The Engineering Society
For Advancing Mobility
Land Sea Air and Space®
400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096-0001 U.S.A.

SAE Technical Paper Series

890740

Further Validation of EDCRASH Using the RICSAC Staged Collisions

Terry D. Day and Randall L. Hargens
Engineering Dynamics Corp.

**Reprinted from SP-777 —
Motor Vehicle Accident Reconstruction:
Review and Update**

**International Congress and Exposition
Detroit, Michigan
February 27 — March 3, 1989**

SAE GLOBAL MOBILITY DATABASE

The papers included in this volume are abstracted and indexed in the SAE Global Mobility Database.

ISSN 0148-7191

Printed in U.S.A.

890740

Further Validation of EDCRASH Using the RICSAC Staged Collisions

Terry D. Day and Randall L. Hargens
Engineering Dynamics Corp.

ABSTRACT

The accuracy of the CRASH computer program was evaluated in terms of its ability to estimate impact speed. A comparison of the results from CRASH2, CRASH3 and EDCRASH were presented along with measured results from twelve staged collisions. Statistical analysis of these results revealed the impact speeds estimated by these CRASH programs were within -6 to +7 percent of the combined impact speeds at a 95 percent level of confidence. Using EDCRASH's extended features to optimize the input data improved the range to within -3 to +3 percent of combined impact speeds. An example was used to illustrate the use of the confidence intervals to estimate the expected range of impact speed for a given reconstruction. The results for oblique collisions were found to be significantly more accurate than the results for collinear collisions. Runs without the trajectory simulation were found to be significantly more accurate than runs with the trajectory simulation, although good steer angle data greatly improved the results. Accuracy for delta-V and separation velocity were not assessed because of errors in the measured (test) values.

A VALIDATION STUDY is important for computer programs used by motor vehicle accident investigators. All investigators, whether compiling statistical information or reconstructing individual accidents, must be able to answer questions regarding program accuracy. Without such a study, the investigator cannot respond to these important questions with confidence. Worse yet, the program results, which are frequently used as a basis for making important societal decisions, may be wrong.

This paper describes a study used to validate the CRASH2, CRASH3, and EDCRASH computer programs [1,2,3]*. This research is an extension of the work originally conducted by CALSPAN, called Research Input for Computer Simulation of Automobile Collisions (RICSAC [4,5,6,7]). In that 1978 study, 12 two-car collisions were staged. Each of the vehicles was instrumented and the collisions were filmed using high-speed cameras. These measured results were used as a basis for comparison to CRASH2 and SMAC results [7].

Several extensions and refinements to the CRASH program have been made since that 1978 study. However, no validation study of these updated programs has been published. The purpose of this paper is to compare the results from CRASH2, CRASH3, and EDCRASH with the actual staged collisions results. Accident investigators can use this information to establish a level of confidence for the amount of error in their individual case studies.

HISTORICAL OVERVIEW

The RICSAC study represents the world's largest single attempt to determine the accuracy of any reconstruction tool. It was conducted under contract with NHTSA, which has used the CRASH program for various statistical studies [8,9,10]. The RICSAC test procedure is summarized below.

RICSAC Study

The RICSAC study was an analysis and reconstruction of 12 two-car staged collisions. The collisions were conducted at CALSPAN's Vehicle Experimental Research Facility (VERF) between November, 1977 and July, 1978. The surface at the facility had a tested friction coefficient of 0.87 (ASTM E-274 [11]).

Impact Configurations

Several impact configurations were tested (see Table 1). These configurations represented those typical of most real-world accidents, and included head-on, rear-end and intersection-type collisions. Head-on and rear-

*Numbers in brackets designate references at the end of the paper.

TABLE 1. RICSAC staged collisions.

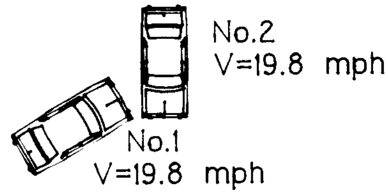
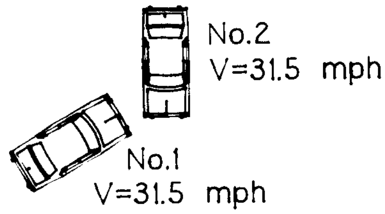
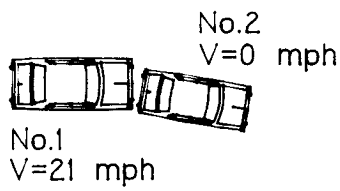
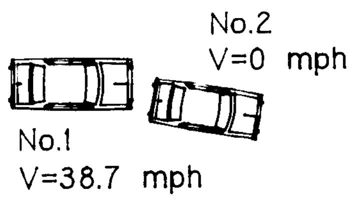
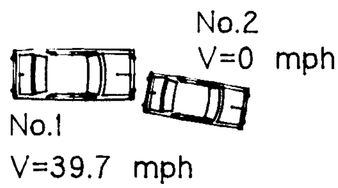
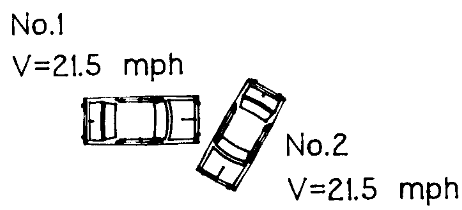
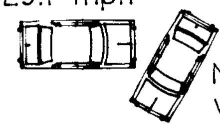
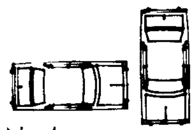
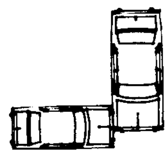
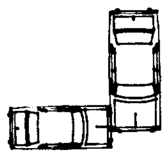
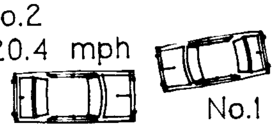
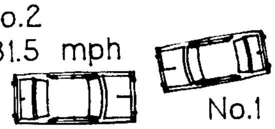
TEST No.	VEHICLES	COLLISION TYPE	CONFIGURATION at IMPACT
1	No. 1 - '74 Chev Malibu No. 2 - '74 Ford Pinto	Oblique	
2	No. 1 - '74 Chev Chevelle No. 2 - '74 Ford Pinto	Oblique	
3	No. 1 - '74 Ford Torino No. 2 - '74 Ford Pinto	Collinear	
4	No.1 - '74 Ford Torino No. 2 - '74 Ford Pinto	Collinear	
5	No. 1 - '74 Ford Torino No. 2 - '74 Honda Civic	Collinear	
6	No. 1 - '74 Chev Chevelle No. 2 - '75 VW Rabbit	Oblique	

TABLE 1 (continued from previous page). RICSAC staged collisions.

TEST No.	VEHICLES	COLLISION TYPE	CONFIGURATION at IMPACT
7	No. 1 - '74 Chev Chevelle No. 2 - '74 VW Rabbit	Oblique	
8	No. 1 - '74 Chev Chevelle No. 2 - '74 Chev Chevelle	Oblique	
9	No. 1 - '74 Honda Civic No. 2 - '74 Ford Torino	Oblique	
10	No.1 - '74 Honda Civic No. 2 - '74 Ford Torino	Oblique	
11	No. 1 - '74 Chev Vega No. 2 - '74 Ford Torino	Collinear	
12	No. 1 - '74 Chev Vega No. 2 - '75 Ford Torino	Collinear	

end collisions are termed *collinear*, because the directions of their pre-impact velocity vectors are within 10 degrees of parallel; the remaining range is termed *oblique*. This important distinction is made because the two collision types are analyzed differently by the CRASH program. Vehicle damage data are used to analyze the impact phase of a collinear impact, while scene measurements and linear momentum are used for analyzing oblique collisions.

Instrumentation

Each vehicle was fitted with a complete instrumentation package described in reference 5. The minimum package for measuring time-histories included:

- a triaxial accelerometer mounted on the firewall (vehicle position, velocity, acceleration).
- linear stroke potentiometers mounted on steering linkage (wheel steer angles).
- electric tachometers on at least three wheels (wheel spin velocity for percent lock-up).
- Teledyne Geotech Model 35500 crash recorders for recording the data.
- a minimum of ten high-speed cameras, including two hand-held cameras, eye-level cameras and cameras mounted on portable towers, for filming each crash test.
- marker paint sprayed from nozzles (two per vehicle) mounted on the unsprung mass approximately 1 inch above ground level for directly identifying each vehicle's path.

Post-crash Inspection

After the collision, the site evidence was documented by professional accident investigators. This evidence included:

- wheel positions at impact and rest
- locations of debris, gouges and spilled fluids
- skidmarks
- vehicle trajectory (spray paint)

See reference [5] for a complete description of the test procedures.

Evaluation By Crash

At the time of the RICSAC study, CRASH2 was the current version of the CRASH program. Subsequently, several changes were incorporated in the CRASH2 program and, in 1981, CRASH3 was released. In 1983, the mainframe CRASH3 version was rewritten for use on the personal computer. This program was called EDCRASH.

As part of the original RICSAC study, the accident site and vehicle inspection results for each of the 12 staged collisions were reduced into CRASH input data sets, and the CRASH2 results were produced. However, since that study, no comparison between the staged collisions and the results produced by CRASH3 or EDCRASH has ever been published.

As part of the current research, the same 12 data sets from the original RICSAC study were also fed into CRASH3 and EDCRASH to obtain the results from these programs.

The measured data reported in this paper were obtained from reference 7 and supplemented by analysis of the high-speed film performed subsequently by NHTSA [12]. The CRASH2 results were obtained from references 7 and 13. The CRASH3 results were obtained on a VAX computer using 1984 source code supplied to Indiana University directly by NHTSA. The EDCRASH results were obtained using Version 4.35 on a Compaq Deskpro 286 PC.

The remainder of this paper deals with a comparison of the results of these CRASH programs with the measured staged collision results as a useful means to assess program accuracy.

VALIDATION RESULTS

CRASH has an optional *trajectory simulation*. When this option is selected, the separation velocities and angles computed by traditional methods are used as the initial conditions for a simulation of the separation-to-rest phase. The purpose of the trajectory simulation is to corroborate the traditionally-computed separation velocities: If they are accurate, the trajectory simulation's vehicle rest positions should match the measured rest positions and the simulation has *converged*. If the simulated and measured rest positions do not match, the traditional separation velocities and angles are modified, and the simulation is repeated. Up to five attempts are allowed. If no match has been achieved after five attempts, the simulation has *failed to converge* and the separation velocities which produced the closest match are used. (See references 1-3 for further information on the trajectory simulation option.)

Table 2 shows the measured test results for each of the 12 staged collisions along with the results computed by CRASH2, CRASH3 and EDCRASH. Impact speed, separation velocity and delta-V are tabulated separately.

Table 2 is divided into two parts. The first part shows the results without the trajectory simulation option; the second part shows the results with the trajectory simulation option, along with the number of runs required before the results converged (F indicates a failure to converge; T indicates the vehicle did not come to rest before the end of the simulation).

Differences in Results Between Programs

Inspection of the results shown in Table 2 reveals differences between CRASH2, CRASH3 and EDCRASH. The reasons for the differences are discussed below.

During the RICSAC study, errors in CRASH2 were identified. These errors related to the calculation of the separation velocities and were subsequently corrected [7,14]. In addition to the errors, previous researchers felt the CRASH2 stiffness coefficients were inadequate.

As part of the upgrading from CRASH2 to CRASH3, the code was restructured to improve the readability which had suffered as a result of several years of revision. Additional program features were added and the crush stiffnesses were updated. Several bugs were removed from the trajectory simulation routine. These changes, described in reference 14, were probably responsible for most or all of the differences between CRASH2 and CRASH3 results.

After the restructuring, several bugs were found in CRASH3 by NHTSA. The corrections were specified in an NHTSA memorandum, dated December 11, 1981 [15].

During the development of EDCRASH in 1983, additional bugs were found in CRASH3. These bugs were identified by *swap testing*. This procedure involved swapping vehicles 1 and 2 and creating new data sets for each of the RICSAC cases to see if the swapped results perfectly matched the original results. EDCRASH passed this test. However, most of the CRASH3 runs failed. The errors found in CRASH3 included failing to reassign the average wheel lockup for the second vehicle (vehicle 2 was assigned the wheel lockup for vehicle 1) and assigning the wrong separation X,Y coordinates for vehicle 2 when its path contained an end of rotation (the separation coordinates are equated to the end of rotation coordinates, instead of the impact coordinates). These findings were transmitted to NHTSA early in 1984 and described in reference 16.

Differences between the CRASH3 and EDCRASH results were found in the current research for tests 3, 5, 7 and 10. Swap testing of the CRASH3 results as described above revealed errors still existed in the 1984 NHTSA code used in this research. Inspection of the CRASH3 source code revealed the average lockup for vehicle 2 was still not assigned correctly. This finding has been transmitted to NHTSA.

PROGRAM ACCURACY

The data in Table 2 were analyzed to determine the accuracy of the CRASH2, CRASH3 and EDCRASH programs. Three basic variables were measured in the RICSAC study: separation velocity, delta-V and impact speed. These variables have the following relationship:

$$V_{imp} = V_{sep} - \Delta V$$

where V_{imp} is the impact velocity, V_{sep} is the velocity at separation (by definition, the same as the velocity at the end of the impact phase) and delta-V is the change in vector velocity during the impact phase (the negative sign before delta-V results from the sign convention).

Because the measured values for separation velocity and delta-V were not independent, program accuracy for separation velocity and delta-V was evaluated together.

Separation Velocity and Delta-V

Several studies published since 1978 have attempted to use the RICSAC delta-V data as a basis for validation of CRASH and other programs, including references 7, 17 and 18. In all cases, researchers found significant differences between the delta-Vs computed by the programs and the delta-Vs measured during the RICSAC study. This has led many researchers to question the accuracy and usefulness of these programs. However, the literature [5,6,7] clearly stated there were problems with the sophisticated data acquisition systems aboard the vehicles. One of the major problems encountered during the study was the fact that the accelerometer data was not taken at the center of gravity (CG), but rather, at the firewall. Thus, any rotation during impact would cause an error in the measured separation velocities and, therefore, the delta-V.

Subsequent to the original study, analysis of the high-speed film was used to improve the test data. However, the high-speed film has not been analyzed for all the staged collisions. In this paper, the high-speed film results have been used where available [12]. Analysis of the best available staged collision results revealed the delta-Vs were not inversely proportional to the vehicle masses (this should be approximately true for a collision when tire forces are small compared to impact forces).

Because of the problems with the RICSAC data for separation velocity and delta-V, the accuracy of these data could not be properly evaluated. Previous program evaluations which used the RICSAC data as a means of validation for delta-V should be viewed as suspect. The program estimates are probably better than stated.

Impact Speed

Because the impact speed was measured with great accuracy using a simple speed trap [5,6], the data acquisition problems described above did not affect the measurement of impact speed. Therefore, the accuracy of the programs when used for estimating impact speed could be evaluated.

Definition Of Accuracy

Accuracy is traditionally defined as the percentage of error in a test value compared to its known value. Mathematically, this is expressed as

$$\text{ERROR (\%)} = (X_{test} - X_{known})/X_{known}*100$$

TABLE 2. Validation results for impact speed, separation velocity and delta-V. Measured test data and results from CRASH2, CRASH3, and EDCRASH *without* the trajectory simulation option.

TEST No.	METHOD	IMPACT SPEED Veh #1 (mph)	IMPACT SPEED Veh #2 (mph)	SEPARATION VELOCITY Veh #1 Lin (mph)	SEPARATION VELOCITY Veh #1 Ang (deg/sec)	SEPARATION VELOCITY Veh #2 Lin (mph)	SEPARATION VELOCITY Veh #2 Ang (deg/sec)	DELTA-V Veh #1 (mph)	DELTA-V Veh #2 (mph)
1	MEASURED	19.8	19.8	11.0	90.0	12.5	0.0	12.2	15.6
	CRASH2	20.6	20.6	11.5	45.3	14.6	23.4	9.6	9.6
	CRASH3	20.7	22.3	11.5	45.3	14.9	48.6	10.2	15.3
	EDCRASH	20.7	22.3	11.5	45.3	14.8	48.6	10.2	15.3
2	MEASURED	31.5	31.5	18.3	150.0	18.3	90.0	19.6	28.9
	CRASH2	29.6	33.3	11.6	0.0	23.5	45.0	20.6	30.9
	CRASH3	27.9	32.6	10.7	0.0	22.4	43.3	20.8	31.2
	EDCRASH	27.9	32.7	10.7	0.0	22.4	43.3	20.8	31.2
3	MEASURED	21.0	0.0	11.7	15.0	15.7	0.0	9.5	15.8
	CRASH2	15.2	10.4	12.1	0.0	15.5	0.0	3.1	4.9
	CRASH3	18.4	4.7	12.1	0.0	14.7	0.0	6.2	9.9
	EDCRASH	19.7	5.1	12.4	0.0	15.1	0.0	6.2	9.9
4	MEASURED	38.7	0.0	20.0	37.0	22.4	30.0	18.7	22.4
	CRASH2	31.9	4.9	23.3	18.2	17.7	0.0	9.1	14.1
	CRASH3	33.3	-6.0	18.1	36.3	18.8	0.0	15.8	24.6
	EDCRASH	33.3	-6.0	18.1	36.3	18.8	0.0	15.8	24.6
5	MEASURED	39.7	0.0	23.4	12.0	25.1	70.0	16.3	25.1
	CRASH2	33.8	10.5	25.7	0.0	25.5	300.5	8.1	14.8
	CRASH3	41.1	-1.5	25.7	0.0	26.5	239.6	15.4	28.0
	EDCRASH	41.1	-2.6	25.7	0.0	25.5	300.5	15.4	28.0
6	MEASURED	21.5	21.5	13.3	30.0	12.2	180.0	9.0	15.4
	CRASH2	24.9	20.5	12.9	0.0	17.0	137.6	12.4	20.4
	CRASH3	24.4	24.5	11.9	0.0	16.3	135.4	14.5	23.8
	EDCRASH	24.4	24.5	11.9	0.0	16.3	135.4	14.5	23.8
7	MEASURED	29.1	29.1	17.9	30.0	19.7	192.0	12.0	20.9
	CRASH2	26.2	27.1	15.3	0.0	19.6	171.7	11.6	25.3
	CRASH3	26.2	34.9	14.3	0.0	20.1	146.2	15.0	32.7
	EDCRASH	25.9	34.7	14.3	0.0	19.6	171.8	14.8	32.1
8	MEASURED	20.8	20.8	11.8	114.0	15.7	18.0	15.6	10.7
	CRASH2	19.5	24.5	14.3	58.6	18.8	53.9	10.3	9.5
	CRASH3	16.7	25.7	14.4	58.2	17.0	54.5	12.6	12.0
	EDCRASH	16.8	25.7	14.4	58.2	17.0	54.6	12.6	12.0
9	MEASURED	21.2	21.2	12.5	180.0	17.8	-45.0	21.4	8.9
	CRASH2	23.2	22.0	9.9	0.0	20.2	54.7	24.2	11.2
	CRASH3	19.5	21.5	10.6	0.0	18.8	52.5	21.4	9.9
	EDCRASH	19.6	21.6	10.6	0.0	18.8	54.7	21.5	9.9
10	MEASURED	33.3	33.3	22.8	300.0	26.9	-72.0	35.1	14.1
	CRASH2	32.7	31.5	20.0	116.0	25.8	0.0	33.6	15.9
	CRASH3	33.9	35.3	18.8	126.0	30.0	0.0	33.8	16.5
	EDCRASH	31.1	33.7	18.8	126.0	27.8	0.0	30.4	14.9
11	MEASURED	20.4	20.4	3.7	-30.0	5.2	0.0	24.0	15.7
	CRASH2	17.2	18.0	3.8	0.0	4.8	0.0	21.1	13.2
	CRASH3	17.0	16.6	3.8	0.0	3.5	0.0	20.9	13.1
	EDCRASH	16.9	16.5	3.9	0.0	4.7	0.0	20.9	13.1
12	MEASURED	31.5	31.5	10.4	-90.0	7.3	-60.0	41.6	26.4
	CRASH2	19.8	30.2	8.5	-106.9	11.6	-22.4	28.2	19.6
	CRASH3	17.8	29.0	8.4	-106.9	11.7	-22.4	26.3	18.2
	EDCRASH	17.8	29.0	8.4	-106.9	11.7	-22.4	26.3	18.2

TABLE 2 (continued). Results with the *with* the trajectory simulation option.

TEST No.	METHOD	IMPACT SPEED Veh #1 (mph)	IMPACT SPEED Veh #2 (mph)	SEPARATION VELOCITY Veh #1 Lin (mph)	SEPARATION VELOCITY Veh #1 Ang (deg/sec)	SEPARATION VELOCITY Veh #2 Lin (mph)	SEPARATION VELOCITY Veh #2 Ang (deg/sec)	DELTA-V Veh #1 (mph)	DELTA-V Veh #2 (mph)	No. of Runs Veh 1	No. of Runs Veh 2
1	MEASURED	19.8	19.8	11.0	90.0	12.5	0.0	12.2	15.6	N/A	N/A
	CRASH2	14.7	20.6	5.9	115.7	14.6	23.4	9.7	14.6	F	T
	CRASH3	15.5	12.9	4.9	95.7	13.3	19.5	10.9	16.4	F	F
	EDCRASH	15.7	13.2	4.9	97.6	13.4	19.4	11.1	16.7	F	F
2	MEASURED	31.5	31.5	18.3	150.0	18.3	90.0	19.6	28.9	N/A	N/A
	CRASH2	32.8	35.6	14.3	0.0	23.4	45.1	22.0	33.0	T	T
	CRASH3	37.4	52.1	18.9	0.0	25.9	34.0	31.8	47.6	F	5
	EDCRASH	37.4	52.1	18.8	0.0	26.0	33.8	31.8	47.7	F	5
3	MEASURED	21.0	0.0	11.7	15.0	15.8	0.0	9.5	15.8	N/A	N/A
	CRASH2	15.2	10.4	12.0	0.0	15.5	0.0	3.1	5.4	T	T
	CRASH3	18.4	4.9	12.1	0.0	15.2	0.0	6.2	9.9	1	F
	EDCRASH	18.3	5.1	12.1	0.0	15.1	0.0	6.2	9.9	2	F
4	MEASURED	38.7	0.0	20.0	37.0	22.4	30.0	18.7	22.4	N/A	N/A
	CRASH2	32.5	2.2	23.3	18.2	17.7	0.0	10.9	15.5	T	T
	CRASH3	25.8	-6.0	18.1	36.3	18.8	0.0	15.8	24.6	F	F
	EDCRASH	26.1	-6.0	18.0	44.5	18.8	0.3	15.8	24.6	F	F
5	MEASURED	39.7	0.0	23.4	12.0	25.1	70.0	16.3	25.1	N/A	N/A
	CRASH2	-	-	-	-	-	-	-	-	-	-
	CRASH3	40.7	1.2	25.2	0.0	29.7	257.9	15.4	28.0	F	F
	EDCRASH	40.7	1.1	25.3	0.0	29.7	257.8	15.4	28.0	F	F
6	MEASURED	21.5	21.5	13.3	30.0	12.2	180.0	9.0	15.4	N/A	N/A
	CRASH2	-	-	-	-	-	-	-	-	-	-
	CRASH3	26.5	38.6	16.5	0.0	15.1	151.3	19.1	31.3	F	3
	EDCRASH	26.7	39.1	16.6	0.0	15.1	151.0	19.4	31.8	F	3
7	MEASURED	29.1	29.1	17.9	30.0	19.7	192.0	12.0	20.9	N/A	N/A
	CRASH2	-	-	-	-	-	-	-	-	-	-
	CRASH3	30.1	54.3	17.6	0.0	24.0	160.0	20.3	44.2	F	3
	EDCRASH	28.0	47.6	16.0	0.0	23.0	183.6	17.4	37.8	F	2
8	MEASURED	20.8	20.8	11.7	114.0	15.8	18.0	15.6	10.7	N/A	N/A
	CRASH2	11.4	25.5	9.8	89.6	18.4	54.6	11.5	11.0	F	T
	CRASH3	19.3	21.8	9.2	95.6	20.4	47.9	18.1	17.2	F	F
	EDCRASH	19.2	22.0	9.2	96.5	20.5	47.3	18.0	17.2	F	F
9	MEASURED	21.2	21.2	12.5	180.0	17.8	-45.0	21.4	8.9	N/A	N/A
	CRASH2	-	-	-	-	-	-	-	-	-	-
	CRASH3	21.1	30.5	30.2	0.0	18.9	52.5	35.4	16.3	F	F
	EDCRASH	40.5	27.9	30.2	0.0	22.5	37.4	48.4	22.3	F	F
10	MEASURED	33.3	33.3	22.8	300.0	26.9	-72.0	35.1	14.1	N/A	N/A
	CRASH2	25.5	30.5	16.8	134.5	25.8	0.0	31.4	15.3	F	T
	CRASH3	28.2	35.9	19.2	142.8	30.0	0.0	34.4	16.8	F	T
	EDCRASH	24.6	34.3	19.0	143.9	27.8	0.0	31.2	15.2	F	T
11	MEASURED	20.4	20.4	3.7	-30.0	5.2	0.0	24.0	15.7	N/A	N/A
	CRASH2	-	-	-	-	-	-	-	-	-	-
	CRASH3	17.0	17.7	3.8	0.0	4.6	0.0	20.9	13.1	F	3
	EDCRASH	17.1	17.8	3.9	0.0	4.7	0.0	20.9	13.1	F	1
12	MEASURED	31.5	31.5	10.4	-90.0	7.3	-60.0	41.6	26.4	N/A	N/A
	CRASH2	20.2	24.3	8.1	-110.0	10.1	-22.3	28.2	21.4	T	F
	CRASH3	19.9	22.9	6.6	-158.6	9.5	-31.2	26.3	18.2	F	F
	EDCRASH	19.9	22.9	6.6	-155.6	9.3	-30.0	26.3	18.2	F	F

TABLE 3. Error expressed in absolute magnitude (mph) and percent.

TEST No.	COMBINED SPEED (mph)	METHOD	ERROR (Based on combined speed) *without* trajectory simulation Veh #1 (mph)	(%)	Veh #2 (mph)	(%)	*with* trajectory simulation Veh #1 (mph)	(%)	Veh #2 (mph)	(%)
1	39.6	CRASH2	0.8	2.0	0.8	2.0	-5.1	-12.9	0.8	2.0
		CRASH3	0.9	2.3	2.5	6.3	-4.3	-10.9	-6.9	-17.4
		EDCRASH	0.9	2.3	2.5	6.3	-4.1	-10.4	-6.6	-16.7
2	63.0	CRASH2	-1.9	-3.0	1.8	2.9	1.3	2.1	4.1	6.5
		CRASH3	-3.6	-5.7	1.1	1.7	5.9	9.4	20.6	32.7
		EDCRASH	-3.6	-5.7	1.2	1.9	5.9	9.4	20.6	32.7
3	21.0	CRASH2	-5.8	-27.6	10.4	49.5	-5.8	-27.6	10.4	49.5
		CRASH3	-2.6	-12.4	4.7	22.4	-2.6	-12.4	4.9	23.3
		EDCRASH	-1.3	-6.2	5.1	24.3	-2.7	-12.9	5.1	24.3
4	38.7	CRASH2	-6.8	-17.6	4.9	12.7	-6.2	-16.0	2.2	5.7
		CRASH3	-5.4	-14.0	-6.0	-15.5	-12.9	-33.3	-6.0	-15.5
		EDCRASH	-5.4	-14.0	-6.0	-15.5	-12.6	-32.6	-6.0	-15.5
5	39.7	CRASH2	-5.9	-14.9	10.5	26.4	-	-	-	-
		CRASH3	1.4	3.5	-1.5	-3.8	1.0	2.5	1.2	3.0
		EDCRASH	1.4	3.5	-2.6	-6.5	1.0	2.5	1.1	2.8
6	43.0	CRASH2	3.4	7.9	-1.0	-2.3	-	-	-	-
		CRASH3	2.9	6.7	3.0	7.0	5.0	11.6	17.1	39.8
		EDCRASH	2.9	6.7	3.0	7.0	5.2	12.1	17.6	40.9
7	58.2	CRASH2	-2.9	-5.0	-2.0	-3.4	-	-	-	-
		CRASH3	-2.9	-5.0	5.8	10.0	1.0	-1.7	25.2	43.3
		EDCRASH	-3.2	-5.5	5.6	9.6	-1.1	-1.9	18.5	31.8
8	41.5	CRASH2	-1.3	-3.1	3.7	8.9	-9.4	-22.6	4.7	11.3
		CRASH3	-4.1	-9.9	4.9	11.8	-1.5	-3.6	1.0	2.4
		EDCRASH	-4.0	-9.6	4.9	11.8	-1.6	-3.8	1.2	2.9
9	42.4	CRASH2	2.0	4.7	0.8	1.9	-	-	-	-
		CRASH3	-1.7	-4.0	0.3	0.7	-0.1	-0.2	9.3	21.9
		EDCRASH	-1.6	-3.8	0.4	0.9	19.3	45.5	6.7	15.8
10	66.6	CRASH2	-0.6	-0.9	-1.8	-2.7	-7.8	-11.7	-2.8	-4.2
		CRASH3	0.6	0.9	2.0	3.0	-5.1	-7.7	2.6	3.9
		EDCRASH	-2.2	-3.3	0.4	0.6	-8.7	-13.1	1.0	1.5
11	40.8	CRASH2	-3.2	-7.8	-2.4	-5.9	-	-	-	-
		CRASH3	-3.4	-8.3	-3.8	-9.3	-3.4	-8.3	-2.7	-6.6
		EDCRASH	-3.5	-8.6	-3.9	-9.6	-3.3	-8.1	-2.6	-6.4
12	63.0	CRASH2	-11.7	-18.6	-1.3	-2.1	-11.3	-17.9	-7.2	-11.4
		CRASH3	-13.7	-21.7	-2.5	-4.0	-11.6	-18.4	-8.6	-13.7
		EDCRASH	-13.7	-21.7	-2.5	-4.0	-11.6	-18.4	-8.6	-13.7

However, the traditional definition of accuracy does not work for accident reconstruction. Consider the case when a stationary car is struck from the rear. If the program estimated the speed of the stationary car as 0.1 mph, the above formula yields

$$\text{ERROR} = (0.1 - 0)/0 * 100,$$

an infinitely large percentage error.

Similarly, expressing the error directly in miles per hour has shortcomings. For example, if a vehicle's impact speed was estimated at 108 mph, while its actual speed was 100 mph, our instinct tells us that's not a bad estimate. However, if the estimated speed was 8 mph and the vehicle was actually stationary, the same 8 mph error might be very significant.

Therefore, it was necessary to establish an error criterion which was independent of the impact speed of an individual vehicle. The combined impact speed of the vehicles was selected as the criterion.

Calculation Procedures

In the present research, the following procedures were used to compute the error for each vehicle:

Step 1 - Compute the Combined Speed, CS:

$$CS = V_{\#1,\text{impact}} + V_{\#2,\text{impact}} \quad \text{(mph)}$$

Step 2 - Compute the difference between the estimated impact speed and the actual impact speed, δV:

$$\delta V_1 = V_{1,est} - V_{1,act} \quad \text{(mph)}$$

$$\delta V_2 = V_{2,est} - V_{1,act} \quad \text{(mph)}$$

Step 3 - Compute the percent error based on combined impact speed, E:

$$E_1 = (\delta V_1/CS)*100 \quad (\%)$$

$$E_2 = (\delta V_2/CS)*100 \quad (\%)$$

The results of these calculations for CRASH2, CRASH3 and EDCRASH are shown in Table 3. Again, the results *without* and *with* the trajectory simulation option are shown separately.

Analysis Of Accuracy

The data in Table 3 represented a substantial amount of statistical data for several different impact configurations. These data expressed the error as an absolute figure in miles per hour and as a percentage of combined impact speed. The miles per hour figures were presented for reference only. The analysis of program accuracy should be based on percentage of combined impact speed, for reasons explained earlier.

According to sampling theory [19], if the collisions used in the RICSAC study were typical of the actual population of accidents being analyzed, they could be used for estimating the expected program accuracy when the program is applied by field accident investigators. Since there was no reason to expect otherwise, these collisions were considered typical. Therefore, the *T statistic* was used, and the 95 percent confidence interval for the expected program accuracy was computed. This confidence interval does not imply a 95 percent level of program accuracy. Rather, the confidence interval means the investigator can be 95 percent confident that the true value of the vehicle speed error lies between the lower and upper boundaries of the confidence interval.

Scenarios Evaluated

Because of the way the data were organized, the influence of several combinations of factors could be analyzed. For example, the most basic analysis was a single confidence interval for all the staged collisions. This analysis was performed with and without the trajectory simulation as a means of assessing the value of that program option.

Additional analyses were performed by separating collinear collisions from oblique collisions to determine if the accuracy for one type of collision was better than the accuracy for the other. Inspection of Table 1 reveals in all cases, vehicle 1 was the striking vehicle and vehicle 2 was the struck vehicle. Thus, a separate analysis was performed to determine if the program results were biased by whether a vehicle was the striking or struck vehicle.

A total of 18 different scenarios was analyzed, each of which is described in Table 4.

TABLE 4. Various scenarios amenable to analysis.

Scenario	Description		
1	*Any collision*	*Either vehicle*	*Without traj*
2	"	"	*With traj*
3	"	*Striking vehicle*	*Without traj*
4	"	"	*With traj*
5	"	*Struck vehicle*	*Without traj*
6	"	"	*With traj*
7	*Collinear Collision*	*Either vehicle*	*Without traj*
8	"	"	*With traj*
9	"	*Striking vehicle*	*Without traj*
10	"	"	*With traj*
11	"	*Struck vehicle*	*Without traj*
12	"	"	*With traj*
13	*Oblique Collision*	*Either vehicle*	*Without traj*
14	"	"	*With traj*
15	"	*Striking vehicle*	*Without traj*
16	"	"	*With traj*
17	"	*Struck vehicle*	*Without traj*
18	"	"	*With traj*

TABLE 5. Confidence interval for various scenarios for CRASH2, CRASH3, and EDCRASH. All results are expressed in percent of combined impact speed (see *Calculation Procedures*, Step 3).

Scenario	Method	N*	Avg. Error	Std. Dev.	Confidence Interval		
1	CRASH2	24	0.2	15.2	-6.2	to	6.6
	CRASH3	24	-1.6	9.9	-5.7	to	6.6
	EDCRASH	24	-1.6	9.9	-5.8	to	6.6
2	CRASH2	16	-3.4	19.2	-14.5	to	7.7
	CRASH3	24	2.0	19.1	-6.1	to	10.0
	EDCRASH	24	2.9	20.2	-5.7	to	11.4
3	CRASH2	12	-7.0	10.6	-13.8	to	-0.2
	CRASH3	12	-5.6	8.2	-10.9	to	-0.4
	EDCRASH	12	-5.5	7.8	-10.4	to	-0.6
4	CRASH2	7	-15.2	9.4	-24.0	to	-6.5
	CRASH3	12	-5.8	12.4	-13.7	to	2.1
	EDCRASH	12	-2.6	19.4	-15.0	to	9.7
5	CRASH2	12	7.3	16.0	-2.9	to	17.5
	CRASH3	12	2.5	10.1	-3.9	to	8.9
	EDCRASH	12	2.2	10.6	-4.5	to	9.0
6	CRASH2	7	8.5	19.6	-9.6	to	26.6
	CRASH3	12	9.8	21.8	-4.1	to	23.6
	EDCRASH	12	8.4	20.3	-4.5	to	21.2
7	CRASH2	10	-0.6	23.7	-17.5	to	16.4
	CRASH3	10	-6.3	12.3	-15.1	to	2.5
	EDCRASH	10	-5.8	12.6	-14.8	to	3.2
8	CRASH2	6	-3.0	27.9	-32.3	to	26.4
	CRASH3	10	-7.9	15.2	-18.8	to	2.9
	EDCRASH	10	-7.8	15.3	-18.7	to	3.1
9	CRASH2	5	-17.3	7.1	-26.1	to	-8.4
	CRASH3	5	-10.6	9.3	-22.1	to	0.9
	EDCRASH	5	-9.4	9.4	-21.0	to	2.2
10	CRASH2	3	-20.5	6.2	-36.0	to	-5.1
	CRASH3	5	-14.0	13.2	-30.4	to	2.4
	EDCRASH	5	-13.9	13.0	-30.0	to	2.2
11	CRASH2	5	16.1	22.6	-12.0	to	44.2
	CRASH3	5	-2.0	14.5	-20.0	to	15.9
	EDCRASH	5	-2.3	15.4	-21.4	to	16.9
12	CRASH2	3	14.6	31.4	-63.5	to	92.7
	CRASH3	5	-1.9	15.9	-21.6	to	17.8
	EDCRASH	5	-1.7	16.2	-21.8	to	18.4
13	CRASH2	14	0.7	4.3	-1.8	to	3.2
	CRASH3	14	1.8	6.3	-1.8	to	5.5
	EDCRASH	14	1.4	6.4	-2.3	to	5.1
14	CRASH2	8	-3.7	11.3	-13.2	to	5.8
	CRASH3	14	9.1	18.8	-1.8	to	19.9
	EDCRASH	14	10.5	20.3	-1.2	to	22.2
15	CRASH2	7	0.4	4.7	-4.0	to	4.7
	CRASH3	7	-2.1	5.6	-7.3	to	3.1
	EDCRASH	7	-2.7	5.5	-7.8	to	2.4
16	CRASH2	4	-11.3	10.1	-27.4	to	4.9
	CRASH3	7	0.1	8.3	-7.6	to	7.7
	EDCRASH	7	5.4	20.0	-13.1	to	23.9
17	CRASH2	7	1.0	4.3	-3.0	to	5.0
	CRASH3	7	5.8	4.2	1.9	to	9.7
	EDCRASH	7	5.4	4.4	1.4	to	9.5
18	CRASH2	4	3.9	6.6	-6.6	to	14.4
	CRASH3	7	18.1	22.5	-2.7	to	38.9
	EDCRASH	7	15.6	20.8	-3.7	to	34.8

*NOTE: *N* is the number of data points for each scenario.

Findings

The results of statistical analysis are shown in Table 5. The average error was used to determine if a program consistently underestimated (negative average error) or overestimated (positive average error) impact speed. The standard deviation expressed the scatter in the results (a small standard deviation indicated the results were closely grouped around the average error). However, the confidence interval provided the most meaningful information. It was used to estimate the expected program accuracy and to determine if the underestimation or overestimation expressed by the average error was significant. Important findings from Table 5 are summarized below.

Scenario 1 - The typical CRASH analysis had a confidence interval of about -6 to +7 percent of the combined impact speed. While the average error was smallest for CRASH2, its standard deviation was the largest. There was no significant difference in the accuracy of CRASH2, CRASH3 and EDCRASH.

Scenario 2 - When the trajectory simulation was used on a typical CRASH analysis, the average error increased, the data standard deviation increased and the confidence interval increased for all programs. Comparison of all trajectory simulation scenarios with their non-simulation counterparts (i.e., 1 vs 2, 3 vs 4,...,17 vs 18) revealed that, with only one exception (struck vehicles involved in collinear collisions), use of the trajectory simulation always reduced the quality of the results.

Scenarios 7 and 13 - Comparison of oblique and collinear collision results revealed the CRASH program was significantly more accurate for oblique collisions than for collinear collisions. Oblique collisions typically involved more complex spinout trajectories than collinear collisions. Thus, a reduction in accuracy for oblique collisions was expected. Since the accuracy was significantly *better*, it was concluded the momentum-based method provided better estimates for delta-V than the damage-based method.

Scenarios 9 and 11 - Comparison of results for striking and struck vehicles involving collinear collisions revealed CRASH3 and EDCRASH tended to produce better results for struck vehicles than for striking vehicles. The average error was lower for struck vehicles, but the scatter was higher. The difference between struck and striking vehicles was not significant. CRASH2 showed significantly greater error for both scenarios, probably because of the poor stiffness coefficients it used.

Scenarios 15 and 17 - Comparison of results for striking and struck vehicles involving oblique collisions revealed all programs tended to slightly underestimate the speed of the striking vehicle and slightly overestimate the speed of the struck vehicle. The difference was not significant at the 95 percent confidence level.

TABLE 6. EDCRASH diagnostic messages issued for RICSAC cases.

TEST No.	MESSAGES*
1	1, 2, 3, 5
2	1, 2, 3
3	4
4	4
5	1, 4
6	1, 5
7	1, 3, 4, 5
8	2, 4
9	2, 3
10	2, 3, 4
11	None
12	None

LEGEND

*Msg.	Meaning
1	*Violation of Newton's 3rd Law. The impact forces, computed independently for each vehicle, are significantly different.*
2	*Discrepancy between momentum and damage results. The user's estimates for PDOFs differ from the PDOFs computed by the momentum analysis.*
3	*Discrepancy between momentum and damage results. The delta-Vs computed by the momentum analysis differ significantly from the delta-V computed by the damage analysis.*
4	*Violation of the conservation of energy. The energy spent crushing the vehicles according to the damage analysis differs from the kinetic energy lost between impact and separation according to the computed impact and separation velocities.*
5	*Common velocity warning. The damage procedure requires and assumes the vehicles reached a common velocity (i.e., plastic impact). A small adjustment of separation velocities was performed to be consistent with this assumption.*

Optimization

It became clear during the analysis of the RICSAC test data that the CRASH input data sets could be improved by the use of several techniques which were not available in CRASH2 or CRASH3. These techniques, available in EDCRASH, are described below.

Use of Additional Diagnostic Messages - CRASH2 issued no warning messages when running the RICSAC input data sets. CRASH3 issued a warning for RICSAC tests 1 and 11. EDCRASH made several consistency checks not made by CRASH2 or CRASH3, and, as a result, issued one or more diagnostic messages for 10 of the 12 cases (see Table 6). These diagnostics suggested improvements to the input which should improve the results.

Use of Graphics - The EDCRASH Impact Configurations graphics display revealed discrepancies in the impact positions used in the original RICSAC data sets. The damage centroids, which are an estimate of the location of the center of impulse, should approximately overlap. In some cases, however, the damage centroids were as much as 5 feet apart. Careful inspection of the original accident schematics [5,6,7] and the Impact Configurations display were used to relocate the vehicle positions at impact.

Use of Actual Vehicle Data - The data (dimensions, weights, moments of inertia and tire cornering stiffnesses) for each vehicle used in the original RICSAC study were supplied by the program automatically. This was achieved using a built-in table of typical parameters for a class of vehicle according to its wheelbase. The results displayed in Table 2 also used this procedure. For optimizing the results, the actual data, obtained from reference 7, were supplied to EDCRASH.

Include Induced Damage - Review of the original RICSAC data revealed that only contact damage was included in the damage profile, consistent with the then-current measurement protocol. Original crush measurements and photographs [5,6] were used in conjunction with the most recent protocol [20] to determine the damage profiles which included induced damage.

Use of Actual A and B Stiffness Coefficients - EDCRASH allowed the user to override CRASH's default A and B crush stiffness coefficients and supply the measured stiffness values for a particular vehicle. The values for the test vehicles were obtained from reference 21 and the manufacturers.

Based on the above information, changes were made to the original data sets (the optimized input data sets are available from the authors) and all 12 cases were rerun. The effect of optimizing the input data on program accuracy is shown in Table 7.

An analysis of the data in Table 7 was performed to assess the improvement due to optimization. The nine *non-trajectory simulation* scenarios which were used to evaluate the original test data were also used to evaluate the optimized data. The average error, standard deviation and 95 percent confidence interval for the optimized runs are shown in Table 8.

A scenario-by-scenario comparison of Table 5 and Table 8 revealed the improvements associated with optimization. All scenarios were improved by the optimization process. However, the greatest improvement was found for collinear collisions (compare scenarios 7, 9 and 11). This improvement was probably due to an improvement in the damage-based estimates for delta-V, caused by replacing the default stiffness coefficients with improved stiffness coefficients.

Trajectory Simulation Validation

A comparison of the measured results and program results in Tables 2 and 3 revealed the trajectory simulation significantly reduced program accuracy in 11 out of 12 RICSAC cases. Even if the trajectory simulation converged, there was a significant reduction in accuracy. This finding was unexpected, since the trajectory simulation had always been thought to improve the results.

Inspection of the raw RICSAC test data revealed the front wheels frequently were steered between impact and rest. However, the original RICSAC input data sets used a steer angle of zero degrees in all runs.

To test the possibility that omitting the steer angle was leading to the significant reduction of accuracy, RICSAC test no. 6 was rerun. This case was selected because it was typical of those tests which exhibited a marked reduction in accuracy when the trajectory simulation option was used (refer to Tables 2 and 3).

The average front wheel steer angle of each vehicle was estimated from the test data [6]. The true value for the steer angles of both vehicles varied between impact and rest. However, CRASH does not allow for this variation and constant steer angles were supplied. Vehicle 1 had an average steer angle of 4 degrees to the right; Vehicle 2 had an average steer angle of 8 degrees to the right.

EDCRASH was rerun with RICSAC 6 test data using the trajectory simulation option and the average steer angles. This single change improved the results significantly. The results are shown in Table 9. Neither vehicle's trajectory simulation converged. The fact that the original trajectory simulation for vehicle 2 converged after 3 runs, yet provided poor results suggests that convergence alone is not a good criterion for evaluating the quality of the results.

These initial findings suggest knowledge of the proper steer angles may be essential when the trajectory simulation option is selected. A thorough analysis of all the RICSAC cases including steer angles is recommended. Until then, the trajectory simulation option should be exercised with caution.

TABLE 7. Optimized EDCRASH results (*without* the trajectory simulation).

TEST No.	METHOD	IMPACT SPEED Veh #1 (mph)	Veh #2 (mph)	ERROR (combined speed) Veh #1 (mph)	(%)	Veh #2 (mph)	(%)
1	MEASURED	19.8	19.8				
	EDCRASH	20.2	22.7	0.4	1.0	2.9	7.3
2	MEASURED	31.5	31.5				
	EDCRASH	28.1	30.2	-3.4	5.4	-1.3	2.1
3	MEASURED	21.0	0.0				
	EDCRASH	20.2	2.3	-0.8	2.1	2.3	2.1
4	MEASURED	38.7	0.0				
	EDCRASH	38.7	0.8	0.0	5.7	0.8	6.2
5	MEASURED	39.7	0.0				
	EDCRASH	38.9	0.2	-0.8	2.4	0.2	5.0
6	MEASURED	21.5	21.5				
	EDCRASH	22.4	22.4	0.9	0.9	0.9	5.2
7	MEASURED	29.1	29.1				
	EDCRASH	25.8	32.7	-3.3	-4.2	3.6	2.6
8	MEASURED	20.8	20.8				
	EDCRASH	21.8	22.9	1.0	-3.8	2.1	11.0
9	MEASURED	21.2	21.2				
	EDCRASH	21.6	23.4	0.4	0.0	2.2	2.1
10	MEASURED	33.3	33.3				
	EDCRASH	30.5	35.0	-2.8	-2.0	1.7	0.5
11	MEASURED	20.4	20.4				
	EDCRASH	17.8	18.9	-2.6	-6.4	-1.5	-3.7
12	MEASURED	31.5	31.5				
	EDCRASH	20.5	32.0	-11.0	-17.5	0.5	0.8

TABLE 8. Confidence Interval for various scenarios (see Table 4) for optimized EDCRASH input. All results are expressed in percent of combined impact speed.

Scenario	Method	N*	Avg. Error	Std. Dev.	Confidence Interval
1	EDCRASH	24	-0.1	5.7	-2.5 to 2.4
3	EDCRASH	12	-3.2	5.5	-6.7 to 0.3
5	EDCRASH	12	3.1	4.1	0.5 to 5.7
7	EDCRASH	10	-1.9	7.2	-7.1 to 3.2
9	EDCRASH	5	-5.9	6.9	-14.4 to 2.6
11	EDCRASH	5	2.1	5.4	-4.6 to 8.8
13	EDCRASH	14	1.3	4.2	-1.2 to 3.7
15	EDCRASH	7	-1.3	3.6	-4.6 to 2.1
17	EDCRASH	7	3.8	3.2	0.8 to 6.7

*NOTE: *N* is the number of data points for each scenario.

TABLE 9. A comparison of trajectory simulation results for RICSAC test no. 6 *without* and *with* steer angles.

Method	Impact Speed (error)			
	Veh #1		Veh #2	
	(mph)	(%)	(mph)	(%)
Measured	*21.5*	*(N/A)*	*21.5*	*(N/A)*
EDCRASH w/o steer	*26.7*	*(12.1)*	*39.1*	*(40.9)*
EDCRASH w/ steer	*21.3*	*(-0.5)*	*25.3*	*(8.8)*

RICSAC test number 9 revealed an interesting result. Due to the previously-described errors in CRASH3 (see Differences in Results Between Programs), the separation velocity for vehicle 2 was computed incorrectly. In this case, the *first* set of separation velocities yielded the lowest error. However, when the proper separation velocities were computed, the *second* set of separation velocities had a slightly lower error score than the first set. Therefore, the second set was assumed to be better and was used. Because of the adjustments made by the trajectory simulation routine, this set also had a separation angle vastly different than the original set. Even though the separation velocities themselves were only slightly different, the change in angle caused a major change in the momentum calculations. The net effect can be seen in Table 2. A comparison of impact speed results for test number 9 reveals CRASH3 was much *closer* to the measured values than EDCRASH. The reason was not at all obvious: The trajectory simulation results for CRASH3 were rejected and the original separation velocities were used.

This finding suggested that trajectory simulation results should be compared closely with the non-simulation results. The user should be suspicious any time the difference is substantial.

EXAMPLE OF USE

The following example illustrates how the investigator can use the information developed in this paper to estimate the accuracy of a reconstruction. This case was an intersection collision.

Step 1 - Obtain good accident site and vehicle inspection data.

Step 2 - Reconstruct the accident. Use warning messages and graphics to optimize the input data. In this case, using EDCRASH without the trajectory simulation, the estimated speeds of vehicles 1 and 2 were 40 and 25 mph, respectively.

Step 3 - Compute the combined speed, in this case, 65 mph.

Step 4 - From Table 4, we find that oblique collisions without the trajectory simulation analysis fall into scenario 13, 15 or 17. If we do not wish to compare striking versus struck vehicle variations, we can select scenario 13.

Step 5 - From Table 8, we find the confidence interval for this scenario when using optimized input data is -1.2 to +3.7 percent of the combined impact speed. Thus, the lower range equates to

$$-0.012*65 = 0.78 \text{ mph}$$

The upper range is

$$0.037*65 = 2.4 \text{ mph}$$

Step 6 - The expected range for the speed of vehicle 1 (rounding to the nearest mph) is

$$40 \begin{cases} -1 = 39 \text{ mph} \\ \quad \textit{to} \\ +2 = 42 \text{ mph} \end{cases}$$

and for vehicle 2, the expected range is

$$25 \begin{cases} -1 = 24 \text{ mph} \\ \quad \textit{to} \\ +2 = 27 \text{ mph} \end{cases}$$

Thus, we are 95 percent confident the true speeds of the vehicles lie between these range of values.

DISCUSSION

The validation results described in this paper apply only to CRASH2, CRASH3, and EDCRASH. The results cannot be extended to similar programs without additional validation.

This paper addresses the accuracy of the CRASH technique. Another issue which is important, regardless of the technique, is the accuracy of the input data. The results described in this paper were obtained using a thorough accident site inspection immediately following the crash. Such excellent data are not often available for real world crashes unless an experienced investigator is on the scene and/or the scene is well documented with photographs.

Improving the results for oblique collisions by optimizing the scene data was not nearly as effective as improving the results for collinear collisions by optimizing the vehicle damage data and crush stiffness coefficients. As a corollary to this finding, optimizing the damage data and stiffness coefficients would have a negligible effect on the accuracy for oblique collisions because the results for oblique collisions are based on the scene data. The damage data are simply displayed as an additional cross-check of the results.

Even though optimizing the damage data was a very effective way to improve the results for collinear (rear-end and head-on) collisions, the optimized damage-based results were not as good as the results based on scene data.

Some of the oblique collisions (test numbers 1, 5, 6 and 7) produced over-ride damage on the struck vehicle. This caused several diagnostic messages from EDCRASH relating to differences in the damage-based and momentum-based delta-Vs. In the absence of good crush stiffness data for the side of a struck vehicle, it appeared that reducing the crush stiffnesses so as to equalize the magnitude of the principal force of the struck vehicle with that of the striking vehicle helped to reduce the difference between damage-based and momentum-based results. While this finding was academic for oblique collisions (the delta-Vs are based on scene data anyway), the procedure might be useful for the analysis of head-on and rear-end collisions involving over-ride. The optimized analysis of test number 5 (a rear-end collision in which the front of the striking Torino over-rode the rear of the struck Honda) suggested, but not conclusively, that this was the case.

When the results obtained in this paper are used by field accident investigators, the general scenario (i.e., scenario 1) should not be used to estimate the range of results. Rather, scenario 7, 9, or 11 should be used for collinear collisions and scenario 13, 15, or 17 should be used for oblique collisions.

A sensitivity analysis should always be performed as an additional means of estimating the final range of results. The methods described in this paper can be applied to the lowest and highest range from the sensitivity analysis to provide a conservative range of the overall speed estimate.

CONCLUSIONS

1. The CRASH program provided reasonable estimates for impact speed, with an expected accuracy better than 7 percent of the combined impact speed when compared to staged collisions.

2. When the input data were carefully optimized through the use of actual vehicle data, informative diagnostic messages and graphics, the expected accuracy of EDCRASH approached 3 percent of the combined impact speed.

3. The accuracy for oblique collisions was substantially better than for collinear collisions. Therefore, CRASH users should evaluate program accuracy according to collision type.

4. The trajectory simulation decreased the accuracy of the results.

5. Field accident investigators can use the results of this research to provide a 95 percent confidence interval on their results. Good accident site and vehicle inspection data are required to apply this data.

6. No general observations could be made using the RICSAC data analyzing the accuracy of the delta-V computed by any program because of measurement errors in the RICSAC test data.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. Nicholas S. Tumbas, Tumbas Associates, for preparing the CRASH3 runs, to Dr. Charles A. Moffatt, Indiana University, for documenting the history of the particular version of CRASH3 used in this paper, and to Dr. Eugene A. Enneking, Portland State University, for his assistance and suggestions regarding statistical analysis of the data.

REFERENCES

1. McHenry, R.R., "Extensions and Refinements of the CRASH Computer Program Part II, User's Manual for the CRASH Computer," NHTSA, DOT HS-801 838, February, 1986.

2. Noga, T., Oppenheim, T., "CRASH3 User's Guide and Technical Manual," NHTSA, DOT HS-805 732, Department of Transportation, April, 1982.

3. Day, T.D., Hargens, R.L., "EDCRASH Program Manual, Version 4," Engineering Dynamics Corporation, Lake Oswego, OR, 1986.

4. McHenry, R.R., Lynch, J.P., Segal, D.J., "Research Input for Computer Simulation of Automobile Collisions - Volume I - Development of a Data Bank," Calspan Corporation, DOT HS-805 037, June, 1977.

5. Shoemaker, N.E., "Research Input for Computer Simulation of Automobile Collisions - Volume II - Staged Collision Tests No. 1 Through No.5," Calspan Corporation, DOT HS-805 038, December, 1978.

6. Shoemaker, N.E., "Research Input for Computer Simulation of Automobile Collisions - Volume III - Staged Collision Tests No. 6 Through No.12," Calspan Corporation, DOT HS-805 039, December, 1978.

7. Jones, I.S., Baum, A.S., "Research Input for Computer Simulation of Automobile Collisions - Volume IV - Staged Collision Reconstructions," Calspan Corporation, DOT HS-805 040, December, 1978

8. Ricci, Leda L., "NCSS Statistics: Passenger Cars," DOT-HS-805-531, June, 1980.

9. *Fatal Accident Reporting System 1986*, DOT-HS-807-245, NHTSA, March, 1988.

10. *National Accident Sampling System: Accident Investigation Procedures Manual*, DOT, NHTSA, 1980.

11. "Standard Test Method for Measuring Skid Resistance of a Paved Surface Using a Full-scale Tire," Volume 4.03, *American Society for Testing and Materials, Standard E-274*-79, Philadelphia, PA, 1979.

12. Personal correspondence from Dr. Russell A. Smith, who performed research on CRASH while on staff at NHTSA.

13. Oppenheim, T., "CRASH2 Maintenance Volume II: Listings of Test Runs," Wilson Hill Associates, DOT HS-805-949, May, 1981.

14. Oppenheim, T., "CRASH2 Maintenance Volume I: Description of Results," Wilson Hill Associates, DOT HS-805-948, May, 1981.

15. Memorandum from NHTSA distributed to all CRASH3 users dated December 11, 1981, regarding CRASH3 coding changes, by Mr. Thomas Noga.

16. Day, T.D., Hargens, R.L., "Differences Between EDCRASH and CRASH3," SAE Paper No. 850253, Society of Automotive Engineers, Warrendale, PA, February, 1985.

17. Smith, R.A., Noga, T.J., "Accuracy and Sensitivity of CRASH," NHTSA, DOT HS-806 152, DOT, March, 1982.

18. Woolley, R.L., Warner, C.Y., Tagg, M.D., "Inaccuracies in the CRASH3 Program," SAE Paper No. 850255, Society of Automotive Engineers, Warrendale, PA, 1985.

19. *Probability and Statistics for Engineers and Scientists*, Walpole, R.E., Myers, R.H., Macmillan Publishing Co., Inc., New York, 1978.

20. Tumbas, N.S., Smith, R.A. "Measuring Protocol for Quantifying Vehicle Damage from an Energy Basis Point of View," SAE Paper No. 880072, Society of Automotive Engineers, Warrendale, PA, February, 1988.

21. Hargens, R.L., Day, T.D., "Vehicle Crush Stiffness Coefficients for Model Years 1970 - 1984, with Damage Profile Supplement," EDC Library Reference No. 1042, Engineering Dynamics Corporation, Lake Oswego, OR, 1987.

Printed in U.S.A.