Using HVE to Simulate a Nine Vehicle Accident Involving a Heavy Truck

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Abstract
Multi-vehicle high-speed accidents that have a high number of vehicle collisions and interaction with a fixed obstacle in the environment are ideally suited for simulation. This paper covers a nine-vehicle collision involving a heavy truck and eight passenger vehicles. We constructed a 3-D environment in AutoCAD based on survey data, along with custom vehicle geometries not available in the HVE database. The final simulation using HVE's EDSMAC4 algorithm matched the physical evidence remarkably well. In addition, HVE allowed us to compare various impact speeds to show why certain scenarios did not match the physical evidence. The resulting simulations were used successfully in trial.

Figure 1: Path of truck


Figure 2: View from top of hill

Accident Summary
The accident occurred at the intersection of 43rd Avenue and Olympic Avenue in San Mateo, California on September 23, 2008. A 1995 International 4900 truck (V-1) rolled almost a quarter mile down a hill from the intersection of 43rd Avenue and Edison Street to the point of impact, as shown in Figure 1. Figure 2 shows the view from the top of the hill where the truck began rolling. According to the driver, the truck was in neutral and the engine was not running during the descent. At the intersection of 43rd Avenue and Olympic Avenue the truck collided with a 2007 Ford Escape (V-2). The Ford Escape was pushed into a 2006 Lexus RX400H (V-3). The truck continued into the parking lot of a grocery store, and subsequent impacts occurred with six other parked vehicles: a 2003 Chevrolet Tahoe (V-4), a 2006 Volvo XC90 (V-5), a 1997 Mercedes C230 (V-6), a 2000 Toyota Echo (V-7), a 1999 Mazda 626 (V-8), and a 1996 Honda Civic (V-9). At the scene the truck was found in neutral with the parking brake disengaged. The Ford Escape was carried all the way from the initial impact to the truck's rest position and came to rest wedged

between the truck and a shopping cart corral. Figure 3 shows photographs of the rest positions of several of the vehicles, the rest position of the Ford Escape, and the rest position of the roofing truck.

The defense attorney retained Principia Engineering to determine whether or not braking was applied during the descent of the truck. Answering this question requires knowing the speed of the truck at the point of impact and comparing this result to the truck's speed without braking. This is a complex accident involving impacts between nine vehicles and a fixed obstacle in the environment, making it difficult to analyze by solving physics equations by hand or computer spreadsheet. The HVE (Human Vehicle Environment) program, however, is an ideal simulation software package for analyzing this accident to determine the impact speed of the truck. Running an HVE simulation requires several steps: building the accident environment, building the vehicles, estimating the vehicles' initial positions, marking the vehicles' final rest positions, and running the simulation until the best match is found with the physical evidence.

Figure 3: Accident photos

Building the Environment

The investigating officers used a Nikon NPL-362 Total Station to survey the physical evidence at the scene. Using this information, we created a computer drawing to scale showing the roadway, the tire friction marks, gouge marks, and vehicle rest positions. Figure 4 shows the physical evidence and the vehicle rest positions.

The surveyed data did not include a shopping cart corral which was just to the left of V-2's rest position. Scene photographs show the rest position of V-2 wedged between a shopping cart corral and V-1 make it clear that simulating the interaction between V-2 and the corral is critical to the accuracy of our results. During our scene inspection we measured the location and dimensions of this shopping cart corral. Figure 5 shows the location of the corral along with the physical evidence from Figure 4. The HVE environment was constructed by making surfaces from the surveyed data and extruding them to create islands, sidewalks, buildings, and the shopping cart corral. The parking stall lines, crosswalks, limit lines, and asphalt roadway were created as surfaces. We also placed the outlines of the vehicle rest positions in the HVE environment as a reference for the simulation. Figure 6 shows the final environment in AutoCAD before export to HVE. Figure 7 shows the final environment in HVE. The colors, textures, trees, and stop sign were all added in the HVE environment editor.

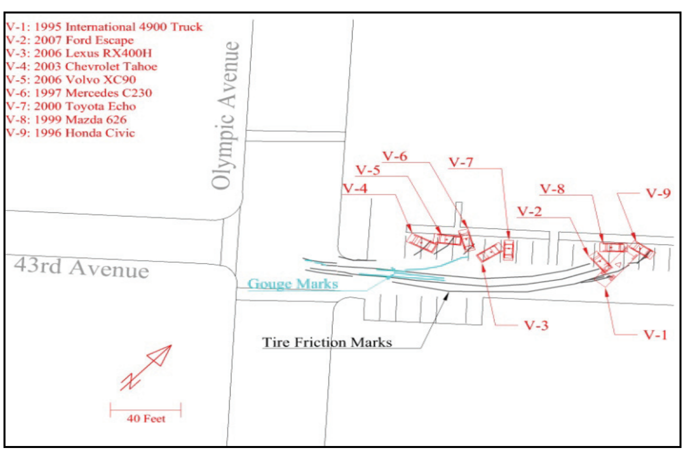

Figure 4: Computer drawing of scene, vehicle rest positions, and physical evidence

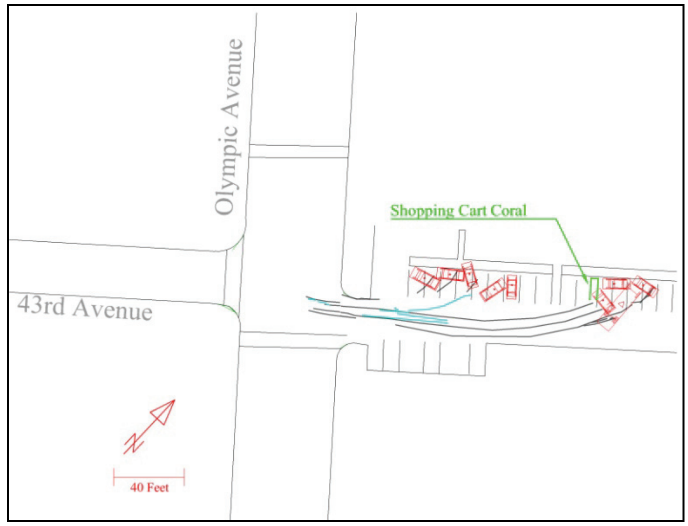

Figure 5: Shopping cart corral location

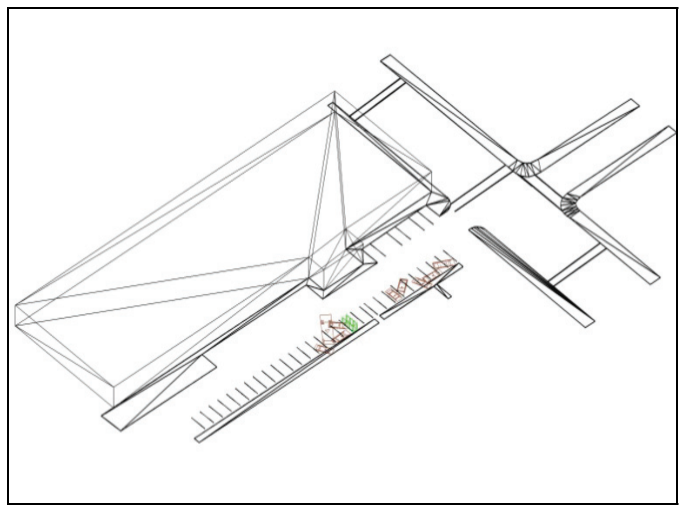

Figure 6: AutoCAD drawing of environment

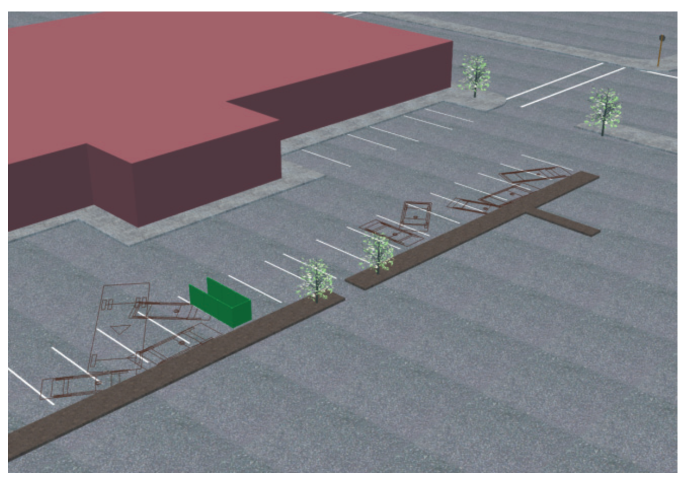

Figure 7: HVE final environment

Building the Vehicles

We created a 3-D model of the International 4900 truck by modifying a computer model of a box truck purchased from 3dcadbrowser.com. Figure 8 shows the original box truck model. We modified the original truck to the correct dimensions and color of the incident truck. In addition, certain features were removed from the original, such as the side door on the cargo box. The final HVE vehicle is shown in Figure 9.

The remaining eight vehicles were either in the HVE vehicle database or were made by modifying existing vehicles. We obtained the parameters for the heavy truck through direct measurements of the vehicle. This included the width, length, wheelbase, and weight. The dimensions and weights for the other vehicles were obtained using Expert AutoStats. We used class appropriate stiffness values for all vehicles. The weights and dimensions for all the vehicles are given in Table 1. We placed an SAE J850 fixed barrier with a width and length of 20 inches at the corner of the shopping cart corral. I removed the body of the fixed barrier so the final simulation would only show the image of the shopping cart corral.

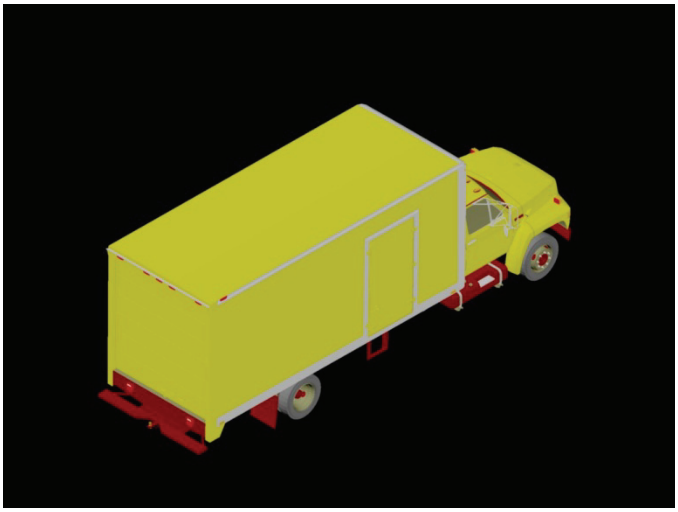

Figure 8: Original CAD model of box truck

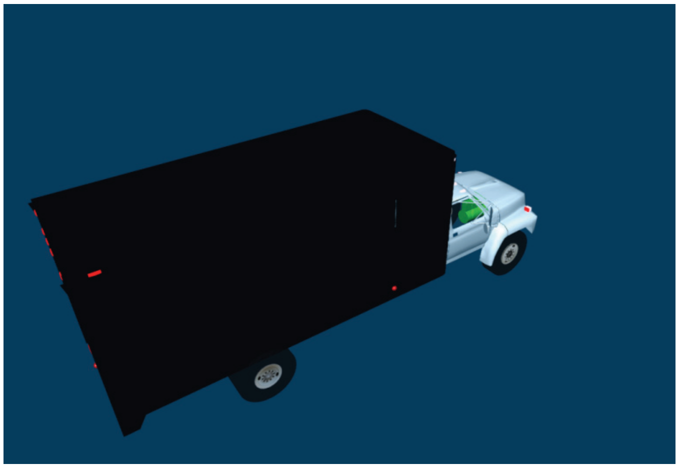

Figure 9: Final HVE model of incident roofing truck

Vehicle	Weight (lb)	Front Axle Location from C.G. (in)	Rear Axle Location from C.G. (in)	Overall Length (in)	Overall Width (in)
1995 International 4900	21700	123.8	103.2	360	96
2007 Ford Escape	3442	43.3	59.7	173	70
2006 Lexus RX400H	4325	49.2	57.8	187	73
2003 Chevrolet Tahoe	4828	55.7	60.3	199	79
2006 Volvo XC90	4700	53.1	59.9	189	74
1997 Mercedes C230	3195	47.7	58.3	177	68
2000 Toyota Echo	2020	37.2	55.8	163	65
1999 Mazda 626	2888	39.9	65.1	187	69
1996 Honda Civic	2388	39.1	63.9	175	67

Table 1: Vehicle properties

Running the Simulation

We used the EDSMAC4 algorithm for simulating this accident. Running the simulation requires placement of each of the vehicles in their initial positions. We determined the initial locations of all the vehicles based on the rest positions of the vehicles and the combination of the tire friction marks and gouge marks shown in Figure 4. Figure 10 shows the initial position of all nine vehicles at the time of impact between the roofing truck and the Ford Escape.

All vehicles used in the simulation had appropriate initial conditions. We used an initial speed for the Ford Escape (V-2) of 10 mph with a hand-wheel angle of 120 degrees, which was appropriate for turning into the parking lot. The Lexus RX400H (V-3) was stopped at the parking lot entrance waiting to pull out into the street. We assumed all the parked vehicles (V-4 through V-9) had the transmission in park or were in gear with the parking brakes set. We used drag factors of half the available friction for the appropriate axles on the parked vehicles. The purpose of this was to prevent free rolling wheels on the parked vehicles. Since the wheels of the parked vehicles were pushed laterally, the simulation was insensitive to the amount of braking applied to the drive wheels of the parked cars. We assumed that no braking was applied after impact, for the vehicles driven at the time of the accident.

We adjusted the truck's impact speed until the rest positions were most consistent with the measured rest positions of the nine vehicles. An impact speed of 40 mph was most consistent with the rest positions of all nine vehicles. Figure 11 through Figure 14 show the path of the vehicles from the time of impact in two second increments. Figure 15 depicts the simulated rest positions of all nine vehicles. The results are remarkably consistent with the measured rest positions of all nine vehicles. The shopping cart corral was necessary to catch the Ford Escape and wedge it between the truck's rest position and the corral. Without the corral in the simulation the Ford Escape came to rest at the front of the International 4900 truck (V-1).

Figure 10: HVE environment with initial positions of vehicles

Figure 11: Impact location

Figure 13: 4 seconds after impact

Figure 12: 2 seconds after impact

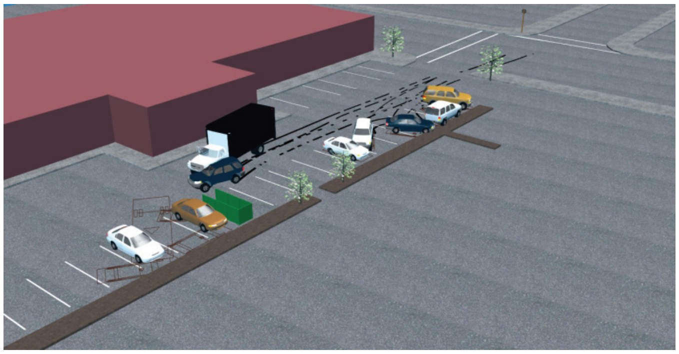

Figure 14: 6 seconds after impact

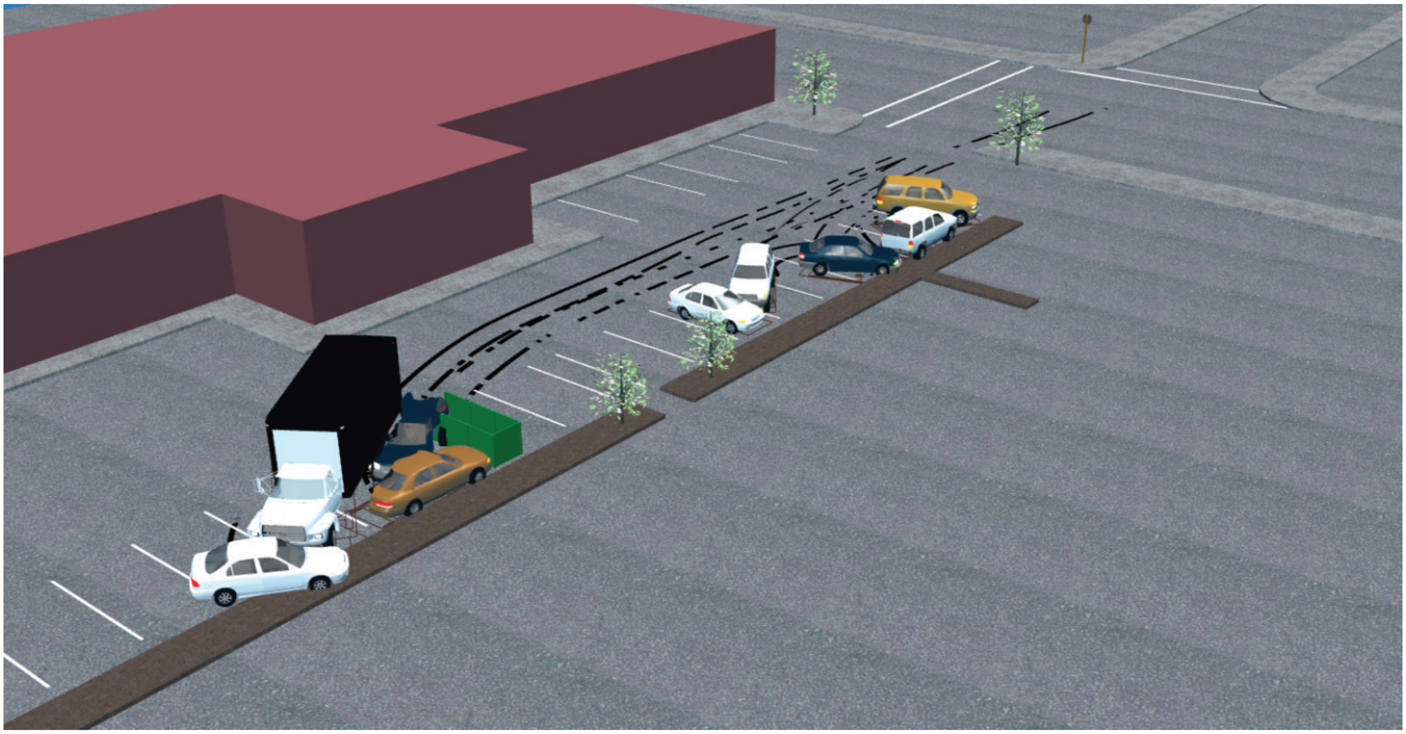

Figure 15: Simulated rest positions

Speed without Braking

We measured the slope of the road at several points along the truck's path to determine the speed of the truck without braking. We calculated the speed of the truck without braking using the measured slope of the road, the rolling resistance of the truck, and the aerodynamic drag. The calculations predict the speed at the point of impact without braking would be 57 mph. The red line in Figure 16 shows the speed of the truck without braking as it travels down the roadway. The 40 mph impact speed obtained from the HVE simulation is shown by the blue dot. Without braking, the 40 mph impact speed of the truck is reached before it is halfway down the hill. This result indicates that the driver applied some braking as the truck went down the hill.

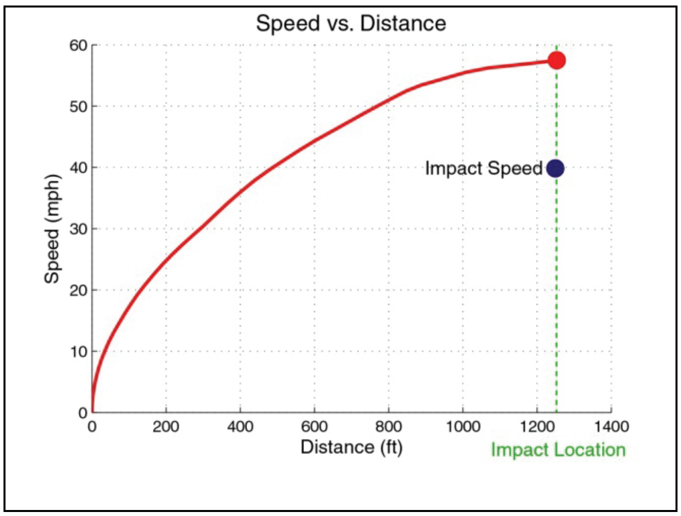

Figure 16: Speed without braking

Using HVE for "What If" Scenarios

Although Figure 16 shows that there is a 17 mph difference between the impact speed from the HVE simulation and the speed without braking, this difference is not a significant speed differential. Energy is related to the square of velocity, and as a result the truck traveling at 57 mph would have twice the energy as a truck traveling at 40 mph. In order to illustrate this we used the HVE simulation and only changed the impact speed of the truck from 40 mph to 57 mph. The results clearly indicate that the energy is too high, and all the vehicles are pushed past their respective rest positions. Figure 17 and Figure 18 show the rest positions at an impact speed of 40 mph and 57 mph, respectively. A side-by-side video of these two impact speeds was a convincing exhibit used at trial to show that a 57 mph impact speed is much too high to be consistent with this accident. California Superior Court admitted all HVE simulation videos as trial exhibits.

Figure 17: Simulation results at 40 mph

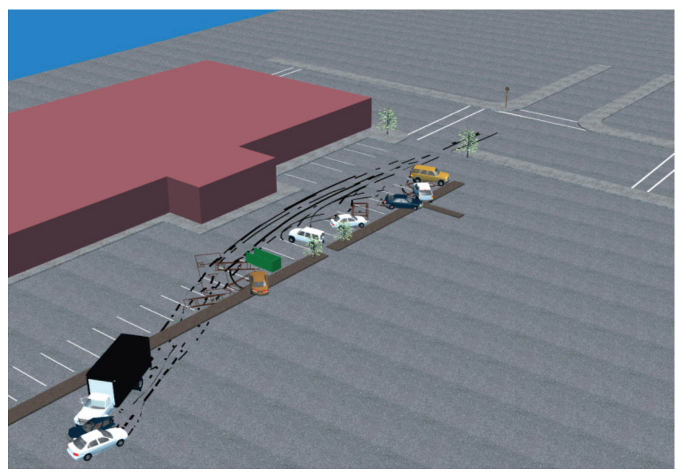

Figure 18: Simulation results at 57 mph

Conclusions

We used HVE's EDSMAC4 algorithm to simulate a nine vehicle collision. An impact speed of 40 mph for V-1 most closely matched the measured rest positions of all nine vehicles. Including the shopping cart corral as a fixed obstacle was necessary for matching the rest position of the Ford Escape (V-2). We compared the simulated impact speed with V-1's impact speed if it had freely rolled down the hill from the top of 43rd Avenue. The truck's freely rolling impact speed of 57 mph has twice the energy as a truck travelling at 40 mph. We used HVE to show that an impact speed of 57 mph is too fast and does not closely match the rest positions of the nine vehicles. Given more time and a larger budget it would be interesting to model the hill of 43rd Avenue in HVE and simulate the entire descent of the truck rather than calculating the speed based on the slope and distance travelled from the top of the hill.

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