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The Scientific Visualization of Motor Vehicle Accidents

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ABSTRACT

This paper describes the use of scientific visualization as a tool for investigating the cause of motor vehicle accidents. A specific accident is reconstructed and simulated. This simulation data is then presented three ways: (1) as a table of numeric results, (2) as a 2-D, graphical simulation viewed from above, and (3) as a fully rendered, 3-D scientific visualization. The advantages and disadvantages of each method are explored, specific data requirements for each method are described, and conformance criteria with preliminary SAE guidelines are reviewed. A distinction between the terms "animation", "simulation", and "scientific visualization" is also provided.

3-D SCIENTIFIC VISUALIZATION is the process of viewing scientific data in three-dimensional (3-D) form. The term has been used for several years by the engineering and scientific community. Examples of industries include modal analysis of structures, computational fluid dynamics, molecular modeling and geotechnical exploration. All of these examples share a common trait: They are systems described by massive amounts of 3-dimensional data. The human mind is incapable of absorbing and understanding these data when presented *numerically*. However, when presented visually, the data are easy for the human mind to comprehend. Thus, scientific visualization has become the medium of choice for researchers in these areas.

Historically, motor vehicle safety researchers have encountered the same problems as the industries cited above. This is especially true for case studies, wherein simulations of the accident sequence produce massive amounts of 2-D or 3-D data. Thus, safety researchers have begun using scientific visualization as a means of analysis.

The purpose of this paper is to examine the use of 3-D scientific visualization, and compare its use with traditional numeric and 2-D graphical output forms. This will be accomplished by reconstructing and simulating a rather typical 2-car accident, then simply viewing the *same simulation results* three different ways:

- numerically,
- 2-D graphical view from above, and
- 3-D rendered view (scientific visualization)

Data requirements for each method will be examined, and the advantages and disadvantages of each method will be explored. Issues related to documentation and validation will also be discussed.

Accident Description

This case study involves the reconstruction of a hypothetical accident. The accuracy of the reconstruction is not addressed in this paper; it is assumed to be acceptable to the researchers. The scope of this paper is limited to various forms of viewing the accident data after they have been produced.

The accident involved an intersection collision (see figure 1) between two passenger cars: a westbound Porsche (veh #1) and a northbound Audi (veh #2). The Porsche was attempting to turn left (southbound) to enter a freeway on-ramp. At the same time, the Audi entered the intersection, apparently against a red light.

Scene data (impact and rest positions and other path information) were well-documented by the on-scene investigators. Vehicle data (dimensions and inertias) were obtained from inspection and other data sources, and the vehicles' damage profiles were measured.

Reconstruction

The results of the reconstruction suggested the driver of the Audi saw the Porsche just before impact and steered to the left. There was no indication of pre-impact braking. There was no indication the driver of the Porsche saw the Audi prior to impact.

An EDCRASH reconstruction revealed the impact speed of the Porsche was 17 to 24 mph, and the impact speed of the Audi was 22 to 29 mph. Table 1 shows a typical

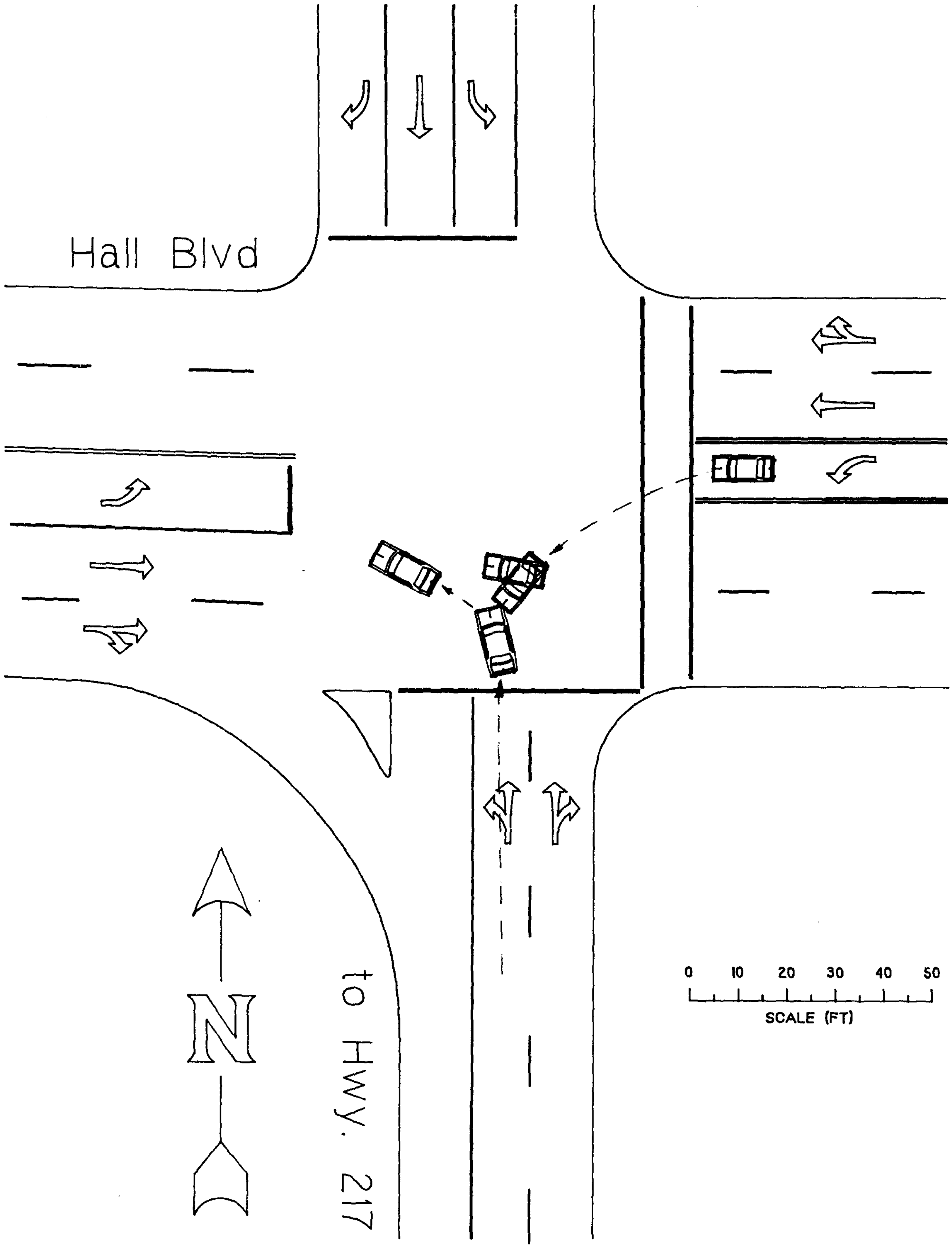

Figure 1 - Scaled accident site diagram

Table 1. EDCRASH Reconstruction of Accident, Summary Of Results

SUMMARY OF RESULTS

IMPACT SPEED (TRAJECTORY AND CONSERVATION OF LINEAR MOMENTUM)

	TOTAL	FWD.	LAT.	SIDESLIP
VEH #1	23.2 mph	23.2 mph	0.0 mph	0.0 deg
VEH #2	27.5 mph	27.5 mph	0.0 mph	0.0 deg

SPEED CHANGE (DAMAGE)

	TOTAL	FWD.	LAT.	PDOF
VEH #1	26.2 mph	-26.0 mph	3.1 mph	-6.7 deg
VEH #2	18.9 mph	-13.7 mph	-12.9 mph	43.3 deg

SPEED CHANGE (LINEAR MOMENTUM)

	TOTAL	FWD.	LAT.	PDOF
VEH #1	24.0 mph	-23.8 mph	2.8 mph	-6.7 deg
VEH #2	17.3 mph	-12.6 mph	-11.9 mph	43.3 deg

ENERGY DISSIPATED BY DAMAGE

VEH #1	42901.7 ft-lb
VEH #2	51783.9 ft-lb

Table 2. EDSMAC Simulation of Accident, Accident History

ACCIDENT HISTORY

		--- POSITION ---			---- VELOCITY ----		
	time (sec)	X (ft)	Y (ft)	psi (deg)	U (mph)	V (mph)	angular (deg/sec)
BEGINNING OF SIMULATION							
Veh #1	0.000	35.0	-30.0	90.0	0.0	0.0	0.0
Veh #2		260.0	18.0	180.0	25.0	0.0	0.0
IMPACT							
Veh #1	5.200	59.2	15.7	37.9	17.6	-0.4	-26.2
Veh #2		69.9	20.3	166.4	23.4	0.5	-21.9
SEPARATION							
Veh #1	5.290	59.6	16.5	47.2	-2.8	5.0	154.9
Veh #2		67.9	21.4	161.8	11.2	-7.7	-92.2
REST							
Veh #1	6.050	56.1	17.1	101.2	0.0	0.0	0.0
Veh #2	7.490	55.4	39.8	118.1	0.0	0.0	0.0

Summary Of Results. A series of EDSMAC simulations confirmed that these speed estimates were reasonable. Table 2 shows a typical Accident History.

The remaining questions dealt with causation and avoidability. To answer these questions, the pre-impact phase was reconstructed and simulated. The Porsche was at rest during the first second of the accident sequence; it was assumed the vehicle then maintained a constant acceleration up to its impact speed of 17 to 24 mph. In the absence of information to the contrary, the Audi was assumed to be travelling at a constant speed of 22 to 29 mph, until just before impact, when the driver steered to the left.

Note that specific speeds were used for this study. Within the ranges stated earlier, other speeds could be used as well.

Table 3. Numeric view of accident data, including position, velocity and acceleration of each vehicle as a function of time.

Time	X #1	Y #1	PSI #1	V tot #1	PSI-dot #1	ACC #1	X #2	Y #2	PSI #2	V tot #2	PSI-dot #2	ACC #2
Sec	ft	ft	deg	mph	deg/sec	g	ft	ft	deg	mph	deg/sec	g
0.000	35.00	-30.00	90.00	0.00	0.00	0.00	260.00	18.00	180.00	25.00	0.00	0.00
0.100	35.00	-30.00	90.00	0.00	0.00	0.00	256.33	18.00	180.00	25.00	0.00	0.00
0.200	35.00	-30.00	90.00	0.00	0.00	0.00	252.67	18.00	180.00	25.00	0.00	0.00
0.300	35.00	-30.00	90.00	0.00	0.00	0.00	249.00	18.00	180.00	25.00	0.00	0.00
0.400	35.00	-30.00	90.00	0.00	0.00	0.00	245.33	18.00	180.00	25.00	0.00	0.00
0.500	35.00	-30.00	90.00	0.00	0.00	0.00	241.67	18.00	180.00	25.00	0.00	0.00
0.600	35.00	-30.00	90.00	0.00	0.00	0.00	238.00	18.00	180.00	25.00	0.00	0.00
0.700	35.00	-30.00	90.00	0.00	0.00	0.00	234.33	18.00	180.00	25.00	0.00	0.00
0.800	35.00	-30.00	90.00	0.00	0.00	0.00	230.67	18.00	180.00	25.00	0.00	0.00
0.900	35.00	-30.00	90.00	0.00	0.00	0.00	227.00	18.00	180.00	25.00	0.00	0.00
1.000	35.00	-30.00	90.00	0.00	0.00	0.00	223.33	18.00	180.00	25.00	0.00	0.00
1.100	35.00	-29.99	90.00	0.00	0.00	0.00	219.67	18.00	180.00	25.00	0.00	0.00
1.200	35.00	-29.96	90.00	0.00	0.00	0.00	216.00	18.00	180.00	25.00	0.00	0.00
1.300	35.00	-29.86	90.12	0.88	-1.74	0.21	212.33	18.00	180.00	25.00	0.00	0.00
1.400	35.00	-29.70	90.15	1.32	-2.59	0.21	208.67	18.00	180.00	25.00	0.00	0.00
1.500	35.00	-29.47	90.12	1.76	-2.76	0.21	205.00	18.00	180.00	25.00	0.00	0.00
1.600	35.00	-29.18	90.12	2.20	-1.74	0.20	201.33	18.00	180.00	25.00	0.00	0.00
1.700	35.00	-28.83	90.09	2.63	-2.55	0.20	197.67	18.00	180.00	25.00	0.00	0.00
1.800	35.02	-28.41	89.94	3.07	-3.66	0.21	194.00	18.00	180.00	25.00	0.00	0.00
1.900	35.04	-27.93	89.64	3.50	-4.92	0.21	190.33	18.00	180.00	25.00	0.00	0.00
2.000	35.08	-27.38	89.16	3.94	-6.23	0.20	186.67	18.00	180.00	25.00	0.00	0.00
2.100	35.13	-26.78	88.54	4.37	-6.68	0.20	183.00	18.00	180.00	25.00	0.00	0.00
2.200	35.20	-26.11	87.86	4.81	-7.17	0.20	179.33	18.00	180.00	25.00	0.00	0.00
2.300	35.28	-25.38	87.12	5.24	-7.76	0.20	175.67	18.00	180.00	25.00	0.00	0.00
2.400	35.38	-24.58	86.31	5.68	-8.39	0.20	172.00	18.00	180.00	25.00	0.00	0.00
2.500	35.50	-23.72	85.44	6.11	-9.03	0.20	168.33	18.00	180.00	25.00	0.00	0.00
2.600	35.64	-22.81	84.51	6.55	-9.67	0.20	164.67	18.00	180.00	25.00	0.00	0.00
2.700	35.81	-21.83	83.51	6.98	-10.31	0.21	161.00	18.00	180.00	25.00	0.00	0.00
2.800	36.01	-20.79	82.44	7.42	-10.95	0.21	157.33	18.00	180.00	25.00	0.00	0.00
2.900	36.23	-19.70	81.32	7.85	-11.59	0.21	153.67	18.00	180.00	25.00	0.00	0.00
3.000	36.50	-18.54	80.12	8.28	-12.23	0.21	150.00	18.00	180.00	25.00	0.00	0.00
3.100	36.80	-17.33	78.87	8.72	-12.87	0.22	146.33	18.00	180.00	25.00	0.00	0.00
3.200	37.15	-16.07	77.55	9.15	-13.51	0.22	142.67	18.00	180.00	25.00	0.00	0.00
3.300	37.54	-14.75	76.17	9.58	-14.15	0.22	139.00	18.00	180.00	25.00	0.00	0.00
3.400	37.98	-13.38	74.72	10.02	-14.78	0.23	135.33	18.00	180.00	25.00	0.00	0.00
3.500	38.48	-11.97	73.21	10.45	-15.42	0.23	131.67	18.00	180.00	25.00	0.00	0.00
3.600	39.03	-10.51	71.64	10.88	-16.06	0.24	128.00	18.00	180.00	25.00	0.00	0.00
3.700	39.65	-9.00	70.00	11.31	-16.69	0.24	124.33	18.00	180.00	25.00	0.00	0.00
3.800	40.33	-7.46	68.30	11.74	-17.32	0.25	120.67	18.00	180.00	25.00	0.00	0.00
3.900	41.09	-5.88	66.53	12.17	-17.96	0.26	117.00	18.00	180.00	25.00	0.00	0.00
4.000	41.92	-4.26	64.71	12.59	-18.59	0.26	113.33	18.00	180.00	25.00	0.00	0.00
4.100	42.84	-2.62	62.82	13.02	-19.22	0.27	109.67	18.00	180.00	25.00	0.00	0.00
4.200	43.83	-0.96	60.86	13.44	-19.85	0.28	106.00	18.00	180.00	25.00	0.00	0.00
4.300	44.92	0.73	58.85	13.87	-20.48	0.29	102.33	18.00	180.00	25.00	0.00	0.00
4.400	46.09	2.43	56.77	14.29	-21.12	0.30	98.67	18.00	180.00	25.00	0.00	0.00
4.500	47.36	4.13	54.62	14.71	-21.75	0.31	95.00	18.00	180.00	25.00	0.00	0.00
4.600	48.73	5.84	52.42	15.13	-22.38	0.32	91.33	18.01	179.85	24.99	-4.18	0.21
4.700	50.21	7.54	50.15	15.54	-23.01	0.33	87.67	18.09	179.03	24.94	-12.57	0.33
4.800	51.78	9.22	47.82	15.96	-23.64	0.34	84.03	18.28	177.32	24.84	-21.35	0.41
4.900	53.47	10.89	45.42	16.37	-24.27	0.35	80.41	18.59	174.85	24.73	-27.67	0.46
5.000	55.26	12.53	42.96	16.78	-24.91	0.36	76.82	19.05	171.86	24.63	-31.80	0.51
5.100	57.17	14.13	40.44	17.18	-25.55	0.38	73.29	19.64	168.88	24.10	-27.07	0.47
5.200	59.19	15.69	37.85	17.58	-26.19	4.65	69.87	20.33	166.44	23.44	-21.88	4.00
5.390	58.83	16.73	61.00	5.44	122.11	0.19	66.71	22.86	152.58	12.66	-90.38	0.40
5.490	58.11	16.96	71.96	4.78	100.13	0.41	65.51	24.22	144.31	12.13	-73.29	0.22
5.590	57.49	17.13	81.12	3.97	82.98	0.45	64.37	25.53	138.03	11.65	-52.30	0.23
5.690	56.97	17.20	88.55	3.14	65.82	0.42	63.29	26.81	133.80	11.14	-33.03	0.27
5.790	56.57	17.20	94.28	2.33	48.75	0.39	62.29	28.05	131.17	10.59	-21.07	0.31
5.890	56.29	17.17	98.30	1.51	31.68	0.37	61.38	29.26	129.38	10.00	-15.48	0.30
5.990	56.13	17.14	100.62	0.70	14.62	0.34	60.56	30.42	127.97	9.40	-12.93	0.29
6.090	56.09	17.13	101.23	0.00	0.00	0.00	59.82	31.53	126.75	8.79	-11.62	0.29
6.190	56.09	17.13	101.25	0.00	0.00	0.00	59.14	32.57	125.63	8.19	-10.76	0.29
6.290	56.09	17.13	101.26	0.00	0.00	0.00	58.54	33.56	124.60	7.58	-10.05	0.28
6.390	56.09	17.13	101.25	0.00	0.00	0.00	58.00	34.48	123.62	6.98	-9.39	0.28
6.490	56.09	17.13	101.25	0.00	0.00	0.00	57.52	35.34	122.72	6.37	-8.71	0.28
6.590	56.09	17.13	101.25	0.00	0.00	0.00	57.10	36.12	121.88	5.77	-8.00	0.28
6.690	56.09	17.13	101.25	0.00	0.00	0.00	56.73	36.83	121.12	5.17	-7.26	0.28
6.790	56.09	17.13	101.24	0.00	0.00	0.00	56.41	37.47	120.43	4.56	-6.48	0.28
6.890	56.09	17.13	101.24	0.00	0.00	0.00	56.14	38.03	119.82	3.96	-5.68	0.27
6.990	56.09	17.13	101.24	0.00	0.00	0.00	55.91	38.52	119.30	3.36	-4.85	0.27
7.090	56.09	17.13	101.24	0.00	0.00	0.00	55.72	38.93	118.85	2.76	-4.01	0.27
7.190	56.09	17.13	101.23	0.00	0.00	0.00	55.57	39.25	118.50	2.16	-3.18	0.27
7.290	56.09	17.13	101.23	0.00	0.00	0.00	55.46	39.50	118.25	1.56	-2.18	0.28
7.390	56.09	17.13	101.23	0.00	0.00	0.00	55.39	39.67	118.10	0.96	-1.23	0.39
7.490	56.09	17.13	101.23	0.00	0.00	0.00	55.36	39.76	118.08	0.00	0.00	0.00

Viewing The Reconstruction Results

The accident data produced by the above simulation will now be viewed three ways:

- numerically
- 2-D graphical view from above
- 3-D scientific visualization

Numeric

Table 3 shows the simulation results (position, velocity and acceleration) numerically for the Porsche and Audi, at 0.10 second output increments.

Inspection of the numeric data revealed the Porsche began moving from its initial accident site coordinates after 1 second, and accelerated at approximately 0.2 g for 4 seconds up to an impact speed of 17.6 mph. Its peak acceleration during impact was approximately 18.03 g at 5.250 seconds*. The duration of impact was 0.090 seconds; its separation velocity was 5.7 mph. The Porsche came to a stop 6.050 seconds after the beginning of the accident sequence.

* To document peak accelerations, the simulation was re-executed using 0.002 second output increments. See Table 4, below.

Table 4. Expanded view of numeric data between 5.100 and 5.400 seconds. During the collision phase, from 5.200 to 5.290 seconds, the output time interval is 0.002 seconds.

Time Sec	X #1 ft	Y #1 ft	PSI #1 deg	V tot #1 mph	PSI-dot #1 deg/sec	ACC #1 g	X #2 ft	Y #2 ft	PSI #2 deg	V tot #2 mph	PSI-dot #2 deg/sec	ACC #2 g
5.100	57.17	14.13	40.44	17.18	-25.55	0.38	73.29	19.64	168.88	24.10	-27.07	0.47
5.150	58.17	14.92	39.15	17.38	-25.87	0.38	71.56	19.98	167.59	23.77	-24.44	0.47
5.200	59.19	15.69	37.85	17.58	-26.19	4.65	69.87	20.33	166.44	23.44	-21.88	4.00
5.202	59.23	15.72	37.80	17.38	-22.01	5.16	69.80	20.35	166.39	23.27	-22.01	4.25
5.204	59.27	15.75	37.76	17.15	-17.14	6.34	69.74	20.36	166.35	23.09	-22.10	4.97
5.206	59.31	15.78	37.73	16.90	-11.79	6.37	69.67	20.38	166.30	22.88	-22.25	5.23
5.208	59.35	15.81	37.72	16.63	-6.43	6.72	69.61	20.39	166.26	22.67	-22.58	5.47
5.210	59.39	15.84	37.71	16.34	-0.59	7.84	69.54	20.41	166.21	22.43	-22.86	6.25
5.212	59.42	15.87	37.71	16.01	5.28	8.58	69.48	20.42	166.17	22.18	-23.38	6.77
5.214	59.46	15.90	37.73	15.65	11.96	9.76	69.42	20.44	166.12	21.90	-23.84	7.60
5.216	59.50	15.93	37.76	15.25	19.23	10.17	69.35	20.45	166.07	21.60	-24.40	7.86
5.218	59.53	15.96	37.81	14.84	26.63	10.76	69.29	20.47	166.02	21.29	-25.06	8.26
5.220	59.56	15.99	37.87	14.43	33.85	10.46	69.23	20.49	165.97	20.97	-25.76	8.01
5.222	59.59	16.01	37.94	14.00	40.89	11.57	69.17	20.50	165.92	20.65	-26.54	8.78
5.224	59.62	16.04	38.03	13.52	47.60	12.19	69.12	20.52	165.87	20.32	-27.59	9.19
5.226	59.65	16.07	38.13	13.02	54.10	12.75	69.06	20.54	165.81	19.98	28.95	9.54
5.228	59.68	16.10	38.25	12.50	60.69	13.22	69.00	20.56	165.75	19.63	-30.30	9.84
5.230	59.70	16.12	38.38	11.97	67.64	13.72	68.95	20.57	165.69	19.27	-31.71	10.15
5.232	59.72	16.15	38.52	11.41	74.50	14.61	68.90	20.59	165.62	18.90	-33.25	10.72
5.234	59.74	16.17	38.67	10.85	81.69	14.84	68.85	20.61	165.56	18.53	34.95	10.83
5.236	59.76	16.20	38.84	10.28	89.07	15.77	68.80	20.63	165.48	18.16	-36.68	11.44
5.238	59.78	16.22	39.03	9.68	96.78	16.13	68.75	20.65	165.41	17.77	-38.59	11.65
5.240	59.80	16.24	39.23	9.11	104.19	16.63	68.70	20.67	165.33	17.39	-40.57	11.97
5.242	59.81	16.26	39.45	8.50	111.63	17.29	68.65	20.69	165.25	17.01	-42.81	12.37
5.244	59.82	16.29	39.68	7.90	119.01	17.13	68.61	20.71	165.16	16.63	45.14	12.26
5.246	59.83	16.31	39.92	7.34	126.05	17.61	68.57	20.73	165.07	16.26	-47.13	12.57
5.248	59.84	16.32	40.18	6.80	133.34	18.38	68.53	20.76	164.97	15.89	-49.21	13.10
5.250	59.84	16.34	40.46	6.29	140.86	18.97	68.49	20.78	164.87	15.52	-51.45	13.51
5.252	59.85	16.36	40.75	5.85	148.77	18.58	68.45	20.80	164.76	15.15	-53.66	13.23
5.254	59.85	16.38	41.05	5.51	156.31	18.97	68.41	20.83	164.65	14.80	-55.73	13.48
5.256	59.85	16.39	41.37	5.26	164.08	18.84	68.38	20.85	164.54	14.47	-57.86	13.36
5.258	59.84	16.41	41.71	5.14	172.07	19.07	68.34	20.88	164.42	14.15	60.01	13.50
5.260	59.84	16.42	42.06	5.15	180.17	19.02	68.31	20.91	164.30	13.85	-62.21	13.45
5.262	59.83	16.43	42.43	5.27	187.38	17.81	68.28	20.93	164.17	13.59	-64.77	12.50
5.264	59.82	16.45	42.80	5.27	187.57	14.47	68.25	20.96	164.04	13.52	-69.36	9.97
5.266	59.81	16.46	43.18	5.29	185.55	14.11	68.22	20.99	163.90	13.51	-74.24	9.74
5.268	59.79	16.47	43.55	5.35	182.52	12.18	68.20	21.02	163.74	13.54	-78.92	8.34
5.270	59.78	16.47	43.91	5.44	179.17	10.60	68.17	21.05	163.58	13.57	-82.88	7.15
5.272	59.77	16.48	44.26	5.51	174.62	8.25	68.15	21.08	163.41	13.62	85.96	5.56
5.274	59.75	16.49	44.61	5.59	170.48	6.36	68.12	21.11	163.24	13.66	-88.04	4.09
5.276	59.73	16.49	44.94	5.64	166.56	4.52	68.10	21.14	163.06	13.69	-89.76	2.72
5.278	59.72	16.50	45.27	5.67	162.88	3.15	68.07	21.17	162.88	13.72	90.90	1.72
5.280	59.70	16.50	45.60	5.68	160.06	1.85	68.05	21.20	162.70	13.74	-91.68	0.82
5.282	59.69	16.50	45.91	5.70	158.54	0.99	68.02	21.24	162.51	13.72	-91.94	0.47
5.284	59.67	16.51	46.23	5.71	157.25	0.47	68.00	21.27	162.33	13.71	-92.10	0.40
5.286	59.65	16.51	46.54	5.71	156.39	0.17	67.97	21.30	162.14	13.69	-92.14	0.54
5.288	59.64	16.52	46.86	5.71	155.59	0.14	67.95	21.33	161.96	13.67	-92.16	0.56
5.290	59.62	16.52	47.17	5.72	154.85	0.11	67.93	21.36	161.78	13.64	-92.17	0.59
5.300	59.54	16.54	48.70	5.71	151.40	0.08	67.80	21.52	160.85	13.53	-92.17	0.63
5.310	59.46	16.56	50.19	5.68	148.07	0.18	67.68	21.68	159.93	13.42	-92.21	0.66
5.320	59.38	16.58	51.66	5.65	144.81	0.19	67.56	21.83	159.01	13.31	-92.25	0.65
5.330	59.30	16.60	53.09	5.61	141.56	0.19	67.44	21.98	158.09	13.20	-92.27	0.64
5.340	59.22	16.62	54.49	5.58	138.32	0.19	67.32	22.13	157.16	13.10	92.27	0.63
5.350	59.14	16.64	55.86	5.55	135.08	0.19	67.20	22.28	156.24	13.00	-92.20	0.61
5.360	59.06	16.66	57.19	5.52	131.83	0.19	67.08	22.43	155.32	12.91	-92.03	0.57
5.370	58.98	16.68	58.49	5.49	128.59	0.19	66.96	22.57	154.40	12.82	-91.70	0.52
5.380	58.91	16.71	59.76	5.47	125.35	0.19	66.83	22.72	153.49	12.74	91.17	0.46
5.390	58.83	16.73	61.00	5.44	122.11	0.19	66.71	22.86	152.58	12.66	-90.38	0.40
5.400	58.75	16.75	62.21	5.41	118.92	0.20	66.59	23.00	151.68	12.60	-89.32	0.34

Inspection of Table 3 also revealed the Audi began at 25 mph from its initial accident site coordinates and travelled at a constant speed for approximately 4.6 seconds. At that time, the Audi's driver took his foot off the throttle and began steering to the left, causing the vehicle's speed to drop to 23.4 mph at impact. Its peak acceleration during impact was approximately 13.51 g at 5.250 seconds. The duration of impact was 0.090 seconds; its separation velocity was 13.6 mph. The Audi came to a stop 7.490 seconds after the beginning of the accident sequence.

Inspection of Table 4 reveals the same data at 0.002 seconds during the collision pulse, which lasted from 5.200 to 5.290 seconds.

Advantages and Disadvantages

The advantages of viewing the data numerically were as follows:

- Position, velocity and acceleration data could be grouped and viewed as a function of time.
- All the data were neatly organized and viewable by others (i.e., good documentation, available for scrutiny)
- Since the data were *quantitative*, they were readily usable for performing related calculations (e.g., perception/reaction time, avoidability)

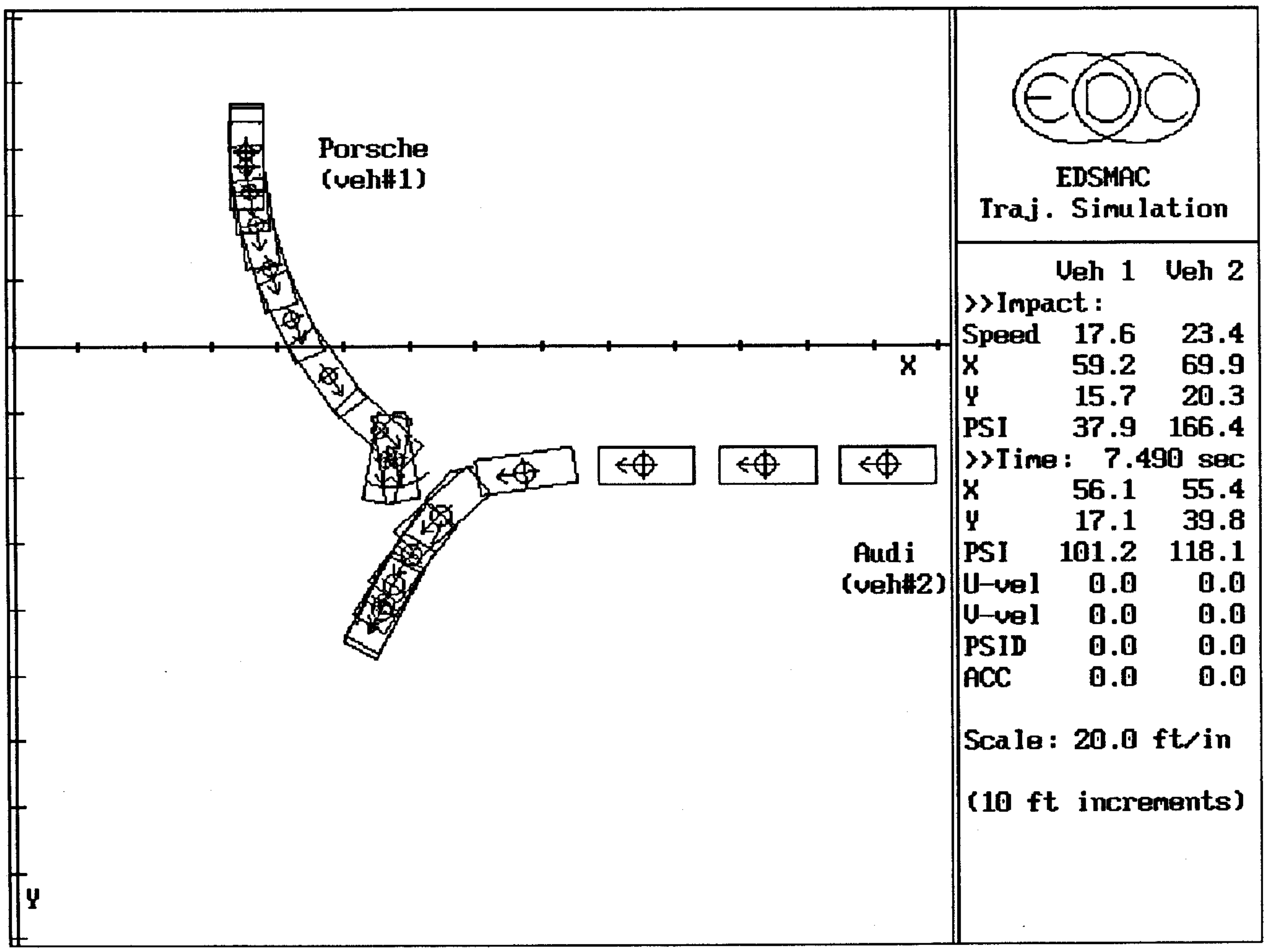

Figure 2 - 2-D graphical (plan) view of accident data, showing positions at user-specified time intervals. Numeric data are also displayed, providing documentation of results.

The disadvantages of viewing the data numerically were:

- The human mind was not capable of fully absorbing and understanding this amount of data.
- The correctness and reasonableness of a driver's judgement was not intuitive from the table, and required interpretation by the researcher.
- Since the data applied to the vehicle's CG, issues relating to a vehicle's *size* (e.g., the clearance between two vehicles during a near-miss) required additional consideration by the researcher.

2-D Graphical View

Figure 2 shows the same simulation results in a scaled, 2-D graphical view from above. The vehicles were shown as rectangles with heading vectors, and printed in *storage mode* (i.e., the trace of all vehicle positions is displayed) at 0.5 second increments.

The simulation could also be displayed (on the computer screen) in *animation mode*, which provided a moving image of the vehicles, shown as rectangles at user-selected time increments. The table along the right edge of the screen (see figure 3) displayed the current values of position, velocity and acceleration. In figure 3, interim results were displayed for the vehicles at 4.5 seconds (0.7 seconds before impact). This view showed the position of each vehicle at the *approximate* moment when the driver of the Audi first saw the Porsche, 1/2 second before steering to the left.

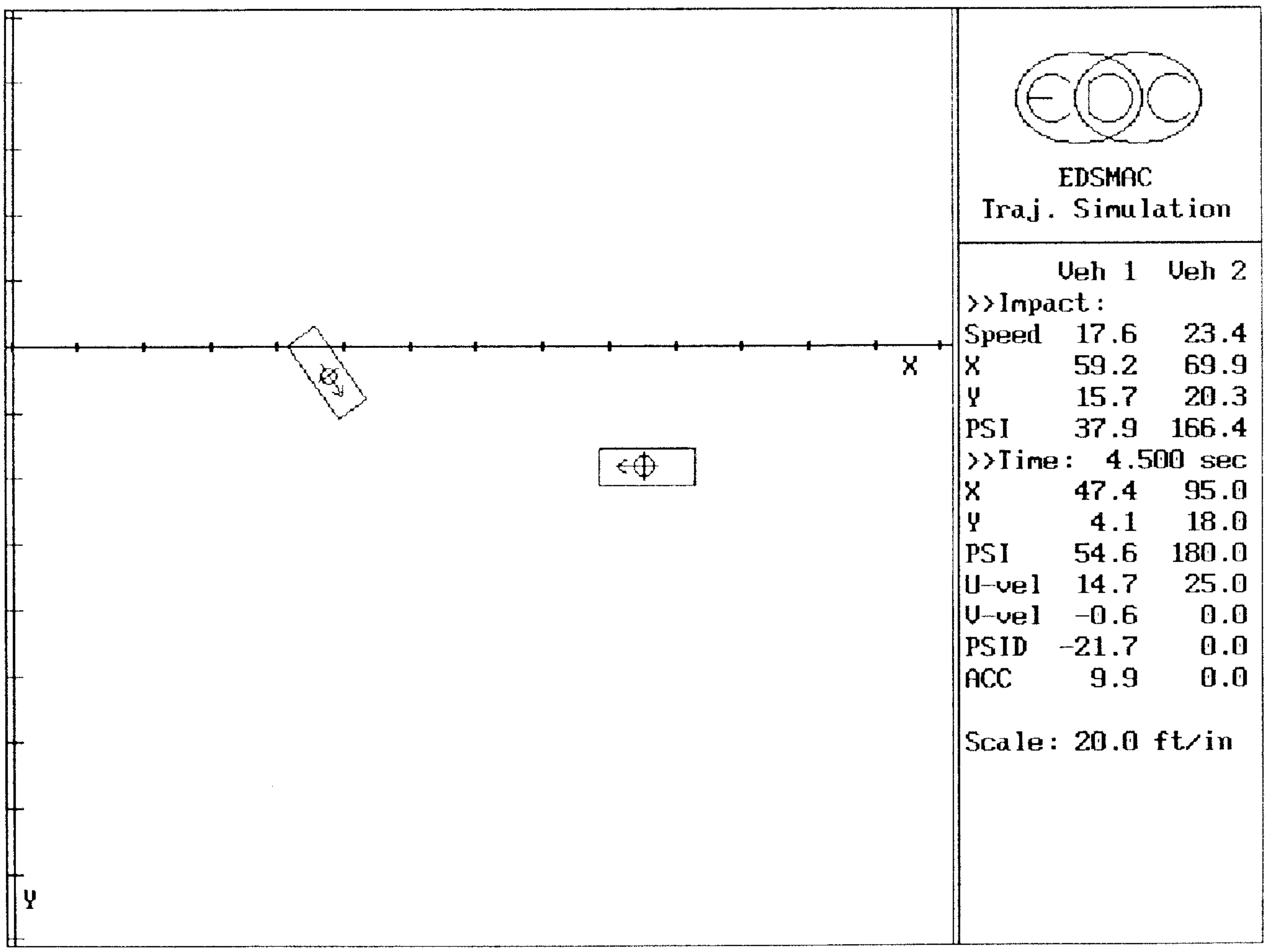

Figure 3 - 2-D graphical (plan) view of accident data, showing positions, velocities and accelerations 0.7 seconds before impact.

Advantages and Disadvantages

The advantages of viewing the data in a 2-D graphical format were as follows:

- Compared to the numeric view, the position data were more easily interpreted by the researcher
- The spacial relationship between vehicles was more readily apparent
- The element of motion was introduced, especially through the use of video (either VCR or Laser-Disc). Thus, accident causation factors were more easily interpreted by the researcher.
- Numeric results *may* be displayed simultaneously with the vehicles' movements (as shown in figures 2 and 3). Like the numeric view, this provided good documentation and made the data available for scrutiny).

The disadvantages of a 2-D graphical view were:

- The position of the view was static (overhead); the view from other perspectives is not possible.
- The vehicles, shown as rectangles, did not *look* like real vehicles. Interpretation by the viewer was required.
- Environmental factors, such as hills, curves and other vision obstructions, and qualitative aspects relating to causation and avoidability (e.g., size, time and distance) still required interpretation by the researcher
- The numeric basis for results may *not* be available for scrutiny; thus, the realism might be used to mask a weak or physically impossible reconstruction (this important subject is discussed below; see **Discussion**).

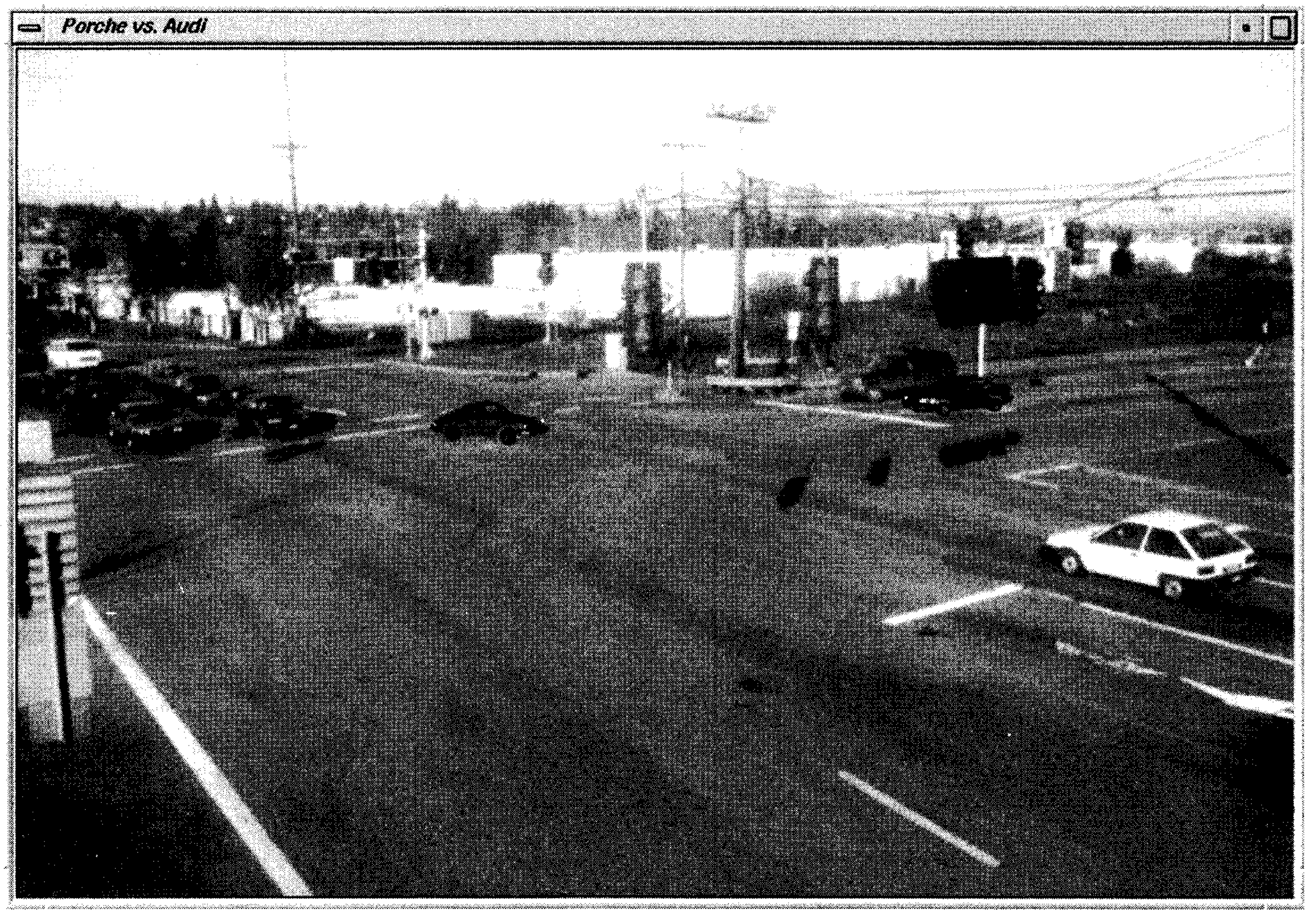

Figure 4 - 3-D scientific visualization of accident data, showing a prespective view of the accident 0.7 seconds before impact.

3-D Scientific Visualization

The same simulation results were displayed at 0.033 second intervals using 3-D scientific visualization. Figure 4 shows a perspective view of the accident site as the vehicles approached each other (t = 4.5 seconds; 0.7 seconds before impact). This view may be compared with figure 3. Again, this view shows the position of each vehicle at the *approximate* moment when the driver of the Audi first saw the Porsche, 1/2 second before steering to the left. Key Results windows (not shown in figure 4) may also be displayed, showing each vehicle's current position, velocity and acceleration.

Advantages and Disadvantages

The advantages of viewing the data in the form of a 3-D scientific visualization were as follows:

- Realism. All the *qualitative* factors pertaining to accident causation (size, spacial relationship, motion) were optimized using 3-D scientific visualization. (Video hardware was required to produce a videotape.)
- Variable perspectives were possible, allowing the researcher to establish the approximate view available to the drivers and witnesses.
- Numeric results *may* be displayed simultaneously with the vehicles' movements (good documentation, available for scrutiny).

The disadvantages of 3-D scientific visualization were:

- The numeric basis for results may *not* be available for scrutiny; thus, the realism may be used to mask a weak or physically impossible reconstruction (this important subject is discussed below; see **Discussion**).
- The cost may be prohibitive in some cases (see **Data Requirements**).

Data Requirements

The data requirements for *any* analysis depend on two factors: the *analysis method* and the *presentation method*. In this example, the analysis method was EDSMAC for all three data views. Thus, the required data were the same:

- vehicle data (2-D dimensions, inertias, tire data and crush stiffnesses)
- scene data (2-D coordinates for initial, impact and rest positions)
- tire/road friction data (slide coefficient of friction)

These same data sources were also used for the EDCRASH reconstruction, which provided the impact velocities required by the simulation. Again, it is important to note that the data sources were the same for all three views.

The presentation method for each view was different. In the numerical and 2-D graphical views, the presentation method required no additional data, although 2-D graphical views are often overlaid on top of a scaled, accident site diagram.

In the 3-D scientific visualization, the following additional data were required:

- an accident site photograph taken from a known, earth-fixed location
- 3-D image files for both vehicles

Accident site photographs are routinely taken by the investigator as part of the documentation process. 3-D image files may be part of a vehicle library or obtained from various vendors [1]*.

Discussion

The use of an accident site photograph as the background was the simplest and most accurate way to produce a well-documented scientific visualization. Other than 3-D image files for the vehicles, the method required only the typical information that is routinely gathered during an investigation (see above).

Different perspectives could be easily provided if additional photographs (with known, earth-fixed camera locations) were available.

There were some significant limitations to the use of background photographs in a scientific visualization. These limitations were as follows:

- *The view must be static.* Because a photograph is viewed from a fixed point, it was not possible to show the accident as seen from a moving vehicle, nor was it possible to pan or zoom. In addition, the earth-fixed coordinates of the camera position and the center of the photograph must be known.
- *The view must be unobstructed.* Because a photograph has no actual depth, a vehicle which traveled behind another object in the photograph (such as a parked car) would appear to go over the top of it. This prevented the use of photographic backgrounds for busy accident sites (e.g., downtown intersections).
- *The world must be flat.* Unless 3-D road surface geometry was provided from another source, changes in elevation were not accommodated.

The above limitations may be eliminated by the use of an environment created by a 3-D editor. This method had some distinct advantages over the use of a background photograph. In particular, one of the greatest benefits of a rendered, 3-D environment was that the accident sequence was viewable from any location, including a moving vehicle. Once the environment was created, virtually *any* view could be quickly accommodated. The view could also include obstructions and needed not be flat. The 3-D environment could also feed physical, 3-D environment information (surface slopes and friction data) directly to the calculation method (see references 2, 3 and 4).

However, the use of environments produced by a 3-D editor had two disadvantages. First, additional time was

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

required to produce a 3-D environment, and second, a 3-D environment required the researcher to collect and document additional data (which, in a photograph tends to be "self-documenting"). Typically, the following additional information was required:

- 3-D accident site topology, possibly requiring a survey of the accident site
- locations of pertinent accident-related artifacts
- locations of pertinent near-by objects (trees, buildings, cars,...)
- *3-D image data* for each of the above artifacts and objects

The process of producing a 3-D environment which included artifacts and objects created two additional questions: *What objects are considered pertinent?* and *How accurately must these objects be drawn?* The Society of Automotive Engineers (SAE) Accident Investigation Practices Committee has formed a Task Group to investigate these questions. One of the stated purposes of that SAE Task Group is to provide the reconstruction community with definitions for requirements of 3-D environments used in scientific visualizations [5].

The SAE Accident Investigation Practices Committee Task Group on Accident Reconstruction Terminology provided important definitions for *simulation*, *animation* and *scientific visualization*:

- *Simulation* - a mathematical model that uses initial conditions, physical properties and the laws of physics to predict or model motion reproducing a sequence of events
- *Animation* - the process by which the movement of objects is illustrated
- *Scientific Visualization* - the process by which scientific data are illustrated

Because videotaped accident sequences are sometimes shown to a jury of laypersons whose responsibility it is to assign fault, these definitions become important and useful. These definitions allow one to distinguish between a *scientific visualization* and an *animation*. The medium for both is usually videotape, and the two methods might appear to the untrained eye to be the same. However, the movement of objects in a scientific visualization is always based on the integrated values of accelerations calculated according to Newton's 2nd Law ($\Sigma F = ma$). This is assured when motion is based on a valid simulation. However, the movement of objects in an animation may be selected according to the desires of the animator; thus, the motion may or may not be valid. When videotape is used in accident reconstruction, it is important that the numeric data used to produce the videotape be well-documented, available and subject to scrutiny.

SAE is currently in the initial stages of developing a recommended practice for engineers and scientists who produce scientific visualizations (see reference 5).

Summary

This paper has shown three methods of viewing scientific data: numerically, 2-D graphics and 3-D scientific visualization. The advantanges and disadvantages of each method were presented. Data requirements for each method were explored and the limitations were discussed.

In general, numeric data provided the most thorough quantitative information regarding accident causation, a 2-D graphical view provided an improved data interpretation capability, and 3-D scientific visualization provided the most qualitative information. The best analysis method was a combination of numeric and 3-D scientific visualization.

By using 3-D scientific visualization for the case described in this paper, it was possible to show the accident as it occurred (according to the researcher's reconstruction) from a perspective view. Because a 3-D environment model was not used, it was not directly possible to study obstructions to visibility between moving vehicles.

Scientific visualization was best-suited to accidents involving issues related to 3-D environmental factors (i.e., vision obstructions) and avoidability.

Conclusions

1. 3-D, scientific visualization combined with numeric data provided the most comprehensive method currently available for accident analysis.

2. For scientific visualization to be accepted by the scientific community, the underlying numeric data must be made available for scrutiny.

Trademarks

EDCRASH and EDSMAC are trademarks of Engineering Dynamics Corporation.

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1. Viewpoint Animation Engineering, Orem, UT, 1993.

2. Day, T.D., "A Computer Graphics Interface Specification for Studying Humans, Vehicles and Their Environment," SAE Paper No. 930903, March, 1993.

3. *HVE Developer's Toolkit*, Engineering Dynamics Corporation, Beaverton, OR 1994 (currently under development).

4. Day, T.D., "An Overview of the HVE Developer's Toolkit," SAE Paper No. 940923, March, 1994.

5. Grimes, W.D., "Classifying the Elements in a Scientific Animation," SAE Paper No. 940919, March, 1994.

Discussion by Wesley D. Grimes
SAE Paper #940922
Terry D. Day, Author
<u>The Scientific Visualization of Motor Vehicle Accidents</u>

This paper presents the results of a collision reconstruction and discusses the different possible presentations available to convey the results to an audience. The author summarizes the presentation methods into three categories: viewing numerical results, two-dimensional graphical "snap shots" of the results, and three-dimensional dynamic visualization.

The first, simply viewing numerical results, requires a great deal of interpretation by the audience. In the case presented, it is extremely difficult to visualize the closing speed of the two vehicles and the spatial relationship by examination of the numerical results alone. Some type of additional information is required to fully comprehend the event, either additional calculations or other visual cues.

In the second method, static plan-views are used to produce a scaled diagram of the spatial relationship of the two vehicles with respect to each other. The dynamic relationship is still not apparent and the spatial relationship to the roadway and environment is not easily visualized by the audience.

The third method, three-dimensional dynamic visualization, utilizes all the available information; the dynamic relationship of the vehicles to each other as well as to the environment, different views of the same event, and other visual cues to convey the maximum amount of information to the audience.

Unfortunately, the case presented does not fully reveal the advantages of using three-dimensional dynamic visualization, there are no vertical components of the analysis discussed; such as line of sight, roadway grades, etc. However, to fully document these advantages would, more than likely, require a more sophisticated analysis and thus make presentation by the two other methods, for comparison, virtually impossible.

It is important to understand, the real advantage of three dimensional visualization, either dynamic or static, is in utilizing this method as a tool in the analysis phase; not just presenting the final results, but as an aid to producing the final results. The best scientific model for understanding events in a three-dimensional world is three-dimensional.

The author also presents a good discussion regarding the documentation of the elements used and relied upon in any scientific presentation. Each element must be thoroughly documented so that the presentation may be scrutinized in accordance with the scientific principles being shown.