

# THE USE OF COMPUTERS IN TRAFFIC ACCIDENT RECONSTRUCTION

Topic 892 of the *Traffic Accident Investigation Manual*

by  
Terry D. Day  
and Randall L. Hargens

1. Introduction .....	3
2. History .....	3
3. Program Types .....	4
4. Admissibility .....	18
5. Implementation .....	20
6. Summary .....	22
7. Sources .....	22

120739

NORTHWESTERN UNIVERSITY TRAFFIC INSTITUTE

## Topic 892

120739

**U.S. Department of Justice  
National Institute of Justice**

This document has been reproduced exactly as received from the person or organization originating it. Points of view or opinions stated in this document are those of the authors and do not necessarily represent the official position or policies of the National Institute of Justice.

Permission to reproduce this copyrighted material has been granted by

Northwestern University  
Traffic Institute

to the National Criminal Justice Reference Service (NCJRS).

Further reproduction outside of the NCJRS system requires permission of the copyright owner.

Copyright 1989 by the Northwestern University Traffic Institute  
P.O. Box 1409 Evanston, Illinois 60204

*All rights reserved. No part of this book may be reproduced in any form or by any electronic or mechanical means including photocopying, recording, or by any information storage and retrieval system, without permission in writing from the publisher.*

---

# THE USE OF COMPUTERS IN TRAFFIC ACCIDENT RECONSTRUCTION

Topic 892 of the *Traffic Accident Investigation Manual*

---

by  
Terry D. Day  
and Randall L. Hargens

1. Introduction .....	3
2. History .....	3
3. Program Types .....	4
4. Admissibility .....	18
5. Implementation .....	20
6. Summary .....	22
7. Sources .....	22

NORTHWESTERN UNIVERSITY TRAFFIC INSTITUTE

# THE USE OF COMPUTERS IN TRAFFIC ACCIDENT RECONSTRUCTION

## 1. INTRODUCTION

The use of computers has become of major importance to individuals in all walks of life, from balancing the family budget to providing control over the entire launch sequence of a space shuttle. It would seem logical, then, that computers could also be used to reconstruct motor vehicle crashes. Indeed, this is the case.

This topic describes the use of computers in accident reconstruction by practicing accident investigators: persons with a working knowledge of accident investigation and reconstruction. You already know how the equations of motion are applied to vehicular accident reconstruction. You want to benefit from the computer's speed and accuracy. Computers do not replace knowledge; they simply allow those who understand the analysis of motor vehicle crashes to analyze them more quickly and more thoroughly and, therefore, more accurately.

The purpose of this topic is to provide an overview of the use of computers in reconstructing motor vehicle crashes, to discuss various types of programs available (including illustrations), to discuss the admissibility of computer-generated results, and, finally, to describe the process of implementing computers in accident investigation.

## 2. HISTORY

Crashes are reconstructed for different reasons by different agencies. For example, the federal government reconstructs crashes for statistical purposes, to develop safety standards, and to perform or fund research on behalf of the general public. Vehicle manufacturers analyze crashes to help design safer vehicle structures and restraint systems. Insurance companies use consultants to reconstruct crashes to determine liability. And law enforcement personnel reconstruct crashes to determine if any laws were violated.

### Role of Government

As a result of the Federal Motor Vehicle Safety Act of 1966, the National Highway Traffic Safety Administration (NHTSA) was formed as a branch of the U.S. Department of Transportation. The main purpose of NHTSA was to determine how and why traffic accidents occur, and how to reduce

the associated death and injury. NHTSA approached its mission by suggesting a statistical study on a large number of accidents. To do this, a large database of accidents was needed, as well as tools to reconstruct these accidents.

In 1966, reconstruction tools for analyzing raw vehicle and accident site data were limited to lengthy calculations performed using a slide rule. No serious study could be performed unless large amounts of data could be analyzed quickly and consistently. Seeing this need, and recognizing the power and capability available in the recently developed digital computer, NHTSA contracted with Cornell Aeronautical Laboratory (now CALSPAN) to develop a suitable computer program. Under the leadership of Raymond McHenry at CALSPAN, several computer programs were developed. This work still stands as the cornerstone for most of the subsequent development in computer programs used for accident investigation.

Since the early seventies, accident statistics have been provided by several studies which use these programs, including the National Crash Severity Study (NCSS),<sup>1</sup> the Fatal Accident Reporting System (FARS),<sup>2</sup> and the National Accident Sampling System (NASS).<sup>3</sup> These studies have helped to shed light on the nation's leading cause of lost human productivity.

### Role of MVMA

At the same time NHTSA was developing new standards, vehicle manufacturers developed methods to meet those standards. Funded collectively through the Motor Vehicle Manufacturers Association (MVMA), the manufacturers developed several sophisticated computer programs used in crash research for passenger cars and heavy commercial vehicles. Most of these programs were developed at the University of Michigan Highway Safety Research Institute (now the University of Michigan Transportation Research Institute, or UMTRI).

### Role of the Courts

Legal reform during the sixties and seventies resulted in a large increase in civil actions between persons involved in traffic crashes. The need to describe to a jury how the crash occurred, especially in those crashes where there were no in-

dependent witnesses, brought about a new need for forensic scientists in the field of accident reconstruction. Lawyers were anxious to use the esoteric, computer-generated results as evidence, although courts usually required the expert witness to demonstrate an understanding of the program before allowing the results to be admitted as evidence. The subject of admissibility is discussed in more detail later in this topic.

### Role of Society

Social pressure also played a significant role in the use of computer programs by supporting the general need for accident reconstruction. Considerable public pressure has been placed on prosecuting attorneys to do something about the greatest single cause of death for people between the ages of two and 40: car crashes.<sup>4</sup> The fact that more than half of these deaths involved the abuse of alcohol brought about the desire to reduce these needless deaths by successfully convicting persons charged with vehicular homicide. Conviction not only required proof that the driver was legally drunk, but also that the driving behavior was extraordinarily impaired by the use of alcohol. This resulted in the need to understand the events surrounding the crash — that is, a good, clear accident reconstruction.

### Role of the Personal Computer

During the late seventies, the computer tools developed at CALSPAN and UMTRI saw widespread use by the federal government, universities, large research institutions, and a few large engineering firms. Using these programs was limited by one factor: they required a mainframe computer costing more than \$100,000.

This all changed when the first personal computer was introduced. As early as 1980, a mainframe program developed at CALSPAN was converted for use on an Apple computer.<sup>5</sup> However, the first major breakthrough in the development of these tools came about as the result of the introduction of the IBM PC in August 1981. This computer was the first to provide large program capacity in a PC environment. The development of PC versions of several mainframe computer programs soon followed.<sup>6</sup>

### Program Design

Computer programs have evolved. No longer does a program user need to be a trained computer scientist. No longer does the user have to create the input data using a key punch or general purpose editor.

Today's computer programs provide simple, question-and-answer-oriented and menu-driven input methods with "help" keys and other ways of simplifying them for accident investigation. Compatibility ("My old programs don't work with my new computer!") is no longer a problem, because today's programs can usually work well with various types of computer hardware. Most programs also allow you to save working files for future use or modification — you don't have to start over.

### Graphics

The ability to produce graphic images (a pictorial representation) from the results significantly enhances the use of computer programs. Many programs are designed for both graphic input and graphic output. Most of today's programs also reproduce high-resolution, color drawings that can be printed or plotted on most standard computer hardware.

### Documentation

An instruction or user's manual describes how to use the program on a particular computer, usually by way of input and output examples and a tutorial section. Some programs include a brief section on theory, although most refer the user to a separate technical reference.

## 3. PROGRAM TYPES

Reconstructionists now use the computer to perform many types of analyses, ranging from simple to extremely complex calculations that previously required several hours. Many of these calculations were not even possible before the computer became available. Computers are also being used for new purposes never envisioned a short time ago, such as drawing accident sites and obtaining scaled accident site dimensions from photographs. This section of the topic describes several different types of these useful computer programs. Computer programs may be broadly categorized into two types:

- General Calculation Programs
- Sophisticated Analysis Programs

### General Calculation Programs

This section of the topic describes a type of computer program that performs general physics calculations easily done by hand. The primary reason for using these programs is their ability to perform these important calculations with speed and accuracy. The equations used by these programs are usually found in the documentation accompanying the program and will not be presented here. Some of the more important calculations are listed below:

*CG Location.* Compute the longitudinal, lateral, and vertical elevation of the center of gravity (CG) from wheelbase, track width, and weight distribution (elevation requires the front of the vehicle to be lifted to a known height).

*Path Radius.* Curve data (radius, tangent offset) when field measurements are available.

*Coefficient of Friction.* Tire/road friction values from test data (vehicle weight and weight distribution, pull force).

*Kinematics (distance, velocity and acceleration versus time).* General equations of motion for skidding vehicles [velocity when skid distance and drag factor are known, acceleration when velocity, distance and time are known, distance traveled when velocity and time are known (and other rearrangements of these formulas), and critical speed in curves when path radius and drag factor are known].

**Flips/Vaults.** General equations for airborne vehicles (velocity when grade and distances are known).

**Energy.** General equations based on the conservation of energy (kinetic energy when velocity and weight are known, skid energy when weight, drag factor and skid distance are known).

**Momentum.** General equations based on the conservation of linear momentum (impact velocities when separation velocities and path directions are known).

The following example illustrates the use of these programs.

### Example 1 - Speed from Skidmarks

A moving vehicle struck a pedestrian. The at-scene investigators measured 105 feet of skidmarks before impact and 35 feet after impact. Then, using a similar car with an accelerometer, a drag factor of 0.72 was obtained when the test car was skidded. The reconstruction required knowledge of the speed before braking and the impact speed. Given 35 feet of post-impact skidmarks and  $f=0.72$ , the impact speed equals 27.61 mi/hr, or 41.2 ft/sec (see Exhibit 1). Next, the deceleration rate (0.72 g, equivalent to  $-23.2$  ft/sec<sup>2</sup>), impact velocity (41.2 ft/sec), and pre-impact skid distance (105 ft) were used to determine the speed at the beginning of braking. As shown in Exhibit 2, the car was traveling 81.05 ft/sec (55 mi/hr) when the driver first applied the brakes.

This type of program can also determine the length of time the vehicle skidded before impact. Given the pre-braking speed (81 ft/sec), the impact speed (41 ft/sec) and the deceleration rate ( $-23.2$  ft/sec<sup>2</sup>), the vehicle skidded for 1.72 seconds before impact (see Exhibit 3). Finally, if the driver's perception/reaction time is assumed to be 1.5 seconds, the pre-braking speed (81 ft/sec) can be used to determine where the driver's vehicle was located when he perceived a need to react. As shown in Exhibit 4, this location was about 121 feet before the location where the skidding was first observed, or about 226 (121 + 105) feet before impact.

Although these calculations could be done quite easily on a hand-held calculator, the computer program has provided the benefit of an organized, question-answer format to the process, greatly minimizing the chance for error. The results can also be printed for file documentation.

As with any analysis method, you need to understand the equations to properly apply them. When properly applied, these programs are an invaluable tool.

### Sophisticated Analysis Programs

Many of the computer programs developed under federal sponsorship at CALSPAN and UMTRI have been significantly refined and enhanced and are now available for use by the general accident reconstruction community. These programs can no longer be considered as a calculation, but rather as a series of calculations. Therefore, they are termed *analysis programs*. Because of the number of individual cal-

COMPUTER-AIDED TRAFFIC ACCIDENT INVESTIGATION  
THE TRAFFIC INSTITUTE, NORTHWESTERN UNIVERSITY

OPTION 6-7: SPEED FROM SKID MARKS

REFERENCE EQUATION NUMBER: 6-7

MEASURE: ENGLISH

ENTER SKID DISTANCE (FT): 35

ENTER COEFFICIENT OF FRICTION: .72

MINIMUM VELOCITY AT BEGINNING OF SKID (MPH): 27.61

ANOTHER RUN (Y/N):

F1: CANCEL F2: MAIN MENU SHFT-PRTS

*Exhibit 1. Output from a general calculation program. This example illustrates the calculation of speed from skidmarks.*

COMPUTER-AIDED TRAFFIC ACCIDENT INVESTIGATION  
THE TRAFFIC INSTITUTE, NORTHWESTERN UNIVERSITY

OPTION 6-5: INITIAL VELOCITY WHEN ACCELERATION RATE, END VELOCITY,  
AND DISTANCE ARE KNOWN

REFERENCE EQUATION NUMBER: 6-5

MEASURE: ENGLISH

ENTER ACCELERATION RATE (FT/SEC/SEC): -23.2

ENTER END VELOCITY (FT/SEC): 41.2

ENTER DISTANCE (FT): 105

INITIAL VELOCITY (FT/SEC): 81.05

ANOTHER RUN (Y/N):

F1: CANCEL F2: MAIN MENU SHFT-PRTS

*Exhibit 2. Output from a general calculation program, initial velocity based on impact velocity, deceleration rate, and skid distance.*

COMPUTER-AIDED TRAFFIC ACCIDENT INVESTIGATION  
THE TRAFFIC INSTITUTE, NORTHWESTERN UNIVERSITY

OPTION 7-1: TIME REQUIRED WHEN ACCELERATION RATE, INITIAL VELOCITY,  
AND END VELOCITY ARE KNOWN

REFERENCE EQUATION NUMBER: 7-1

MEASURE: ENGLISH

ENTER ACCELERATION RATE (FT/SEC/SEC): -23.2

ENTER INITIAL VELOCITY (FT/SEC): 81

ENTER END VELOCITY (FT/SEC): 41

TIME (SEC): 1.72

ANOTHER RUN (Y/N):

F1: CANCEL F2: MAIN MENU SHFT-PRTS

*Exhibit 3. Output from a general calculation program, calculating the skidding time from deceleration rate and initial and final speeds.*

COMPUTER-AIDED TRAFFIC ACCIDENT INVESTIGATION  
THE TRAFFIC INSTITUTE, NORTHWESTERN UNIVERSITY

OPTION 5-4: DISTANCE TRAVELED WHEN CONSTANT VELOCITY AND TIME ARE KNOWN

REFERENCE EQUATION NUMBER: 5-4

MEASURE: ENGLISH

ENTER CONSTANT VELOCITY (FT/SEC): 81

ENTER TIME (SEC): 1.5

DISTANCE (FT) TRAVELED: 121.50

ANOTHER RUN (Y/N):

F1: CANCEL F2: MAIN MENU SHFT-PRTS

*Exhibit 4. Output from a general calculation program, showing the distance traveled during the perception/reaction phase before braking.*

culations and the amount of built-in flexibility and sophistication, these programs usually go beyond what is practical to perform on a hand-held calculator. However, each of these programs was developed using laws of physics according to well-established engineering principles. Many have also been validated by staged collision studies.

These techniques generally lend themselves to graphics, and are capable of producing drawings as well as numeric results. The graphics are particularly useful because the accident investigator frequently must present his results to lay persons. Graphics also assist the investigator by uncovering facts that might otherwise remain buried in the wealth of data produced by the program.

This section of the topic describes some of the sophisticated analysis programs available to accident investigators.

**HVOSM.** The HVOSM (Highway-Vehicle-Object Simulation Model) computer program was the first of several programs developed under federal sponsorship by R.R. McHenry at CALSPAN.<sup>8-10</sup> HVOSM can be used to simulate the three-dimensional motion of a four-wheeled vehicle. Two versions of the program were developed: a roadside design version (HVOSM-RD) and a vehicle dynamics version (HVOSM-VD).

HVOSM is used to study how vehicles interact with highway medians, barriers, and other objects (roadside design version) and to study the complicated interaction between the vehicle and its driver (vehicle dynamics version). It remains the only validated computer program capable of analyzing a car which is simultaneously rolling, pitching and yawing, and traveling on an unlevel surface. It is also the only program which can correctly simulate the flight of an airborne vehicle. All this power comes at a great expense, however. HVOSM is a huge mainframe program (not currently available for use on a personal computer) and requires a huge amount of input data describing the vehicle and road. It also calls for considerable technical and computer expertise. As a result of its complexity and the frequent lack of all the necessary input data, it is not used routinely for accident reconstruction, but as a general research tool. An interesting example of the use of HVOSM follows.

### Example 2 – Simulating a Stunt

In the James Bond movie *Man with the Golden Gun*, the vehicle Mr. Bond was driving was to be launched airborne during a chase scene. While traveling at high speed, the vehicle was to roll 360 degrees, return to earth, and continue the chase. Instead of using trial and error (at the expense of several stunt drivers and cars), the producers used a computer simulation to determine where to place the ramps, what the ramp angle should be, and how fast the car was to be driven. HVOSM was used to simulate the stunt, and by varying the simulated ramp positions and angles, they were able to determine the correct speed (see Exhibit 5). Back at the movie set, the ramps were placed at the specified locations (strategically behind bushes) and the stunt was properly performed in

### COMPUTER PREDICTION

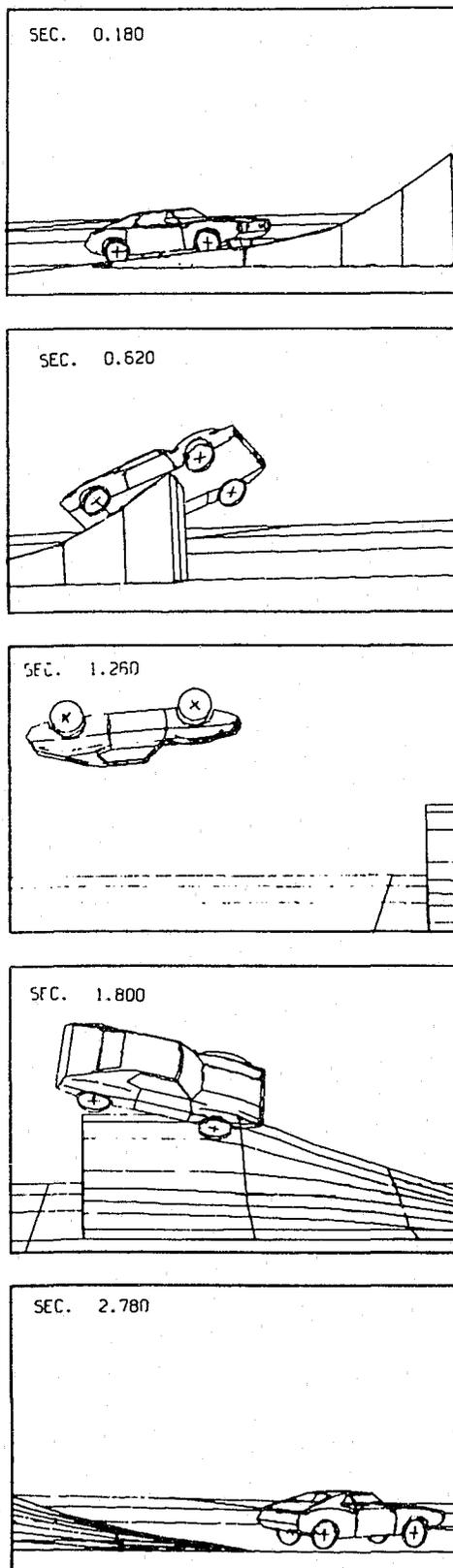


Exhibit 5. Simulating a stunt using HVOSM.<sup>10</sup>

one take. This example does not relate directly to accident reconstruction, but it does illustrate the power of a validated computer simulation.

**SMAC.** The SMAC (Simulation Model of Automobile Collisions) computer program was developed following HVOSM, again by McHenry while at CALSPAN.<sup>11-15</sup> A PC version of SMAC is available.<sup>16</sup> The SMAC program is used to simulate two-car collisions. It starts with the user's estimates of vehicle speed and position at impact. Based on these initial conditions, SMAC predicts the outcome of the accident — that is, where the vehicles should come to rest and what the vehicle damage pattern should look like.

Unlike HVOSM, the SMAC program cannot be used to study rollover accidents. Like HVOSM, however, the SMAC program produces a time-history of the vehicle motion from the initial conditions until the vehicle comes to rest, making it very useful for animation. You can use SMAC to determine how an accident may have occurred. By repeated adjustments of the initial speeds and directions, you will converge on those which best match the known accident site evidence (rest positions and vehicle damage).

A useful feature of SMAC is the ability to test various possible accident scenarios. This is called a "what-if" analysis. Different impact speeds can be tested and changed to assess the effect on the outcome of the accident. The following example illustrates this application.

### Example 3 – Are Witnesses Telling the Truth?

A vehicle was at a stop sign when it was struck from the rear by another vehicle. The four occupants in the struck vehicle, all reportedly seriously injured, stated the other vehicle was traveling at least 40 mi/hr when their vehicle was struck. The vehicles are shown in Exhibits 6 and 7.

SMAC will be used to test the theory that the striking vehicle was traveling 40 mph at impact. The impact positions for both vehicles are selected to provide the proper damage overlap between vehicles. The impact speeds for the struck vehicle (#1) and striking vehicle (#2) are entered as 0 and 40 mi/hr, respectively.

The SMAC results in graphic form are shown in Exhibits 8 and 9. Comparison of the large amount of predicted damage with the small amount of actual damage strongly suggests the impact speed was much slower. The distance the struck vehicle traveled after impact (55 ft simulated versus 22 ft actual) also supports this conclusion. Based on these results, the investigator concluded that the witnesses were not telling the truth!

The SMAC program was originally intended for use as a statistical analysis tool by various NHTSA crash injury studies.<sup>3</sup> However, as a simulation program, SMAC requires estimates of the vehicles' impact speeds. The source of this information was witness statements, or trial and error by the investigator. However, NHTSA soon found these methods were too time-consuming. NHTSA returned to CALSPAN



*Exhibit 6. Photograph of Vehicle #1, a Datsun 210, struck in the rear. Damage was relatively minor.*



*Exhibit 7. Photograph of front of Vehicle #2, a Renault Medallion, which struck the rear of Vehicle #1 (see Exhibit 6).*

requesting a computer program to provide initial speed estimates for SMAC. As a result, CALSPAN developed the CRASH program.

**CRASH.** The CRASH (CALSPAN Reconstruction of Accident Speeds on the Highway) computer program was the third major program developed at CALSPAN under federal sponsorship.<sup>17-20</sup> A PC version of this program is also available.<sup>21</sup> Originally, the CRASH program grew out of the need to provide impact speed estimates for the SMAC program.

The CRASH program is used to reconstruct single- and two-vehicle accidents. The program determines the impact speeds and severity of impact, using information obtained from accident site and vehicle inspections.

The output from CRASH depends on the amount of information supplied. The minimum amount of information is the vehicle weights and a description of vehicle damage, or *damage profile*.

Based on these results alone, CRASH will estimate the severity of impact by computing a quantity called the speed change, or *delta-V* (change in occupant compartment velocity

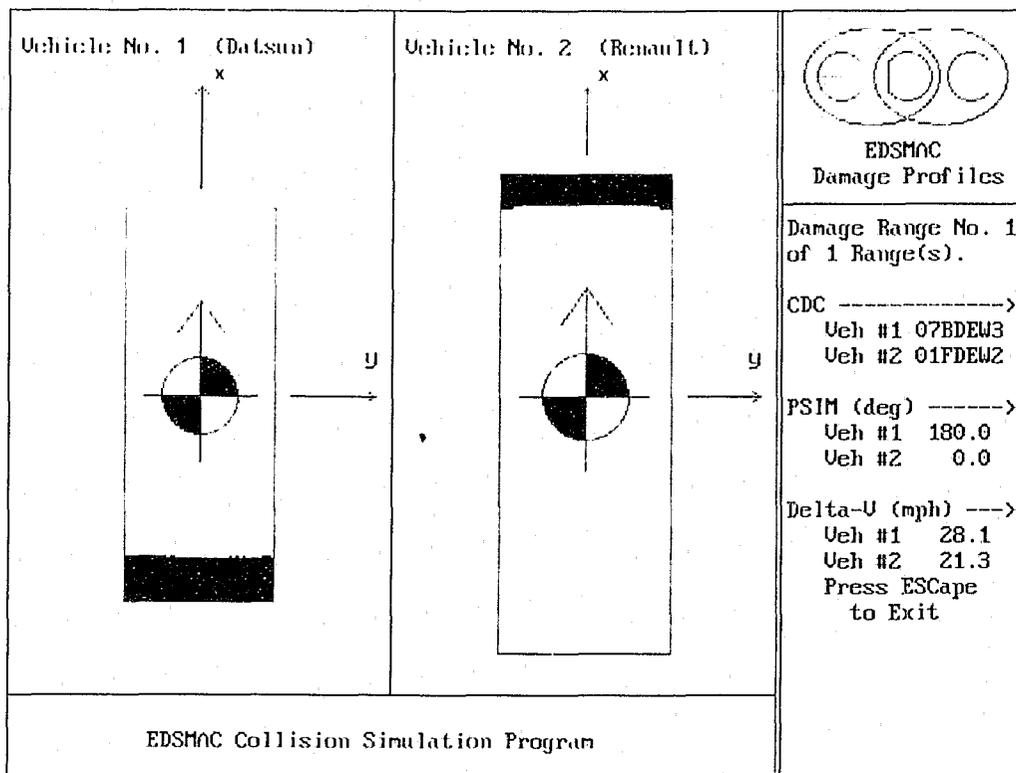


Exhibit 8. Damage profiles simulated by SMAC program,<sup>16</sup> illustrating what damage would be expected from a 40 mi/hr impact with a stationary vehicle. Comparison with the actual damage (see Exhibits 6 and 7) suggests the impact speed was much lower than 40 mi/hr.

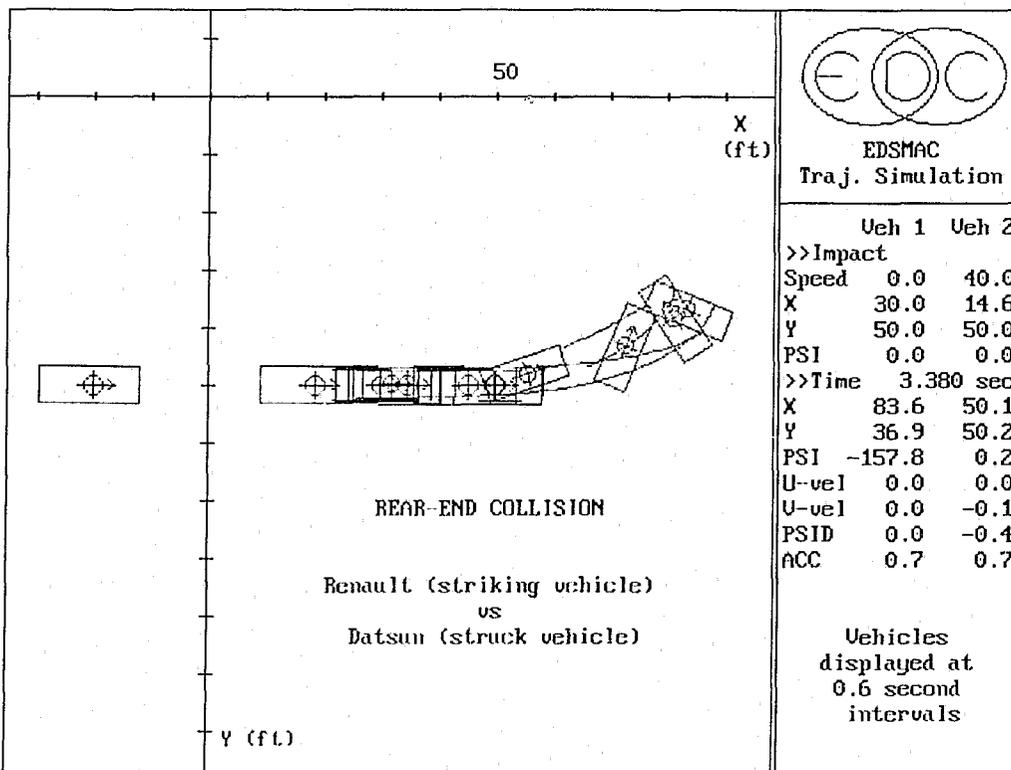


Exhibit 9. Vehicle trajectories simulated by SMAC,<sup>16</sup> illustrating how far the vehicles would be expected to travel after a 40 mi/hr impact with a stationary vehicle. Comparison of these post-impact path lengths (55 and 35 ft for Vehicles 1 and 2, respectively) with the actual path lengths (22 and 20 ft) suggests the impact speed was much lower than 40 mi/hr.

## SUMMARY OF RESULTS

## IMPACT SPEED (TRAJECTORY AND DAMAGE)

	TOTAL	FWD.	LAT.	SIDESLIP
VEH #1	0.2 mph	0.2 mph	0.0 mph	0.0 deg
VEH #2	22.1 mph	22.1 mph	0.0 mph	0.0 deg

## SPEED CHANGE (DAMAGE)

	TOTAL	LONG.	LAT.	PDOF
VEH #1	14.2 mph	14.2 mph	-0.0 mph	180.0 deg
VEH #2	10.2 mph	-10.2 mph	0.0 mph	0.0 deg

ENERGY DISSIPATED BY DAMAGE: VEH #1 17299.8 ft-lb VEH #2 17918.8 ft-lb

ENTER: ESCape Home End or <RETURN>

*Exhibit 10. Output from CRASH program,<sup>21</sup> showing the impact speeds and delta-V's (speed changes) during the rear-end collision. Note the speed of the struck vehicle is estimated at 0.2 mi/hr, very close to the known speed.*

during the impact phase, also approximately the speed at which an unbelted occupant strikes the vehicle interior).<sup>22,23</sup> If accident site measurements (impact and rest positions) and friction values are supplied, CRASH will compute the impact speeds.

For most types of collisions, CRASH uses two independent methods of analysis. One method is based on the damage profile, the other on linear momentum (if accident site measurements are supplied). Because the two methods are independent, the two results can be compared for consistency. This is normally done via built-in warning messages.

The following example illustrates the use of CRASH.

#### Example 4 – Impact Speed Estimates

This example is a continuation of Example 3. CRASH will be used to estimate the actual speeds of the vehicles involved in the rear-end collision (note that if the results are perfect, the speed computed for the struck vehicle should be exactly zero mi/hr; thus, we have a way to cross-check our results).

This reconstruction requires the vehicle weights, impact and rest positions, the drag factor, and damage profiles. After entering these data, the results for impact speed and speed change (delta-V is synonymous with speed change) are displayed (see Exhibit 10).

The graphic results can also be displayed (see Exhibits 11, 12 and 13). The CRASH analysis reveals the impact speed of the striking vehicle was 22 mi/hr. Note that the speed of the struck vehicle is estimated by CRASH to be 0.2 mi/hr, very close to the known speed, zero mi/hr.

**TBST/TBSTT.** The TBST and TBSTT (Truck Braking and Steering) programs were developed at the UMTRI by a group of researchers headed by H. Moncartz under sponsorship by the MVMA.<sup>24,25</sup> TBST is a single-vehicle simulator (SVS) and TBSTT is a vehicle-trailer simulator (VTS). PC versions of both of these programs are available.<sup>26,27</sup>

These computer simulation programs are useful for studying the response of a vehicle to braking and steering efforts by the driver.

Although originally developed for studying commercial vehicles, these programs are applicable for studying passenger cars as well. Accident investigators can use these simulation programs to determine how a driver may have lost control of his vehicle as a result of excessive speed, braking, over-correction, and other driver-related errors. By repeated adjustments of the braking and steering input tables, the path of the simulated vehicle will begin to match the accident site evidence. The final result is obtained when a satisfactory match is achieved. These programs can also be used to study the handling effects due to changes in friction, weight distribution, wheelbase, track width, CG height, and other parameters. The following examples illustrate typical program applications.

#### Example 5 – Simulating Loss of Control

A late-model passenger car with normal handling characteristics has been simulated. The simulation will show how this typical vehicle can spin out in a turn if the rear tires are under-inflated. Low inflation pressure affects a tire's corner-

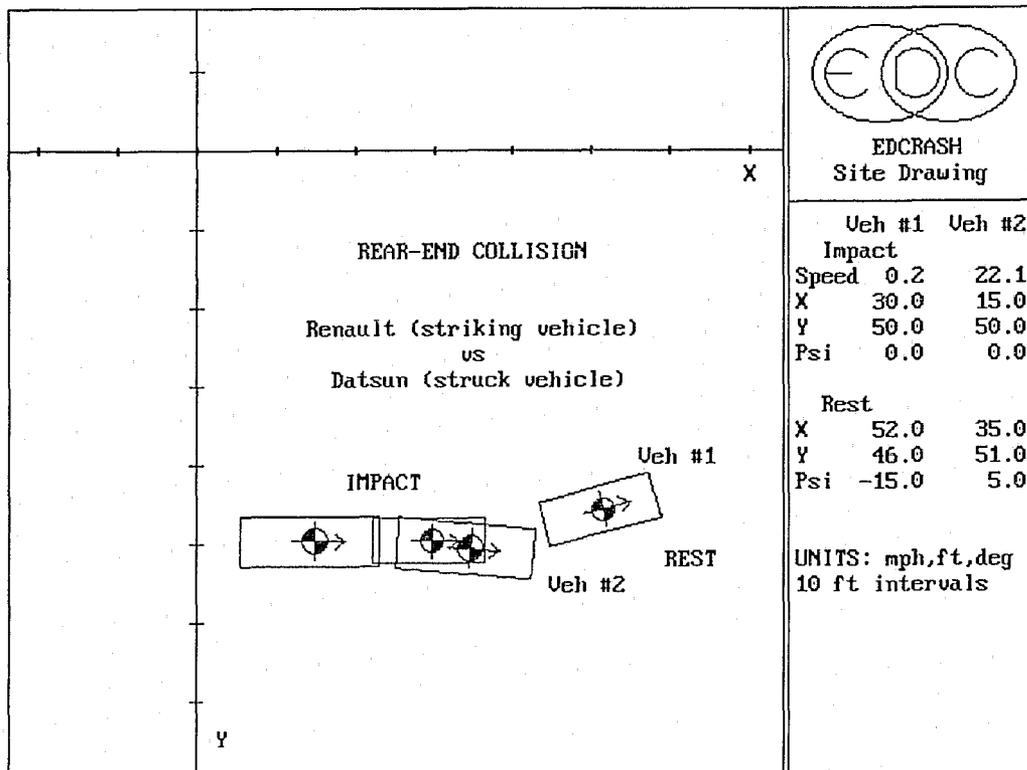


Exhibit 11. CRASH site drawing.<sup>21</sup> This graphic shows the vehicles at their impact and rest positions. Pertinent data, including impact speed, are displayed to the right.

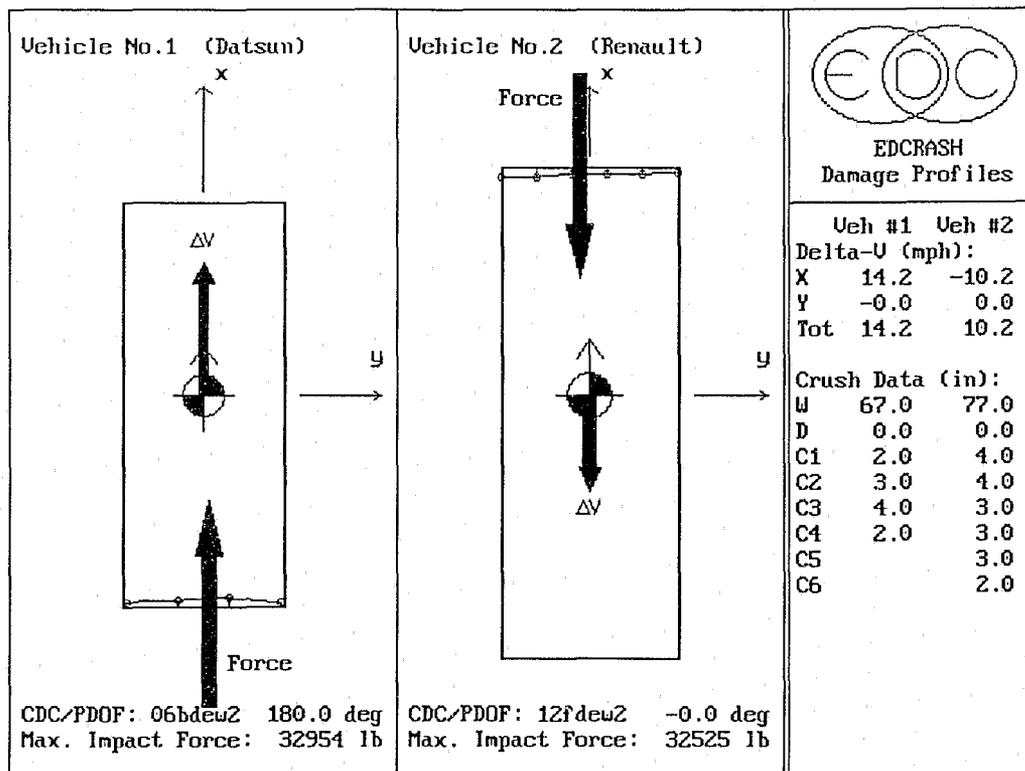


Exhibit 12. Vehicle damage profiles and principal directions of force (PDOF) from CRASH program.<sup>21</sup> These damage profiles are scaled from the actual crush measurements. Compare these actual profiles with those which would be expected from the 40 mi/hr collision, simulated in Exhibit 8.

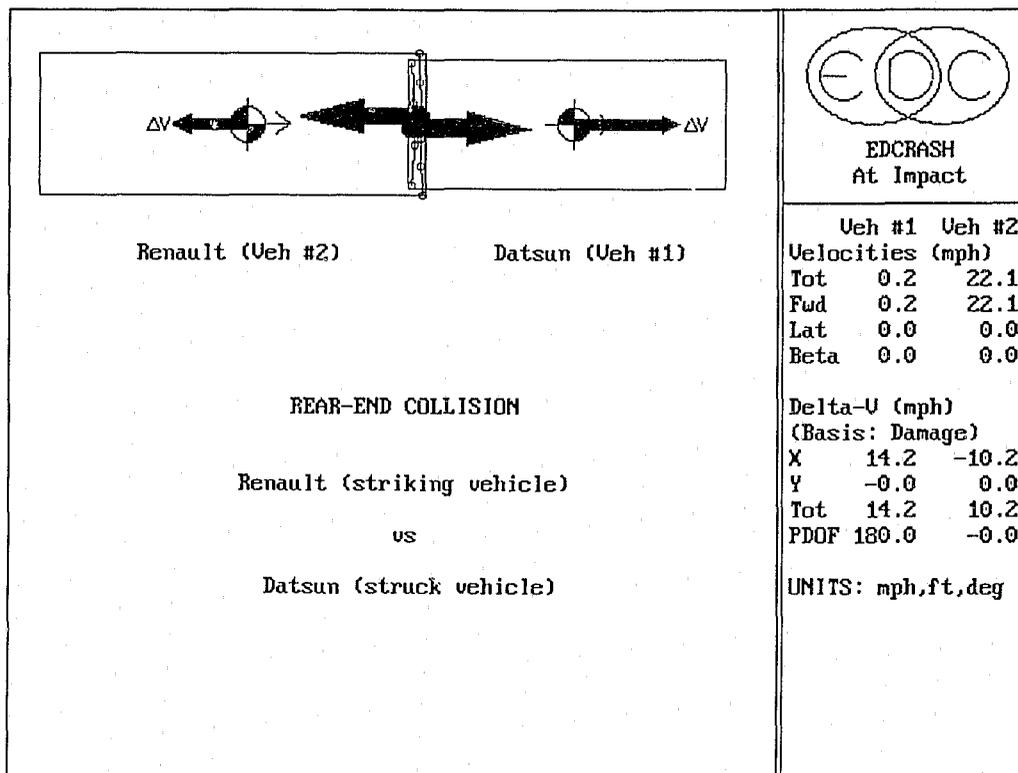


Exhibit 13. CRASH results showing the configuration at impact.<sup>21</sup> Speeds are also displayed, along with the basis for results (damage).

	R/F	L/F	R/R	L/R
Normal	131	131	121	121
Reduced	131	131	90	90

Exhibit 14. Tire cornering stiffness (lb/deg) for normal and reduced inflation pressure.

ing stiffness. The tire data for the run with normal inflation pressure and low inflation pressure are shown in Exhibit 14.

All the remaining vehicle data are loaded by the program automatically, according to the vehicle's wheelbase. The only remaining data are the wheel force and steer tables. In this example, the driver had entered a curve too fast and braked moderately, attempting to slow down. The resulting driver input table is shown in Exhibit 15. The program output is both numeric and graphic. Exhibit 16 shows the path taken by the normal vehicle, while Exhibit 17 shows the path taken by the vehicle with under-inflated rear tires. A comparison of Exhibits 16 and 17 clearly shows how under-inflation can cause a vehicle to lose control in a curve.

Similar investigations can be conducted for a tractor-trailer vehicle or a passenger car pulling a trailer. The following example illustrates a potential handling problem for a passenger car and trailer combination.

Time (sec)	Wheel Force(lb)				Steer Angle (deg)
	R/F	L/F	R/R	L/R	
0.0	0	0	0	0	1.25
1.2	0	0	0	0	
1.3	-384	-384	-256	-256	

Exhibit 15. Driver braking and steering vs. time for vehicle negotiating a 375 ft radius curve.

### Example 6 – Simulating an Over-braked Trailer

In this example, a passenger car is pulling a trailer. The heavy-duty trailer is lightly loaded. The simulation illustrates how trailer brakes, which must be designed to stop the trailer when it is fully loaded, can cause the trailer to skid when it is empty (this is a classic design conflict).

All the vehicle data are loaded automatically, according to the vehicle's wheelbase. The trailer dimensions are added separately. Then, the wheel force and steer tables are entered (see Exhibit 18).

The resulting vehicle path is shown graphically in Exhibit 19. Note that when the trailer begins to skid, it loses directional control and begins to slide wide in the curve. This, in turn, pulls the back end of the tow vehicle around. This serious condition will inevitably end up in an accident, regardless of the driver's attempt to regain control of the vehicle by any combination of braking and steering.

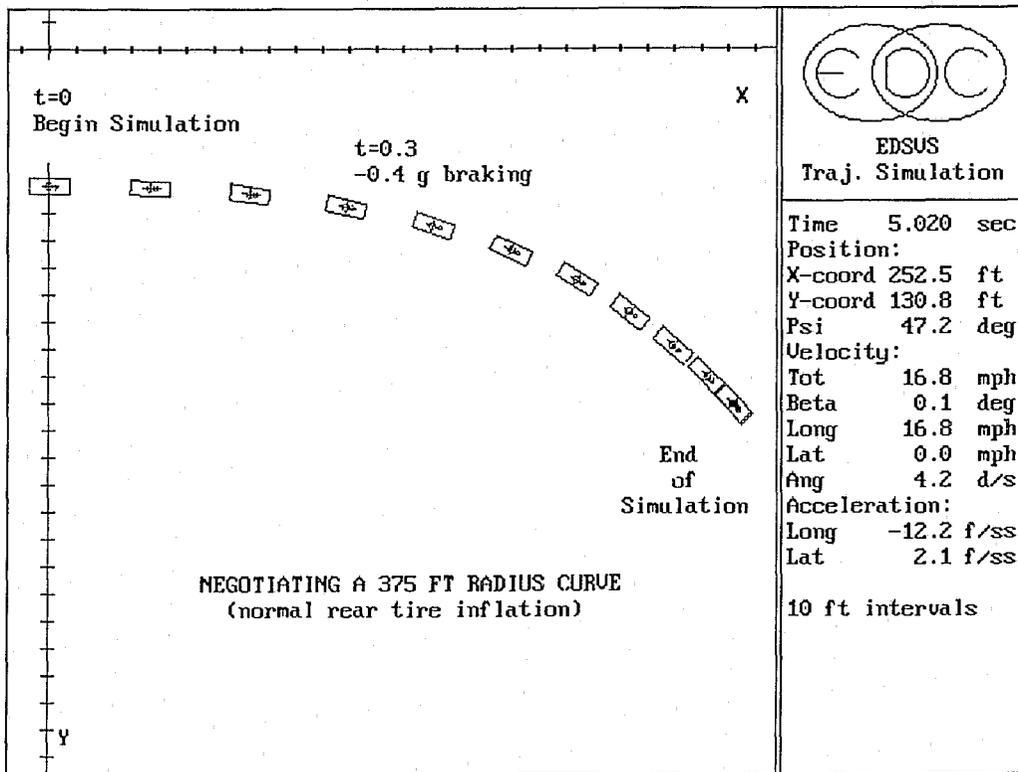


Exhibit 16. Results from single vehicle simulator program<sup>26</sup> showing the vehicle successfully negotiating the curve.

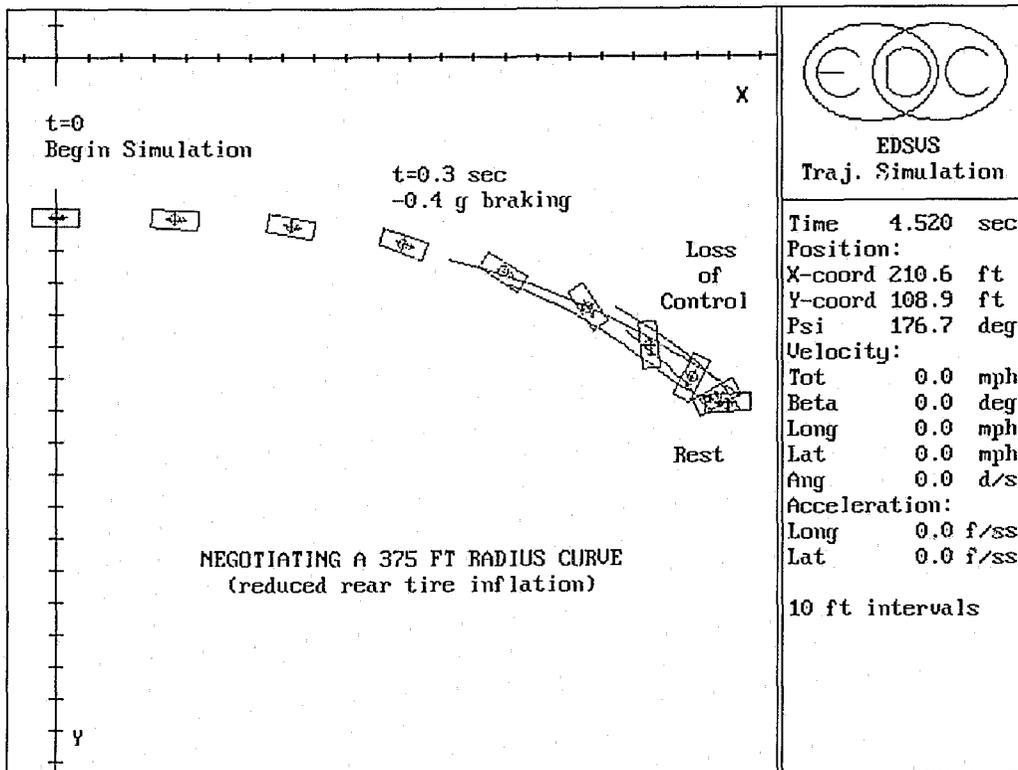


Exhibit 17. Results from SVS program<sup>26</sup> showing the vehicle with low rear-tire inflation pressure losing control in the curve.

Time (sec)	Wheel Force (lb)						Steer Angle (sec) (deg)	
	R/F	L/F	R/R	L/R	R/T	L/T	(sec)	(deg)
0.0	0	0	0	0	0	0	0	0
0.025	-310	-310	-155	-155	0	0	.5	10
0.040	-490	-490	-250	-390	-200	-200		
0.050	-540	-540	-280	-400	-350	-350		
0.060	-545	-545	-300	-390	-440	-440		
0.075	-540	-540	-320	-390	-440	-440		
0.100	-530	-530	-350	-390	-440	-440		
0.150	-530	-530	-380	-390	-440	-440		

Exhibit 18. Driver braking and steering vs. time for passenger car pulling a trailer while braking in a curve.

**IMPAC.** The IMPAC (Impact Momentum of a Planar Angled Collision) program was developed by Collision Safety Engineering.<sup>28,29</sup> It can be used to reconstruct the impact phase of a two-car collision using the conservation of linear and angular momentum. A PC version of IMPAC is available.

IMPAC requires scene data (position and orientation at impact, estimate of initial velocities) and uses this information

to compute the separation velocity. The best solution is obtained by adjusting the initial velocities until the separation velocities match the target velocities obtained from an independent analysis, such as a single-vehicle simulator<sup>26</sup> or general analysis program.<sup>7</sup>

The following example illustrates the use of IMPAC in an angled collision.

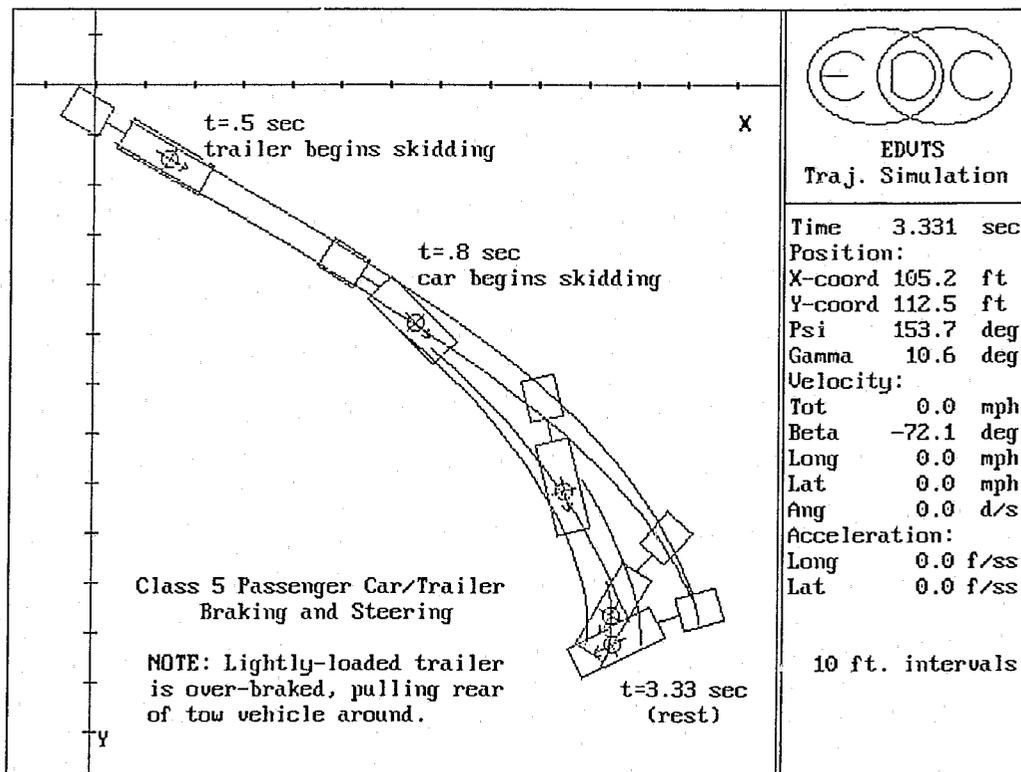


Exhibit 19. Results from vehicle/trailer simulator program<sup>27</sup> showing the trajectory of the passenger car pulling a trailer as it attempts to negotiate a curve while applying the brakes. Note how the trailer wheels begin to slide, then pull the rear of the tow vehicle around, causing it to lose control.

	"Target" Post-Impact Conditions	
	Vel (mph)	Ang (deg)
Veh A	22	0
Veh B	16	19

Exhibit 20. Estimated separation velocities and angles.

### Example 7 – Computing Impact Speed from Scene Data

In this example, the separation velocities were estimated from the skid-to-rest paths for each vehicle using one of the general programs described earlier. Next, the separation angles were estimated from scene measurements transferred to a scaled accident site diagram.<sup>41</sup> These target post-impact conditions are displayed in Exhibit 20. Finally, several trial sets of impact speed estimates for both vehicles were entered until a set resulting in the target separation velocities and angles was obtained. As shown in Exhibit 21, these impact speeds for vehicles A and B were 48 and 26 mi/hr, respectively.

### Photogrammetry

Photogrammetry is defined as the use of photographs in making maps. The process involves transforming dimensions scaled directly in a photograph to the actual dimensions of the objects or scenery portrayed in the photograph.

Photogrammetry is extremely useful in accident investigation because it allows you to locate information, particularly skidmarks and debris visible in accident site photographs but not measured at the time of the accident.

The following example illustrates the use of computerized photogrammetry.

### Example 8 – Locating Accident Site Skidmarks

In this example, a set of skidmarks was found at the accident site, believed to have been caused by one of the vehicles involved. The skidmarks were not measured at the time of the accident, so their locations and lengths were unknown. However, a good-quality photograph clearly showed them, along with four points which were measured (see Exhibit 22).

The first step in locating the skidmarks is to identify four points in the photograph whose X,Y coordinates *were* (or can be) measured. These points, called *calibration points*, are shown in Exhibit 23. Next, the photographic coordinates of each calibration point are determined by measuring them directly off the photograph shown in Exhibit 22. The resulting photographic coordinates for each calibration point are also shown in Exhibit 23.

The calibration points and their matching photographic coordinates are fed into the photogrammetry program, labeled as points REF1, REF2, REF3, and REF4 (see Exhibit 24).

The photogrammetry program uses these points to calculate a special matrix, called a *transformation* matrix. This matrix has a very important property: when it is multiplied by a new set of photographic coordinates (in this example, the start and end coordinates of the skidmark), it will calculate the actual accident-site X,Y coordinates of the skidmark!

The next step is to measure the photograph to determine the coordinates at the start and end of the skidmarks. Once these points are entered, the program calculates the actual coordinates, in feet, for the skidmarks. For reference, these points have been labeled SKID1 through SKID6 (see Exhibit 24). Because we now know where the skidmarks begin and end, we can draw them on our scaled accident site diagram. These skidmarks, in turn, can be used for further analysis and reconstruction of the accident.

### Other Sophisticated Programs

Several other programs have also been developed. Although not currently in widespread use by accident reconstructionists, many are powerful tools, and commercially available versions are under development. These programs are described below.

**PHASE4.** The Phase4 program is the culmination of a major effort undertaken at the University of Michigan.<sup>31</sup> This program is a vehicle dynamics simulator (VDS) used to simulate the response of a single vehicle or vehicle-trailer combination (up to triples) to driver braking and steering. The program has very elaborate methods for studying tires, suspensions, and anti-lock braking systems. It also requires a substantial amount of input data. Because the simulated vehicle is not constrained to a flat highway, the program is well suited to analyses beyond the scope of simpler programs. Such applications include the study of truck rollovers at highway off-ramps having a grade, super-elevation, and spiral curve.

**EES-ARM.** The EES-ARM (Equivalent Energy Speed Accident Reconstruction Method) program was developed by Daimler-Benz and is used by European accident investigators. It employs a combination of conservation of energy and linear and angular momentum to reconstruct the impact phase of a crash. The post-impact phase must be handled separately; it has been described in the literature,<sup>35,36</sup> but applications in North America are not common.

**Human Impact Simulators (HIS).** These programs are used to simulate the response of human occupants and pedestrians to impact. Several programs have been developed, including MVMA-2D,<sup>37</sup> CVS-3D,<sup>38,39</sup> and H3D.<sup>30</sup> These mainframe programs are large, extremely complex, and require a massive amount of input data. User-friendly, personal computer versions of these programs are under development.<sup>40</sup>

ex3

IMPACT MOMENTUM OF A PLANAR ANGLED COLLISION.

Exercise 3 -- Example Reconstruction of an Angled Frontal Collision

Vehicle A:	PROGRAM IMPAC - INPUT	Vehicle B:
Medium car		Small car
3531.0 lbm	Vehicle mass	2860.0 lbm
54.0 inches	Radius of gyration	49.0 inches
74.4 inches	Impulse center, fwd from veh CG	80.4 inches
31.2 inches	Impulse center, lat from veh CG	-24.0 inches
30.0 degrees	Vehicle heading at impact	-110.0 degrees
48.0 mph	Forward speed at impact	26.0 mph
.0 mph	Lateral speed at impact	.0 mph
3.0 deg/sec	Pre-impact rotational velocity	-15.0 deg/sec
80. millisec	Time duration of impulse	
.0 deg	Angle of slip plane (relative to vehicle A)	
.0 % slip	Slip velocity, % of approach vel along slip plane.	
24.0 inches	Selected point-1, fwd from CG	24.0 inches
18.0 inches	Selected point-1, lat from CG	18.0 inches
24.0 inches	Selected point-2, fwd from CG	24.0 inches
-18.0 inches	Selected point-2, lat from CG	-18.0 inches

version: R88L02W08

Exercise 3 -- Example Reconstruction of an Angled Frontal Collision

A: Medium car	PRE-IMPACT CONDITIONS	B: Small car
30.0 deg	Vehicle Heading	-110.0 deg
48.0 mph @ 30.00 deg	CG Velocity	26.0 mph @ -110.00 deg
3. deg/sec	Rotational Velocity	-15. deg/sec
271962. 3.ft-lb	Linear & Rotational KE	64631. 51.ft-lb
----- IMPACT CONDITIONS -----		
30.8 mph @ -129.00 deg	Crash Severity Index (^V)	38.1 mph @ 51.00 deg
-4635. lbf-sec	Longitudinal Impulse	-4694. lbf-sec
-1779. lbf-sec	Lateral Impulse	1617. lbf-sec
3.8 inch @ 20.07 deg	Collision Radius(h); PDOF	4.9 inch -19.97 deg
	Approach Velocity - CG's	69.9 mph @ 43.82 deg
	Separation Velocity- CG's	8.7 mph @ -35.92 deg
	Impulse Duration	80 milli-sec
	Approximate Mutual Crush	4.11 ft
3.7 ft & 1.4 ft	X & Y Impact Motion of CG	.4 ft & -1.1 ft
Approach Vel @ IC: 68.6 mph tangential & 14.7 mph normal to slip plane.	Slip Velocity along plane	.0 mph @ 30.92 deg
	Crush Energy of Collision	252884. ft-lbf
----- POST-IMPACT CONDITIONS -----		
31.8 deg	Vehicle Heading @ runout	-108.1 deg
22.2 mph @ .08 deg	Runout velocity	15.9 mph @ 18.90 deg
43. deg/sec	Runout rotational speed	64. deg/sec
16.6 ft	Runout Work / Weight	8.8 ft
19.5 mph @ 6.13 deg	Velocity @ impulse-center	19.5 mph @ 6.13 deg
21.0 mph @ 1.41 deg	Velocity @ point-1	17.8 mph @ 18.79 deg
22.3 mph @ 3.37 deg	Velocity @ point-2	16.5 mph @ 12.56 deg
57946. 633.ft-lb	Linear & Rotational KE	24273. 911.ft-lb

Collision Safety Engineering

**Exhibit 21.** Output from IMPAC.<sup>28</sup> Top portion shows input data, while lower portions show computed pre-impact and post-impact conditions. Note the computed conditions (22.2 mi/hr and .08 deg for Vehicle A and 15.9 mi/hr and 18.9 deg for Vehicle B) are very close to the target conditions (see Exhibit 20).

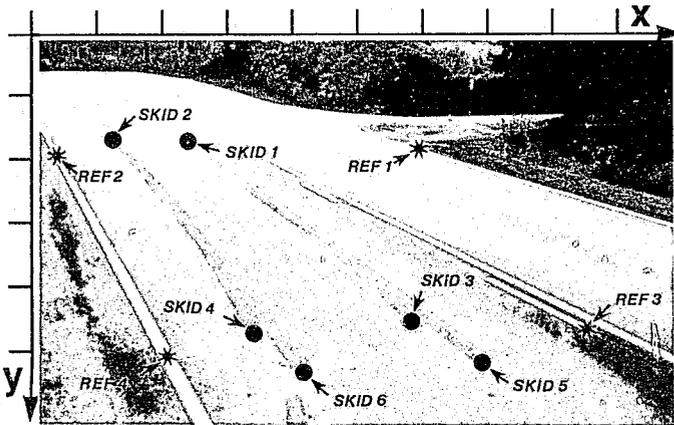


Exhibit 22. Photograph of accident site showing skidmarks. The locations of four points, REF 1-4, were measured at the site. However, the starting and ending points of the skidmarks, SKID 1-6, were not measured. Photogrammetry can be used to determine their locations.

	Callibration Points			
	Acc. Site X <sub>r</sub> Y <sub>r</sub> (feet)		Photo X <sub>p</sub> Y <sub>p</sub> (millimeters)	
REF 1	0	0	73	16
REF 2	0	22	5	16
REF 3	76	11	104	49
REF 4	76	22	24	49

Exhibit 23. Table of calibration points and matching photographic coordinates. The accident-site X, Y coordinates of points REF 1 through REF 4 were measured during inspection of the accident site. Their photographic counterparts were measured directly from Exhibit 22.

Source File: FIGURE24      EDITING TRANS4 DATA POINTS      OVERTYPE  
 Date 10/24/88      By TDD Case EX. 9      Roll A      Frame 21      Run 2      Plot P      0.50L  
 COMMENTS:      Photo Units mm      +/- 0.500      Real Units feet

Locating skidmarks from photgraphic Exhibit 22.

C1=-2.5202070E+02      C2= 0.0000000E+00      C3= 1.5751300E+01      C4= 0.0000000E+00  
 C5= 1.1917100E-01      C6= 1.8038860E+01      C7=-9.4041450E-01      C8= 3.1632130E+00

DIGITIZER NOT ALIGNED

Pt. No.	NAME	MEAS, - PHOTO		MEAS. - REAL		COMPUTED REAL COORDINATES			
		Xp	Yp	Xr	Yr	Xc	Yc	Dx	Dy
BP	REF1	73.00	16.00	0.00	0.00	0.0	0.0	2.7	0.6
BP	REF2	5.00	16.00	0.00	22.00	0.0	22.0	2.7	0.2
BP	REF3	104.00	49.00	76.00	11.00	76.0	11.0	0.5	0.2
BP	REF4	24.00	49.00	76.00	22.00	76.0	22.0	0.5	0.1
5	SKID1	31.00	16.00	0.00	0.00	0.0	13.6	2.7	0.3
6	SKID2	17.00	16.00	0.00	0.00	0.0	18.1	2.7	0.2
7	SKID3	72.00	48.00	0.00	0.00	75.0	15.2	0.5	0.1
8	SKID4	43.00	49.00	0.00	0.00	76.0	19.4	0.5	0.1
9	SKID5	85.00	56.00	0.00	0.00	82.1	15.0	0.4	0.1
10	SKID6	52.00	58.00	0.00	0.00	83.6	19.3	0.4	0.1

1HEADER 2BASE P 3INVERS 4 SAVE 5ABANDN 6ADD LN 7DEL LN 8 HELP 9DIGTZR 0 CALC

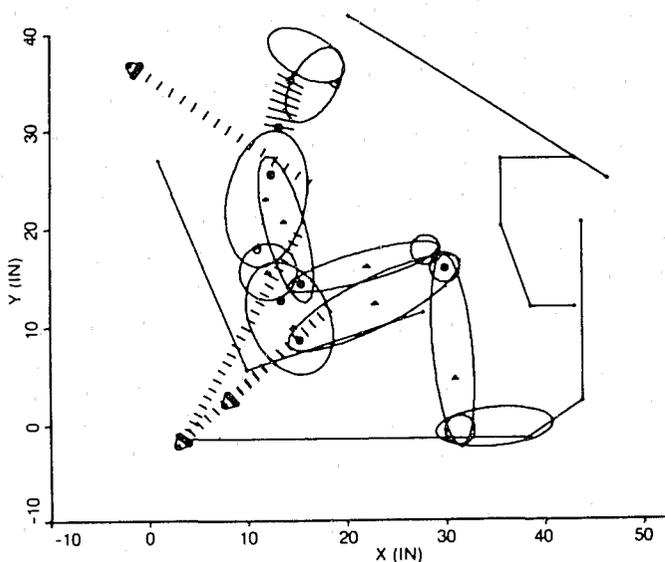
Exhibit 24. Example from TRANS4 photogrammetry program.<sup>32</sup> The first four data points, labeled REF1 through REF4, are the calibration points. The last six data points, labeled SKID1 through SKID6, were computed by the program. These are the actual X, Y coordinates (in ft) of the beginning and end of the skidmarks found at the accident site. (See also references 7, 33, 34, 41.)

Human impact simulators use several geometrical shapes to simulate the human body, and several contact surfaces to simulate the vehicle interior (dash, floorboard, seat) or exterior (bumper, grille, hood). Each of these surfaces is assigned physical properties defining its size, initial location, and how hard or soft the surface is.

Various programs use varying numbers of masses to model the human body. Programs with a large number of masses (MVMA-2D has nine masses for the head, neck, upper and lower torso, hips, upper and lower arm, and upper and lower leg; see Exhibit 25) require significantly more

input information than do programs with fewer masses (H3D has three masses for the head, torso and legs). Programs with a larger number of masses and contact surfaces (see Exhibit 26) provide more detailed information about occupant injuries, at the expense of several hours of computer calculation time. Programs with fewer masses and contact surfaces provide less specific information about occupant motion and injuries, but require substantially less calculation time.

Human impact simulators can be either two- or three-dimensional. The former requires less input data and simulates motion only in a single plane (i.e., side view or front view),



**Exhibit 25.** Example of output from MVMA-2D,<sup>37</sup> a two-dimensional computer program used for studying occupant injury. This program uses nine masses to model the human body.

while the latter requires more input data, but simulates motion in all three directions.

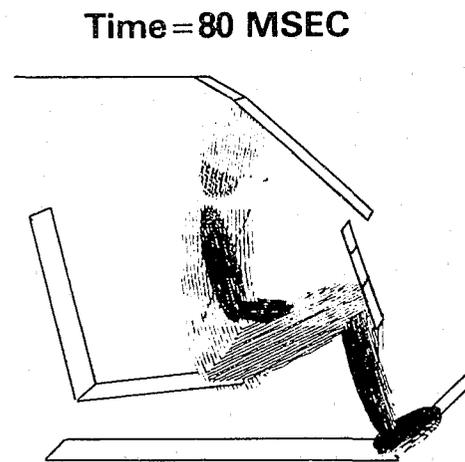
Accident investigators can use these programs to determine how vehicle occupants and pedestrians are injured during impact. Occupant injury studies may include the effect of interior design, the use (or non-use) of restraint systems, and the effectiveness of headrests. For pedestrian collisions, human impact simulators can be used to determine throw distances from impact speed, as well as to study how injuries relate to vehicle exterior design. These programs are not normally useful for determining who was driving in a complex rollover accident. As their use by reconstructionists increases, however, human impact simulators may become an important tool for illustrating the conditions causing injury during a crash.

### Presentation Tools

An accident reconstructionist is always faced with the need to present his results to others, whether in the form of a report or courtroom exhibits. An ineffective presentation will make even the most thorough reconstruction useless. To meet the presentation need, the reconstructionist prepares a scaled diagram of the accident scene, showing the highway, vehicles and highway evidence. Until recently, these drawings were prepared by hand, using the same techniques a draftsman would use for preparing building plans.

The newest application for computers is the preparation of drawings. This grew out of the high-technology industries, such as aerospace, which use the computer to design components and prepare final design drawings. These programs are ideal for preparing accident site diagrams.

An accident site drawing program is actually a mapping program. It must have some special features that distinguish it from a program for drawing building design plans. As a



**Exhibit 26.** Example output from CVS-3D,<sup>38</sup> another program used to study occupant injury. This program simulates three-dimensional motion of occupants and pedestrians.

mapping program, it must use the same coordinate system other programs use. As with all drafting programs, it should also have a built-in library of frequently-used objects (in this case, highways, intersections, cars, road signs, etc.).

Drawing programs can be lumped into two major categories: CAD (computer-aided drafting) programs and paint programs. Both types of programs are described below, along with examples.

**CAD.** CAD programs are drafting programs designed to draw lines according to an established scale. Each line, therefore, is positioned according to real-world coordinates, making it easy to locate lines and other objects precisely, using accident site measurements. Thus, it is also easy to produce scale diagrams, an essential part of a reconstruction. A typical CAD accident site drawing is shown in Exhibit 27.

A CAD program essentially replaces a ruler and pencil. The investigator uses CAD to draw a scale diagram for purposes of analysis. Then, if necessary, the same drawing can be enhanced or rescaled on the computer for preparing report or courtroom exhibits.

**PAINT.** Paint programs are designed to be used as an artist's tool. As such, paint programs work by keeping track of points on the computer's screen rather than using real-world measurements. This makes it very easy to draw and erase lines and circles, or even portions of lines and circles. It also is very easy to produce multiple copies of certain areas on the screen. These same features, however, place restrictions on their use in accident reconstruction, because it is usually not possible to place an object at a known coordinate location or produce scale diagrams using paint programs except by trial and error. A typical accident site drawing using a paint program is shown in Exhibit 28.

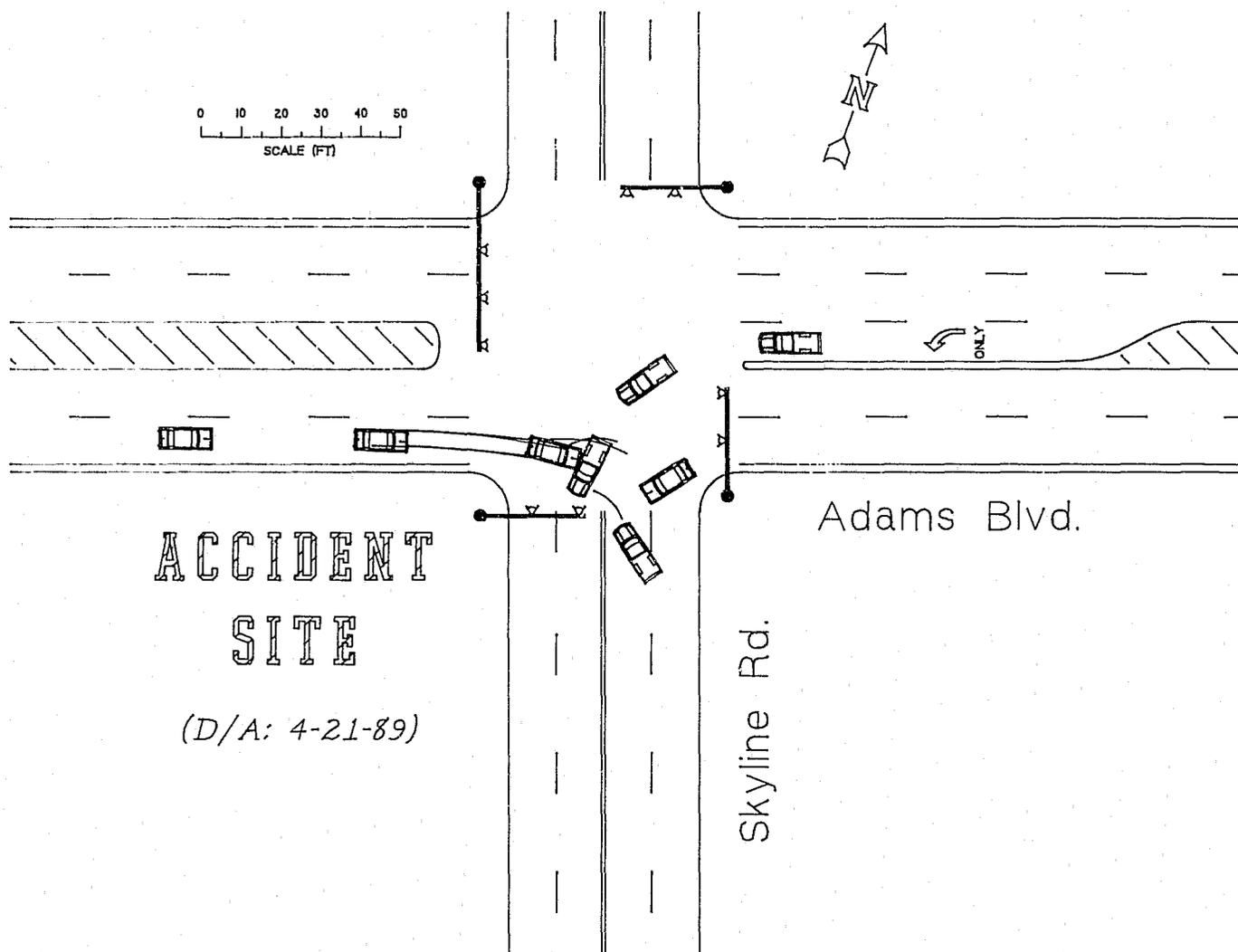


Exhibit 27. An example of a scaled accident-site drawing using a CAD program." The vehicles, trees, north direction indicator and scale are all part of a built-in accident site template.

#### 4. ADMISSIBILITY

An investigator who understands the calculations performed by a computer program seldom has any difficulty getting his results admitted in a court of law. However, any good lawyer will challenge an analysis, whether it was done using a hand calculator or a computer. This section provides an overview of the things you should remember when using a computer analysis as part of your testimony.

*The computer is just one tool.* You will seldom base all your conclusions on only one source of information. In every investigation, several methods of analysis are used. These methods include experience, other supporting calculations, and comparison with independent eyewitnesses. It is important to realize when testifying that the computer is just one of several tools at your disposal. It is even likely that more than one computer program will be used on a particular accident.

*Computers are not mysterious.* Any computer program is simply a pre-programmed series of calculations. In the case

of accident reconstruction programs, the calculations represent the solution to a physics problem—nothing more, nothing less. It is inappropriate to label the results as accurate just because they were produced by a computer. The calculations are only as correct as the input data that produced them. The saying "garbage in, garbage out" applies to all calculation methods, including computer programs. However, a good computer program will provide you with warning messages alerting you to data inconsistencies. You should simply use and present the computer as a technical tool in your investigation.

*Remember the history.* Experience has shown that courts are much more willing to admit scientific evidence produced by an independent engineering analysis tool than scientific evidence produced by a tool specifically developed for litigation. All the sophisticated programs described in this topic were specifically developed as tools to improve traffic safety. Their application in litigation is a by-product of that important purpose.

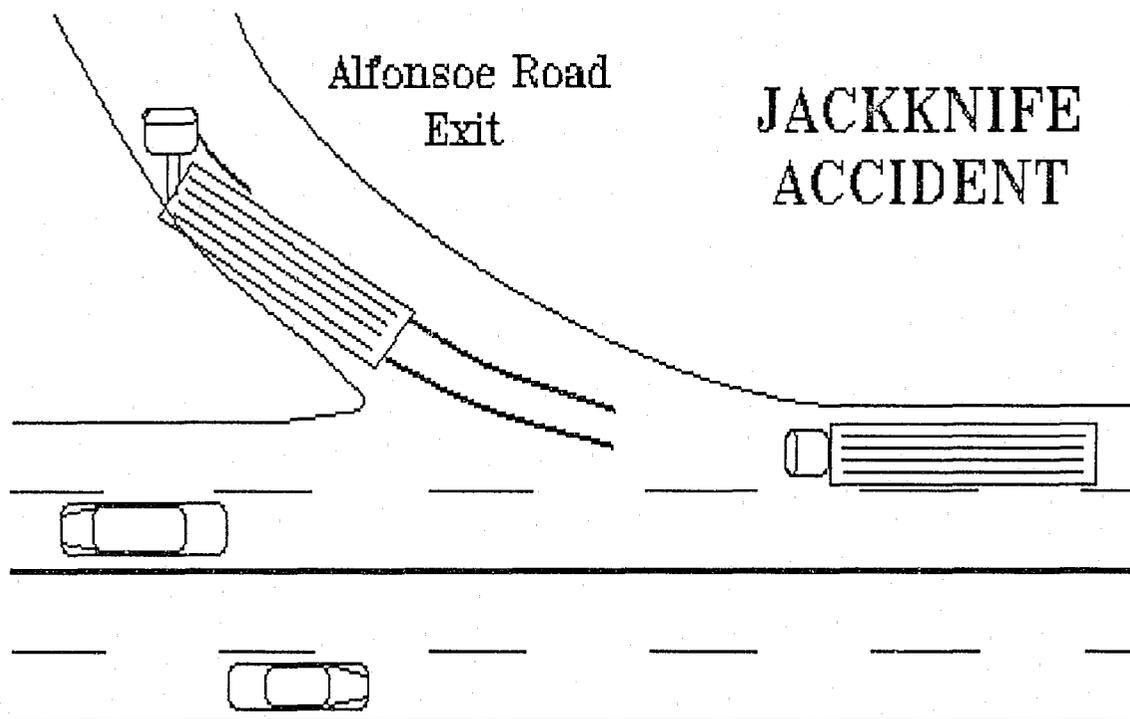


Exhibit 28. An example of a scaled accident site drawing using a paint program.<sup>42</sup>

As a result of their development by NHTSA for improving highway safety, all of the analysis tools described in this topic have been tested for validity (see References). While a validation study cannot prove the accuracy of every reconstruction, it does provide a valid basis for the program's use.

*You don't need to be a programmer.* As an accident investigator using a computer program, you need not understand each and every line of computer language in the program. Indeed, it would be wise to state at the outset of your testimony that this is not the case; you did not write the program and are not familiar with every line of code. Rather, you are a user of the program, just as hundreds of others are, and understand the procedures extremely well. As an investigator, however, you can and should expect to be questioned on the procedures used by the program.

*Stay within the scope of analysis.* When used properly, computer programs usually work quite well. It is essential to use the program only for its intended purpose. A program may provide a solution for an unintended purpose; but if this other purpose is untested, the investigator cannot be certain of the results — and those results will be subject to scrutiny.

*Understand the assumptions and limitations.* All computer programs incorporate certain basic assumptions and limitations. To properly apply the program, you must understand what they are. These are normally listed in the documentation.

You make assumptions as well, and must be prepared to defend those assumptions. A basic understanding of the program points toward the need for adequate training.

One of the advantages of computer analysis is the organization it provides. You can always review your input to see exactly what information was used. But so can others! Therefore, be ready to defend the input. An understanding of how the program works is essential.

*Do not exaggerate the accuracy.* Lastly, do not exaggerate the importance or accuracy of the results, just because they were generated by a computer. Go back to the basics: a computer program is simply a pre-programmed series of calculations. The program may display the speed of a vehicle as 53.54 mi/hr, but the true accuracy is not quite that good. Always perform a series of analyses using a range for important variables, such as friction and impact positions. The resulting range in speed estimates is much more important (and believable) than showing you can determine the speed of a vehicle with two-decimal-place accuracy.

The above concepts provide a basis for using computer programs in accident reconstruction. If you are to present your results in court, you must be prepared for the qualification process. This is a five-step process:

- Qualify the Expert
- Qualify the Hardware
- Qualify the Software
- Qualify the Input
- Qualify the Output

Each of these steps is described below.

*Qualify the Expert.* Using the computer does not make you an expert. In fact, it places additional demands on your expertise. Qualifications for expert testimony vary from state to

state, and it is up to the individual to demonstrate a true knowledge and experience in the field of accident reconstruction, as well as an understanding of the use of computers.

*Qualify the Hardware.* Although not generally necessary, it does no harm if you state that the results were obtained using recognized brand-name hardware. However, if the results were obtained using an untested prototype computer, it will be necessary to show that the computer produces valid results.

*Qualify the Software.* The third step is to show that the computer program is valid, usually through the use of a study comparing the computer results with actual test data.

*Qualify the Input.* Each input variable is subject to scrutiny. You must be able to explain the source of the data.

*Qualify the Output.* The final step is to explain how the results were obtained and what they mean. This step is required for any technical presentation of findings, and provides the basis for your opinions.

## 5. IMPLEMENTATION

The benefits of computerized accident investigation can only be realized if the computerization is implemented correctly. To properly implement the system requires a general understanding of four major areas:

- Management Support and Encouragement
- Software Selection
- Hardware Selection
- Training

Each area is necessary for the overall implementation; skipping any of these four will guarantee an incomplete system and the risk of failure. Computer systems (whether in accident investigation or other fields) that have failed can be attributed to one of the four basic areas of successful implementation. Each of these important areas is described below.

**Management Support and Encouragement.** The first step in implementation is to gain the support and encouragement of management. This usually involves a cost vs. benefit analysis and an overall implementation plan. Although management may not need to know the technical aspects of the hardware or software, they do need to know the system capabilities and general requirements.

Gaining management support should start by illustrating the need for computerizing. This means comparing the present method of operation with how accident investigation might be improved by computerizing. Lost opportunities can also be equated with lost time and revenue.

One method of presenting and reviewing computer alternatives with management is called an *options comparison*. An options comparison lists the advantages and disadvantages of each alternative. Many of the advantages can be summarized from the benefits of the cost/benefit analysis. Other advantages may be less tangible. Where possible, try

to quantify the advantages or disadvantages in dollars. The most appropriate system usually becomes apparent after weighing the costs and benefits of each alternative.

**Software Selection.** After reviewing the alternatives and comparing the costs and benefits, you should select the software. This should be done *before* selecting hardware. Although the typical software program may cost less than the total hardware costs, the total costs to the company resulting from choosing the wrong software will far exceed the hardware costs. These may be costs resulting from additional manpower, procedures, or lost revenue directly traceable to selecting the wrong software.

In selecting software, be aware of the effects it might have on other aspects of your accident investigation practice. Ask for a demonstration of the program(s) to see what you are buying. Knowing how the program is used and actually seeing how the information is entered and the results displayed will greatly increase your understanding of the program and how well it will meet your needs. A demonstration is also useful when confirming compatibility with a potential hardware selection.

**Hardware Selection.** Hardware selection is simply a matter of identifying the appropriate computer and devices to effectively run the selected software. The options available can be obtained from the software vendor. Other items that should be considered when selecting hardware are:

- *Compatible equipment* (sometimes called clones). Although these devices might represent significant savings and be advertised as a "true compatible," subtle differences may cause problems now or in the future — after the software is updated. It can be stated categorically: there is no such thing as a true 100% compatible.

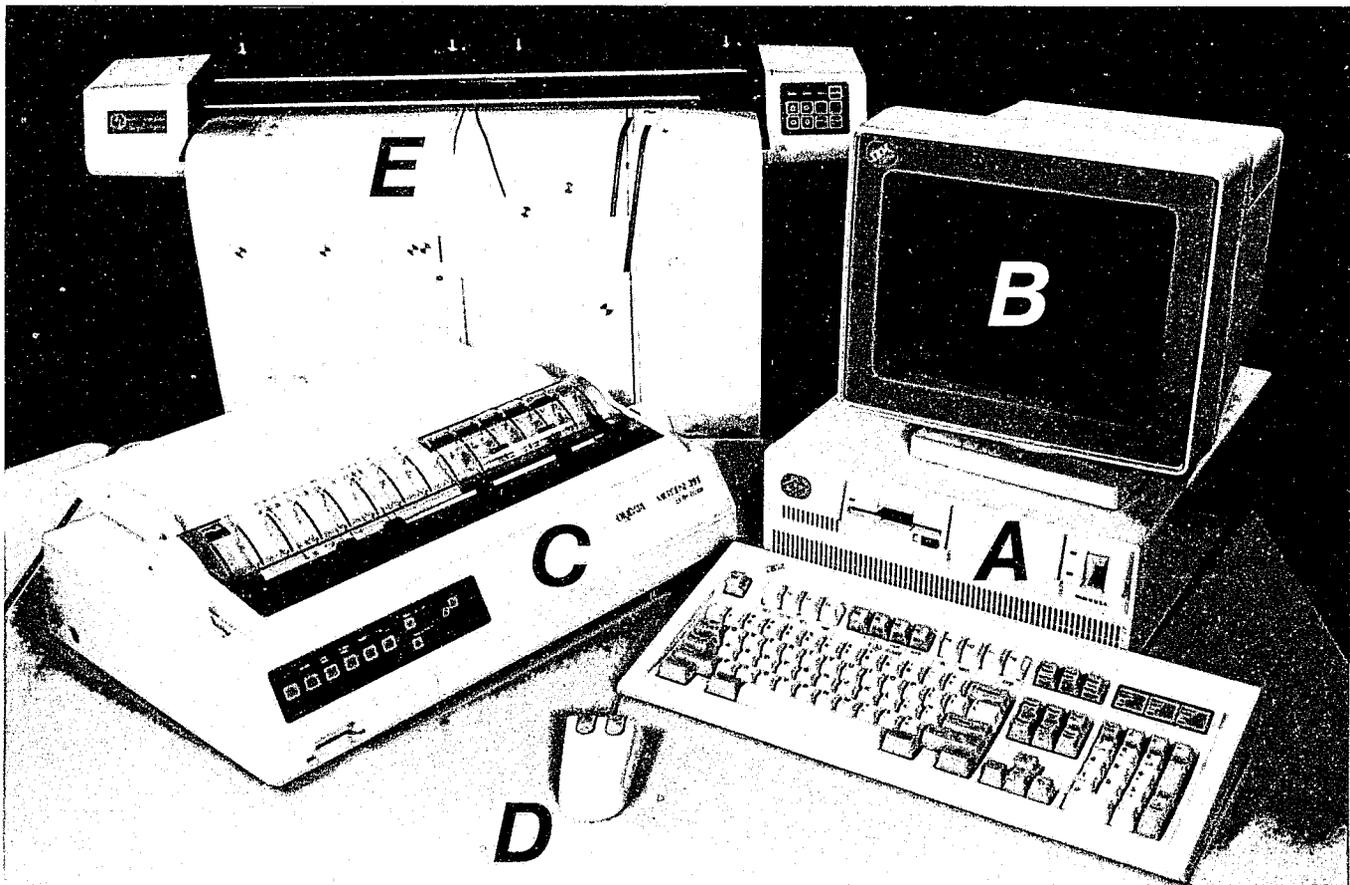
If you do purchase a clone, you may incur additional costs in the future (such as product updates, lost time spent on troubleshooting problems, or additional software costs).

- *Other business needs.* Depending on the size of the company or agency, other business functions can be automated and used on the same computer. Keeping in mind the original cost/benefit analysis, this should only be done if it does not hinder the original objectives.

- *Future needs and capabilities.* Hardware "expandability" is critical in today's market of ever-expanding hardware technology. Purchasing a "close-out sale" computer guarantees obsolescence and eliminates the possibility of future expansion. Computer hardware can generally be classified into one of three categories:

- Mainframes
- Minicomputers
- Microcomputers

Although the distinction among these has become less clear-cut with the advancements in hardware technology, historically the differences have been due to computer size,



**Exhibit 29.** An example of a complete computer hardware system. The system includes (a) the microcomputer with keyboard and disk storage, (b) the display, with high-resolution graphics option, and (c) the dot-matrix printer. This system also includes some enhancements useful for many accident reconstruction programs. These enhancements include (d) a mouse and (e) a plotter. Also, not visible inside the computer is a math coprocessor, which greatly increases the calculation speed.

single or multiple processors, number of terminals, and processing speed. Unless otherwise noted, the software referenced in this topic was developed for microcomputers.

In selecting microcomputer hardware, you should be familiar with the basic components and optional attachments. Exhibit 29 identifies the primary components of a microcomputer system. Other devices that can be added to enhance the system are also included in Exhibit 29. These devices provide easier methods of input, and improved output, processing, or storage. They include the following:

**Graphics display and adapter.** These devices allow the computer to produce graphic images or pictures, as well as text. They are usually required for accident reconstruction software. Besides offering different colors, they also may offer varying screen resolution which determines the amount of detail the screen can display.

**Math coprocessor.** This optional chip can be added to the computer to increase the speed of performing math functions. Most simulation programs can benefit from adding a math coprocessor, since they are calculation-intensive. However, not all software was developed to take advantage of the

math coprocessor, and not all hardware has the capability of adding the chip.

**Mouse.** A mouse simplifies the input process and locating data on the screen. It's a pointing device for directing a set of crosshairs on the screen. Buttons on the mouse assist in selecting the desired item. A mouse is very helpful when using presentation software.

**Digitizer.** A digitizer provides another method of entering data. It is an electronic tablet used to enter the coordinates of specific points of graphic information into a computer. Like the mouse, it lets you point to the location on a known map, drawing, or picture with a stylus or cursor, and the coordinate data is automatically sent to your computer. Certain photogrammetry and presentation software programs are greatly enhanced by this device.

**Plotter.** A plotter uses one or more pens to draw graphic images on paper or transparencies. Since standard "dot-matrix" printers use several small wire pins to form characters, they can be programmed to produce graphic images as well. But diagonal lines in dot-matrix output sometimes appear jagged, as opposed to plotter output, which is smooth and continuous. (For an example of the latter, see Exhibit 27).

**Training.** Training is the fourth component in the process of computerizing. Perhaps the most overlooked, training can be the most important component in implementing a successful system. This is especially true in a technical field such as accident reconstruction, where the engineering aspects and terms must also be known.

The most popular form of training is self-learning. By reading the program tutorial and other available reference materials, an investigator can frequently learn to use the program satisfactorily. However, this type of training takes time, and mistakes usually occur along the way.

The alternative to self-learning is a one-week training seminar. These seminars are usually given several times a year at particular locations or on-site. They usually focus on the use of a specific program. Seminars offer the opportunity to learn the greatest amount of information in the least amount of time.

## 6. SUMMARY

There are two primary benefits in using computers for accident reconstruction. The first is speed. By programming a computer to perform the necessary calculations, an analysis normally requiring several hours of hand calculation can be done in seconds. Not only does the analysis take less time, but also a whole series of possible scenarios can be analyzed, resulting in a much more thorough analysis.

The second benefit is freedom from mistakes. Once the equations are properly programmed, they will always give the correct answers to the given equations. This is of major importance in a complicated analysis, where hundreds or thousands of separate calculations are required.

There are additional benefits. The computer only works as a logical extension of the user. As a result, it forces you into using a logical procedure. (Some may think of this as a disadvantage!) The output from a well-written computer program is neat and well designed, allowing you to quickly find important data.

Finally, the use of computers can also provide a learning experience, because in the normal process of studying a crash, the investigator typically gains a tremendous amount of knowledge about accident reconstruction. As a direct result, the investigator's ability to communicate his findings to others, whether a district attorney, trial lawyer, insurance adjuster, jury, or another investigator, is vastly improved. The end result is a better understanding of what causes accidents. And that, after all, is the primary reason for accident reconstruction.

## 7. SOURCES

### Authors

*Terry D. Day, P.E.*, is a mechanical engineer and a member of the Accident Investigation Practices subcommittee of the Society of Automotive Engineers. Mr. Day is president of

Engineering Dynamics Corporation and has written several technical articles on the use of computers for accident reconstruction.

*Randall L. Hargens*, a computer scientist, has been developing computer programs for over 21 years. He has a certificate in data processing and is a member of several national data processing organizations. Mr. Hargens is a co-founder of Engineering Dynamics Corporation, and has written several articles on data processing, computer selection, and system implementation.

## References

1. Ricci, Leda L., "NCSS Statistics: Passenger Cars," DOT-HS-805-531, June 1980.
2. *Fatal Accident Reporting System 1986*, DOT-HS-807-245, NHTSA, March 1988.
3. *National Accident Sampling System: Accident Investigation Procedures Manual*, DOT, NHTSA, 1980.
4. Petrucelli, E., "The USA and Safety Belt Use: A Prognosis for the Remainder of the '80s," SAE Paper No. 840324, Society of Automotive Engineers, Warrendale, PA, 1980.
5. Hess, R.L., "Microcomputer Programs Useful for Aspects of Accident Reconstruction," SAE Paper No. 800174, Society of Automotive Engineers, Warrendale, PA, 1980.
6. Day, T.D., and R.L. Hargens, *Engineering Dynamics Vehicle Analysis Package (EDVAP)*, Engineering Dynamics Corporation, Lake Oswego, OR, 1984/1986/1988.
7. *A-I-CALC Program User's Guide*, Northwestern University Traffic Institute, Evanston, IL, 1987.
8. McHenry, R.R., and N.J. DeLeys, "Vehicle Dynamics in Single Vehicle Accidents - Validation and Extensions of a Computer Simulation," CAL Report No. VJ-2251-V-3, Cornell Aeronautical Labs, Buffalo, NY, 1968.
9. Segal, D.J., "Highway-Vehicle-Object Simulation Model," FHWA-RD-76-162, Federal Highway Administration, Washington, DC, 1976.
10. McHenry, R.R., "The Astro Spiral Jump - An Automobile Stunt Designed Via Computer Simulation," SAE Paper No. 760339, Society of Automotive Engineers, Warrendale, PA, 1976.
11. Solomon, P.L., "The Simulation Model of Automobile Collisions (SMAC) Operator's Manual," U.S. DOT, NHTSA, Accident Investigation Division, Washington, DC, 1974.
12. McHenry, R.R., "Development of a Computer Program to Aid the Investigation of Highway Accidents," DOT HS-800 621, December 1971.
13. McHenry, R.R., D.J. Segal, J.P. Lynch, and P. Henderson, "Mathematical Reconstruction of Highway Accidents," DOT HS-800 801, January 1973.
14. Bartz, J.A., D.J. Segal, and R.R. McHenry, "Mathematical Reconstruction of Highway Accidents - Analytical

- and Physical Reconstruction of Ten Selected Highway Accidents," DOT HS-801 150, March 1974.
15. Jones, I.S., J.P. Lynch, and R.R. McHenry, "Mathematical Reconstruction of Highway Accidents - Scene Measurement and Data Processing System," DOT HS-801 405, February 1975.
  16. *Vehicle Analysis Package - EDSMAC Program Manual, Version 2*, Engineering Dynamics Corporation, Lake Oswego, OR, 1989.
  17. McHenry, R.R., "Extensions and Refinements of the CRASH Computer Program Part II, User's Manual for the CRASH Computer Program," DOT HS-801 838, February 1976.
  18. Jones, I., and A. Baum, "Research Input for Computer Simulation of Automobile Collisions, Vol IV - Staged Collision Reconstructions," DOT HS-805 040, December 1978.
  19. Campbell, K., P. Cooley, R. Hess, R. Scott, and C. Winkler, "Training Materials for Accident Investigation, Volume 1 - Reference Manual," DOT HS-801 968, May 1979.
  20. *CRASH3 User's Guide and Technical Manual*, US DOT, NHTSA, 1981.
  21. *Vehicle Analysis Package - EDCRASH Program Manual*, Engineering Dynamics Corporation, Lake Oswego, OR, 1986.
  22. Day, T.D., and R.L. Hargens, "An Overview of the Way EDCRASH Computes Delta-V," SAE Paper No. 870045, Society of Automotive Engineers, Warrendale, PA, 1987.
  23. Day, T.D., and R.L. Hargens, "An Overview of the Way EDSMAC Computes Delta-V," SAE Paper No. 880069, Society of Automotive Engineers, Warrendale, PA, 1988.
  24. Moncartz, H.T., J.E. Bernard, and P.S. Fancher, "A Simplified, Interactive Simulation for Predicting the Steering and Braking Response of Commercial Vehicles," University of Michigan, UM-HSRI-P-75-8 August, 1975.
  25. Bernard, J.E., "A Computer-Based Mathematical Method for the Prediction of Braking Performance of Trucks and Tractor-Trailers," SAE Paper No. 730181, Society of Automotive Engineers, Warrendale, PA, 1973.
  26. *Vehicle Analysis Package - EDSVS Program Manual*, Engineering Dynamics Corporation, Lake Oswego, OR, 1988.
  27. *Vehicle Analysis Package - EDVTS Program Manual*, Engineering Dynamics Corporation, Lake Oswego, OR, 1988.
  28. Woolley, R.L., "IMPAC User's Guide and Technical Manual," Version R84L12W03, Collision Safety Engineering, Orem, UT, 1985.
  29. Woolley, R.L., "The IMPAC Computer Program for Accident Reconstruction," SAE Paper No. 850254, Society of Automotive Engineers, Warrendale, PA, 1985.
  30. Robbins, D.H., R.O. Bennett, and V.L. Roberts, "HSRI Three-Dimensional Crash Victim Simulator: Analysis, Verification and User's Manual, and Pictorial Section," University of Michigan, DOT HS-800 551, June 1971.
  31. MacAdam, C.C., P.S. Fancher, G.T. Hu, and T.D. Gillespie, "A Computerized Model for Simulating the Braking and Steering Dynamics of Trucks, Tractor-Semitrailers, Doubles, and Triples Combinations - User's Manual," University of Michigan, UM-HSRI-80-58, Ann Arbor, MI, September 1980.
  32. *TRANS4 Photogrammetry Programs for Accident Investigation*, Kinney Engineering, Inc., and MC2, Inc., Corvallis, OR, 1988.
  33. Brelin, J.M., *FOTOGRAM*, GM Technical Center, General Motors Corporation, Warren, MI, 1986.
  34. Brelin, J.M., W.G. Cichowski, and M.P. Holcomb, "Photogrammetric Analysis Using the Personal Computer," SAE Paper No. 861416, Society of Automotive Engineers, Warrendale, PA, 1986.
  35. Das EES - Unfallrekonstruktions-program, DEKRA-Hauptverwaltung, Postfach, 810207, 7000 Stuttgart 80.
  36. Zeidler, F., H. Schreier, and R. Stadelmann, "Accident Research and Accident Reconstruction by the EES-Accident Reconstruction Method," SAE Paper No. 850256, Society of Automotive Engineers, Warrendale, PA, 1985.
  37. Bowman, B.M., R.O. Bennett, and D.H. Robbins, "MVMA Two-Dimensional Crash Victim Simulation, Version 4, Volume 2," University of Michigan, UM-HSRI-79-5-2, Ann Arbor, MI, June 1979.
  38. Fleck, J.T., and F.E. Butler, "Validation of the Crash Victim Simulator, Volume 3, User's Manual," Calspan Corp. Report No. ZS-5881-V-3, NHTSA Contract No. DOTHS-6-01300, February 1982.
  39. Digges, K.H., "Reconstruction of Frontal Accidents Using the CVS-3D Model," SAE Paper No. 840869, Society of Automotive Engineers, Warrendale, PA, 1984.
  40. *Vehicle Analysis Package - EDHIS Program Manual*, Engineering Dynamics Corporation, Lake Oswego, OR (under development).
  41. *Vehicle Analysis Package - EDCAD Program Manual*, Engineering Dynamics Corporation, Lake Oswego, OR, 1988.
  42. *Microsoft Paintbrush User's Guide*, Microsoft Corporation, Redmond, WA, 1986.

## ACKNOWLEDGMENTS

The authors wish to thank the following people for their assistance and contributions to this topic:

*Dr. Ronald L. Woolley*, Collision Safety Engineering

*Ms. Janet M. Brelin*, General Motors Corporation

*Dr. J. Rolly Kinney*, Kinney Engineering, Inc.

*Mr. Lynn B. Fricke*, Northwestern University Traffic Institute

## TRADEMARKS

PC Paintbrush is a trademark of ZSoft Corporation.

Microsoft is a registered trademark of Microsoft Corporation.

EDVAP, EDSVS, EDVTS, EDCRASH, EDSMAC and EDCAD are trademarks of Engineering Dynamics Corporation.

IBM is a registered trademark of International Business Machines Corporation.