research Institute, DOT/HS 801 933. 100p. June, 1976. (34575)

Observations include: (1) passenger car traffic was down 14.7 percent, (2) truck traffic was up 1.2 percent, (3) involvement of cars in crashes was down 45.1 percent, (4) involvement of trucks in crashes was down 16.6 percent, (5) average speed was down by about eight mph., and (6) accident-rates overall were reduced by much more than could be accounted for by travel alone. Accident severity was reduced, leading to a 47 percent reduction in fatalities.

Carlson, W.L., and Kaplan, R.J. "Case Studies Considered as Retroactive Experiments." Accident Analysis and Prevention, Volume 7, Number 2, pp. 73-80. June, 1975. (52459)

Fits multiple regression model to predict injury (AIS) from in-depth case studies (CPIR/MADI data). Predictor variables include CDC/VDI damage extent index, impact vehicle velocity squared, ejection, windshield bond separation, and single/multiple vehicle. Relative velocity was found to result in a worse prediction of injury. Other velocity effect measures considered included case vehicle velocity squared, sum of velocity squared for both vehicles, and crash energy (sum of $MV^2/2$ for each vehicle).

Coleman, J., and Stewart, G. "Accident and Accident Severity Prediction Equations." In Proceedings, National Conference on Railroad-Highway Crossing Safety, U.S. Department of Transportation, pp. 56-62. 1975. (32304)

Predicts injury and fatality rates at railroad-highway crossings in terms of vehicle speed, train speed, type of warning device, urban/rural, vehicle traffic volume, and train volume.

Council, F.M., and Hunter, W.W. Seat Belt Usage and Benefits in North Carolina Accidents. North Carolina University, Highway Safety Research Center. 77p. July, 1974. (30512)

Evaluation of restraint system benefits based on belt usage rates and injury reductions in North Carolina accidents. Analyses were conducted on accident type, impact type, estimated speed just prior to impact, and belt usage. Results were reported for three (low, medium, and high) speed ranges.

Council, F.M., et al. An Examination of the Effects of the 55 mph Speed Limit on North Carolina Accidents. North Carolina University, Highway Safety Research Center. 99p. April, 1975. (32562)

Both TAD severity and "estimated speed prior to accident"decreased in 1974; the driver injury distribution did not change significantly on interstates. In fact, the injury distribution appeared to have shifted slightly upwards. All roadways experienced initial decreases in speeds (mean), but these initial decreases were fully recovered by November, 1974, except on interstate highways.

Dalby, T., Petersen, E.A., and Nordentoft, E.L. "The Type, Location and Severity of Injuries in Car Occupants in Relation to Accident Situations and Car Damage." In Proceedings, International Conference on the Biokinetics of Impacts, Organisme National de Securite Routiere, Laboratoire des Chocs, Lyon-Bron, pp. 199-212. May 25, 1973. (28048)

Presents data about accidents in and around "Odense University hospital" over a period of 15 months viz 6/1/71-9/1/72. The data are studied according to type of lesions, influence of location in the car, effect of safety belts, influence of collision situations, and influence of collision direction. Degree of internal damage to the car had significant influence upon lesion severity.

Emori, R.I. Mechanics of Automobile Collisions. California University, Los Angeles, Department of Engineering. 22p. No Date. (22179)

Vehicle collisions are modeled with a mass and a nonlinear, energy-absorbing spring. Two-dimensional models are based on impulse-momentum principles of rigid bodies. The relative vehicle displacements (not necessarily deformation) were obtained by double integration of acceleration-time data. Effective collision speed is related to the coefficient of restitution, deceleration,and relative displacement.

Emori, R.I. Vehicle Mechanics of Intersection Collision Impact. SAE 700177. January 1970. (24677)

The mechanics of intersection collisions are discussed in this pair of papers. This one deals with the collision itself, while the next paper addresses the post-collision movements of the vehicles. During the collision phase, the vehicles are treated as rigid bodies and the principles of impulse-momentum are applied. Available full-scale tests are cited to indicate that the coefficient of restitution is approximately zero and that the coefficient of friction between the colliding vehicles is in the neighborhood of 0.4.

Emori, R.I., and Masanori, T. "Vehicle Trajectories After Intersection Collision Impact. Automotive Engineering Congress, SAE 700176. January, 1970. (24678)

The vehicle trajectory after intersection collision is assumed to be a plane motion governed by inertia force and external retarding force due to tire friction. Four-wheeled automobile was replaced by two-wheeled equivalent and calculation of trajectory was computerized to accommodate braked or unbraked wheels and steered wheels. The study also indicated the considerable effect of front-wheel steering angle on the trajectory.

Garrett, J.W., and Hendricks, D.L. "Factors Influencing the Performance of the Energy-Absorbing Steering Column in Accidents." Fifth International Technical Conference on Experimental Safety Vehicles. Report. GPO, pp. 369-394. 1975.

Considers performance in terms of inches of vehicle crush, area of impact, direction of force, vehicle rotation, and height of impact.

Grattan, E., and Hobbs, J.A. Windscreen Glass Injuries to the Head in Front Seat Occupants of Cars and Light Vans. Transport and Road Research Laboratory, Crowthorne (England). 30p. September, 1975. (33911)

Uses collision severity to permit a valid comparison of injury effects of two different types of windscreen glass. The method used to estimate the equivalent barrier speeds is not noted.

Grime, G., and Jones, I.S. "The Frequency and Severity of Injuries to the Occupants of Cars Subjected to Different Types of Impact in Accidents: an Investigation of British Road Accidents From Police

Records." In Proceedings, International Conference on the Biokinetics of Impacts. Organisme National de Securite Routiere, Laboratoire des Chocs, Lyon-Bron, pp. 27-36. May 25, 1973. (28048)

Presents tables including percentage of injury accidents vs. type of accidents (single car, head-on, etc.) and type of vehicle (commercial vehicle, buses); severities of impact vs. type of impact; and speed of struck vehicles by type of road (rural, urban) based on data from 1596 accidents in three areas of Britain.

Grunwald, A. Analysis of Literature on Skid-Marks, Vehicle Damage and Speed in Relation to Road Accidents. Road Safety Centre, Haifa (Israel). 63p. November, 1971. (27138)

Reconstructs how the accident occurred from data collected after the accident. In attaining equilibrium (when the bodies are finally at rest), various moments take place, and energy during these moments is used up on the form of deformation, friction, and lifting. If the total deformation is deduced from vehicle damage, and total displacement is deduced from the marks, total energy may be found.

Gustavsson, H. "Road Accident Investigation - Accidents in Sweden with Saab 99, Report of First Phase." Fourth International Conference on Experimental Safety Vehicles, NHTSA, pp. 393-407. 1973. (29313)

Both CDC damage extent codes and cost of vehicle repair are used as crash severity measures.

Hall, R.G. Fact Book: A Summary of Information About Towaway Accidents Involving 1973-1975 Model Cars. Volume II. Final Report. DOT/HS 802 036. 267p. September, 1976. (35919)

Contains 264 tables and figures of descriptive statistics on 21,611 level-2 restraint study cases collected by five NHTSA-sponsored field investigative teams. Results cover who, what, where, when, and why. Crashes are described in terms of configuration, impact area, CDC damage extent code, direction of impact force, and car size.

Hartemann, F., et al. Description of Lateral Impacts. Peugeot-Renault Association. 47p. 1976. (36397)

Characterized a sample of 296 lateral impacts having caused occupant injuries by impact points and angles; distribution of car speed variation (delta V); and frequency and degree of side deformation.

The mass ratio affects injury freqeuncy and severity. Delta-V is calculated assuming that the impacted car is stationary. Crash test results were used as a standard for speed comparisons as the energy absorbed was impractical. With passenger compartment intrusion the occupant wall contact speed may be higher than the car delta-V. Cumulative delta-V is plotted for all occupants and severe + fatal occupants in car-to-car and car-to-fixed objects.

Huboi, K.A. "Securite des Occupants d'un Vehicule Automobile - Aspects Techniques Actuels (Safety of Automobile Occupants - Current Technical Aspects). Revue Belge du Transport, Number 2, pp. 25-32. 1971. (19060)

This French language paper plots the number of accidents by accident speed.

Hutchinson, T.P. "Witnesses' Estimates of the Speeds of Traffic Accidents." Accident Analysis and Prevention. Vol. 7, No. 1. pp. 27-35. May 1975. (52453)

Investigates the agreement existing between observers' estimation of speeds of automobiles involved in accidents. Two different approaches were used: (1) correlating estimates by different people of initial speeds, and (2) relating the existence of vehicle damage to estimated impact speed. First approach established quite high correlation (approximately 0.6) between different estimates, and in the second a positive association was found between speed and damage. Estimate speeds were proportioned to some power of the actual speed, e.g., 1.4 for enroute estimates. Actual speed was judged by the author, based on review of police report documentation.

Joksch, H.C. Analysis of the Future Effects of Fuel Shortage and Increased Small Car Usage Upon Traffic Deaths and Injuries. The Center for the Environment and Man, Inc. 194p. January 1976. (34125)

Relates automobile size and the frequency of occupant death and injury through literature review and accident data analysis. Relationship between relative frequency of fatal accidents and traveling speed is presented. The relationship of accident frequencies by speed for six states is also plotted with varied results. Cumulative travel speeds in free-flowing traffic are considered.

Jones, I.S., Segal, D.J. "The Application of the SMAC Accident Reconstruction Program to Actual Highway Accidents." American Association for Automotive Medicine - 18th Annual Meeting. p. 19. September 12-14, 1974. (30697)

Describes the use of SMAC computer program in reconstructing several highway accidents. Since the computer is able to use very small time increments and to compute the effects of tire forces and collision forces simultaneously, a higher degree of precision is claimed. Input to the program consists of initial conditions, vehicle dimensional properties, control inputs (steer, braking, etc.), and vehicle structural crush properties. Output generates both printed and magnetic tape output. The latter can be run as input to an auxiliary computer graphics program to generate a graphic display. The printed output provides displacements, orientations, velocities, and accelerations of two vehicles as a function of time, together with damage patterns, VDI's, and the velocity change to better than 5 percent. Delta V is defined as the velocity change experienced by the passenger compartment during the collision. The Calspan scene measurement van is described in an appendix.

Jones, I.S. "The Results of Selected Application to Actual Highway Accidents of SMAC Reconstruction Program." Proceedings 18th Stapp Car Crash Conference. SAE. pp. 89-111. 1974. (30826)

Illustrates how SMAC is used to reconstruct actual highway accidents. The computer program has capability of simulating collision between two vehicles, or a single vehicle and a fixed obstacle, continuously through the pre-impact, impact, and spin-out phases. Start routine of the program automatically generates the inputs required for SMAC, including collision speed estimates, from a minimum amount of information available at the accident scene. Start input may be adjusted to obtain a best fit with the minimum number of iterations. (The Start program evolved into the CRASH program). Most of the paper describes four actual examples of reconstruction, with first two cases in detail, with the input changes made at each step and their effect on final reconstruction. The paper concludes that using the velocity change as a measure of accident severity and correlating it with injury data would allow the relative protective ability of different vehicles and/or devices to be evaluated.

Jones, I.S. Automated Accident Reconstruction. SAE 750894. 8p. 1975. (32917)

Two computer programs are described (START and ITERATES) which automatically execute the SMAC program iteratively to optimize the input velocities and provide a "best fit" reconstruction (final rest position within 5% error) to the available scene data. Emphasis is placed on the theory and development of the iterative routine with examples to illustrate its operation. The programs described adjust only the vehicle impact speeds and monitor only the vehicle final rest positions to determine the "accuracy" of the reconstruction. The author points out that it may also be desirable to adjust additional parameters such as the initial orientation of the vehicles and to monitor the accuracy of other aspects of the reconstruction such as the vehicle damage. The author concludes that the feasibility of an automated accident reconstruction program has been demonstrated. The iterative approach is somewhat more expensive at this time, costing $40-60 to yield accuracy within 5%, while the CRASH program provides accuracy within 12% at about $5 per case.

Kahane, C.J. Usage and Effectiveness of Seat and Shoulder Belts in Rural Pennsylvania Accidents. DOT/HS 801 398. 69p. December 12, 1974. (32314)

Notes that police-estimated pre-impact speed is poor substitute for velocity change during impact and is not a sharp measure of accident severity. The belted occupant injury rates are standardized to the pre-impact speed vs. belt usage, injury rates, and injury of pre-impact speed vs. belt usage, injury rates, and injury reduction are provided. The relationship of ejection and pre-impact speed is discussed along with cumulative speed curves for ejectees, and nonejectees (belted and unbelted).

Mackay, G.M., and Ashton, S. Injuries in Collisions Involving Small Cars in Europe. SAE 730284. 10p. 1973. (27443)

Collision severity is estimated by comparing the damage in the actual crash to the damage in one of 11 standard types of impact tests. Results are presented for 636 accidents investigated in the United Kingdom. Distributions of equivalent test speed are shown for various collision types. Case studies are presented to illustrate the more detailed aspects.

Mason, R.R., Whitcomb, D.W. The Estimation of Accident Impact Speed. CAL Report No. YB-3109-V-1. August, 1972. (19714)

Presents several formulas, one for each type of vehicle impact, which can be used to estimate a vehicle's impact speed. Car-to-car impacts considered are symmetrical frontal, offset frontal, side, and rear impacts. Car-to-object impacts considered are rigid pole, breakaway poles, stationary vehicles, guardrails. Car size and type are also considered. Impact velocity is computed from crush (c) by the relationship of $V = a+bC$, with a and b determined from least squares fits to available data. Emori's studies of collision dynamics concluded that the front-end of typical vehicles of the time (about 1956) behaved as a plastic spring such that crush = .9 velocity. This report includes a thorough listing of the results of staged collisions which have been reported in the literature.

McHenry, R.R., et al. Determination of Physical Criteria for Roadside Energy Conversion System. CAL No. VJ-2251-V-1. PB-175-919. 234pp. July 1967. (10035)

Summarizes the findings of a research program undertaken to develop analytical means for evaluating existing and proposed roadside energy conversion systems. An eleven-degree-of-freedom, nonlinear, mathematical model of an automobile traversing a variety of irregular terrain features and encountering a variety of roadside obstacles was formulated and programmed for a digital computer. Simulated responses and test results were compared for cornering, ride, ditch traversal, curb impact, and guardrail impact responses. Two dynamic and two static tests were conducted to obtain sample dynamic and static load-deflection properties of automobile structures. Velocity change was determined by four methods--momentum change, energy balance, accelerometer data, and photographic data--with similar results. The coefficient of restitution was also similar to previous research. During impact the vehicle structure is treated as a rigid mass surrounded by a layer of isotropic, homogeneous material which exhibits plastic behavior. Dynamic pressure (lb/in^2) is assumed to increase linearly with depth of penetration, up to 18 inches. See also McHenry, 1971.

McHenry, R.R., DeLeys, N.J. Development of Analytical Aids for Minimization of Single-Vehicle Accidents. CAL No. VJ-2251-V-10, PB 204 583. 150 p. July 1971. (17061)

Summarizes five years and nine volumes of research effort to develop HVOSM, Highway-Vehicle-Object Simulation Model. HVOSM is a computer simulation of single-vehicle accident dynamics, including three-dimensional motions from traversal of irregular terrain and from collisions of the sprung mass with simple roadside barriers. Full-scale tests were used for validation. The creation of crash forces evolved to new treatment termed "point profile" in which the vehicle outline is described. The concept of dynamic pressure is used to represent the vehicle crush properties, with the pressure increasing linearly with depth of penetration. Several parallel planes were used to describe the vehicle in three dimensions. The "point profile" concept approach was subsequently used in SMAC. Some versions of HVOSM also provided for three "hard points." e.g., wheel-axle-suspension.

McHenry, R.R. Development of a Computer Program to Aid the Investigation of Highway Accidents. CAL No. VJ-2979-V-1. DOT HS 800 621. 104p. December 1971. (17261)

Describes a computer program and an associated optical measurement system developed to investigate highway accidents. These constitute the major components of a system that will provide a capability for processing and evaluating data via radio contact with the operator of a time-sharing computer terminal, while the investigators are at the accident scene. Reconstruction follows the general approach of Marquard*in reconstructing the post-collision, or "spin-out," phase upon rest position, trajectories, and impact points, and then approximating the collision phase velocities, positions, and orientations at initial contact. While crush properties do not affect the conservation of momentum, they do permit relative motions during the finite duration of the impact phase. They also permit generation of damage patterns. The vehicle is defined as a rectangle of points that move radially inward so as to achieve equal dynamic pressures for the two mutually deformed bodies. Peak accelerations from the program and crash tests were comparable.

McHenry, R.R. A Comparison of Results Obtained with Different Analytical Techniques for Reconstruction of Highway Accidents. SAE 750893. 17p. 1975. (32926)

Introduces the CRASH (Calspan Reconstruction of Accident Speeds on the Highway) computer program. An early START program, used to generate initial approximations for the SMAC program, was refined to include improved spin-out trajectory analysis and interpretation of vehicle damage data. Either the VDI/CDC or actual damage measurements can be used. The results of CRASH and SMAC results are compared for four staged collisions. Techniques for estimating frontal impact velocity from vehicle damage developed by Emori (full width) and by Campbell (partial width contact) were extended to the entire peripheral structure. The energy absorbed without residual crush is assumed to be proportional to contact width rather than a constant. Delta-V for low-speed collisions is underestimated because the rebound velocity produced by the coefficient of restitution is not included.

McHenry, R.R., Jones, I.S., Lynch, J.P. Mathematical Reconstruction of Highway Accidents - Scene Measurement and Data Processing System. Final - Part 2. CAL No. ZQ-5341-V-2, DOT-HS 801 405. 170p. (31977)

Summarizes the results achieved in the third year of the study for the development and field testing of a measurement and data pro-

---

*Marquard, E. "Progress in the Calculations of Vehicle Collisions" Automobitechnische Zeitscheift, Jahrv 68, Heft 3, 1966, pp 74-80 (22730) cessing system for use in investigation of accidents, including details on the Calspan accident investigation vehicle and SMAC refinements, e.g., START program (to develop initial SMAC inputs) output of Delta V calculations. Delta V is defined as the velocity change experienced by the passenger compartment during those time periods when the resultant acceleration exceeds 1.0 g's.

McHenry, R.R. *Extensions and Refinements of the Crash Computer Program. Part I, Analytical Reconstruction of Highway Accidents. Part II, Users Manual for the Crash Computer. Part III, Evaluation of the Accuracy of Reconstruction Techniques for Highway Accidents*. DOT-HS 801 837, DOT-HS 801 838, DOT-HS 801 839. Calspan Corporation. 121p. February 1976. (33959, 33960, 33961)

Documents CRASH modifiations to (1) improve trajectory prediction accuracy, (2) permit 2, 4, or 6 damage measurements, (3) improve oblique collision interpretation, and (4) adapt as a SMAC preprocessor. "Part II" contains detailed user instructions and outlines the analytical basis of program calculations. The accuracy evaluation (Part III) was impeded by lack of realistic and suitable staged collisions.

McHenry, R.R. *The SMAC and CRASH Computer Programs and the Accident Evidence Required for Their Application*. Calspan Corporation. 5p. March 15, 1976. (34166)

Briefly describes the SMAC and CRASH computer programs and the corresponding evidence requirements. In the CRASH program evidence is entered directly and the output includes Delta-V. In the SMAC program the input includes trial collision speeds, and the reconstructed output is compared with evidence.

McHenry, R.R. "The CRASH Program - A Simplified Collision Reconstruction Program." *Motor Vehicle Collision Investigation Symposium. Vol. I: Proceedings*. Calspan Corporation. DOT-HS 801 979, pp. 298-341. August 1976. (35846)

Compares SMAC and CRASH results for nine staged collisions. CRASH was ± 12% accurate versus ± 5% for SMAC. See also, McHenry, 1975.

McHenry, R.R. "Computer Aids for Accident Investigation." *Mathematical Modeling. Biodynamic Response to Impact.* SAE 760776. pp. 85-96. October 1976. (35875)

Notes that both SMAC and CRASH are limited to flat-surface collisions that do not include secondary collisions with roadside obstacles, effects of terrain features (e.g., gradients), and rollovers, although SMAC could be rerun for each separate impact time segment.

It also notes that both programs assume a force-deflection characteristic which is linear for increasing load and that the structural damage produced by a given speed change of a vehicle is independent of the speed range of the collision. The extent of damage does depend on the mass and stiffness of the struck obstacle.

McHenry, R.R., Lynch, J.P. CRASH 2 User's Manual. Final Report. Calspan Corporation. DOT-HS 802 106. 84p. November 1976. (36487)

Contains detailed instructions for users of the CRASH 2 computer program in interactive or batch mode. Two separate and independently derived speed estimates are computed. One is based upon work-energy relationships for spin-out trajectories and the principle of conservation of momentum for the collision. The other is based upon deformation of the two vehicles and energy calculations.

McHenry, R.R. Yielding-Barrier Test Data Base Refinement of Damage Tables in the CRASH Program. Calspan Corporation. DOT-HS 802 265. 58p. February 1977. (36920)

Summarizes efforts to refine CRASH 2 empirical crush coefficients and test effect of changes on the reconstruction of 22 staged collision cases. The CRUSH program was developed to extract empirical coefficients from staged collision data through use of an analytical procedure that constitutes the inverse of the damage analysis procedure in the CRASH program. CRUSH produces a linear fit to the results of two staged collisions at different speeds involving a given portion of a particular category of vehicle. (A procedure for more than two data points could be added.) Average error for the 22 cases was reduced from ± 10% to ± 5%. It is also noted that in most staged collisions, Delta-V has not been directly measured at the center of mass and that CRASH does not account for variations of stiffness in different zones of the vehicle's side, or the effects or underride/override.

McHenry, R.R., Lynch, J.P. Mathematical Reconstruction of Highway Accidents - Further Extensions and Refinements of the CRASH Computer Program. Calspan Corporation. DOT-HS 802 287. 38p. March 1977. (37205)

Modification of CRASH 2 to (1) incorporate SMAC trajectory routine, (2) provide optional abbreviated format, (3) provide optional batch mode, and (4) revise and extend output format. The total number of vehicle categories was extended from 4 to 7, including 6 car sizes and an SAE moving barrier. The crush properties of the minicar and large car are identical to the subcompact and full-size car, respectively.

McHenry, R.R., Baum, A.S., Neff, D.O. Yielding Barrier Test Data Base, A Study of Side Impact Cases in the Multi-Disciplinary Accident Investigation (MDAI) File. Calspan Corporation. DOT-HS 802 319, 71p, April 1977. (37127)

Summarizes reconstruction of 259 MDAI side impact cases using CRASH 2 program. Injury thresholds were measured as a function of Delta-V and direction of occupant motion. The MDAI cases provide poor documentation for CRASH 2; 38 were rejected because of lack of sufficient information. See also McHenry, February, 1977.

Mela, D.F. A Source of Substantial Error in Estimating the Distribution of Traveling Speed for Accident-Involved Vehicles. NHTSA, 3p. September 3, 1968. (37181)

Finds that when using estimated impact speeds (ACIR data) to determine speed distributions the fraction of vehicles in the 20-30 mph and 70-80 mph ranges are overestimated by 3, and the fractions below 20 mph and over 80 mph are overestimated by a factor of 17.

Mela, D.F. "How Safe Can We Be in Small Cars?" In Proceedings, Third International Congress on Automotive Safety. Volume II, GPO, pp. 48.1-48.30, 1974. (30080)

A shift on the U.S. passenger car population from its present weight distribution to one composed primarily of compact and subcompact cars could produce up to 25 percent more serious and fatal injuries than if there was no change in weight distribution. Increased use of safety belts could mitigate the harmful effects of weight reduction. It does not appear that a reduction in maximum speeds would by itself completely offset the effect of a shift to small cars. It is estimated that current 55 mph speed limit, if it actually reduces maximum speeds to 60 mph, will reduct fatalities by about 12 percent.

Mela, D.F. A Statistical Relation Between Car Weight and Injuries. NHTSA, DOT/HS 801 629. 10p. February, 1975. (32476)

Analyzes of accident data from New York and North Carolina police reports to obtain quantitative expressions of the relationships between vehicle weight and the likelihood of serious injury to the driver. Relationships were found for two-car crashes. Car weight was not greatly related to injury in single-vehicle crashes. In two-car crashes the likelihood of injury is more dependent upon the weight of one's own car than upon the difference in weight bewteen the two cars. No other vehicle or crash parameters were used as control variables.

Mela, D.F. "NHTSA's Evaluation of Air Cushion Restraint System Effectiveness (ACRS)." Fifth International Technical Conference on Experimental Safety Vehicles. GPO, pp. 395-403. 1975. (32385)

Evaluation plans include the stratification of the ACRS data into severity classes. Four means were considered: police descriptors (e.g., pre-impact speed); economic descriptors (e.g., dollar damage), damage descriptors (e.g., crush); and engineering descriptors (e.g., velocity-vector change during impact). Police and economic descriptors are judged as inadequate. Engineering descriptors are best but were rejected because they are not adequately defined (e.g., aggressiveness). Engineering methods (recorders or programs) not available in time, and these methods are expensive. Use of the VDI/CDC was selected with controls for vehicle structural parameters.

Moffatt, C.A. "Computer Reconstruction and Accident Severity." Motor Vehicle Collision Investigation Symposium. Volume I; Proceedings. Calspan Corporation. pp. 252-261. August 1976. (32846)

Suggests that as an objective measure, crash severity should increase as the potential for harm in the accident increases. Delta V is a rough measure of severity, but better than traveling or impact speed because the vehicles need not be at rest following the impact. It does not reflect the abruptness of the deceleration. Equivalent stopping distance (Delta S) is the second integral of the acceleration pulse. Crash severity is a function of Delta V and Delta S. Vehicle crush is a function of relative velocity or closing velocity, not the absolute velocities.

Moffatt, E.A. "Occupant Motion in Rollover Collisions." In Proceedings Nineteenth Conference, American Association for Automotive Medicine, AAAM, pp. 49-59. 1975. (33203)

Crush itself does not cause injury particularly in rollover and side impacts. The example of an occupant in a falling elevator is given. The occupant's injury severity is related to the number of floors the elevator fell and not the crush in the elevator sides.

Mohan, D., et al. "Air Bags and Lap/Shoulder Belts - A Comparison of Their Effectiveness in Real-World, Frontal Crashes." In Proceedings, Twentieth Conference, American Association for Automotive Medicine, AAAM, pp. 315-335. 1976. (35858)

Compares front seat occupants using no restraints, lap-shoulder belts, or air bag restraints in frontal collisions. Crash severity was controlled for by separating front-distributed and front-corner damage. The CDC extent codes 1 to 5 were then used as a crash severity measure in each group. Vehicle size was restricted to full-size and luxury cars.

National Highway Traffic Safety Administration. A Characterization of Collisions, Resulting Damage, and Occupant Injury. NHTSA, 31p. August, 1972. (19481)

Presents an analysis of data from the MDAI, Washtenaw County (Michigan), and Cornell Level-I files in terms of accident types, as events, and areas of contact. Impacts are reviewed in terms of speed (investigator reported) and damage extent (CDC) distributions. Injuries are tabulated in terms of force directions, area damage, source, and severity. Finally, indices of occupant injury are presented in terms of collision damage.

Niederer, P., and Walz, F. "Stability Considerations in the Mathematical Reconstruction of Traffic Accidents." Mathematical Modeling. Biodynamic Response to Impact. Society of Automotive Engineers, pp. 75-84. October, 1976. (35875)

Cautions against the arbitrary use of computerized simulation of traffic accidents without knowing beforehand whether appearing instabilities are tolerable or not, since motions of several interacting bodies are prone to be highly instable, meaningless results could be produced. Two methods are then introduced which allow for an assessment of the stability of a motion: calculating a differential equation for the variations, and adding random perturbations at each integration step.

O'Day, J., Carlson, W.L., Douglass, R.L., Kaplan, R.J. Statistical Inference from Multidisciplinary Accident Investigation. Final Report. UM-HSRI-SA-73-4, DOT-HS-801-111. 237p. August, 1974. (30171)

Uses regression model approach to controlling for crash severity when comparing injury reduction countermeasures. It was found that 53% of the reduction in injury from crash could be explained by using the CDC/VDI damage extent code, crash impact velocity squared, indication of windshield bond separation, and occupant ejection.

O'Neill, B., Joksch, H., and Haddon, W., Jr. "Empirical Relationships Between Car Size, Car Weight, and Crash Injuries in Car-to-Car Crashes." Fifth International Technical Conference on Experimental Safety Vehicles. Report., GPO, pp. 362-368. 1975. (32385)

Develops relationships between car size, car weight, and injury severity in car-to-car crashes from field accident data. Increased vehicle size is protective while increases in weight are hostile, indicating the desirability of large, lightweight vehicles. Vehicle size and intervehicle mass differences were used as predictors. Six weight classes are used. Front-to-front, front-to-side, and front-to-rear were considered separately. Size and weight effects are not separable in the data used.

Ontario Ministry of Transportation and Communications. Preliminary Report on Speed and Accidents. Research and Development Division, Toronto (Canada). 45p. August 16, 1974. (32270)

Speed, particularly average speed, is not necessarily an important accident cause. Road conditions, traffic volume, speed variance may be more important. Speed is an important determinant of accident severity.

Owings, R.P., Cantor, C. Simplified Analysis of Vehicle Change in Momentum During Impact with Breakaway Support. ENSCO Inc., Springfield, Va. 24p. 1976. (53378)

Presents an analysis of the impact of an automobile with a breakaway support for a sign or luminaire. This is based on vehicle change in momentum and plays an important part in the development of rational and practical laboratory methods for testing of breakaway supports.

Preston, F.L. "Interactions of Occupant Age, Vehicle Weight, and the Probability of Dying in a Two-Vehicle Crash." Hit-Lab Reports, Volume 5, Number 12, pp. 1-8. August, 1975. (52601)

Presents various curves for probability (fatality/accident) vs. age for various classes of own car weight, two aggregated car weight classes, and two models along with fitted regression curves. Both models are for quadratic determinations of occupant age to probability-of-fatality relationship. Model I assumes that age effect is independent of the effect of one's own vehicle weight. Model II assumes that effect of the other car's weight is independent.

Pudinski, W. Accident Changes Under Energy Crisis; Report on Accident Reduction Variables. California Highway Patrol, Sacramento. 116p. July, 1974. (32268)

The speed-fatality relationship has been analyzed repeatedly. The results consistently indicate that, for upper speed ranges, the higher the speed at which a collision occurs, the greater the likelihood of fatality.

Reinfurt, D.W., Silva, C.Z., and Seila, A.F. *A Statistical Analysis of Seat Belt Effectiveness in 1973-1975 Model Cars Involved in Towaway Crashes. Volume 1. Final Report.* DOT/HS 802 035. 171p. September, 1976. (35839)

Derives standardized injury rates and seat belt effectiveness measures from a probability sample of towaway accidents involving 1973-1975 model cars investigated by NHTSA-sponsored teams in five different geographic regions. Control variables include crash configuration (10 levels), vehicle damage severity (4 levels), vehicle weight (4 levels), and occupant age (3 levels). Controlling for vehicle damage is most important, with crash configuration next in importance.

Richter, P. "Nomograms for Impact Calculations." *Stapp Car Crash Conference, 11th. Proceedings.* SAE. pp. 153-158. 1967. (04293)

Presents nomograms for calculating velocities, moments, and energy distribution based upon mass ratio, degree of elasticity. Delta E is defined as the actual loss of translatory kinetic energy resulting from impact.

Riley, B.S., and Radley, C.P. *Traffic Accidents to Cars with Directions of Impact from the Front and Side.* Transport and Road Research *Laboratory, Crowthorne (England).* Report Number: PA 257/76. 18p. October, 1976. (36417)

Gives background data on Great Britain traffic accident data, including object struck, impact direction, injuries, frontal width of car impacted. Four overlap ranges are tabulated by impact direction and injury. Velocity changes are not tabulated because damage may indicate energy absorbed but does not account for rebound and is not straightforward for small overlaps and glancing impacts.

Robertson, J.S., McLean, A.J., and Ryan, G.A. *Some Findings in the First 200 Accidents. Second Report (Revised).* Adelaid University, Department of Pathology (Australia). 67p. May, 1964. (27817)

Judges vehicle damage to be in one of five categories: nil, minor, moderate, severe, extremely severe. Speed before and on impact are also reported (from an unidentified source). Increased speed produced increased vehicle damage, and increased vehicle damage produced increased injury levels.

Rosenthal, F., et al. *The Mechanics of Automobile Collisions.* Naval Research Laboratory, Applied Mechanics Branch, Washington, D.C. AD 743 449. 91p. May, 1972. (19179)

Treats damage and injury from automobile collisions as a mechanical problem in mitigating the shock from collisions. General principles of energy and momentum are described and applied to the collision problem. Present auto safety work is reviewed and vehicle design recommendations are provided.

Seiffert, U., and Schwanz, W. "Performance Matrices of Four Restraint Systems." In *Proceedings, Third International Conference on Occupant Protection*. SAE, New York, pp. 283-297. 1974. (30029)

Presents a study of the performance of five different restraint systems in combination of velocity change, peak deceleration, and pulse shape. Also points out that it is necessary to know not only the vehicle travelling speed, but what happened during the impact itself. Therefore, it is important that while establishing requirements for higher test speeds, we do not depend on concept of EBS alone to judge crash severity but give due regard to the more detailed data of crash recorders in the field tests.

Serizawa, Y. "Motor-Vehicle Accidents in Japan." *Fourth International Technical Conference on Experimental Safety Vehicles. Report.* NHTSA, pp. 567-570. 1973. (29313)

Provides a plot of vehicle speed vs. accident rate. Source of data and accident definition (e.g., threshold) are not provided.

Smith, R.A., and Moffatt, C.A. "Accident Experience in Air Bag-Equipped Cars." In *Proceedings, Nineteenth Conference of American Association for Automotive Medicine*, AAAM, pp. 60-79. 1975. (33203)

Provides a summary of injury and crash severity for 69 air-bag deployment accidents. Both CDC and Delta-V are reported. Eleven Delta-V's were measured by crash recorders. The remainder were computed from simple collision mechanics or from SMAC computer runs. Based upon crash recorder data and reconstruction of vehicle damage with a finite element frame deformation model, three deployments have occurred well below the 11-mph barrier impact deployment threshold claimed by General Motors. A number of possible data analysis techniques are outlined.

Solomon, P.L. *The Simulation Model of Automobile Collisions (SMAC) Operator's Manual.* NHTSA, 40p. October 4, 1974. (00000)

Describes input and output for SMAC program, including suggested parameter values. Manual was prepared by NHTSA Accident Investigation Division for use by their MDAI field accident investigation teams. Input data includes vehicle properties, calculation constants, initial conditions, and control parameters. The accident investigator reruns the program with varying input data until the output corresponds to the collision. (See also Jones and McHenry).

Sorewon, W.W., Gardner, R.E., and Cassassa, J., II. Patterns of Automobile Crash Damage. SAE 740065. 22p. 1974. (29646)

Presents an analysis of 15,000 repair estimates on 1973 model passenger cars. Among the findings presented are distribution of impact points about the car, distribution of repair cost, repair and replacement frequencies of certain components, and an analysis of repair by component assembly.

Staffield, S.E. "Structural Modeling and Collision Reconstruction - An Alternative." In Volume I: Proceedings, Motor Vehicle Collision Investigation Symposium. DOT/HS 801 979. pp. 362-380. August, 1976. (35846)

Presents a more detailed model of SMAC collision reconstruction program (for a 1975 Chrysler standard size car). The detailed model has been developed from experimental data and FORTRAN subroutines that make an evaluation possible with only minor changes to the SMAC. It provides a method for easy generation of detailed intrusion pressure functions specifically tailored to crush properties of 1975 Chrysler standard size car. Same technique used to develop Chrysler model, can easily be extended to other vehicle types.

Strassenburg, A.A., Impeduglia, G. Automobile Collisions; A Module on Energy and Momentum. New York State University, Binghamton. 90p. 1974. (32143)

An elementary primer on the physical laws describing conservation of momentum and energy, with illustrations taken from automobile safety applications.

Waydick, J.N. Traffic Killers - Speed vs. Traffic Volume or Miles Driven, Comparing 1973-1974 Accident, Speed, and Mileage Trends on Wisconsin Highways. Wisconsin Department of Transportation, Office of Policy Research and Public Information, Madison. 13p. 1975. (34361)

Says that analysis of data shows no correlation between urban fatal accident experience and vehicle miles travelled. Differences experienced in traffic volumes and miles travelled had little impact on fatal accident experience. On the other hand, rural fatal accident experience has shown a correlation with the changes in average speeds.

Wilson, J.F. "Two-Vehicle Reconstruction: A Rational, Computer-Aided Approach." Vehicle System Dynamics. Vol. 2, No. 4. pp. 205-223. December 1973. (51650)

Presents method for predicting either initial speeds or impact locations for two inelastic vehicles on a collision course. Forty system parameters are distinguished, of which up to 35 can be deduced from post-collision data, e.g., crush, mass, moment of inertia, impact vectors. The analysis is based upon plastic impact deformation energies and the friction work along the post-impact trajectories.

Wilson, R.A., Savage, C.M. "Restraint System Effectiveness - A Study of Fatal Accidents." In Proceedings, Automotive Safety Engineering Seminar, General Motors Corporation, pp. 27-38. 1973. (28833)

Estimates the ability of restraint systems to mitigate injury by using 706 fatalities. Each case is judged on an individual basis in terms of intrusion, crash severity (frontal barrier equivalent mph), interior loose objects, and several occupant parameters. No measures of intrusion or crash severity are provided.

SECTION 3

CRASHWORTHINESS

This section includes citations on vehicle impact testing (actual and simulated) and on overall vehicle and structural crashworthiness. These reports often consider human tolerance and occupant kinematics and therefore tend to overlap the subject of biomechanics presented in Section 4.

The 53 citations are primarily concerned with crash energy management (by the vehicle) and passenger compartment collapse as related to the trauma sustained by the vehicle occupants, i.e., occupant crash-protection. There are several measures of a vehicle's impact response. Their relative importance is a function of occupant parameters, e.g., restraint usage. Velocity change is important for the unrestrained occupant, while impact duration is important for the restrained occupant.

Other concerns expressed include vehicle aggressiveness or vehicle compatibility (effect of subject vehicle on other vehicles), and appropriate test criteria. Results from controlled crash tests (full-scale and model) and computer simulations are covered.

Aasberg, A., Larsen, L.S., and Runberger, S. *From Experimental to Production Safety Vehicles*. Volvo Company, Goteborg. 25 p. October, 1976. (36400)

Asserts that reduction of the frontal crash deformation force level requires low-force level, long-deformability, and energy-absorbing front part of the vehicle.

Alfa Romeo. *Non-symmetrical Front Impact Against Barrier Analysis of the Behaviour of the Different Car Models and Consequences to the Occupants*. Alfa Romeo, Milan. 27 p. October, 1976. (36407)

Discusses reasons for using non-symmetrical impact tests. The absolute majority of car occupants casualties in frontal impacts are related to non-symmetrical impacts. The Fifth ESV Conference has already proposed that for future safety regulation, a non-symmetrical test as frontal impact against barrier be chosen. Because of the above, Alfa Romeo conducted six comparative symmetrical and non-symmetrical tests against barriers. It was found that (1) The compartment motion components that cause occupant stresses are the same in symmetrical and non-symmetrical impacts. The basic deceleration direction of the compartment is straight and longitudinal; (2) Independently of the test type, the severity classifications between car models remain unchanged; (3) the compartment deceleration levels in the non-symmetrical tests are lower than in the symmetrical tests.

Appel, H., and Tomas, J. *The Energy Management Structure for the Volkswagen ESV*. SAE 730078. 21 p. 1973. (27249)

Considers two aspects of vehicle design structure--"occupant crash-protection" and "aggressiveness"--to improve crashworthiness. These two aspects are opposed in their effects; any measure that increases occupant crash protection also increases aggressiveness of the car, and vice versa. A vehicle for nearly perfect occupant protection will be a very serious danger for smaller cars.

Appleby, M.R., and Morris, A.G.R. *Automobile Damageability and Insurance* Costs. SAE 740305. 11p. 1974. (29661)

Deals with damageability resulting from low-speed collisions (less than 10 mph.). Data from crash tests for model years 1969-1972 show that manufacturers are building more robust vehicles. 1973 model vehicles will incur lower repair costs as a result of low-speed collisions. Real-life data suggest that benefits will accrue to consumers.

Bekiroglu, H. A Laboratory Approach to Automobile Crash Experiments. SAE 760798. 5p. 1976. (36007)

Uses rigid-body impact theory to study side impacts. Above certain speeds, the collision is essentially plastic, i.e., coefficient of restitution is practically zero. Coefficient of friction between vehicles was approximately 0.4. Compression velocity is the velocity component in the direction of compression. Double integration of acceleration-time crash data was used to determine relative displacements and resultant crush characteristics.

Bozich, D.J. Research in Crashworthiness of Vehicle Structures. Volume I of V. Wyle Laboratories, Huntsville, Alabama. DOT/HS 800 019. 82 p. March, 1968. (07138)

Describes criteria for crashworthiness indices. With an increase in impact velocity, the probability of a survivable structured collapse decreases, since the capability of the vehicle structure to absorb energy is soon reached, reducing the probability of occupant survival. To conduct a meaningful program aimed at improving overall structural crashworthiness, a means of measuring crashworthiness is essential. Two simple indices of crashworthiness could be (1) the degree of passenger compartment collapse under standard crush conditions; and (2) the levels of deceleration experienced by restrained occupants during the crash. These indices reflect the influence the structural considerations. Further Crashworthiness inidces can be established for (1) damage sustained by each structured zone; (2) injuries sustained by the occupants; and (3) the distortion and damage incurred by the interior seat, restraint, and second collision system. These indices would reflect damage, injury (or survivability) and environment severities over discrete severity levels of, say, 0, 1, ..., 10. Crashworthiness would then be a function of these indices and their associated probabilities or utilities.

Carr, R.W. Automobile Consumer Information Study Crash Test Program. Volume I. Summary Report. Final Report. Dynamic Science, Phoenix, Arizona. DOT/HS 801-875. 26p. April, 1976. (34273)

Reviews the crash test results and after examining the predicted and measured data, concludes that (1) in general, the vehicle model is a better predictor than an occupant model; (2) the tests for crashworthiness should be different from the tests for damage susceptibility since the variation in damage parameters occurs over a lower range of speeds than the variation in crashworthiness parameters; (3) vehicle response should be measured for all tests, but occupant response should only be measured for the crashworthiness tests; (4) the crashworthiness tests should be primarily frontal impacts with one impact at an EBS greater than 30 mph. but less than 35 mph; and (5) the overall correlations between crash test data and predictive data are not sufficient to warrant use of analytical models at this time to provide data for establishing damage susceptibility or crashworthiness rating.

Danner, M., and Langweider, K. "The Frequency of Corresponding Vehicle Damage in Crash Tests and Actual Accidents." Fifth International Technical Conference on Experimental Safety Vehicles. Report. GPO, pp. 421-426. 1975. (32385)

Points out that present ESV crash tests can reproduce some 20 to 25 percent of actual accidents with injuries to occupants (mainly head-on tests against a fixed barrier and pole). Damage categories that occur most frequently in real life (i.e., angled head-on collisions with overlapping)are not taken into account in the ESV crash test programs. Damage category B (one-sided overlapping in non-angled head-on collisions with 78 percent proportion of actual accidents) cannot be demonstrated by present ESV tests.

Davis, S. Application of the Shock Response Spectrum to Some Automotive Crashworthiness Problems. SAE 720071. 11p. 1972. (16840)

Uses the shock response spectrum approach to show that there is no best deceleration pulse for frontal barrier impact, but that in the 8-12 Hz frequency range of current restraint systems, the idealized square wave does appear to offer significant reduction in peak deceleration response for fully restrained occupants.

Davis, S. and Carr, R.W. Vehicle Damage and Crashworthiness Data for 1973 Intermediate-Size Cars. SAE 750922. 9p. 1975. (32986)

Presents graphs for barrier impact speed vs. occupant head HIC response, occupant chest SI, and occupant femur load for front, rear, and side impacts.

Dynamic Science. AMF and Fiat ESVs - Vehicle-to-Vehicle Impact Tests. Final Report. Dynamic Science, Phoenix, DOT/HS 800 981. 126p. November, 1973. (28846)

Representative of a number of similar studies involving different vehicles. For different kind of tests (i.e., front-to-front, front-to-rear, etc.), the following measurements were noted: impact speed, vehicle test weight, static and dynamic crush, average deceleration, force, pre-impact energy, theoretical maximum energy absorbed, conservatively estimated limits of percent energy absorbed, force deflection characteristics, and time-displacement curves.

Emmerson, E.C., Fowler, J.E. "Simulation of Frontal Vehicle Impacts." Vehicle Safety Legislation - Its Engineering and Social Implications. Discussion Volume. Mechanical Engineering Publications, Ltd. pp. 125-134. 1975. (33685)

Asserts that good correlation between predicted and measured results makes possible an accurate assessment of the frontal impact problem using computer simulation technique. Accuracy of prediction is largely due to selection of a model which adequately describes the vehicle configuration and use of realistic stiffness characteristics which were determined experimentally. Computer simulation can be of great help in assessing the effects of proposed changes at an early stage in vehicle development. Comparisons of predicted and actual results were based on static crush measurements and passenger compartment acceleration.

Fischer, R.G. "Occupant Protection in Car-to-Car Impact." International Technical Conference on Experimental Safety Vehicles, Fourth. NHTSA pp. 579-585. 1973. (29313)

Investigates the occupant and the vehicle as an integrated system in order to describe performance in real crashes. Barrier impact performance is intended to approximate car-to-car conditions. Considers vehicles of equal barrier performance but different masses, and vehicles of different barrier deceleration characteristics but equal crush and mass. Plots of occupant velocity vs. time are provided for occupant without car, with stiff car (27 g square wave) and with soft car (17 g square wave). A car-to-car impact model calculates vehicle velocity, displacement, crush, potential energy, barrier forces, mutual and individual car-to-car impact characteristics, and chest severity index. Input is the barrier deceleration time history of the vehicle and its mass. Occupant deceleration is input as a square wave deceleration. Plots of chest severity index, occupant-to-car impact velocity, vehicle crush, and vehicle rebound are plotted by vehicle mass ratio. (See also Fischer, 1974).

Fischer, R.G. Occupant Protection in Car-to-Car Impacts. SAE 740316. 8p. 1974. (29718)

Deals with the compatibility of vehicles with different g-t characteristics, based on occupant severity. The technique ranks the vehicles tested in an inverse order of average severity index for occupant spacings tested (highest number is lowest SI). These rankings are arranged into matrix form, and the rank of any vehicle impacting another vehicle, including itself (barrier equivalent equal 30 mph) can be determined. This ranking is little affected by occupant spacing. Vehicle to barrier acceleration time wave shape has an effect on SI in car-to-car crashes. Square wave acceleration time wave shape tends to be the most compatible with others studied. Graphs include crush ratio vs. mass ratio, occupant velocity and severity vs. mass ratio, and several time/velocity curves.

Friedman, D. "Development of Advanced Deployable Restraints and Interiors." Vehicle Safety Research Integration Symposium, NHTSA, pp. 55-68. 1973. (29301)

Presents various graphs for deflection vs. force, displacement vs. deceleration, and initial velocity vs. deceleration for frontal and oblique impacts.

Greene, J.E. "Computer Simulation of Car-to-Car Collisions." International Automobile Engineering Congress, Society of Automotive Engineers, 11p. March 1977. (36545)

Presents a lumped mass, resistive element modeling approach to computerized car-to-car collision simulation. Also presents graphs and compares simulation and test data: time vs. acceleration, velocity, and displacement for head-on collisions, flat barrier impacts, front-to-side impacts, and front-to-rear impacts.

Gross, L. "Mathematical Model of Vehicle Safety Deformation Under Impact Design for Safety." Journal of Engineering for Industry, Volume 94, Number 4, pp. 961. November, 1972. (27258)

Finds that under impact, when the velocity is reduced from its initial value Vo to zero over a very short period of time, the deceleration a, and its rate of increase $\dot{a}$ (the principal parameters determining the survival of occupants) are dictated by the length of the vehicle deformation and by its dynamic process. The model is $a = Kt^n$. Constants K and n depend on the design of the vehicle deformation and on deformation conditions. The basic concept is "safety deformation" of the vehicle body, i.e., absorption of the impact energy without detriment to the driver and passenger space. This is conditional on an adequate deformation length and suitable time pattern, so that a and $\dot{a}$ does not exceed the limit within which death or serious injury can be avoided. The limits are not easy to define.

Herridge, J.T., and Mitchell, R.K. Initial Crash Screening Studies Utilizing the NHTSA/BCL Computer Simulation Program for Collinear Car/Car and Car/Barrier Collisions. Final Report. NHTSA, Washington, D.C. DOT/HS 800 730. 182p. August 31, 1972. (19618)

Asserts that the FMCCM Program is very effective for screening candidate full-scale crash tests and is a convenient aid when it is necessary to assess probable performance of vehicles equipped with a highly-velocity-sensitive energy management system. When highly-velocity-sensitive energy absorbers are involved, it is difficult to establish a truly equivalent fixed barrier test which can be substituted for a given moving barrier test. Velocity-sensitive bumper systems such as those used on the AMF and Fairchild ESV Prototypes are an effective means of providing both good fixed barrier crashworthiness performance and reduced aggressivity.

Herridge, J.T., and Mitchell, R.K. Development of a Computer Simulation Program for Collinear Car/Car and Car/Barrier Collisions. ASME 73-ICT-34. 16p. 1973. (28620)

Finds that the FMCCM (Four Mass Per Car Collinear Collision Model) Program is a useful tool for predicting complex interactions of current experimental and production vehicle energy management systems in car/car and car/barrier collisions.

Higuchi, K. "Characteristics of Body Energy Absorption and Restraint System." Fifth International Technical Conference on Experimental Safety Vehicles. Report. GPO, pp. 796-800. 1975. (32385)

Studies the effect of the vehicle crush characteristics and ELR locking time on HIC of occupants with the help of computer simulation. Among various crush pulses, a square wave is suited most to small vehicles. High frequency components in excess of 50 Hz frequency to be superimposed on a crash pulse have little effect on HIC. It is important for a crash pulse to have a good rise in the beginning for utilization of the ride down effect. With respect to ELR locking time, "the quicker the better" is true, however, the "better" the initial rise a crash pulse has, the quicker the locking time is required to be.

Hofferberth, J.E. "Vehicle Crashworthiness." In Proceedings, National Conference on Highway Traffic Optimization for the 1980's. University of Tennessee, pp. 143-150. 1973. (31575)

Finds that stopping distances are important for controlling crash forces. The shorter the stop, the less distance one has to work with, the higher the G level. Also, to prevent injury at a given force level, it should be spread as evenly as possible. Short stops require high forces, high forces require broad load distribution, to be tolerable.

Hofferberth, J.E., and Tomassoni, J.E. "A Study of Structural and Restraint Requirements for Automobile Crash Survival." In Proceedings, Third International Concress on Automotive Safety. Volume II. GPO. 88p. 1974. (30080)

Asserts that the crash response characteristics of an automobile structure have a direct influence on the probability that the occupants of the vehicle will survive a crash and on the chances of survival for the occupants of another vehicle structure, relatively minor adjustment of the engine location, and downward deflection of the engine to provide more stopping distance, appear to have a significant influence on the probability for survival in single vehicle and car-to-car frontal crashes. These changes take the form of expansions or reductions in the "zones of compatibility" wherein survival is possible in one or both vehicles throughout ranges of crash speed, vehicle size and mass combinations.

Holmes, B.S., Gran, J.K., Colton, J.D. "Developing a New Vehicle Structure with Scale Modeling Techniques." Measurement and Prediction of Structural and Biodynamic Crash-Impact Response. New York, ASME, pp. 17-32. 1976. (36525)

Discusses the use of scale model experiments in developing crashworthy structure for a new research safety vehicle (RSV), which resulted in considerable saving in time and money. Scale model experiments were also used to evaluate major design modifications without risking expensive full-scale vehicles.

Kajio, Y., and Hagiwara, I. Non-Linear Analysis of Car Body Structure. SAE 760022. 11p. 1976. (33769)

Develops a non-linear program for a framed structure and applies the same to the analysis of an actual automobile body. It was found that in a static analysis, the maximum load of the structure can be determined, although it is difficult to simulate entire process of deformation of the car body accurately. This enables the effectiveness of the component members to be examined in the design stage. An estimation of the acceleration of the body under impact imposition is enabled by dynamic analysis.

Kamal, M.M. "Analysis and Simulation of Vehicle to Barrier Impact." In 1970 International Automobile Safety Conference Compendium, SAE, pp. 940-945. 1970. (13115)

Develops an analytic experimental technique which can predict barrier performance using three new tools. (1) Computer simulation program of barrier impact which requires as input the static crush characteristics of eight tone structural components. (2) Vehicle Component Crusher. (3) Mathematical model representing a first approximation of the Passenger Compartment, valid in the elastic range. Combined system provides the means for a better understanding of barrier impact and development of improved crashworthiness.

Krupka, R.M., and Krueger, A.B. Vehicle to Vehicle Collisions Utilizing Energy Absorbing Units. SAE 750110. 15p. 1975. (31735)

Investigates the possibility of utilizing shock absorbers to decrease the aggresivity of a large car towards a small car at an impact speed of 40 mph. There was a definite decreased aggresivity of the larger car. Increase of shock stroke did cause the larger car to be crushed more in car-to-car collisions. However, this occurred at speeds below 25 mph, not at 40 mph.

Lim, G.G. Crash Data Analysis. SAE 720496. 18p. 1972. (17981)

Develops an alternate approach to extensive testing, a technique to predict the vehicle collapse velocity and deceleration histories with minimum of testing by using the Polynomial Approximation technique and the Multiple Curve Interpolation technique.

Lin, K.H., Kamal, M.M., and Justusson, J.W. Effect of Vehicle Mix on Two-Car Head-on Impact. General Motors Corporation, Research Laboratories, Report No. GMR-1676. 54p. August 13, 1974. (33593)

Presents a mathematical model to compare the dynamic response (acceleration , velocity and crush) of two dissimilar cars (differing in weight and crush characteristics) when they impact each other head-on. Five points are made: (1) for a given pair of vehicles, the deceleration history depends on closing speed, not on their absolute velocities, (2) duration of impact is fairly insensitive to impact speed; (3) head-on impact of two cars which are not identical results in a bumper-level crush distance generally different from sheet metal crush. The magnitude and sign of this difference can vary as a function of closing speed; (4) due to nonlinearity of vehicle crush characteristics, the fraction of total energy dissipated by each car varies as a function of their closing speed; (5) it has not been possible to relate mathematically, with a high degree of accuracy, the vehicle frontal crush with occupant survivability or injury scale.

Lowe, W.T., Al-Hassani, S.T.S., and Johnson, W. "Impact Behavior of Small Scale Model Motor Coaches." Journal of Automotive Engineering, Volume 3, Number 1, pp. 19-26. January, 1972. (50602)

Says that one measure of crashworthiness of a vehicle is its ability to collapse in a controlled fashion at a level of retardation compatible with occupant safety. Since motor coach is basically tubular in construction, it lends itself to simpler "tube" analysis. All the models, when axially compressed were found to crumple, however, a distinct difference in the nature of the crumpling was found between static and dynamic loading. Whtn statically loaded the models were found to buckle at any point along their length. When dynamically loaded, the deformation was confined mainly to the impacted end of the model.

Martin, D.E., and Kroell, C.K. Vehicle Crush and Occupant Behavior. SAE 670034. 42p. January, 1967. (00676)

Presents the findings of an analytical study of right angle barrier crashes conducted to evaluate the influence of vehicle crush distance, occupant spacing, and interior crush stiffness on the severity of occupant to interior impact, with particular attention to the influence of the vehicle deceleration-time history wave shape. Injury is dependent on vehicle stopping distance (crush), occupant spacing, and the crush behavior of the interior surface struck by the occupant. The average "g" load that a conventional vehicle experiences is dependent on impact velocity, i.e., peak frame deceleration decreases with impact velocity.

Matsui, S. A Method of Estimating the Crashworthiness of Body Construction. Nissan Motor Company, Ltd., Vehicle Research Department, Hiroshi Nohsho, 17p. October 14, 1976. (36406)

Introduces RD Index (Residual Deformation) as a measure of estimating to what extent the car body affects occupant protection in a vehicle collision. This RD can be easily determined from crash stroke-time curve and vehicle body. The use of RD index permits the relationship between the vehicle front-end characteristics and the maximum occupant G to be definitely arranged. As vehicle RD increases, the maximum occupant G decreases. RD can be obtained from the vehicle stroke-time curve by a very simple procedure.

Matthews, H., et al. Characterization of Vehicle Deceleration Time Histories in the Analysis of Impact Dynamics. SAE 770013. 8p. 1977. (36547)

Develops a technique based on polynomial and Fourier-type series approximations, goodness of fit criteria related to both least squared error and satisfaction of boundary condition; to construct vehicle deceleration history which is simpler than its actual time history. With this method, as few as four parameters are adequate to describe the primary effects of complex vehicle deceleration time histories as they influence occupant dynamics.

Miller, P.M., Mayor, R.P. Basic Research in Automobile Crashworthiness. Final Technical Report. CAL Report No. YB-2684-V-6. 130 p. November, 1969. (14945)

Presents a summary of the results from nineteen full-scale crash tests. Experiments primarily attempted to demonstrate possible changes in structural performance by making modifications for frontal and side impact. Four modifications concepts were considered--engine deflection, forward structure modification, rear engine vehicle, and side impact modification concepts. It was found that a significant improvement in the capability of the structure to dissipate energy in a controlled manner in front and side collision is possible. It was also found that for a given impact velocity a decrease in the vehicle collapse distance can be produced without significantly increasing the peak values for the compartment deceleration. Forward structure modification concept requires structural changes that could be readily incorporated into conventional vehicle designs, while engine deflection and rear engine concepts required extensive changes.

Miller, P.M. Basic Research in Crashworthiness II - Summary Final Report. CALSPAN Corporation. DOT/HS 800 887. 162 p. 1973. (28451)

Summarizes the major findings of the three-year research program. The program was directed towards development of a crashworthy vehicle design to provide protection during front, side, and rollover collisions. It was observed that structural modification could reduce passenger compartment intrusions, but maximum decelerations were largely unchanged. Analog/digital data acquisition and reduction system was also developed. Also, analytical methods for analyzing frame structures undergoing dynamic impact with fixed objects were developed for both two- and three-dimensional structures. Performance of precise experiments proved the existence of reasonable correlation between experimental and analytical results. Of particular interest are the baseline crash tests conducted prior to vehicle modification. These tests provide time-deceleration histories and force deflection curves for luxury (full size), compact, and subcompact cars for several types of impact, e.g., front-object, front-side, front-front.

Naab, K.N. Basic Research in Crashworthiness II - Low-Speed Impact Tests of Modified Vehicles. Interim Technical Report. CALSPAN Corporation, Buffalo, N.Y. Report No. CAL YB-2987-V-17, DOT/HS 800 860. 92p. May, 1973. (27767)

For adequate energy management, the frame members and forward section of a number of conventional vehicles were redesigned and strengthened. These vehicles, which were structurally modified to improve their high-speed crash performance, were tested in frontal impacts. It was concluded that there are essentially no differences in occupant acceleration between occupants of the

Modified and conventional vehicles. Also the data from the two driver position dummies of the modified cars fell well within the envelope of the right front passenger data, indicating that the two seat positions were comparable with regard to acceleration exposure. It was also observed that the size variations of the various modified vehicle produced no consistent differences in occupant responses.

O'Neill, J.F. "Multiplexing Takes the Measures of Crashes." Instruments and Control Systems, Volume 47, Number 4, pp. 41-44. April, 1974. (33005)

Points out that determination of severity of strains on the occupant during a crash requires minimum of eight test points for each passenger: 3 accelerometers to measure yaw, pitch, and roll of chest; 3 detecting similar motions of the head; and a femur force guage on each leg to measure upward thrust.

Park, K.C. "Formulation, Solution Strategies and Computer Implementation of Structural Crash Simulation." Measurement and Prediction of Structural and Biodynamic Crash-Impact Response, ASME, pp. 49-62. 1976. (36525)

Reviews existing computer simulation programs and the development of a new simulation model.

Renault, "Doubts About Car Collision Test." New Scientist, Volume 65, Number 933, p. 204. January, 1975. (33983)

Asserts that the present standard barrier test gives a gross overestimate of the severity of injuries in collisions. In a head-on collision, the stiffness of the whole of the front is available to resist the crushing force. The deceleration suffered by car occupants is thus severe. In 60^{0} oblique crash, however, the car's front is effectively much "SOFTER" and so crushes more easily, thus reducing deceleration felt by passengers. In addition, energy is absorbed by the sliding of the car along the face of the barrier and by its rotation about a vertical axis. Renault also claims that the nature of obstacle struck is an important factor. The head-on barrier test assumes that one car is generally going to strike another of about same stiffness. But this does not hold good in real life. There is also confusion between what causes injury to human beings and what causes deformation of metal structure. For human injury - the change in velocity is the only thing that matters (i.e., the velocity of "second collision" with seat belt on car interior). But structural deformation requires energy which is proportional to the difference between squares of the initial and final speeds. In an accident at 50 mph in which car is brought to rest - the second collision speed equals 50 mph. but structural deformation is proportional to $(50)^2$ on 2500 units. In an accident involving drop from 100 mph to 50 mph the second collision speed is 50 mph., but structural deformation is proportional to 7500 units $(100)^2 - (50)^2$.

Rosti-Rossini, L. "Some Considerations of Body Structure Crushability in Relation to Impact Speed." In Fifth International Technical Conference on Experimental Safety Vehicles. GPO, pp. 692-698. 1975. (32385)

Reviews the relationship between impact speed and the dynamic consequences on the vehicle structure and occupants. Barrier impact speed and crush are related to passenger compartment acceleration. A crash-energy balance is used to determine the energy-absorbing capability of the structure between the passenger compartment and the impact area as a function of barrier impact speed. The masses of the energy-absorbing parts (e.g., engine), of the undeformed parts (e.g., passenger compartment) and of the occupants are given separate consideration.

Ryder, M.O., Jr. Classification of Automobile Frontal Stiffness/Crashworthiness by Impact Testing. Final Technical Report. CALSPAN Report CAL-ZP-5714-V-1, DOT/HS 801 966, 549p. August, 1976. (35851)

Tries to identify the late model automobile as soft, nominal, or stiff, based on their frontal Crash Performance. Nominal is an average characteristic, while "soft" and "stiff" represent deviations from the mean value. Its effect on overall crashworthiness performance was not considered.

Sato, T.B., et al. "Dynamical Considerations on Automobile Collision. Part II. Front-end Collision Tests." Society of Automotive Engineers of Japan Bulletin, Number 1, pp. 8-12. 1969. (51195)

Presents various graphs of effective impact velocity vs. duration of impact, peak deceleration, co-eff. of restitution, changes in momentum, loss of kinetic energy, crash horse power, maximum deformation, and permanent deformation. These graphs are based on car-to-barrier and car-to-car collision tests.

Seiffert, U.W. "Simulation of Road Traffic Accidents with Barrier Impact Tests." International Technical Conference on Experimental Safety Vehicles, Fourth. NHTSA. pp. 543-547. 1973. (29313)

Plots actual and simplified vehicle force-distance patterns. Vehicle-barrier and vehicle-vehicle collisions are compared. Speed at impact is extrapolated via the absorbed energy for a single vehicle where deformation of the other vehicle is unknown. The result is defined as an equivalent barrier impact speed. Deceleration and velocity change are plotted vs. time for car-to-car and car-to-barrier collisions. Equivalent barrier impact speed differs from actual impact speed and is biased towards the vehicle investigated. A VW distribution of equivalent test speed and fatalities is compared with NHTSA and Mackay's results to demonstrate the wide variance.

Shieh, R.C. Some Analytical Crashworthiness Studies of Automobile Front Structure. SAE 730612. 17p. May 1973. (27656)

Presents the results of some analytical crashworthiness structural studies of modified front structure. Optimization problem of a car front frame structure has been studied based on the matrix displacement method of frame analysis. The displacement and deceleration results were found to correlate reasonably well with full-scale tests.

Shimoe, H., et al. "Development of Front-end Structure with Energy-Absorbing Device. (Tube-expanding construction). Society of Automotive Engineers of Japan Bulletin, Number 7, pp. 84-95. April, 1976. (53325)

Describes the development of ESV at NISSAN. The NISSAN ESV, E_2 was intended to provide occupant protection in an 80 mph. frontal barrier collision solely through use of a belt system. This required a front-end construction provided with crashworthiness matching the occupant protection system installed. In that case, crashworthiness curve should be as flat as possible and it is essential that deceleration 'G' produced on the vehicle be lowered and that crush stroke at the front end be increased. It was experimentally found that the vehicle accomplished necessary crashworthiness and insured sufficient occupant survival space in the occupant compartment.

Tanner, R.B. Crashworthiness of the Subcompact Vehicle. Final Report. Minicars, Inc. Goleta, Calif. DOT/HS 801 969. 300p. August, 1976. (35800)

Discusses the development of a modified design which improved the crashworthiness in the most significant modes. Specifically, the modified design provided safety in the frontal aligned mode to at least 50 mph. BEV, in the offset and oblique mode to at least 50 mph. and in the side impact mode to at least 30 mph. The modified design relies extensively on use of foam-filled sheet metal sections throughout the vehicle. The all directional nature of volumetric structure provided good energy management in all impact modes. At the same time the weight of the vehicle was increased by only 5.3%.

Thompson, J.E. "Occupant Response Versus Vehicle Crush: A Total System Approach." Proceedings. Twelfth Stapp Car Crash Conference. SAE. pp. 220-239. 1968. (06742)

Finds that both analytical methods of evaluation and experimental methods have serious disadvantages. Hence the author proposes a new method which combines the analytical and experimental approaches and thus minimizes the difficulty of depending entirely on one or the other. Two different analytical models are used. An occupant car model is used to predict occupant and vehicle dynamic and kinematic response; and a structural model which relates these responses to structural crush. This will help to predict the dynamic and kinematic response of a restrained occupant model to the decelerations of his vehicle in a crash situation and predict the amount and rates of crush of the vehicle structure required to absorb the impact of the car and produce the predicted occupant response and use of a car structure model reproduces this crash under the same load environment by changing the load carrying capacity of specific elements of the model.

Thompson, J.E. Vehicle Crush Prediction Using Finite Element Techniques. SAE 730157. 14p. 1973. (27165)

Develops an analytical tool in form of computer program which enables one to predict crush characteristics of a given car structure due to forces generated in a variety of impact modes. The predictive capability is embodied in two large computer programs. "TELSAP" forms, reduces and inverts the vehicle structure mass matrix expressed relative to a datum coordinate system and writes the mass matrix and its inversion onto a file for reading by a "CRUSH" program. CRUSH is a general matrix structural analysis program which calculates the large, plastic, rate sensitive response of an inter-connected beam structure due to known dynamic boundry displacement inputs.

Tien, J.K., and Testa, R.B. *Critical Assessment of Social and Economic Implications of Safety Cars*. Columbia University, School of Engineering and Applied Science, 100p. August, 1974. (30873)

Finds that the first safety vehicles were built to protect their own occupants without adequate consideration of occupants of other cars with which it might collide. It was assumed that the number of traffic deaths would be reduced by 63 percent in the first year of introduction of ESV, but after considering its aggressiveness, more realistic estimates show that the number of traffic deaths would actually increase for several years. Lap and Shoulder harnesses, combined with a strictly enforced 55 mph. speed limit and a uniform car population are so effective in reducing deaths and injuries that they practically eliminate the need for ESV.

Ventre, P. "A Contribution Towards Better Compatibility Between Vehicles." In *Proceedings. Third International Congress on Automotive Safety. Volume I.* Washington, D.C. National Motor Vehicle Safety Advisory Council, pp. 10.1-10.31. March, 1975. (32488)

Based on results of experiments, concludes that: (1) increasing obstacle deformability results in lengthening of crash duration, and (2) increased crash duration results in a reduction of performances on restraint system.

Ventre, P., Rullier, J.C., and Verollet, J.P. *The Behaviour of Vehicles and Occupants in Asymmetrical Frontal Collisions*. Regie Nationale des Usines Renault, Crashworthiness Department, Billancourt (France). 37p. October, 1976. (36377)

Finds from a review of statistical data that nearly 2/3 of frontal collisions are asymmetrical ones. The 90^0 test with a fixed barrier is unduly severe and is not selective. A vehicle considered acceptable in such a test may be incapable of ensuring occupant protection in a real asymmetrical accident. Among all types of tests, ¼ wall, ½ wall, centered or offset post, test with fixed barrier inclined at 30^0, would seem to give the best structure/restraining device compromise for approaching what happens on the roads. The collision test with a fixed barrier inclined at 30^0 is a test capable of improving car safety because it allows the structural behaviour in asymmetrical collisions to be better evaluated and because it allows the protection afforded by the restraining device to be realistically appreciated.

Welch, R.E., Bruce, R.W., and Belytschko, T. *Finite Element Analysis of Automotive Structures Under Crash Loadings. Volume I and II. Final Report*. DOT/HS 801 846 and DOT/HS 801 847. 178p. March, 1976. (33964)

Divides the present analytical procedures into two broad categories: (1) lumped parameters or equivalent system, and (2) formal approximation technique (primarily finite element). In the first procedure, the vehicle is treated as an assemblage of lumped masses and resistances. The properties of the various elements of such models are determined by a static and dynamic crush testing, direct measurement and judicious use of simple analysis procedures. But these are heavily reliant on previous testing and are weakly tied to basic principles of structural behavior. The second procedure represents an attempt to make up for limitations inherent in the lumped parameter analysis by employing more formal approximation techniques in the discretization of the structure and a greater reliance on more fundamental structural representation and properties.

Wolfe, J.A.B. "The Use of Models in Automobile Impact Research." Towards Safer Road Vehicles, Transport and Road Research Laboratory, Crowthorne (England), pp. 116-131. 1972. (19520)

Develops mathematical models of vehicle and occupant to give greater insight into behavior of both during accident situations Injury severity has been considered a function of acceleration enabling prediction of overall occupant response for a particular occupant/vehicle configuration.

Young, J.W. CRASH: A Computer Simulator of Non-Linear Transient Response of Structures, Basis for Car Crash Simulation. Philco-Ford DOT-HS-800 698. 117p. March 1972. (19526)

Develops a mathematical model for digital computer simulation of highway vehicle impact. Philco-Ford presents the assumptions, approximations, and formula to represent the car primary structure as a frame subjected to time-varying loads. It defines the solution process and error control methods to predict non-linear transient response of the frame. The whole analysis is based on energy formulation.

SECTION 4

BIOMECHANICS

This section covers both human tolerance and occupant simulation. Human tolerance includes whole-body and specific-region tolerance, as well as biodynamic injury criteria. Of particular interest are studies relating impact tolerance to the automotive impact environment.

The 32 biomechanics citations illustrate both the early human tolerance indexes based upon severity threshholds empirically derived from acceleration-time histories and the more current indexes based on biomechanical models. The cited studies have used several different measures of occupant impact severity, including HIC, GADD, displacement, rate-of-change of energy levels, restraint loads, peak load, stopping distance, shape of acceleration history, rate of onset, and effective acceleration. Their relative importance is a function of body region, e.g., acceleration of the head, deflection of the chest, load on the leg. The level of trauma is also affected by such factors as muscle contraction, age, weight, and variation in bone properties and superficial soft tissues.

Bowman, B.M., Schneider, L.W., and Foust, D.R. "Simulated Occupant Response to Side-Impact Collisions." In *Proceedings, Nineteenth Stapp Car Crash Conference,* SAE, pp. 429-454. 1975 (33279)

Describes occupant response to 10- and 30-mph side-impact collisions, using a mathematical vehicle/occupant model. Establishes that neck muscle contraction may significantly lessen the likelihood of hard-tissue injury.

Chander, S., and Pilkey, W.D. *Predicting the Limiting Performance of Automobile Structural Components Under Crash Conditions. Final Report*. Control Data Corporation, Professional Services Division, Rockville, MD. DOT/HS 802 007. 134 p. September 1976. (35692)

Discusses severity indices which are applicable to computer modeling, which includes the *Wayne State Index* and the *Gadd Severity Index*. Both are based on acceleration time history. *Effective displacement index* (EDI) is the most recently proposed severity index. The excitation to be evaluated (acceleration vs. time) is applied to the base of the mathematical model, which is a single degree of freedom, damped spring, mass model of the head. Selecting the damping value based on biomechanical consideration is proposed. Selection of the damping level or damping ratio would automatically fix the other parameters of organ frequency. The relative motion between base and mass is calculated as a function of time. The peak value of the relative motion is then considered as the effective displacement index. As opposed to the earlier indices, EDI is inherently insensitive to long low amplitude pulses and EDI also fits Wayne State Head tolerance Curve better than GADD's S.I.

Delays, N.J. "Crash Victim Simulation - a Potential Aid for Reconstruction of Accidents." In *Proceedings, Motor Vehicle Collision Investigation Symposium*, Volume I. pp. 342-361. DOT-HS-801-979. August 1976. (35846)

Describes the three-dimensional computer simulation of crash victim dynamics developed by Calspan. The simulation predicts occupant response to vehicle crash stimuli. Inputs include the crash victim description, the geometric and compliance properties of the vehicle interior surfaces, the vehicle deceleration time history, and restraint system geometry and parameters. Output includes time histories of occupant accelerations, velocities, displacements, and the forces/deflections resulting from occupant contact with vehicle surfaces. Severity indices can also be computed from the output. Ten MDAI cases are reconstructed using SMAC. The SMAC time deceleration histories were input to the occupant simulator. The same ten were also physically simulated in accelerator sled tests. While the kinematic results are similar, the injury indices were not similar.

Dickenson, R.P., Wall, J.W., and Hutton, W.C. "The Impact Properties of Bone." In Proceedings, Second International Conference, Biomechanics of Serious Trauma, pp. 249-256. Bron, IRCOBI. 1975. (32768)

Discusses bone impact properties in terms of energy absorption, loading rate, and tensile strength.

DiLorenzo, F.A. Power and Bodily Injury. SAE 760014. February, 1976. (33775)

Attempts to establish a correlation between bodily injury and the rate-of-change of energy levels (power) of the body. Early biomechanical injury severity indexes were attempts to analyze acceleration-time pulse in an attempt to empirically derive a law relating the acceleration time traces to injury. The Gadd (SI) and Head Injury Criterion (HIC) are integrals involving acceleration and time. The HIC also considers pulse width in order to smooth out large ripples and spikes. Both SI and HIC are arbitrary and provide no insight into injury mechanics. A collision is considered as a sudden change in energy level.

Eppinger, R.H. "Prediction of Thoracic Injury Using Measurable Experimental Parameters." National Highway Traffic Safety Administration, Washington, D.C. 6th International Technical Conference on ESV, August 20, 1976. (36410)

Uses a statistical analysis of volunteer and cadaver test data to determine if any meaningful relationship exists between any of the measured engineering parameters (e.g., forces, accelerations, deflections) and injury. It was found that the number of thoracic fractures is a function of the maximum upper torso belt force, and occupant age and weight. A multiple step-wise linear regression algorithm was used.

Fleck, J.T., Butler, F.E., and Vogel, S.L. An Improved Three Dimensional Computer Simulation of Vehicle Crash Victims. Volume I, Engineering Manual. Final Report. Calspan Corporation, Buffalo, New York. 292 p. April, 1975. (32231)

Describes computer program that simulates in three dimensions one or more crash victims. The passenger compartment motion description has six degrees of freedom. Forces produced by contact are determined by a force deflection routine which allows for energy losses.

Kaleps, I. "Thoracic Dynamics During Blunt Impact." In Aircraft Crashworthiness. University Press of Virginia, Charlottesville, pp. 235-252. 1975. (34179)

Presents a model capable of reflecting the actual dynamic characteristics of the chest wall, using lumped parameter analysis. The model includes chest wall deflection properties and some internal reactions. Chest deflection is related to rib fracture, and intrathoracic overpressure is used as a predictor of internal trauma. No statistically meaningful relationship between the chest impact event and resulting injuries is available in known research studies.

King, A.I. "Biomechanics of the Spine and Pelvis." Biomechanics and Its Application to Automotive Design. Society of Automotive Engineers, New York, 13 p. January, 1973. (27005)

Reviews spine and pelvic biomechanics. A few unvalidated models exist. There are few references on the subject.

King, A.I., and Chou, C.C. "Mathematical Modelling, Simulation, and Experimental Testing of Biomechanical System Crash Response." Journal of Biomechanics, Volume 9, Number 5, pp. 301-317. 1976. (52922)

Provides a detailed review of models simulating biodynamic response to impact acceleration, along with experimental validation studies. The types of models surveyed include gross motion simulators, head injury models, spine and thoracic models. Most of the models are of the deterministic type. The gross motion simulators consist of a body dynamics model and a contract model (the weakest component).

Krouskop, T.A., et al. "An Index for Predicting Tissue Damage Due to Impact." In: Proceedings, Third International Congress of Automotive Safety. Volume I. GPO, pp. 6.1-6.18, 1974. (30079)

Uses kinematic data and average stress to calculate the strain energy associated with seven body regions. Threshholds for specific injuries are related to AIS injury severity.
Tables of injury threshhold levels by AIS and body region are then tabulated. Thus kinematic variables are related to injury severity.

McElhaney, J.H., Roberts, V.L., and Hilyard, J.H. Biomechanics of Trauma. Volumes 1, 2, and 3. Duke University, Durham, North Carolina. 1311 p. January, 1976. (35666)

A composite of published biomechanics knowledge covering anatomy; human tissue; whole body tolerance; and head, neck, thoracic, abdominal, and pelvic impact tolerance and injury criteria. Describes test devices and applications.

Melvin, J.W., and Evans, F.G. "A Strain Energy Approach to the Mechanics of Skull Fractures." In: Proceedings of Fifteenth Stapp Car Crash Conference, Society of Automotive Engineers, pp. 666-685, 1972. (17505)

Considers the mechanical properties of an individual body structure, the skull.

Melvin, J.W., Mohan, D., and Stalnaker, R.L. Occupant Injury Assessment Criteria. Highway Safety Research Institute, Ann Arbor, Mich., SAE 750914. 12 p. 1975. (32953)

Presents a review of human injury mechanisms and impact tolerance. The status of knowledge in the biomechanics of trauma to the head, neck, chest, abdomen, and extremities is discussed. Six head injury criteria are summarized.

Melvin, J.W., et al. "Impact Response and Tolerance of the Lower Extremities." In Proceedings, Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, SAE 751159. pp. 543-559. 1975. (33279)

Discusses why the location of femur fractures is mainly dependent on occupant kinematics and not on severity of impact. Peak load alone is not an adequate indicator of impending fracture. It appears that a sufficient high energy or momentum level must be associated with the impact to produce fracture.

Nahum, A.M., et al. "Tolerances of Superficial Soft Tissues to Injury." Journal of Trauma, Volume 12, Number 12, pp. 1044-52. December, 1972. (51198)

Observes that relatively little has been done to quantify threshholds for significant injury to the superficial tissues. Severity is a function of tissue geometry, the underlying bone, mass, and shape, etc., of target area. Superficial tissues can also affect the force or acceleration attenuating characteristics of a body region.

Neathery, R.F., Kroell, C.K., Mertz, H.J. "Prediction of Thoracic Injury from Dummy Responses." In Proceedings, Nineteenth Stapp Car Crash Conference, Society of Automotive Engineers, pp. 295-316. SAE 751151. 1975. (33279)

Finds that chest injury (mean AIS) is a statistically significant function of chest deflection, chest depth, and cadaver age at death.

Patrick, L.M. "Human Tolerance to Impact and Its Application to Safety Design." Biomechanics and Its Application to Automotive Design. Society of Automotive Engineers, New York, 15 p. January, 1973. (27005)

Provides a general review of crashworthiness. Change in velocity alone is a poor criterion of potential injury. Stopping distance and acceleration history (e.g., half-sine) are also important. Human tolerance data for the whole body and several body areas are tabulated. Vehicle frame acceleration time histories for 30-mph barrier impacts are provided along with a plot of vehicle front crush inches vs. impact speed. Most of the front crush in a barrier collision occurs in the early part of the impact; e.g., half of the crush occurs in the first quarter of the total stopping time. In a 30-mph barrier collision, the vehicle is usually stopped before the unrestrained occupant hits the interior. HIC and Gadd Severity Indices are plotted by stopping distance and stopping time as a function of velocity.

Patrick, L.M. Trauma as a Function of Forces and Accelerations in Collisions. Final Report. Wayne State University, PB 231 430. 114 p. March 15, 1974. (30045)

Describes forty-five frontal impacts of full size automobiles (65 occupants) reproduced experimentally with a 50th percentile dummy on the WHAH II impact sled. Barrier equivalent velocity (BEV) were estimated by Wayne and General Motors staff from field reported vehicle damage. Both the BEV and AIS vs. BEV distributions are plotted. Regressions of AIS on BEV were unsatisfactory (R=0.53). Head, chest, and knee AIS's were each considered as a function of BEV. Injury criteria obtained from dummy occupants were compared with similar field reported injuries under the same BEV. Injury indices (e.g., HIC and Gadd) are related to BEV and AIS.

Patrick, L.M., and Levine, R.S. Injury Assessment of Belted Cadavers. Final Report. Wayne State University. 127p. May, 1975. (32333)

Assesses nine restrained cadaver tests at 20, 30, and 40-mph, barrier equivalent velocity collisions. Their injuries ranged from AIS-1 through AIS-8. An AIS vs. velocity curve was derived. The injuries occurred at lower BEV in the cadavers than is observed on the highway.

Reddi, M.M., et al. Thoracic Impact Injury Mechanism. Volume I. Final Report. Franklin Institute Research Laboratories, 230 p. August, 1975. (32899)

Describes a mathematical model of the thorax under impact conditions. Results, when compared with the behavior of Rhesus monkeys under impact conditions, are comparable.

Robbins, D.H. "Simulation of Human Body Response to Crash Loads." Shock and Vibration Computer Programs: Reviews and Summaries. Shock and Vibration Information Center, Washington, D.C. pp. 365-380. 1975. (33361)

Reviews ten mathematical simulations of gross human body motions in terms of occupant description, contact surfaces, force input, and computer applications. Force inputs are in terms of tabular accelerating-time histories, vehicle position as a function of time, time dependent forces applied to the body, and/or surfaces moved into contact with the victim.

Robbins, D.H., and Roberts, V.L. "Michigan Injury Criteria Hypothesis and Restraint System Effectiveness Index." In Proceedings, Fifteenth Stapp Car Crash Conference, Society of Automotive Engineers, New York, pp. 686-709. 1972. (17505)

Discusses an injury criteria model consisting of three parts: (1) An injury rating based on human tolerance data, including type of injury, seriousness, and magnitude of physical quantities, e.g., force and acceleration. The Van Kirk injury scale is adopted. (2) A relative motion criterion is based upon movement ability of adjacent body segments. (3) The probability of a particular crash event occurring is defined as the joint probability of accident type (e.g., front), occupant seated position, and restraint use. Velocity of impact was not included in this part due to lack of accurate data. Overall system effectiveness is also related to occupant weight and geometry, impact velocities and directions, the restraint environment, as well as the above three parts.

Robbins, D.H., Melvin, J.W., and Stalnaker, R.L. "The Prediction of Thoracic Impact Injuries." In Proceedings, Twentieth Stapp Car Crash Conference, SAE. pp. 697-729. 1976. (35839)

Quantifies the thoracic impact response of cadaver and baboon subjects in experiments which vary G-level, velocity, and direction of impact. Resulting injuries were recorded at autopsy and an AIS rating assigned. Using kinematic accelerometer data, injury-predictive functions were generated using statistical regression procedure.

Saczelski, K.J. "Modeling and Analysis Techniques for Prediction of Structural and Biodynamic Crash-Impact Response." *Finite Element Analysis of Transient Nonlinear Structural Behavior*. ASME, New York, pp. 99-117. 1975. (33497)

Examines the interrelationships, viability, and selection of some finite-element modeling techniques for biodynamic and structural crash impact response. The vehicle modeling is intended for use in the design stage considerations of crash energy management and structural collapse into occupant regions.

Snyder, R.G. *State-of-the-Art - Human Impact Tolerance. Revised.* SAE 700398. 73 p. August, 1970. (14284)

Provides an extensive overview of current impact tolerance knowledge. History, methods, and tolerance results are reviewed and tabulated.

Society of Automotive Engineers. The Human Thorax - Anatomy, Injury, and Biomechanics. SAE P-67. 84 p. 1976. (35920)

Five papers review thorax anatomy, blunt trauma, and impact tolerance to frontal and lateral loading.

Stalnaker, R.L., Roberts, V.L., and McElhaney, J.H. *Door Crashworthiness Criteria. Final Report.* UM-HSRI-BI-73-2, DOT HS-800-294. 96 p. September 1973. (28729)

Asserts that since accident data indicate that most occupant deaths were partly due to head injuries suffered when the head struck windows, door pillars, and other rigid objects. Hence most of the data for this study were generated by impacts to the monkey head of short duration against unyielding surfaces. This data was then extrapolated to man by use of dimension analysis and theory of modeling. The results were then presented as tolerance curves generated by the Maximum Strain Criterion (MSC) for head injury.

Versace, J. "A Review of the Severity Index." In *Proceedings, Fifteenth Stapp Car Crash Conference*, SAE. 26p. 1972. (16346)

Finds that the SAE Severity Index is unsupportable as an approximation to tolerance limit data. Distinctions have not been made between fitting a formula to the tolerances limit data, scaling of severity as such, and measuring the "effective acceleration" or the acceleration magnitude of a pulse. Current formulas could be made to better fit the tolerance limit data. Even more appropriate would be a measure of injury severity that would result from head impact data in such a way as to reflect the probability of brain injury. The probability of survival is predicted by a logistic function of effective acceleration.

Viano, D.C., and Gadd, C.W. "Significance of Rate of Onset of Impact Injury Evaluation." In *Proceedings, Nineteenth Stapp Car Crash* Conference, SAE. pp. 807-819. 1975. (33279)

Substantiates the conclusions that a single rate of onset tolerance level is not warranted and that the rate of onset is not a proven injury potential index. Data show that extremely high rates on onset are tolerable without injury. There is a reciprocal relationship between onset and rise time.

Wall, J., Lowne, R.W., and Harris, J. *The Determination of Tolerable Loadings for Car Occupants in Impacts*. Transport and Road Research Laboratory, Crowthorne (England). 16p. October, 1976. (36396)

Discusses method used to determine tolerable occupant impact loadings based on correlating injuries received by living human car occupants in accidents with measurements made on dummies or test devices. The proportion of the population at risk who will suffer injury at any given level of loading is predicted when sufficient data are available. Crash severity is determined by matching accident vehicle damage with reproduced impacts for knee impacts with vehicle fascias and vehicle side impacts. Change in velocity is used for seat belt wearers, as determined by matching damage to known frontal impact test speeds. Three examples are discussed: knee/thigh/hip loading, safety belt loading, and occupant loading in side impacts.

Williams, J.F., and McKenzie, J.A. "The Effect of Seatback Stiffness and Collision Severity on the Dynamic Behavior of the Head During 'Whiplash'." In: *Proceedings, International Conference on the Biokinetics of Impacts*. Organisme National de Securite Routiere, Laboratoire des Chocs, Lyon-Bron, pp. 329-338. May 25, 1973. (28048)

Proposes a model which reproduces the planar motion of the head and neck during rear end impact. From the relationship between impact severity and head rotational acceleration, it was seen that even for low grade collisions the head may reach acceleration levels that may cause cerebral concussion. Also, the magnitude of head and shoulder accelerations is related to seatback stiffness.

APPENDIX A

CONFLICTING CRASH SEVERITY MEASURES

The lack of a clear and common understanding of the term "crash severity" has led to differences of opinion within the research community and between the research community and the political community, as evidenced by the following two examples.

1. The NHTSA* has noted the need for a consistent and accurate crash severity index. The results of field accident investigation efforts and crash recorder results are tabulated (Table 1). The disparities are attributable to (a) terminology differences and (b) measurement differences (systematic or bias errors, and random errors). Several terms have been used to indicate a measure of vehicle speed: traveling speed, impact speed, impact velocity, speed difference at impact, velocity change, barrier equivalent impact velocity, and recorder disk resultant velocity change. While everyone has used "miles-per-hour," everyone has a different definition.

Table 1. NHTSA Comparison of Accident Speeds.

Recorder Results	Accident Investigation Results
1. 17.8 mph	25-35 mph impact speed
2. 14.9 mph	20 mph barrier equivalent
3. 19.1 mph	30 mph police-reported
4. 15.4 mph	22 mph impact, MDAI; 5 mph, GM
5. 18.6 mph	30 mph impact, MDAI; 20 mph, police
6. 14.7 mph	50-60 mph traveling, MDAI; 50 mph, police; 25 mph difference at impact, GM
7. 10.3 mph	24-26 mph impact, MDAI; 50 mph, police; 25 mph impact, GM
8. 13.0 mph	25-35 traveling, MDAI; 30 mph, police
9. 10.5 mph	0-1 mph impact, MDAI; 30 mph, police
10. 19.9 mph	50 mph, police

---

*Teel, S.S., Pierce, S.J., Lutkefedder, N.W. "Automotive Recorder Research - A Summary of Accident Data and Test Results," National Highway Traffic Safety Administration. In _Third International Congress on Occupant Protection_, SAE, pp. 14-70, July 1974.

2. During the William Coleman (former Transportation Secretary) air bag decision process, a Detroit News reporter* noted the apparent ACRS case discrepancies between insurance industry claims and NHTSA field investigations. His report only confounded the existing confusion concerning the definition of crash severity.

Table 2. Detroit News Comparison of Accident Speeds.

Case	Insurance Industry	NHTSA
Somers, N.Y.	Between 45 and 50 mph	Car speed of 31 mph, Barrier equivalent of 16 mph
Schiller Park, Ill.	Combined speed of 60-70 mph	Combined speed of 23 mph
Homewood, Ala.	Hit tree doing 30 mph	Barrier equivalent of 10 mph

---

*Peterson, J.E., "Coleman Reportedly Found Public Misled on Air Bags." In The Detroit News, p. 2-E, February 2, 1977.