

Collection of Field Data and Special Effects to Enhance HVE Simulations of Large Commercial Vehicle Collisions

Lawrence Jackson, P.E., Kristin M. Bolte, Ph.D., Shane Lack
National Transportation Safety Board

ABSTRACT

Many of the highway crash investigations undertaken by the National Transportation Safety Board involve collisions of several large vehicles, large vehicle rollovers, or other highly dynamic and complex scenarios. The collision simulations were enhanced with detailed scene and vehicle documentation. A variety of tools were used in an effort to best replicate the physical evidence at the scene and the crush characteristics of the vehicles within the HVE¹ system. The purpose of this paper was to detail the large commercial vehicle crashes simulated using HVE and associated 'special effects' in an effort to address safety issues.

INTRODUCTION

The primary mission of the Safety Board is to investigate accidents, to determine probable cause, and to make recommendations to prevent accidents and/or mitigate the severity of the accidents and resulting injuries. The Safety Board conducts investigations and develops simulations to aid in the identification of safety issues such as roadway design, human factors, vehicle design and crashworthiness, along with issues related to occupant protection. The seriousness and complexity of these accidents require detailed modeling and simulation to accurately represent the

accident scenarios. The purpose of this paper is to illustrate the methods for collecting and displaying accident data to accurately represent the accident scenarios and enhance HVE simulations.

Six recent highway investigations have involved either a collision of a large vehicle or a single, large vehicle crash. A short time ago, the Safety Board designated a special team of investigators to document the forensic evidence at the crash scene, to map the topography and roadway design of the scene and to document the damage to the vehicle as compared to an exemplar vehicle. Many times, the damage to the vehicle is so severe that traditional hand measurements are not feasible.

Safety Board investigations typically involve severe crashes with significant damage to the vehicle and/or loss of life. During single vehicle crashes where the involved vehicle is a motor coach, severe damage was identified to either the roof or the undercarriage of the vehicle. Furthermore, these crashes mainly occurred on portions of road and roadside that had dramatic changes in topography over a short distance. These crashes were challenging to simulate due to the complexity of the vehicle and the complexity of the environment with which the vehicle interacted. Collisions of large vehicles also presented challenges due to the size of the vehicles and the duration of the events. Detailed model construction was essential to

accurately replicate the damage to the vehicles. At times, separation of the body from the chassis occurred during the collision sequence resulting in more complex dynamics. These simulations provide an approach for the creation of complex, large vehicle models, scene models, and the resulting vehicle dynamics. Special effects were also added to enhance the simulation and the general understanding of the crash scenario and survivability issues.

A variety of programs were used to create the vehicle models, the accident scene, and in some cases, the damaged vehicle models. These programs include AutoCAD2000², AutoCAD Land Development³, 3D Studio Max⁴, and Corel Photo Paint⁵. All of the products of these programs can be imported into the HVE system. In addition, several of the Media Tools available in the SGI O2^{*} workstation were used to enhance the simulation

The purpose of this paper was to detail the large commercial vehicle crashes simulated using HVE and associated 'special effects' in an effort to address safety issues. The rest of this paper discusses specific commercial vehicle simulations, the development of models, unique simulation problems, and special effects utilized.

NEW ORLEANS – MAY 9, 1999

About 9:00 a.m. on May 9, 1999, a 55-passenger motor coach was traveling eastbound on Interstate 610, in New Orleans, Louisiana. The bus, with 43

* The Silicon Graphics® O2® visual workstation uniquely integrates high-quality graphics and powerful processing with built-in video in an affordable entry-level UNIX® system.

passengers, departed the right side of the highway, crossed the improved shoulder, and entered the grassy side slope alongside the shoulder. As the bus continued in the side slope it struck the terminal end of a breakaway cable guardrail, vaulted over a depressed golf cart walkway, collided with the far side of the embankment, and slid upright, to its final rest position (see Figure 1). Twenty-two passengers were fatally injured, nine of the fatally injured and the driver who survived, were ejected. All ten ejectees were found on the grass at or near the front of the bus. The driver and 21 passengers sustained minor to critical injuries and were transported to four area hospitals.



Figure 1: A photograph showing the final rest position of the accident bus after it impacted the embankment above the golf cart underpass.

The accident site was mapped by the New Orleans Police and supplemented with measurements by Safety Board staff. These two files were then combined and three-dimensional surfaces were created in AutoCAD2000 to represent the accident environment. This information was then transferred into the HVE system. The Safety Board staff also mapped the accident vehicle

RIGHT SIDE VIEW

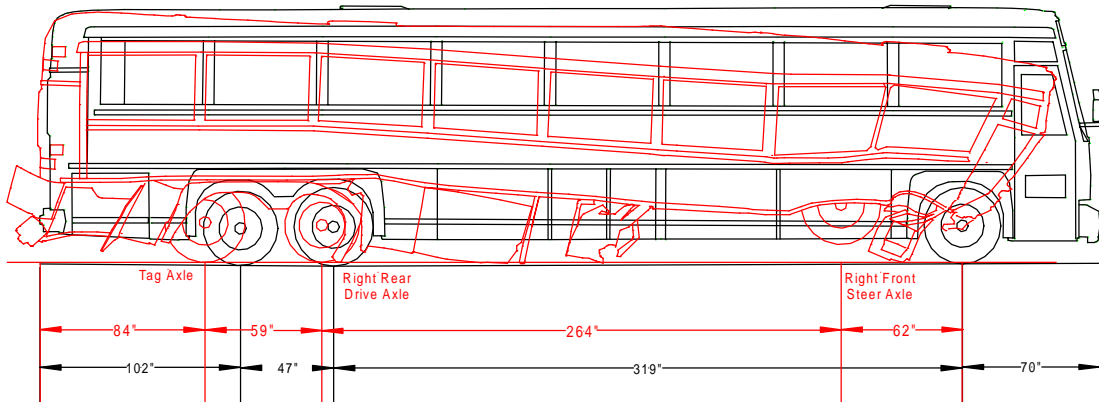


Figure 2: The damaged vehicle overlaid on an exemplar vehicle.

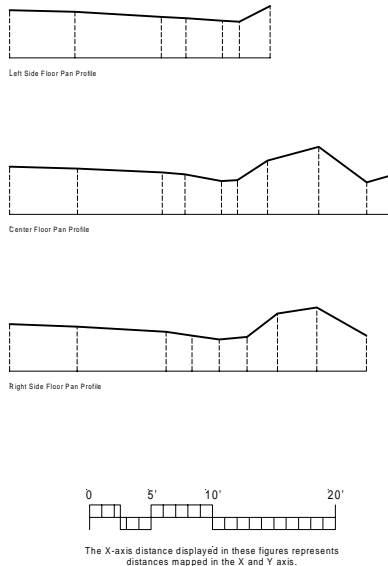


Figure 3: Damaged vehicle floor plan profile.

and an exemplar vehicle. The mapping of the exemplar vehicle provided the surfaces with which a three-dimensional model of the bus was created using AutoCAD. In addition, the mappings provided a measure of the deformation experienced by the bus during the accident. Figure 2 illustrates the mapping on the right side of both the accident bus and the exemplar vehicle.

Figure 3 shows the deformation to the inner floor of the accident bus.

Because a modern three-dimensional bus model was not available in the HVE or Viewpoint6 libraries, the front, back, and the side of the bus were mapped. These three views were combined three-dimensionally, rotated and the side was duplicated and moved to form a three-dimensional box in AutoCAD, as shown in Figure 4. Then surface faces were created. In another crash we were able to use a manufacturer's 2-dimensional AutoCAD files to build a similar bus.

Once the three-dimensional bus model was developed in AutoCAD, 3D Studio Max was implemented to create the lettering and decorations matching the accident bus. In addition, the bus model was deformed using the free form deformation (FFD) modifier[†] in 3D Studio Max based on the mapping of the accident bus (see Figure 5).

[†] Free-form deformations (FFDs) provide a method of deforming an object by adjusting the control points of a lattice. The offset position of the control points to the original lattice source volume causes the distortion of the affected object.

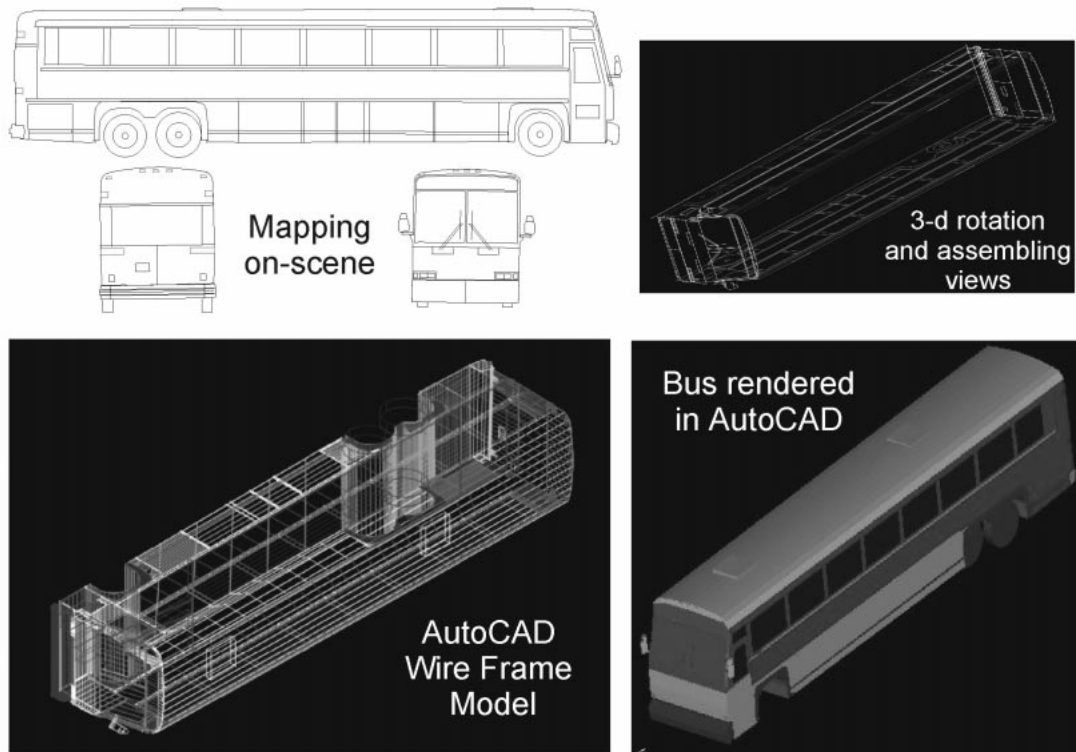


Figure 4: The development of a three-dimensional vehicle model from the mapping on the side, front, and rear of the vehicle.



Figure 5: The three-dimensional model of the accident bus after deformation in 3D Studio Max at the final rest location

The deformed bus model was essential to the simulation and due to the complexity of the model and the EDVSM[‡] physics program calculations. In order to replicate the accident, the vehicle body needed to interact with the embankment. Currently, the EDVSM model does not calculate deformation to the vehicle body until the vehicle rolls approximately 90 degrees, such as the case where the vehicle overturns. Engineering Dynamics Corporation modified the EDVSM program so that the program would not assume a 90-degree roll or pitch angle before allowing the vehicle body to interact with the environment. This modification enabled the front of the bus to interact with the embankment but this modification also significantly increased the processing time required.

EDVSM assigns the stiffness values of the bus body based on the number of vertices defining the model. Therefore, if two buses are assigned the same stiffness properties and one bus is constructed of twice the number of vertices, then that bus will be approximately twice as stiff as the first if the same stiffness values are used. In addition, the more complex model will require more processing time. Based on these limitations, a generic motor coach bus model was scaled to the original bus model. The generic model was created with significantly fewer vertices and therefore minor modifications could be made to the stiffness properties and the tire properties without significant additional processing time. The use of the generic model may have slightly affected the results of the impact into the embankment due to slight differences in

front end and bumper design but its use was essential given that the simplified model reduced the computation time from 24+ hours to less than 1 hour per run. The deformed bus model was substituted into the HVE system after the impact with the embankment, through the use of ReadDataFile⁷, so that the video presentation of the simulations showed a deformed bus.

BURNT CABIN, PENNSYLVANIA – JUNE 20, 1998

On June 20, 1998, at about 4:05 a.m., a 47-passenger coach bus was westbound on the Pennsylvania Turnpike near Burnt Cabins, Pennsylvania. The bus traveled off the right side of the roadway and into an “emergency parking area” where it struck the back of a parked truck tractor semi-trailer. The truck tractor semi-trailer was pushed forward and struck the left side of another truck tractor semi-trailer that was parked in the area.

The bus driver and six passengers were killed, and the remaining 16 bus passengers were injured. Two occupants of the first truck tractor semi-trailer struck were injured and the sole occupant of the second truck tractor semi-trailer was not injured.

This simulation was conducted to determine the estimated speed and path the bus was traveling prior to impact and to identify which marks the bus may have made. EDSMAC4[§] was used for the simulations of the accident dynamics and the vehicle’s trajectories at various speeds. Additional software programs

[‡] Engineering Dynamics Corporation Vehicle Simulation Model, Engineering Dynamics Corporation, 1998.

[§] Engineering Dynamics Corporation Simulation Model of Automobile Collisions, 4th Revision, Engineering Dynamics Corporation, 1998.

used to show the total crash dynamics included: EDVDS** and EDGEN††.

The roadway was not mapped for this accident. Inputs into the environment for this study included a three-dimensional model of the interstate based on a two-dimensional accident diagram. The accident diagram was used to construct the three-dimensional surfaces detailing the forensic evidence.

The three-dimensional bus model developed during the New Orleans accident investigation was similar to the accident bus in the Burnt Cabins, PA accident. Because a bus model from the Burnt Cabins accident was not available nor was an exemplar vehicle able to be mapped by the Forensics Team, the three-dimensional New Orleans bus model was used and modified. The bus was scaled to match the dimensions of the accident bus using SceneViewer, an SGI software program, and 3D Studio Max was again implemented to decorate the sides and roof of the bus to match the styling of the Greyhound bus. Figure 6 shows the three-dimensional model of the accident bus.

The semi-trailers and the Kenworth tractor used models imported from Viewpoint that were modified with lettering and simple company logos and were scaled as required using SceneViewer. Figure 7 shows several views from the final simulation.

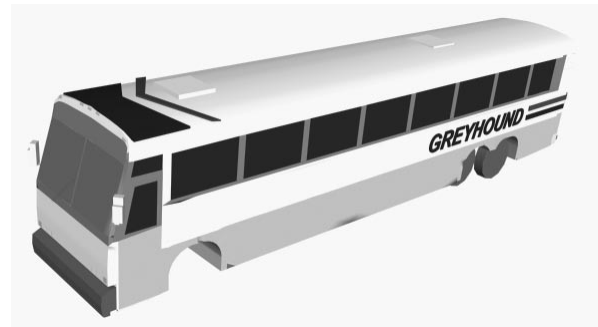


Figure 6: A picture of the three-dimensional Greyhound bus model.

JACKSON, TENNESSEE – JUNE 3, 1999

About 6:12 a.m. on June 3, 1999, a 1999 Freightliner conventional three-axle truck tractor in combination with a van type semi-trailer was westbound in the outside traffic lane of Interstate 40 near the town of Jackson, Tennessee. The combination unit was loaded with approximately 40,375 pounds of clothing and was being operated by a 41-year-old male truck driver. A 32 year-old male co-driver was also in the vehicle, and was occupying the sleeper berth. In addition to the two drivers, an unauthorized female passenger also occupied the vehicle, and was sitting in the front passenger seat.

The combination unit was passing by a roadside rest area. The section of the rest area's parking lot allocated for truck parking was filled to capacity, and several trucks were parked along the outside edge of the acceleration lane leading back onto Interstate 40. As the truck approached the merging lanes of the Interstate and the rest area's acceleration lane, it traveled on the grass surface for approximately 293 feet and struck a highway warning sign.

** Engineering Dynamics Corporation Vehicle Dynamics Simulator, Engineering Dynamics Corporation, 1998.

†† Engineering Dynamics Corporation General Analysis Tool, Engineering Dynamics Corporation, 1998.

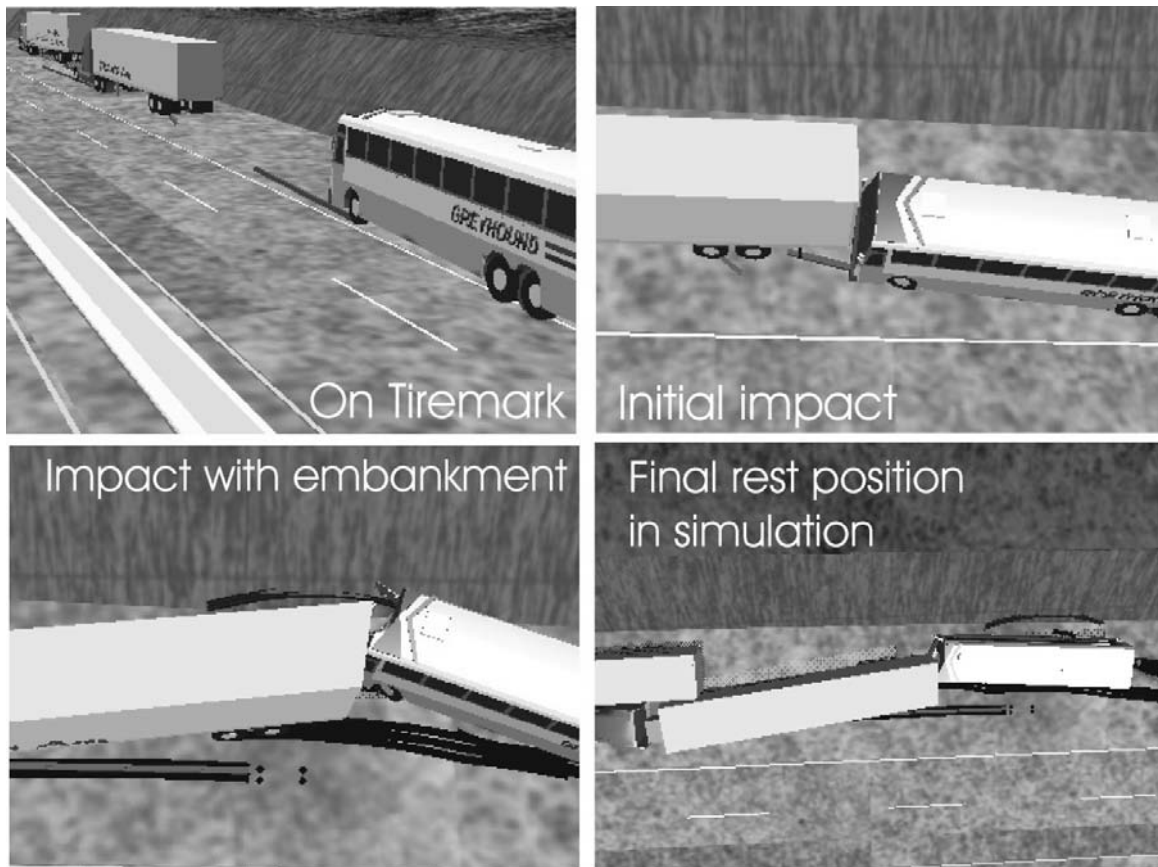


Figure 7: Images from the final HVE simulation of the Burnt Cabins, PA accident investigation.

Following the collision with the sign, the truck ascended a positive 28 percent grade leading from the grass right-of-way to the rest area's acceleration lane leading onto Interstate 40. At the top of the sloped surface, the vehicle became airborne and vaulted over the acceleration lane toward a parked tank truck, which had previously been loaded with liquid oxygen. The combination unit traveled about 76 feet before its right front wheel impacted the top of the tank truck's cargo tank at the back left upper corner. The tractors of the two vehicles then slid forward as their trailers rolled over and the two tractors collided with another semi-trailer and pushed the third tractor semi-trailer into

a fourth tractor semi-trailer. The collision resulted in an ensuing fire to both tractors, the semi-trailer that vaulted, and part of the semi-trailer on the third vehicle.

The environment was built from a combination of an environment in the HVE library, aerial photography of the accident site and topography available from <http://terraserver.microsoft.com/default.asp>. This data was supplemented with the accident scene diagram based on measurements by the on-scene investigators and AutoCAD was used to develop the three-dimensional surfaces. The AutoCAD drawing was imported

into a new HVE file as an environment in a “.3ds” format. The parking area was colored and textured and then all the surfaces were grouped together and saved into the environment library. The HVE interstate scene had the shoulder separated and displaced from the roadway. The parking area environment library file was added where the shoulder was previously located.

The simulation used the HVE 1993 Freightliner FLD 120 tractor vehicle model and default values. A Viewpoint Premier Kenworth 89 model was used for the tractor shell. The HVE default semi-trailer was utilized for all the van trailers and a gasoline tank semi-trailer from Viewpoint was used for the oxygen tank semi-trailer.

The two dimensional data from the EDSMAC4 collisions dynamics was used along with the EDVDS vault data for input into ReadDataFile^{‡‡} to animate the entire 3-dimensional accident sequence. Additional inputs accounting for the rollovers, vehicle separations, and the adjustment in final rest positions were used for the animation. The animation of fire in the accident was developed in 3D Studio Max. Using the instructions within 3D Studio Max for creating combustion, a fire-like animation was created. The fire was then placed on the rendering screen in 3D Studio in the same location as the tractor in the HVE screen. The movie was rendered as a QuickTime movie file (*.mov) in 3D Studio and then exported to the HVE system. The movie was imported into the SGI MovieMaker

^{‡‡} ReadDataFile is an HVE compatible program developed by Collisions Engineering Associates that animates vehicle or object dynamics based on the time history of the linear and angular positions.

along with the movies created within HVE so that both movies occupied the same region of the time line. Highlighting the fire movie, the video effect luminance, was applied. For this scenario, the file was created in the uncompressed format. The result of this video effect was that the dark background on the fire movie was made transparent so that the HVE movie was seen through the fire movie and thus, the tractor appeared to catch on fire. Figure 8 shows several images from the final video.

CENTRAL BRIDGE, NY - OCTOBER 21, 1999

About 10:30 a.m. on October 21, 1999, near Central Bridge, New York, a school bus was transporting 44 students, 5 to 9 years old, and 8 adults on a field trip. The bus was traveling north on State Route 30A as it approached the intersection with State Route 7. Concurrently, an empty dump truck that was towing an empty utility trailer was traveling west on State Route 7. The dump truck was occupied by the driver and a passenger. As the bus approached the intersection, it failed to stop as required and was struck by the dump truck. The bus was equipped with seat belts and most of the belts were being used. Seven bus passengers sustained serious injuries; 28 bus passengers and the truck driver received minor injuries. Thirteen bus passengers, the bus driver, and the truck passenger were uninjured.

In addition to mapping the accident intersection and the area surrounding the final rest positions of the vehicles, the team also photographed all the signs and the scenery surrounding the intersection. The film was developed onto a CD to

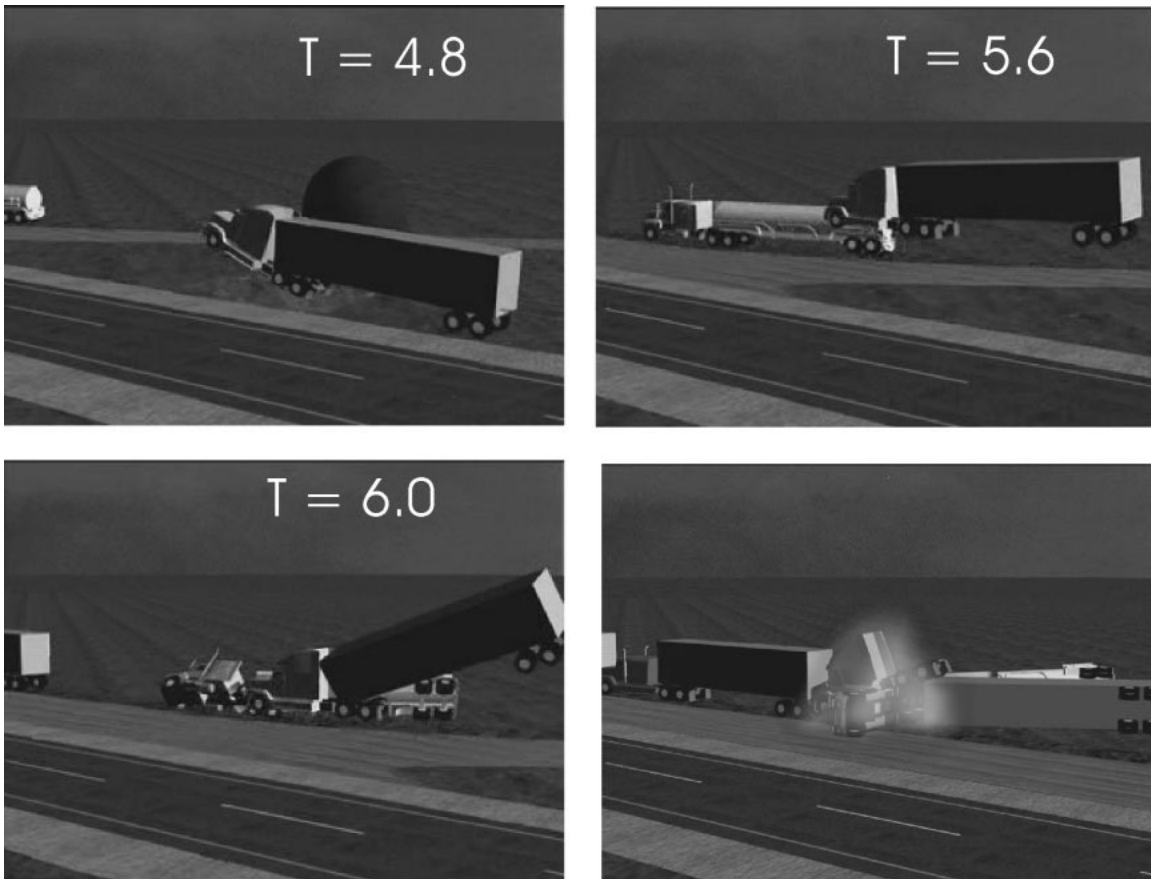


Figure 8: Images from the final MovieMaker simulation of the Jackson, TN accident investigation.

facilitate importing pictures into the HVE texture files for use in the scene. Measurement of the height and the width of the signs and their height above the ground were taken. In the Environment mode, 3-dimensional rectangles were made to the correct size, moved onto a signpost and then the picture taken of the sign was assigned as a texture to that rectangle. A similar process was used to make background images in the simulation.

At the intersection where the collision occurred, there were overhead flashing signals: yellow for the truck and red for the bus. These signals were modeled as cylinders in the environment editor,

assigned an emissivity of 1.0, imported into the HVE vehicle library, created as a vehicle, (see Figure 10 9 and Figure 10) and were then moved back and forth replicating the flashing frequency, using ReadDataFile.

The on-scene investigators also mapped the vehicles and three-dimensional models were created. In addition, detailed measurements of the side emergency exit door on the accident school bus enabled the ViewPoint bus model to be modified.



Figure 9: The school bus driver's potential view toward the intersection.



Figure 10: A single image from the Central Bridge, NY HVE simulation immediately prior to the collision between the dump truck and the school bus.

MORIARTY, NEW MEXICO – JANUARY 14, 1999

About 7:45 a.m. on January 14, 1999, a 1999 Peterbilt conventional three-axle truck tractor in combination with a van type semi-trailer was eastbound in the right traffic lane of Interstate 40 near the town of Moriarty, New Mexico, and was traveling at a driver reported speed of 75 mph. The combination unit was loaded with approximately 16,500 pounds of women's apparel.

Two passenger vehicles, which were also proceeding eastbound on Interstate 40, were in front of the combination unit. The first vehicle, a 1988 Dodge Aries, was operated by a 17-year old driver and was carrying 2 teenage passengers. This car was followed by a 1996 Chevy Astro van, which was being operated by a 16-year old driver who was transporting 1 pre-teen and 3 teenage passengers. Both passenger vehicles had been traveling on Interstate 40 for about 5 miles at a witness reported speed of between 25 to 35 mph. The posted speed limit for this section of Interstate 40 was 75 mph. Additionally, both vehicles were utilizing their hazard flashers, and windshield wipers despite the fact that there were no environmental or mechanical conditions present that would have warranted their use, except the morning sun.

The purpose of the simulation was to investigate a relatively new crash warning system (intelligent transportation technologies – ITT) to determine if future accidents such as this one could be prevented with the system.

Inputs into the HVE environment for this study included a 3-dimensional model of the interstate that was available in the HVE library. As in the Jackson simulation the HVE model's right shoulder was separated from the roadway. A new shoulder and side embankment were built in AutoCAD at the same slope as measured on-scene. A two-dimensional accident scene that included the vehicles' final rest positions and tire marks, made in AutoSketch, was imported into AutoCAD and added to the 3-dimensional slopes. Fence posts and some other physical features were added. After importing to

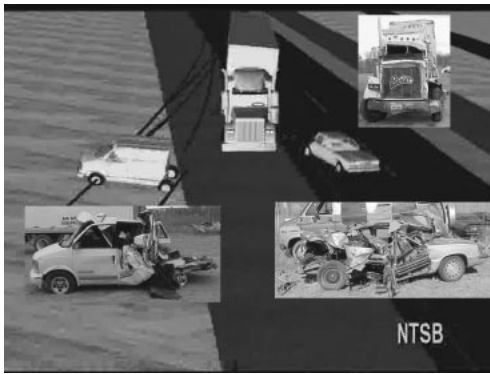


Figure 11: The initial impact between the van, truck, and the passenger car from HVE with pictures of vehicle damage.

HVE, pictures taken on-scene were used to texture the sides of the road, median, sky, and the morning sun at the east end of the environment. The picture of the morning sun was placed on a large white rectangle with an emissivity of 1.0. A picture of the morning sun taken the day after the accident was scanned and imported into HVE as a texture in a palette. The texture was assigned to the large rectangle to give a bright corona.

Vehicle inputs for each vehicle used in the simulation were obtained on the world wide web.^{8,9,10,11.} EDSMAC4 was used for the simulation of the truck/van/car accident dynamics, as shown in Figure 11. The EDVDS program was used for the truck's trajectory after impact as it drove down the embankment and overturned. The anti-lock brakes on the tractor were not modeled. EDVSM was used to model portions of the van's rollover and the data from the EDVSM simulation was used in EDGEN to develop the van's full rollover and slide to rest. The car's final trajectory, after it left the roadway, and a camera car were also modeled using EDGEN.

EDSMAC 4 was also used to conduct a parametric study to determine various reaction times and combinations of braking and steering to avoid impact. This parametric study indicated that the later the driver reacted, the harder the driver would have had to steer and the less stable the maneuver became. EDVDS was also used to simulate evasive action and to help evaluate the proposed design of new truck collision avoidance devices.

New technology available for trucks includes collision-warning systems (CWS) that can help reduce rear end accidents. One CWS company manufactures a high frequency radar system that transmits radar signals from the front and side of the vehicle. When the system detects a potential hazard, a small display unit on the dash emits a combination of lights and audible tones. When the distance between the approaching vehicle and another vehicle is less than 350 feet, a yellow light is turned on. Three seconds before a predicted collision an additional orange light is activated. Two seconds before a predicted collision, a single beep is emitted. One second before a predicted collision a red light is activated and a double beep occurs. One half second before a predicted collision, a series of beeps are emitted. This system can also begin to activate a Jacobs Brake if available, three seconds before a predicted collision.

In order to simulate the CWS, a photograph of a commercially available advance CWS was taken and then imported into the 3D Studio Max system. Three sets of indicator lights were overlaid with spheres of corresponding color in 3D Studio Max, as shown in Figure 12. The shininess

strength and the self-illumination, under the material properties for each object, were varied between 5% and 100% to correspond to the illumination of each indicator light. The timing for the illumination and dimming was based on the vehicle's closing speeds determined in HVE.



Figure 12: A photograph of the intelligent transportation system with the indicator lights animated in 3D Studio Max.

The 3D Studio movie was again rendered as a QuickTime movie and imported into the SGI MovieMaker program. The 'picture in picture' option within MovieMaker was used to place the animation of the advance collision warning system in the corner of the

vehicle dashboard, as it would be installed. The manufacturers provided sound waves of the various beeps and the sound of the engine retarder. They were inserted at the appropriate time using MovieMaker. The simulation helped the staff to formulate proposed recommendations for the Safety Board to consider to the U.S. Department of Transportation for rulemaking and the need for standards to address obstacle detection distance, timing of alerts, and human factor guidelines, such as the mode and type of warning.

CANON CITY – DECEMBER 21, 1999

On December 21, 1999 at about 9:05 p.m. a 1999 motor coach carrying 60 occupants was traveling eastbound on U.S. Highway 50 about 5 miles west of Canon City, Colorado. The wind was blowing, it was snowing intermittently, the temperature was below freezing, and the roadway was slippery in spots. After traveling about ½ to ¾ mile down the grade passengers related that the bus "fishtailed", however the driver was able to straighten it out. The motor coach continued down the hill that had several curves and downhill grades ranging from 3% to 6%. About 1 mile after having "fishtailed", the driver lost complete control of the vehicle. The vehicle went off the north side of the roadway, backwards, rolled 270 degrees as it descended an 80-foot embankment and came to rest on its right side. The driver and two students were ejected and fatally injured. The remaining 57 occupants sustained injuries ranging from minor to critical.

The bus descended a hill about 2.5 miles before it ran off the road to the right. The cross sections for the 2.5-mile roadway were mapped at 80-foot increments. The slope adjacent to where the bus went off the road to the right, the embankment, and the area where the bus overturned were mapped. This data was imported into AutoCAD Land Development and a three-dimensional environment was created automatically, as shown in Figure 13. AutoCAD Land Development was used because three-dimensional surfaces developed in AutoCAD 2000 must be manually aligned and small holes in the surface are almost unavoidable. These holes can result in excessive tire forces when the

vehicle passes over the hole in the surface. Land Development was essential in creating the surfaces in the region of the overturn because the software creates a continuous surface automatically.

In the Canon City simulation, the three-dimensional surfaces of the surrounding topography were created with DEM files¹². In order to simulate the different wet pavement friction patterns along the 2.5-mile roadway, obtained with the Colorado State skid trailer, the road was built in segments to allow different frictions to be assigned. The varying road segments also enabled friction surfaces representing snow and ice to be modeled. In addition an in-depth weather study was performed that was used to model road conditions.

The deformed bus and an exemplar bus were mapped two-dimensionally. In addition, the curvature of the front of the bus and pictures of bus details were taken and a three-dimensional model is being developed (see Figure 14).

This bus had an engine control model (ECM4) that recorded the speed of the vehicle, the engine rpm, the length of brake application, and other engine information. The bus was equipped with a transmission retarder with six settings and anti-lock brakes. This information was used in the simulation to study the vehicle's loss of control and to model the overturn of the vehicle.

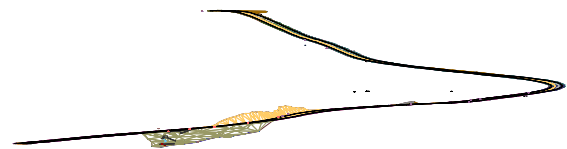


Figure 13: A side view of the three-dimensional surfaces representing the 2.5 mile roadway from Canon City, CO.



Figure 14 – A model of an exemplar bus from mapping and extra measurements

CONCLUSIONS:

The HVE system is a detailed and complex system that provides the user much flexibility in creating vehicles, environments, and video representations of vehicle and occupant simulations. This paper discussed a variety of methods for creating, altering, and adjusting the vehicle and environment models, along with methods for enhancing the HVE graphics. Although the final product is often attractive, caution needs to be exercised when creating highly detailed vehicle and

environment files. The speed of the simulation is often dependent on the complexity of the models and therefore, simple scenes are recommended initially that involve the portions of the roadway and off-road portions as needed. The detailed scene and vehicles can then be added after the simulations are complete but prior to rendering movies. Before using the less complex vehicle model ensure that the dynamics remain the same, especially for simulations involving vehicle body interaction with the environment.

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⁹ <http://195.154.250.226/truck/tires/23/specs.html>

¹⁰ <http://www.jakebrake.com/products/engine/cat3176.htm>

¹¹<http://carpoint.msn.com/compare/choose.asp?Year1=&Make1=Dodge&Model1=Aries&Year2=&Make2=&Model2=&pt=used>

¹² USGS geographic data, <http://edc.usgs.gov>.