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Simulating Train Collisions with Highway Vehicles using EDSMAC4 and other programs

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Disclaimer: Positions and opinions advanced in this paper are those of the author and not necessarily those of the National Transportation Safety Board. This paper discusses two crashes currently under investigation and is desensitized to present technical issues. There is no discussion of probable cause, issues, analysis or recommendations, and the paper focuses strictly on technical issues.

ABSTRACT

This paper describes the successful application of the HVE system, EDSMAC4 and additional software to simulate highway-rail grade crossing crashes.

On June 3, 1998, a Union Pacific Railroad train struck a 1990 Dodge 350, 15-passenger capacity van. The train's recorder indicated that the train was going 46 mph at impact with the van. Some of the young occupants of the van indicated that the van might have stopped prior to going across the crossing. A conventional momentum analysis was attempted, but due to the lateral resistance in the tracks, and the mass differences of the vehicles, large variations in speed, ranging from 16 to 156 mph, were obtained for the van. A simulation was performed using an HVE system and the EDSMAC4 physics model. The simulation indicated that the van was traveling about 35 mph at impact and the simulation reproduced the damage to the van. Based on the successful Wagoner simulation, EDSMAC4 and supporting programs have been used for two additional grade crossing crashes, one being completed and one recently initiated involving trains and large vehicles. The simulations provided good information and resolved some of the uncertainties surrounding the crashes.

The three simulations indicate that EDSMAC4 and supporting programs can be used to simulate highway/railroad crashes. The three crashes simulated had good train recorder data; two crashes involved impacts at the rear of the highway vehicles and the other just rearward of the center of gravity, followed by rotation of the highway vehicles. These types of crashes, with similar data, can be simulated successfully using EDSMAC4.

INTRODUCTION

In 1999, there were 3,420 highway-rail crossing incidents that resulted in 399 fatalities and 1,360 non-fatal injuries[1]. Due to the mass of the trains, many of these crashes are very serious, and simulations may be warranted. This paper describes the one highway-rail grade crossing crash successfully simulated by the National Transportation Safety Board, using the HVE system with EDSMAC4 and supporting software and two others in various stages of simulation.

WAGONER, OKLAHOMA CRASH

About 6:20 p.m. on June 3, 1998, a Union Pacific Railroad Company train was traveling south at an event recorder logged speed of 46 mph. The 7,469-foot-long, 19,353-ton train was approaching on East/West Wagoner County Road 69 in Wagoner County, Oklahoma. As the 135-car coal train approached the crossing, a 1990 Dodge 350, 15-passenger capacity van with 2 adults and 7 children, ages 2-11, on board was traveling west on County Road 69 at a train engineer estimated speed of 35 mph. The van entered the crossing and the lead locomotive collided with the van.

At impact, the pilot plow of the lead locomotive contacted the right rear side of the van with approximately 34 inches of overlap. The Dodge van received extensive damage with inward crush reaching a maximum depth of 22 inches on the right rear corner of the van. From the impact area the van rotated clockwise approximately 340 degrees about its vertical axis, traveled onto the south roadside on the west side of the crossing, and came to rest on its right side. The van traveled about 80 feet from the impact area to its rest position. The train traveled approximately 3,050 feet south of the crossing before coming to a stop.

During the movement of the van following the initial impact, the 6 and 7-year-old unrestrained children seated in the rear bench seat of the van were ejected. Both children were fatally injured. The remaining occupants of the van received minor to moderate injuries. There was no train derailment or post-crash fire. The two-man train crew was not injured.

At the time of the crash the weather was clear and the pavement was dry. State Troopers investigating the collision indicated that neither the train crew nor the van driver appeared to be using drugs or alcohol; therefore, no post-crash toxicological tests were performed.

An 8-year-old unrestrained child reportedly seated in the left side of the second bench seat, behind the driver's seat of the van stated that the van driver stopped at the crossbucks and then pulled across the railroad tracks in front of the train. She indicated that the radio was playing and the air conditioner was on in the van and that she did not hear the warning horn on the train. She also stated that the van driver had seen the approaching train and had stated everybody put your seatbelts on because we need to go across the tracks because we're late for church. However, the engineer/train handler stated that the van never stopped, but kept traveling at a steady speed of about 35 mph into the path of the train.

Another 8-year-old child, reportedly restrained and seated next to this child (in the second bench seat behind the driver in the right seat) stated that she could not remember if the van driver had stopped before crossing the railroad tracks. An 11-year-old lapbelt restrained child seated in the third bench seat stated that she also was unsure if the van driver had stopped before crossing the railroad tracks. The 28 year-old van driver served part-time as the driver of his church van.

A momentum study was conducted to determine the estimated speed at which the van was traveling since statements by the train engineer and the students varied. Initially a linear momentum analysis was conducted but the results varied greatly and were unreliable due to the differences in mass between the train and the van. Speeds of 16 to 156 mph were obtained for the van. In part, this momentum calculation was invalid because the tracks provided lateral resistance to the train, and kept the train going in the direction of the tracks. Additionally, the mass of the train was much greater than the mass of the van.

EDSMAC4

Next, the Human Vehicle Environment (HVE) system was used to conduct a computer simulation analysis. The software version used was HVE version 2. An EDSMAC4 computer software program was used for the simulations of the crash dynamics and the van's trajectories at various speeds. This was the first version of EDSMAC4 that deformed the vehicles. Additional software programs used to show the total crash dynamics included EDVSM and EDGEN[2].

For this study, an existing model of a two-lane highway was utilized. The road was modified to reflect several different surfaces. The crossing, tracks and crossbucks were added, and the area of final rest of the van was shown in gray as a target for the final rest position of the van. After the impact speed was determined from preliminary EDSMAC4 simulations, additional simulations were conducted to show the potential view from the van. For this simulation, two piles of railroad timbers and a windrow of trees were added.

The simulation utilized two vehicle models provided with the HVE system, a generic van and a moveable barrier. The van was modified to use a Chevrolet panel van body. The van was stretched and the wheels were moved to match the actual van. At the time the simulation was being developed, George Washington University (GWU) was researching a similar Dodge 350 van to make a finite element for the National Highway Traffic Safety Administration. GWU provided the center of gravity and the loads on each wheel. This information was used to calculate the yaw moment of inertia and the model parameters were adjusted appropriately.

The locomotive was created using a Viewpoint model. The train models were colored similar to that of the actual train. The yaw moment of inertia for the locomotive was estimated based on length, width and weight to be 70,262,611 lb-sec^2-in. and the locomotive weight was recorded as 415,000 pounds. The locomotive speed (46-mph) was determined from the locomotive recorder as the locomotive approached on the track.

Numerous runs were made to best simulate the trajectory of the van in the subject crash. The first preliminary run simulated the van at an estimated speed of 30 mph. In this run, the trajectory of the van remained straight, but the van went beyond the final rest position. The brakes were applied at 80 percent of the available friction building up from impact to 0.1 seconds after impact to stop the vehicle near the area of final rest. In addition, the right front tire was blown 0.8 seconds after impact as it went off the pavement and the left rear tire was blown 1.2 seconds after impact as it went off the pavement, to approximate the observed condition of the damaged van. The simulation was rerun and the vehicle stopped to the left of the target, as seen from above. Simulations including the van approaching at 10, 20, 25, 30, 35, 40 and 45 mph, were then assessed using the same conditions, except the speed of the van was changed. The simulation at 35 mph slid directly over the final rest area and stopped just past the target. At speeds below 35 mph the van went to the left of the target and at speeds above 35 mph, the van went to the right of the target. From the impact point to final rest, the angle was calculated for 30, 35 and 40 mph as measured to the left of the original forward straight path of the van as –62.8, -68.5 and –77.6 degrees, respectively. The target was –68.55 degrees from impact, indicating that 35 mph was a very close approximation of the trajectory. From the final resting positions, it appeared that the most accurate speed of the van when struck by the train was 35 mph. The 35-mph simulation was adjusted to stop at the final rest area by increasing braking to 100 percent of the available friction.

For the EDSMAC4 impact the locomotive was not constrained laterally by the tracks and could have rotated. Due to the large mass of the locomotive, its speed was reduced only 0.1 mph at impact and it rotated only 0.1 degrees clockwise in the 0.08 seconds after impact, prior to separation of the vehicles. This change in velocity is an unnoticeable amount.

EDSMAC4 is a two-dimensional program and shows the trajectory of vehicles after they strike each other, but will not enable a vehicle to roll over as was indicated by the van's final position. To roll the van as it did, 0.21 seconds after impact, the van's location, speed, yaw and sideslip were placed into an EDVSM simulation program.

EDVSM

EDVSM was utilized to simulate the travel of the van from 0.21 seconds after impact until it rolled 90 degrees (additional roll forces were added to enable a complete roll) and struck the ground, about 1.7 seconds after impact. The EDVSM simulation, which began 0.21 seconds after impact, had a duration of 1.5 seconds. In that time, the van rotated 324.6 degrees, rolled 84.5 degrees, slowed 7 mph, and traveled 50.3 feet. EDGEN was used to slide the van into its final position after EDVSM rolled the vehicle. The van stopped after rolling onto its right side in about 17 feet and 1.15 seconds. The average deceleration factor was 0.81 G.

WAGONER SIMULATION RESULTS

The simulations indicated that the van was traveling at about 35 mph when struck in the right rear corner by the train. The van yawed 375 degrees, rolled 90 degrees, and came to rest about 2.85 seconds after impact. The Delta-V for the center of gravity of the van was 17.1 mph for the van. The peak acceleration at the center of the van occurred 0.06 seconds after impact at 22 g.

The EDSMAC4 simulation at 35 mph was also used to examine the potential view of the van driver as the train approached the crossing. The simulation was started six seconds before impact. The side of the train that was visible to the van driver was shaded from the sun, since the train was traveling south and the van was traveling west. This decreased the conspicuity of the locomotives. A windrow of trees blocked the visibility of the train for the first 0.6 seconds. Then the front of the first locomotive was behind the A-pillar of the van for another 0.2 seconds (See figure 1). The tops of the rest of the train began to become visible after 0.8 seconds, but the bottom portion of the cars were behind two piles of railroad ties. About 1.4 seconds after starting, the second locomotive started to emerge from behind the timbers and became visible from the ground to the top of the locomotive. Two seconds after starting, the rear of the lead locomotive was viewed in the top of the vent window, and the bottoms of the front two cars were still behind the timbers. From 2.8 to 2.9 seconds the nose of the first locomotive was still behind the A-pillar and the nose of the second locomotive was behind the vertical support for the vent and side window. At 4 seconds the front of the lead locomotive began to emerge from the A-pillar. At 4.4 seconds (1.6 seconds before impact) the lower center light of the lead locomotive was visible in the top of the side vent window (see figure 2). About 0.2 seconds later, the top center lead locomotive light was visible. At 4.9 seconds, the two locomotives would have been visible in the side window but the vertical post behind the van's vent window would have blocked the lead locomotive's light. At 5.3 seconds the front of the lead locomotive was in the back two-thirds of the side window. The last view of the locomotive in the side window was 5.7 seconds.

To stop on the gravel/asphalt approach from 35 mph would have required 74 feet, assuming a 0.55-g deceleration. The van was 222 inches long and the locomotive struck 34 inches of the rear of the van. The locomotive was 9 feet 11 inches wide. Thus the van would have had to start full braking at 35 mph, about 100 feet before impact or 1.95 seconds prior to the eventual impact to stop short of the train. The van driver would have been able to see the rear of the first locomotive and the side of the second locomotive and the cars at the time he would have had to have applied the brakes fully. He would have had at most 3.2 seconds of visibility of the train after emerging from behind the trees, but during that time, the stacked timber piles, as well as the van's A-pillar and the vertical post behind the vent window would have obstructed portions of the train. Slowing the van as it approached the crossing would have given the driver a better chance to see the approaching train.

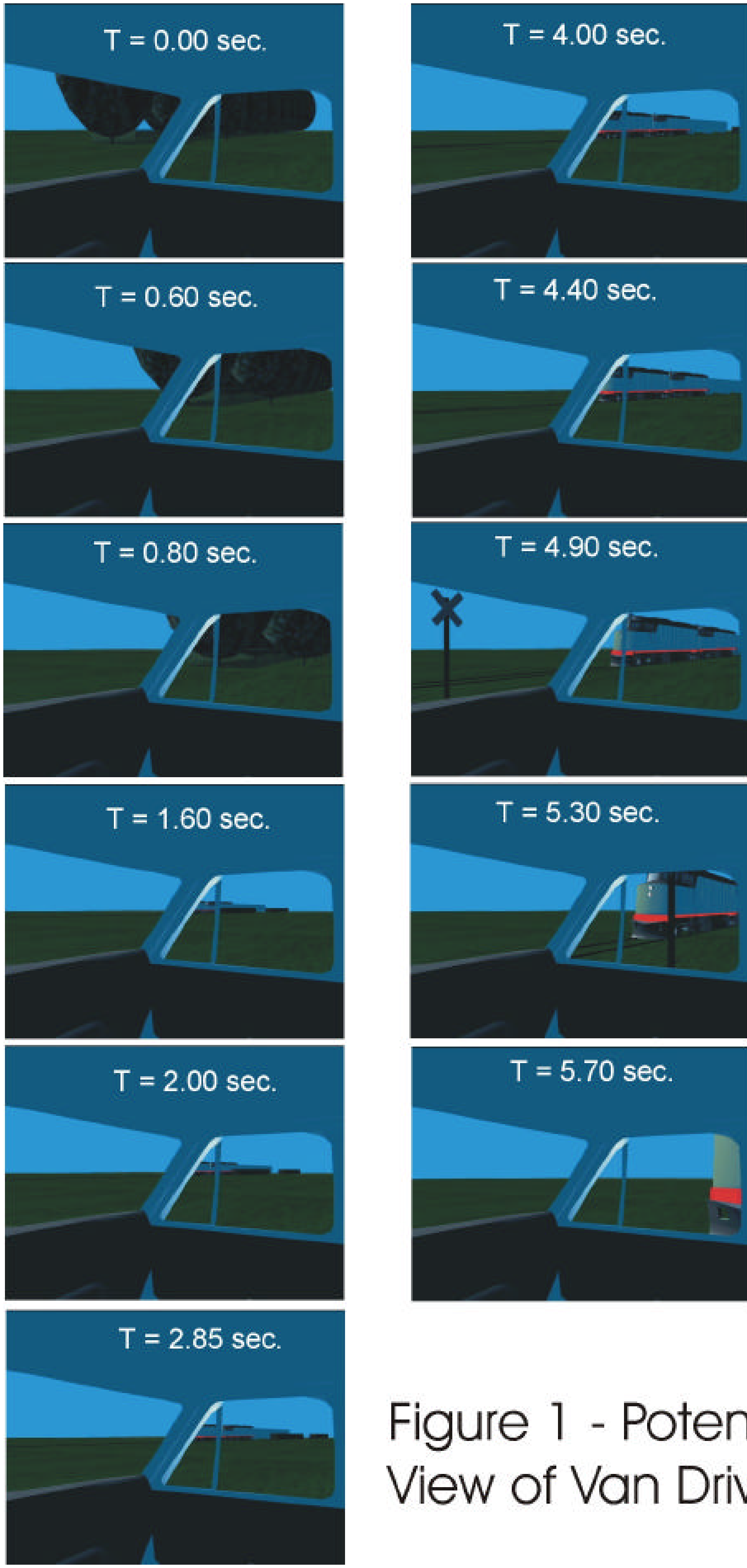
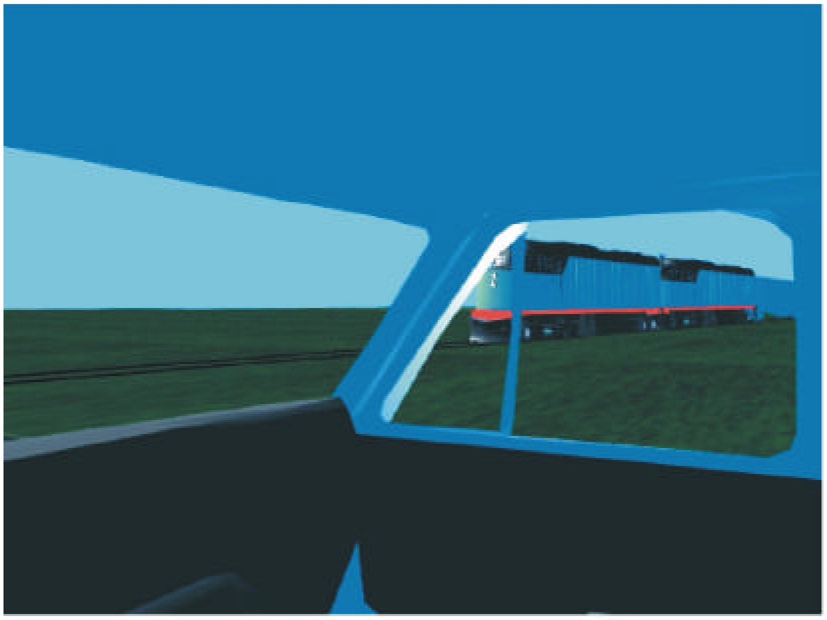
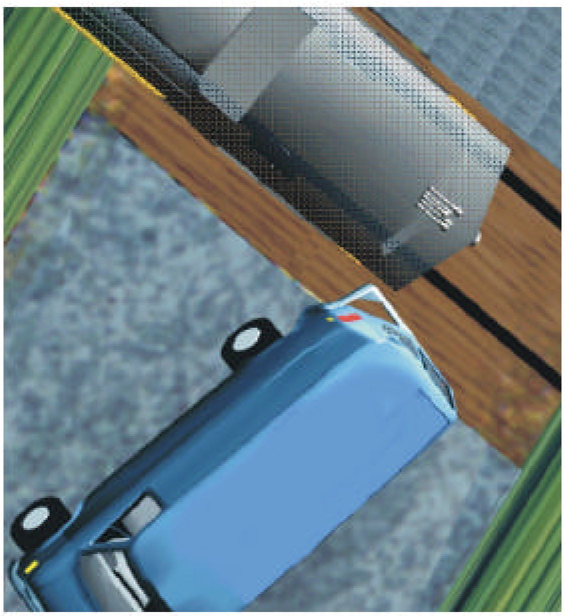


Figure 1 - Potential View of Van Driver



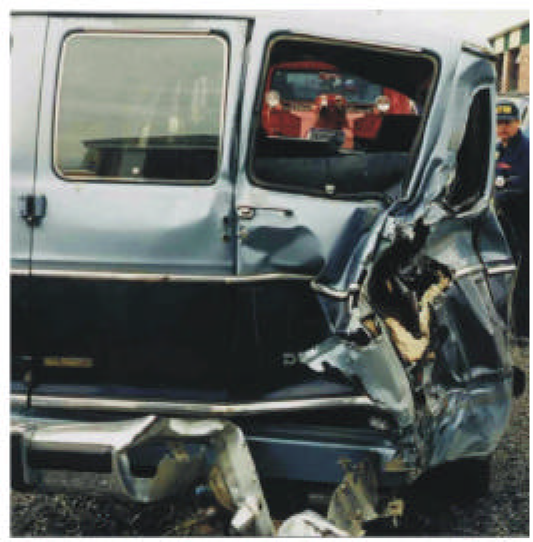
Potential van view
1.33 seconds
before impact

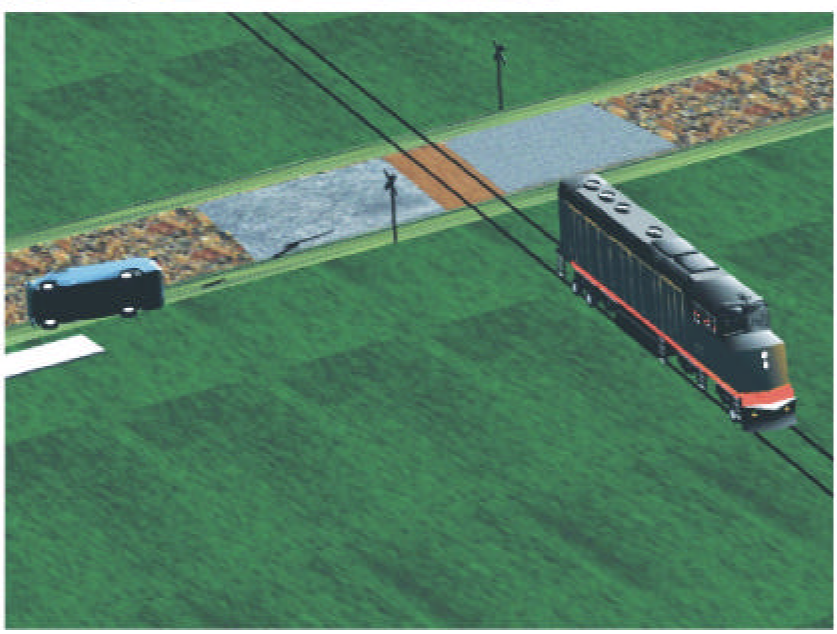
Right rear side
of van



Predicted deformation
to the van,
0.1 seconds
after impact

Rear of
van





Predicted
tiremarks
and location of
van overturn
1.7 seconds
after impact

In this case the HVE system and EDSMAC4 simulation helped to resolve the speed of the van and indicated that the van driver most likely did not stop before the crossing. The simulation of the van's approach helped to identify restrictions to visibility and their relative roles in the crash, but indicated that the van driver could have seen the train and been able to stop. If the driver had slowed on the approach, he would have been more likely to see the train and could have stopped. The simulation and report were completed in about two to three weeks.

SIMULATION NEARING COMPLETION

A train, consisting of two locomotive units and 14 cars, struck a truck tractor, semi-trailer at a railroad/highway grade crossing. The truck had been loaded with steel that overhung the end of the semi-trailer. This simulation has been worked on sporadically for about 9 months and is not yet complete.

The truck driver stated that he was moving between 15 to 20 mph and had begun to traverse the crossing when the warning lights activated. The train engineer stated that he saw the truck slowly moving through the crossing and blew the train whistle to warn the driver. A witness, two vehicles behind the truck testified that the truck was going about 7 mph across the tracks and the gate came down on the rear portion of the semi-trailer. A truck driver reported that he heard a "Jake" brake. A crane operator, located hundreds of yards away, described what he saw as he was operating the crane, and it indicated that the signals might have worked properly. A recorder circuit board on the railroad signals indicated that they should have flashed for 26 seconds before the train arrived at the crossing. According to the event recorder in the lead locomotive, the train was traveling at a speed of 79 mph immediately before the collision. The train struck the left rear of the semi-trailer on the semi-trailer's rear axle.

This simulation was conducted to help determine the estimated speed of the truck, the relative location of the truck as it crossed the tracks, the timing of the truck crossing the tracks, the signal activation, driver actions, and also to determine if the truck driver could have stopped prior to the crossing. This study was conducted to help resolve witness statements that conflicted with the recorder circuit board. The simulations were used to determine if the signals were delayed and when they would have had to come down to clear the trucks exhaust system if the truck was straddling the centerline as it approached the crossing as described by a witness.

An HVE system was used to conduct numerous simulation scenarios such as: the truck going around the gates at the maximum within gear speed of 19.6 mph (the speed indicated by the driver), the truck going down the middle of the road as the signals descended late at about 19.6 mph, the truck crossing at 7.6 mph, the top speed in third gear with the gate coming down late and the near side gate stuck up.

For these simulations, a two-dimensional scene of the crash site was developed from field surveys of the crash site. In addition, based on pictures, buildings and surveys, other 3-dimensional features were added to the scene. The road was modified to reflect several different surfaces: the road, the crossing timbers, and the tracks. The railroad signal heads and gate stanchions were also added. The final rest of the truck was shown as a dark gray, flat target. A tiremark indicated in the survey on the timbers was also used as a positional reference for the truck.

The truck was built as an articulated tractor/semi-trailer. The tractor was built using the HVE model for a 1993-4 Freightliner. Many of the default values for the tractor were used. The wheel locations for the default vehicle were modified to represent the crash vehicle. Additional inputs included the transmission ratios, rear differential, steering gear ratio, and the engine horsepower curve. The efficiency of the truck brakes was calculated and braking was adjusted accordingly. The tractor was modeled with Goodyear tires.

The semi-trailer body was modeled in AutoCAD 14[4] and imported into HVE. The properties of the semi-trailer were calculated based on the dimensions and weights of a sister vehicle. The program did not allow the steel to fly off the trailer after being struck by the train.

The first two units or locomotives of the train were modeled as a truck and trailer, connected by a ball and hitch at the couplers. Each locomotive was modeled with three axles, one at the front and two at the back. The body of the locomotive was developed in AutoCAD from design plans. The weight and center of gravity were determined from design plans. The yaw moment of inertia was calculated. The train units were modeled to run on generic tires and were placed as indicated by design plans.

The "EDSMAC4" computer software program was used for the simulations of the crash dynamics between the train and the truck and the truck's resulting trajectories at various speeds. Additional software programs used included: EDVDS, to show the truck's approach, EDGEN, a general analysis tool to create chase vehicles and the train approach; and ReadDataFile to activate the train flashers and gates.

EDSMAC4

The locomotive speed (79-mph) was determined from the locomotive recorder as the locomotive approached on the track. For the EDSMAC4 simulation, the locomotive was not constrained laterally by the tracks and could have rotated. Due to the size of the locomotives and the semi-trailer carrying steel, for calculations, the angular sweep interval and the radial depth interval had to be increased to 2.75 degrees and 0.25 inches respectively.

Initially several test simulations were made of the train striking the rear axle of the trailer as the truck speed increased from 5 to 25 mph in 5 mph increments. In these simulations the truck went down the center of the road without steering or braking and the end of the steel was modeled as the end of the semi-trailer. The simulations indicated that at lower speeds (5 to 10 mph) the semi-trailer pulled the truck too far rearward and into and along the side of the train. At speeds of 15 to 20 mph the truck appeared to stay in the area of the truck's final rest. At 25 mph, the tractor continued to pull the trailer forward down the road. It was noted that at 10 mph, the truck's tiremarks went over those recorded in the scene survey.

In the simulation, with the end of the semi-trailer modeled as the end of the steel, and the truck going around the gates at 19.6 mph, the truck came to rest near the final position, but the tiremarks did not match. In the simulation the software did not indicate a separation time, but it appeared to be about 0.43 seconds using a frame by frame analysis as the lead locomotive ran over or through the semi-trailer, the semi-trailer remained in contact with the side of the lead locomotive as it went by. It looked like a third of the locomotive ran over the semi-trailer.

In another simulation, with the end of the semi-trailer modeled as the end of the steel, the truck going down the middle of the road at 19.6 mph, the software did not indicate a separation time, but it appeared in a frame by frame analysis to be about 0.52 seconds visually. In this simulation the truck came to rest near the final position, but the tiremark did not match. Separation of the two vehicles occurred after two-thirds of the lead locomotive ran over or along side of the rear of the semi-trailer.

A third scenario was developed using the semi-trailer modeled as the end of the steel, with the truck going down the middle of the road at 7.5 mph (top speed in this gear was 7.6 mph), based on a witness statement that estimated the truck speed as about 7 mph. The truck was pulled backward and down the track along side the train, and this simulation did not match any of the physical evidence, but it was done for illustrative purposes.

In another simulation, the truck straddled the yellow centerline with its left wheels over the line, at 7.6 mph, with the end of the semi-trailer modeled at the actual end of the semi-trailer, but with the steel used to calculate the semi-trailers mass and moments of inertia properties. In this simulation, the tiremark and the final rest position of the tractor could be replicated. The semi-trailer stopped just short of its final rest position in this simulation. The tiremarks documented on-scene by the highway group were overlaid on an overhead view of the simulation. The tiremarks from the simulation followed a similar path and went over the surveyed marks. The front axle of the semi-trailer struck the rail in the exact location. The rear axle was a little beyond the indicated marks. The discrepancy in the rear axle could be a result of the separation of the axle from the semi-trailer, or the bending of the truck, which is not modeled by the 2-d software. These simulations reinforced the preliminary simulation that indicated at about 10 mph, a mark would be similar to the one observed. By shortening the length of the modeled semi-trailer from the end of the steel to the actual end of the semi-trailer, different results were obtained and the results were more consistent to the physical evidence. This was the only simulation for which the software calculated a separation time, and the vehicle dynamics appeared to be what would be expected of a crash. Separation of the two vehicles occurred after the locomotive ran through the semi-trailer. There appeared to be little interface between the semi-trailer and the side of the locomotive.

In the initial simulations, without steering and with the truck in the middle of the road, the tractor did not come to final rest in the area in which it was observed. In the first five simulations discussed, it was found after numerous simulations, that the tractor had to steer so its right front was near the right front's final rest position, before the truck would stop in that position. From the simulations, it appeared that the truck had to have enough forward momentum to resist the semi-trailer being pulled back into the train. The semi-trailer rotated about the fifth wheel, and when it was past 90-degrees to the tractor, it started to rotate the tractor counter-clockwise and pull it rearward.

At impact, the articulation angle of the semi-trailer to the tractor affected the dynamics of the crash. To determine the potential angle of the semi-trailer, prior to finalization of the EDSMAC4 runs, EDVDS programs had to be implemented. These runs helped to develop approximate locations on the road and yaw angles of the tractor and the semi-trailer.

A sensitivity analysis was conducted and the runs were rendered using EDSMAC4 with the end of the semi-trailer modeled at the actual end of the semi-trailer. One simulation looked at moving the truck and train 6.41 feet laterally to the left of the truckdriver to avoid the near side gate if it was down. This required more steering to the right (increased from 150 to 320 degrees at the steering wheel) for the tractor to come to rest near its final rest position. In this simulation the tiremarks were at the same curvature but were inside the marks observed. The 6.41-foot distance was continually reduced in half, steering was reduced proportionally, and the simulations were re-run. These simulations indicated that the truck could be no further away than 0.65 feet to the left to leave tiremarks similar to that on the survey or no further than 1.3 feet to the right with two locomotives modeled. The semi-trailer may have been as far as 1 to 2 feet to the left to leave a mark on the left side of the center line in the direction of the truck, but a simulation with the truck 1 foot to the left would not match the impact on the rail from the front semi-trailer tires or the surveyed tiremark. A speed sensitivity study was performed at 5, 10, and 15 mph (an earlier simulation was done at 7.6 mph). The tiremarks indicated that the 5-mph speed was too slow, and the 10-mph speed was too fast. In these sensitivity simulations, the point of impact was the same, but steering was changed and the angle of the semi-trailer was not the same in the runs. Finally, two more cars were added behind the two locomotives (the maximum allowed by the program). This simulation indicated that the impact might have occurred 0.85 feet more to the left, closer to the beginning of the mark observed at the crash site. With two more cars, the semi-trailer spun closer to where it came to rest, and went over the tiremarks.

EDVDS

Speed tests were made with the actual tractor and a similarly loaded semi-trailer from the nearby plant to the crossing. EDVDS is a simulation analysis that was used to model the approach of the truck from the truck scales at the nearby plant, around the corner to the right and on the approach to the crash site. The results of the speed tests were used in the modeling. Three separate simulations using EDVDS were created for the approach to the crossing. The first simulation (A) started the truck in the plant parking lot near the scales, at 0.5 mph. The truck was accelerated toward the intersection with the road to a speed of about 15-mph. In the beginning of simulation, the truck bounced initially due to loads settling and the acceleration of the truck. Another simulation (B) was used to turn the truck around the corner with no acceleration (throttle increase) and to get to the next opening for the plant parking lot. In the simulation, the speed of the truck slowed to 14.5 mph as it turned around the corner due to side scuffing of the tires and at the second plant exit, the speed of the truck was 14.4 mph. Simulation C was broken into three different simulations to represent going around the gate (C1), straddling lanes (C2), and with the left tires over lane (C3). Simulation C3 was developed from the parking lot entrance nearest the crossing to the crossing. During the first simulation (A), the truck accelerated from 14.5 mph, braked momentarily, and then changed into the left lane as if it was going around the gates. The truck brakes were initially applied and released. Then the truck was accelerated to the maximum speed within sixth gear of 19.6 mph. The steering was increased to 250 degrees to the right as the truck began to steer to the right at the crossing.

Simulation C2 was developed for the second simulation from the parking lot entrance nearest the crossing to the crossing. During this simulation, the truck accelerated from 14.5 mph, braked momentarily, and then began to change lanes and straddle the centerline of the road. Then the truck was accelerated to the maximum speed within sixth gear of 19.6 mph. Steering was increased to 250 degrees to the right as the truck got on the crossing. For this scenario the signals were activated late to clear the exhaust stack of the tractor (See ReadDataFile later).

Another simulation (D) was developed for scenarios that matched the tiremarks best (7.6 mph) from the parking lot entrance nearest the crossing to the crossing. During this simulation, the truck started at 14.4 mph, and was braked lightly to 7.6 mph as the truck began to change lanes and straddle the centerline of the road with its left wheels. Then the truck continued at a speed of 7.6 mph (maximum speed within third gear). The steering was increased to 148.8 degrees to the right as the truck began to steer to the right when on the crossing.

EDGEN

EDGEN was used to develop camera cars for the chase simulations and to have the train approach at the outer extents of the simulation's environment.

READDATAFILE

This software program was developed by Collision Engineering Associates, Inc. to accept an ASCII data file that contains motion data for selected objects, reads the data file, and loads the motion into the HVE system. This program allows data to be entered from an outside source. The program is not a simulation, however it may be used to create visualizations of simulation results. The data file must contain time-dependent position data for the objects selected. This program was used to animate the flashing of the railroad signals and the lowering of the gates. The flashers began to flash at 0.5 second increments for 4 seconds, and then the gates were lowered over the next 8 seconds at a constant rate as the signals continued to flash for a total of 26 seconds, prior to impact. In some simulations, the signal activation was delayed for the near side gate to clear the tractor's exhaust stack in the model. The gate passed through the truck's load of steel, so the movement was modified to hold the angle of the gate as it rubbed along the steel. After the gate passed the end of the steel, hanging beyond the trailer, the gate was allowed to continue to drop at the initial rate of rotation. In another simulation, the near side gate was held up until just after impact and the far side gate and the signals were started on time.

SIMULATION RESULTS

The individual EDSMAC4, EDVDS, EDGEN, and ReadDataFile simulations were combined to form the ten scenarios of the crashes. Then one to four views of each scenario were rendered including:

1. A chase view of the truck
2. The truck driver's potential front view
3. The truck driver's potential side view
4. A view from the far side of the tracks looking at the truck's approach and the operation of the railroad signals at the crossing.

The initial simulations (with the end of the truck at the back of the steel rebars) indicated that the truck was traveling at about 15 to 20 mph when it was struck in the left rear axle of the semi-trailer by the train. In the simulations, the lead locomotive went to the left (as seen from above) and the second locomotive went to the right of the track as found at the scene. These scenarios matched the vehicle's final rest position, but did not match the tiremark on the timbers. In the simulations, neither scenario duplicated the mark on the roadway at the right side of the timbers, but the second scenario was a little closer to that mark.

In the other simulations, where the end of the vehicle is modeled as the end of the semi-trailer, the tiremark on the timber and the final rest position of the truck can be replicated closely if the truck is going about 7.6 mph at impact and the left wheels of the truck are over the centerline prior to steering to the right near the crossing.

A RECENT CRASH

A recent crash involved a train and a bus. The day after the crash, a good aerial photograph was available from the web. About 10 pictures were available, some showing the bus body and the separated chassis. We were aware that the speed of the train was about 50 mph at impact. Based on the pictures and using previous vehicle models a preliminary simulation was run, replicating the action of the bus body (the bus body separated from the chassis, but the motion of the chassis was not simulated). This preliminary simulation was completed in about 4 hours, including three renderings and making a movie using Moviemaker. Within 8 hours, compressed ".mpv" files (using mediaconvert) were available that could have been sent to help the investigation team. After arriving on scene the next day, it was observed that the simulated impact of the bus was too far forward, by about four feet, and the bus was probably going a little too slow in the simulation. However the simulation was useful to highlight areas to look for tiremarks on the rail, paths in the gravel, the path through broken branches, and to visualize the movement of the bus and the expected movement of the occupants. The additional information gathered on-scene will help to more accurately simulate the crash. One potential use of HVE is to try to match the view of the bus occupants and the environment to a video tape that was captured by a camera mounted on the front of the bus that was pointed rearward. This might help to estimate the speed of the bus on the approach at various locations. In the preliminary simulation, the train veered from the tracks, however the actual train did not derail. In a subsequent simulation, on return to the office, the yaw moment of inertia of the locomotive was increased to the maximum value. This kept the train traveling straight, and might be useful in other train simulations that do not involve derailments of the train.

SIMULATION PROBLEMS

To simulate train/truck collisions O2 machines may require more RAM and a larger hard drive or an external hard drive. These simulations were developed on O2s with 512 megabytes (Mb) of memory. Some of the simulations were 51 seconds long from truck start up to final rest. The simulations had to be at least 26 seconds long to get the flasher/gate sequence and additional time is desirable. When several files are saved together in a Moviemaker format the files may get huge (500 MB to 900 MB). This will require a larger drive or an external drive. When the 51-second simulation was viewed within the HVE "playback" mode, it was noted that the simulation played faster (in about 42 seconds). The simulation was exported into Moviemaker and when viewed the timing was correct.

When doing these simulations, make sure you have a back up with a different file name. For unknown reasons, the simulation crashed once and the file could not be opened again, unfortunately a backup file was not made and a lot of work was lost. After that incident 3 to 5 copies of the file were saved as different names. If an external hard drive is used, don't fill the external hard drive completely. We lost a large portion of the data on the hard drive and could restore only a few of our moviemaker files. Make copies on videotape before you go on to other projects or consider backing up another system.

In this simulation, the locomotive was built using the bottom portion of a Viewpoint model of a locomotive. The bottom portion was modified for the new model. The top portion was built using squares for the left, right, back and top sides. The front was built to model the pointed nose. These 5 pieces were colored differently, and were imported into HVE where scanned bitmaps were placed on the squares. While the train looked very good prior to the impact, the bitmaps moved downward on the sides at impact as the train's vertices were deformed. In these simulations the cameras were focused on the truck, and the train was visible only for a very short time after impact.

The truck semi-trailer simulation was very sensitive to overlap of the vehicles and the angle of the semi-trailer relative to the locomotive. This will mandate that many more simulations will need to be run compared to other types of crashes to get accurate results.

The EDSMAC4 analysis showed that care must be used when setting up vehicle models. The change between the end of the model being at the end of the overhanging steel, or the end of the semi-trailer created a significant difference in probable speeds (19.6 versus 7.6 mph), probable vehicle location at impact, and the matching of tiremarks which would have effected the determination of the factors and cause of the crash. Future generations of EDSMAC4 perhaps should have the load separated as in EDVDS and it would be good to analyze the movement of the load separately and to look at load restraints!

CONCLUSION

This paper described the successful application of the HVE system, EDSMAC4 and additional software to simulate three rail/highway grade crossing accidents. The Wagoner, OK simulation indicated that the van was traveling about 35 mph prior to impact and the simulation program reproduced the damage to the van very closely. The other simulations have not been completed, but the simulations appear to be very useful.

The three simulations indicate that EDSMAC4 and supporting programs can be used to simulate some highway/railroad accidents. The three accidents simulated had good train recorder data, and involved impacts to the rear of the highway vehicles' center of gravity, followed by rotation of the highway vehicles. This type of accident, with similar data, can be simulated successfully using EDSMAC4.

REFERENCES

1. Federal Railroad Administration, Office of Safety Analysis web page, April 14, 2000, http://safetydata.fra.dot.gov/officeofsafety/
2. *HVE Operations Manual*, Version 2, Third Edition, Engineering Dynamics Corporation, Beaverton, OR, July 1999.
3. Wes Grimes, *Installation Instructions*, Collision Engineering Associates, Inc., 1998
4. AutoCAD Release 14, Autodesk, Inc., 1997