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Human Performance - Can Visual Phenomena Be Recreated In HVE?

Lawrence E. Jackson, **P.E., M.S., ACTAR**
National Transportation Safety Board

Kristin M. Poland, **Ph.D.**
National Transportation Safety Board

Paula Sind-Prunier, **Ph.D.**
National Transportation Safety Board

ABSTRACT

On Saturday October 13, 2001 at about 2:00 pm, a 22-year-old male was driving a 2000 Thomas 78-passenger school bus westbound on Nebraska State Route 6 at about 40 mph, and was approaching a bridge. The roadway was under construction. Witness statements and Safety Board observations on-scene indicated that the school bus driver might have perceived that the one of the three oncoming vehicles veered into his lane thus causing him to steer rapidly to the right to avoid a collision.

A simulation was developed to replicate the school bus motion and also that of the oncoming traffic. This simulation resulted in the observation of several visual phenomena, which may have contributed to the accident. The purpose of this paper is to present a simulation of a school bus negotiating a narrow, curvy roadway in a construction zone with oncoming traffic and to detail visual phenomenon contributing to the accident.

INTRODUCTION

THE ACCIDENT

On Saturday October 13, 2001 at about 2:00 pm, a 2000 Thomas Built Buses, Inc., 78-passenger school bus carrying 27 Seward High School students and 3 adults (excluding the driver) was traveling westbound through a work zone on U.S. Route 6 in Omaha, Nebraska. (See Fig 1)

The roadway was under construction and traffic was channeled into two 10.5-foot-wide travel lanes, one lane in each direction by 4-foot-tall orange and white reflectorized barrels. As the school bus approached the West Papillion Creek Bridge, the roadway shifted slightly to the driver’s left and then to the right. The weather was clear and dry with gusting westerly winds of 20 miles per hour.

As the Seward (accident) bus entered the work zone lane shift at the approach to the West Papillion Creek Bridge, it encountered a 1986 Motor Coach Industries 52-passenger motor coach carrying Norfolk High School students traveling eastbound. Witnesses estimated the vehicles' speed at about 40 to 45 miles per hour. Although no collision occurred between the two oncoming Norfolk motor coaches and bus and the accident bus, the westbound accident school bus departed the traveled roadway on the right. It then struck the W-beam barrier on the approach to the bridge with the right rear of the bus, and abruptly steered further to the right, striking the W-beam guardrail again with the right front of the bus. Finally, the accident bus impacted a three-rail barrier between the guardrail and the concrete/metal bridge railing. The bus passed through the remains of the three-rail barrier, rode up onto the bridge's sidewall, and rolled 270 degrees clockwise as it fell about 49 feet, landing on its left side in a foot-deep creek below the bridge. Three students and one adult sustained fatal injuries. The remaining passengers and the bus driver sustained injuries ranging from serious to minor. Because of the seriousness of his injuries, the accident bus driver stated that he could not recollect his perceptions at the time immediately preceding the accident

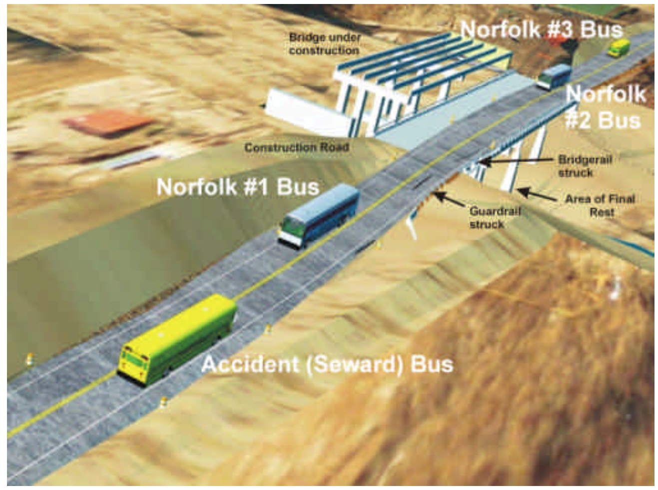

Figure 1 – Accident scene – from the simulation

HUMAN PERFORMANCE

The Seward school bus driver was observed by witnesses to drift toward the right edgeline on the Interstate earlier in the day and to contact the rumble strip. The accident bus driver was a 22-year-old, full time college student and had just begun his third year as a bus driver. Normally he drove a 59-passenger Thomas Built conventional school bus on his daily route. He had driven the 78-passenger Thomas Built transit-style bus three or four times in the previous 2 years and had 3 hours of "behind the wheel" training on the accident bus.

Witness statements and Safety Board observations on scene indicated that the accident bus driver might have perceived that one or more of the two oncoming Norfolk motor coaches and bus may have crossed the centerline because of the changes in roadway elevation and curvature. The bus driver may have steered rapidly to the right in response. To test this theory, Safety Board investigators obtained an exemplar vehicle and videotaped a "Driver's eye view" during several westbound passes over the West Papillion Creek Bridge. These passes were conducted at roughly the same time of day as the accident; weather conditions and traffic volumes were also similar (but there were no oncoming buses), and the driver maintained speeds consistent with those reported by witnesses to the accident. The videotape indicated the existence of a visual phenomenon that might have been sufficient to cause the school bus driver to mistakenly believe that one of the approaching motor coaches or the oncoming school bus was crossing over into his lane.

Naturally occurring visual phenomenon or distortions can affect a driver's ability to accurately perceive an object's location in three-dimensional space, especially beyond a distance of 66 feet (20 meters), in which monocular visual cues predominate as the eye-brain visual system works to develop a three-dimensional representation of the spatial environment. Such distortions may also be compounded when the viewer, the target, or both are in motion. Three visual phenomena that may have affected the driver's actions were the interposition[1] of the three Norfolk buses, the linear perspective[2] of the three Norfolk buses in a row and the motion parallax[3] of the three Norfolk buses relative to the Seward bus. The on scene videotape of the bus driver's view captured the dynamic interplay between the roadway characteristics (especially vertical and horizontal alignment), vehicle characteristics (in particular, the relative speeds and changes in acceleration of approaching vehicles), and visual phenomena that may have affected the driver's actions including interposition, linear perspective and motion parallax.

Methods

HVE Protocol

A simulation study was developed to examine the conditions associated with two-lane/large vehicle traffic in this construction area and included two oncoming motor coaches and an oncoming school bus.

The simulation was developed using the SIMON[1] physics program contained in the Human Vehicle Environment (HVE) system[2] to determine if the oncoming vehicles appeared to cross over into the lane of the accident bus. To best represent the driver's potential view, a detailed scene and similar motor coaches with similar designs and similar school buses were developed. Numerous simulations were run with the bus and motor coaches passing each other at different locations and with different headways for the oncoming motor coaches and bus to determine which combination may have produced a

[1] Interposition of objects provides spatial information because closer objects in the same visual path can obscure objects that are further away. Interposition is a monocular cue of relative spatial location.

[2] Linear perspective refers to the monocular visual spatial cue in which parallel lines in a perspective image appear to converge toward a single point at the most distant location in the image (the horizon or infinity). Nearby objects will also appear larger than similar objects at a distance; due to size constancy (the recognition that it is the perception that changes with distance, rather than the real size of the object); consequently, an observer perceives this change as one of distance. Additionally, the apparent shape of an object changes to reflect a change in spatial orientation or distance from the observer (that is, a rectangular door appears as a trapezoid shape as it is opened away from the observer); due to shape constancy (the recognition that the object retains its original shape, while it is our perception of it that it changes), this feature provides spatial information.

[3] Motion parallax refers to the differences in apparent angular velocity of objects, when the viewer and/or the image are in motion. The apparent velocity is inversely proportional to real distance, that is, nearby objects appear to move (or pass) rapidly by, while those at a distance move/pass much more slowly. Consequently, this dynamic monocular cue permits one to judge distance to an object when the object and/or observer are in motion. However when both the object and the observer are in motion, the accuracy of judgments of distance is diminished.

phenomena that the approaching vehicles were in the accident bus's path.

The simulation was developed using the HVE system and SIMON for the approach of the motor coaches and buses toward the bridge.[4] The Seward bus positions were matched to the physical evidence and the buses' witness estimated speeds of 40 to 45 mph. Spacing of the oncoming Norfolk motor coaches were initially based on the Norfolk driver's statements[5]. The Norfolk motor coaches were positioned and guided close to the centerline, but still within their lane.

To explore potential views of the accident driver, the scene and vehicles needed to closely represent the actual operating environment. This was accomplished through the on-scene mapping of the vehicles and roadway and through the development of a detailed three-dimensional scene in HVE. The vehicle models can be seen in Figures 2 and 3. Detailed information concerning the development of the scene and the vehicle models can be found in the NTSB public docket[3].

To allow different headways between the oncoming motor coaches and bus and different places for the Seward bus and Norfolk motor coaches to pass each other, each vehicle was simulated as a separate SIMON event. The first motor coach was simulated starting the approach at 40 mph. This motor coach was simulated to travel at speeds of 38 to 42 mph as it approached the Seward bus. At the far side of the bridge the first motor coach was traveling 41 mph. All the motor coaches were steered to stay in their lane but near the centerline. The second motor coach also started at 40 mph, but was slowed to 35 mph on the approach based on the bus drivers' statement, and was traveling about 36 mph at the end of the bridge as the Seward bus was passing it. The third bus was started at 40 mph and slowed to about 36 mph on the approach (based on the bus drivers' statements) and 37 mph at the end of the bridge. (See table 1 for a comparison of vehicle speeds in the simulation).

Figure 2 – Comparison of pictures of the Norfolk motor coach to the HVE model

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4 Engineering Dynamics Corporation Simulation of Automobile Collisions (EDSMAC4) and Engineering Dynamics Corporation General Analysis Tool (EDGEN) were also used to model the impact with the barrier and the roll and vault to the riverbed but will not be further discussed in this paper.

5 This was later modified as numerous simulations were rendered with different headways.

Figure 3 – Comparison of the sister bus and the HVE model.

Table 1 – Comparison of vehicle speeds in the simulation (in mph)

Vehicle	Starting Speed	Speed Range	Speed at of bridge
Seward bus	40	40 – 43	42
Norfolk MC 1	40	38 – 42	41
Norfolk MC 2	40	40 – 35	36
Norfolk bus 3	40	40 – 37	37

The Seward bus's approach to the bridge was also simulated using SIMON. The speed of this bus was also started at 40 mph. The speed increased to 43 mph going down the hill to the bridge and slowed to 42 mph just before the beginning of the bridge. Steering inputs were entered to place the vehicle in the center of the lane, but then it was allowed to drift slightly to the right near the edgeline, prior to the bridge to align with subsequent marks where the left wheel was near the middle of the lane. SIMON does not simulate collisions with other vehicles or fixed objects. The SIMON simulation was stopped just prior to the bridge to switch to the EDSMAC4 software to allow impact with the guardrail.

Using the individual SIMON events a matrix of simulations were rendered in playback to look at different headways between the buses and at different times when they passed each other. Views were changed and the positions of the buses were observed relative to each other.

Results

The simulation that was most consistent with most witness's statements was the simulation that had a spacing of 387 feet between the first and second Norfolk motor coaches and 202 feet between the second motor coach and third bus. In visualizations of this simulation, the first Norfolk motor coach was in a tangent section of the roadway and from the Seward bus's driver's potential view, the first Norfolk motor coach appeared headed for the Seward bus. Figure 4 depicts pictures from the simulations that show the Seward bus driver's potential view as the bus approached at about 40 mph. The time indicated on the frames was from the start of the simulation. The pictures showed that between T=21.7 and 23.7 seconds (the top 4 pictures in figure 4), the Seward bus was steered to the right of the lane, perhaps to avoid the oncoming Norfolk motor coach that was in a straight away and at that time, the Norfolk motor coach needed to steer right to avoid crossing the centerline.

The accident bus may have also been steered right because the subsequent second and third Norfolk motor coaches appeared to cross the centerline. The continuation of the yellow centerline behind the 2nd Norfolk motor coach appeared to be to the left of the bus. The centerline disappeared, as viewed from the Seward bus, in a dip in the road prior to the far side of the bridge, in a curve. The centerline became visible beyond the dip and appeared to extend from the middle of the Norfolk motor coach. The accident bus was also observed to drive

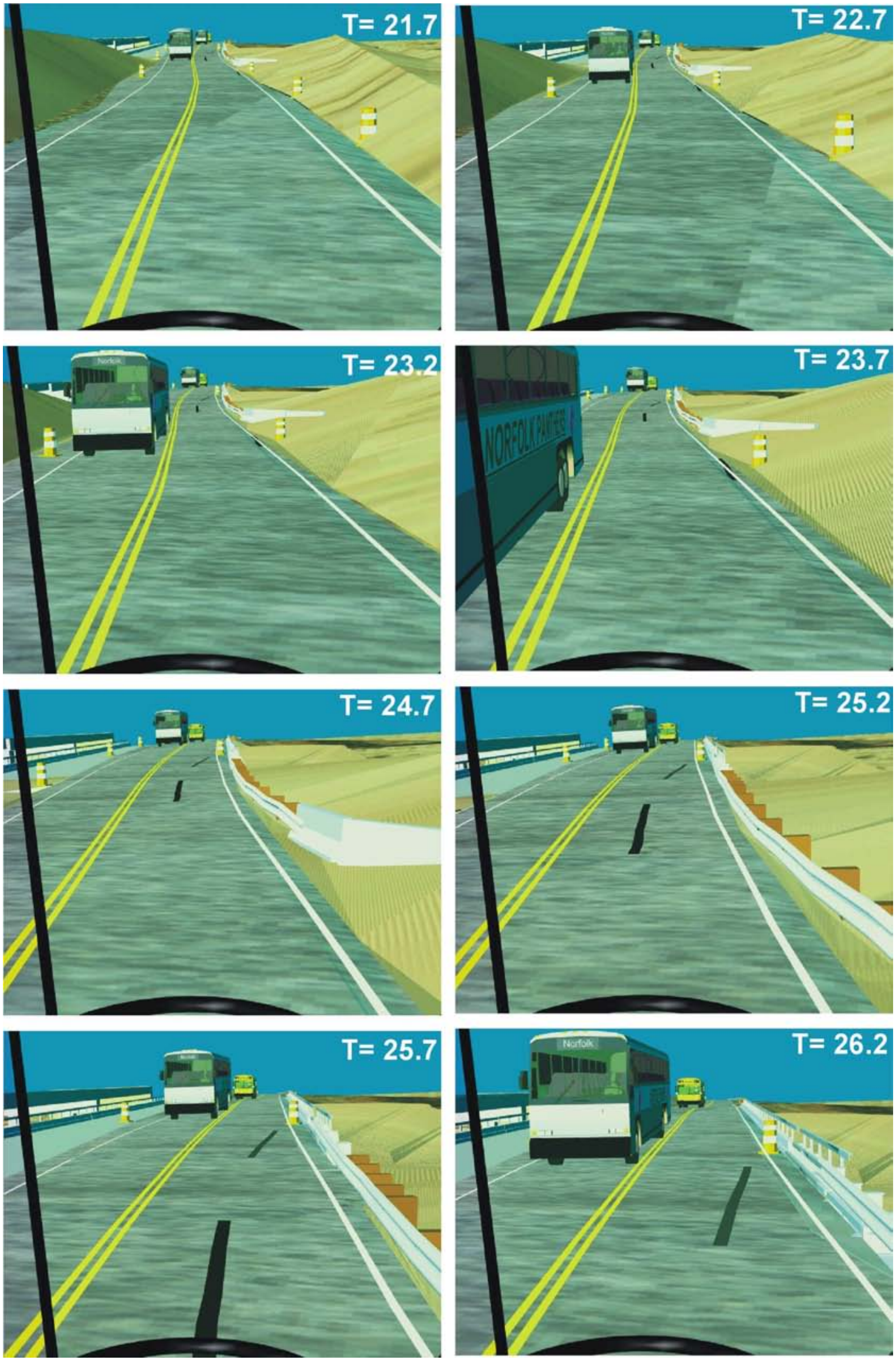

Figure 4 - The Seward school bus driver's potential view (Time shown in the upper right is from the start of the simulation)

along the edgeline on the first part of the trip and may have just been following a path along the edgeline and not reacting to the oncoming Norfolk motor coaches.

As the bus approached the bridge, with the right tires of the bus near the right edgeline a corrective left steer action was needed to avoid striking the concrete median barrier and the first segment of the guardrail that tapered from the barrier toward the road, with the front of the bus. At T= 24.7 seconds, (the 3rd frame down in the left column of figure 4), the bus was being steered to the left. This action caused the Seward bus to head toward the left lane and the second Norfolk motor coach.

At T=25.2 to 26.2 seconds (the bottom 3 frames in figure 4) the accident bus may have looked potentially like it would cross the centerline and strike the second oncoming Norfolk motor coach unless steered right. The bus was steered to the right and the right rear tire began to scrape on the guardrail due to off tracking[6]. This inhibited the steering of the bus further to the right. The bus was steered further to the right, but did not respond as the right rear tire rubbed on the guardrail. Finally the right rear wheel of the bus got past the guardrail restriction as the angle of the guardrail taper changed, and the bus steered sharply to the right and continued through the bridge rail, falling to the creek bed below. (See figure 1). At this time the third Norfolk yellow bus was in the dip and also appeared to be across the centerline.

Discussion

Possible Impingement on Accident Vehicle's Travel Lane

The persistent, rightward bias of the vehicle in its lane demonstrates the driver's unfamiliarity with the accident bus; it is insufficient to explain the circumstances of this accident. Additional evidence regarding the roadway geometry of the work zone and handling characteristics of the larger vehicles suggests that the driver's inability to accurately judge the lateral distance to the bridge rail was not solely responsible for this accident and that drivers traveling in both directions may have crowded each other's lanes.

Figure 5 shows the width of the lane lines, the widths of the buses, and the direction of off tracking as the first Norfolk motor coach approached the accident bus, based on a simulation of the accident.

Data from the Safety Board's simulation study indicated that on this curve, at speeds of about 40 mph, the Norfolk motor coach would have off-tracked about 3 inches; in other words, the drive

[6] Off tracking refers to the tendency of a long vehicle's rear tires to follow a different path from the vehicle's steering tires. As a vehicle goes around a turn at low speeds, the rear tires of the vehicles track inside the front tires. This phenomenon is similar to that of a bus at an urban intersection where the front tires are perhaps 10 feet or more from the curb at the start of the turn but the rear tires come very close to the curb as the bus turns. As speed increases and the radius of the turn becomes greater, the amount of off tracking declines. At higher speeds in a turn, the vehicle begins to slip at the rear tires, and the rear tires track outside the front tires.

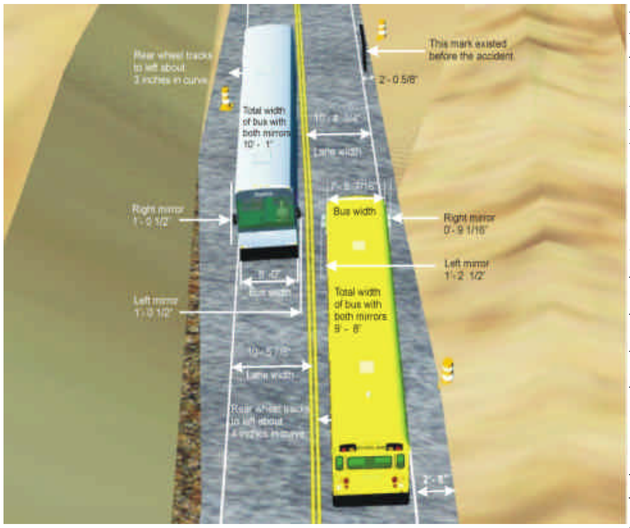

Figure 5. Bus and lane widths (Norfolk motor coach, top left, and accident bus, lower right).

axle tires would have been about 3 inches closer to the edgeline than the front tires. Similarly, on this curve, the accident bus would have off-tracked about 4 inches, and the rear tire would have been closer to the centerline than the front tires.

When one considers the width of the eastbound and westbound lanes (each about 10 1/2-feet wide) and the widths of the bus bodies with drivers' side mirrors (about 9 feet wide), along with an additional 3 to 4 inches of off-tracking for each bus, clearly both lanes were almost fully occupied. Further, if the Norfolk motor coach was near the centerline to avoid the dirt embankment on the right, the accident bus may have been driven near the edgeline on the outside of the curve.

As the accident bus approached the guardrail and bridge, the simulation indicates that, if the right side of the bus was near the edgeline, the operator would have had to steer the bus to the left about 70 degrees[7] to avoid striking the guardrail. The rear of the bus tracked inside the front by about 4 inches at 41 mph. For the accident bus driver to avoid going across the lane and striking the second Norfolk motor coach, the accident bus would have been steered to the right and would have tracked about 5 to 8 inches toward the guardrail. During this corrective right steer,[8] the bus struck the guardrail and then the bridge rail.

Although the roadway might have been wide enough to permit the second Norfolk motor coach and the accident bus to pass one another on a straightaway, given the off-tracking, overhang, and turning radii characteristics of the two vehicles, it may not have been wide enough for either driver to comfortably maneuver his vehicle through the series of curves at the speeds at which the vehicles were traveling. The Safety Board concluded that the roadway geometry in the work zone resulted in extremely tight tolerances on driver performance, which may have been exceeded when the second Norfolk motor coach and the accident bus approached the West Papillion Creek Bridge. The Safety Board further concluded that although it cannot be determined whether the driver of the oncoming Norfolk motor coach encroached upon or crossed the

[7] Equivalent to a radius of about 500 feet.

[8] To follow the tiremarks, the bus required about a 175- to 290-degree right steer in SIMON after the 70-degree left steer. At 175 degrees or more right steer, the bus would have followed a curve radius of about 150 feet. Above 175 degrees, the bus would have followed about the same radius as at 40 mph but would have yawed and sideslipped. Above 175 degrees, the bus would have rolled over after a quarter of a turn. The steering input may have been reduced slightly due to the right-rear tire dragging along the face of the guardrail.

centerline, the narrowness of travel lanes in the work zone relative to the space occupied by the buses left the accident bus driver little room for error.

The Safety Board's simulation further supported the theory that the accident driver may have experienced visual phenomena of the approaching bus impinging his travel lane. (See figure 4 frames T=22.7 to 25.7 seconds).

The simulation showed that the first Norfolk motor coach may have been on a tangent line headed toward the accident bus as the two buses met at a curve,[9] thus the accident bus driver had no indication of where the Norfolk driver would turn as he got to the curve or how much of the roadway the Norfolk motor coach would occupy. In addition, at the same time, the 2nd Norfolk motor coach and bus passed into the curve and a depression in the roadway prior to crossing the bridge, they appear to cross the centerline because the centerline visually "disappears" into the depression.

If the Norfolk motor coaches impinged on the centerline or crossed slightly into the other lane, the perception that the Norfolk motor coaches were crowding the accident bus was exacerbated. The phenomenon of crowding was further supported by the driver's statement from the bus following the accident bus that stated, "the accident bus was traveling close to the right side of the road".

Physical evidence collected during the accident investigation further supported the theory that the accident bus driver feared a frontal collision with the Norfolk motor coach. The only way that the rear of the bus could have initially struck the guardrail without the front of the bus striking the guardrail first was for the bus to have been steered right and for the rear of the bus to have off-tracked inside the front of the bus. The theory that the right-rear tire initially struck the guardrail is supported by the physical evidence of tire smear found on the guardrail and the tire print matching the right-rear tire found in the soil between the edge of the pavement and the guardrail. The simulation also shows that the accident bus steered hard to the right to avoid hitting the second Norfolk motor coach with its left-front side, even though the tire mark indicated that the left tire was about 4 feet, 10 inches, right of the centerline. The Seward bus driver sensed he was over the centerline because he was several feet forward of the left front tire, and then over steered.

In both the videotape of the driver's view and the simulation, the approaching vehicles appeared to be further to the right of the centerline in the accident bus's lane, due to the simultaneous change in vertical and horizontal alignment at the end of the bridge, and may have led the accident bus driver to exacerbate his tendency to over steer. This distortion was also noted as the two preceding Norfolk motor coaches approached the accident site. The HVE simulation did not include shadows as observed in the video. If HVE included shadows, the phenomena may have been further enhanced.

These visual distortions, together with the accident bus driver's unfamiliarity with the bus and his relative position to the tires, the width of the buses relative to the width of lanes, and a small amount

[9] The curve radius is 1,500 feet, based on the Safety Board's mapping.

of off-tracking, combined to create the difficult situation that the driver encountered as he neared the edgeline in this curve. As the view from the simulation demonstrated, a collision with the second Norfolk motor coach appeared to be imminent and evasive action appeared to be necessary. The Safety Board concluded that the roadway geometry in the work zone created a visual phenomena that caused the accident bus driver to perceive the oncoming Norfolk motor coach as impinging upon its lane, regardless of whether it did or not.

Because of the seriousness of his injuries, the accident bus driver stated that he could not recollect his perceptions at the time immediately preceding the accident. Douglas County Sheriff's Office and Safety Board investigators interviewed a large number of witnesses who were in a position to observe the buses as they passed. Those witness reports were consistent with the types of visual phenomena previously discussed in this section.

Conclusions

In this case, the HVE system was able to replicate and enhance the visual phenomenon that was observed on scene during a reenactment. Using motor coaches and a schoolbus at close intervals, operating at about 40 mph, enhanced the phenomena that the approaching vehicles crossed into oncoming traffic when compared to video footage from the schoolbus with just normal oncoming traffic. In the simulation, it could be determined that this visual phenomena occurred because of a simultaneous horizontal and vertical curve prior to the bridge, in which the centerline disappeared and then reappeared as if it was coming out of the middle of the back of the vehicles. The phenomena may have been enhanced even more if HVE vehicles were able to cast a shadow on the roadway.

In addition to the phenomena that the oncoming motor coaches and bus may have appeared to be crowding the centerline, two additional phenomena were noted during the simulation. The phenomena of passing an oncoming large vehicle in the curve where lanes are narrow and the action of the oncoming vehicle is uncertain, would encourage a bus to be driven to the outside of the curve. The phenomena due to the driver being in front of the tires as it headed toward the second motor coach where an impact appeared imminent was observed. These phenomena were not observed on scene during the reenactment and thus helped the Safety Board to determine the probable cause.

The National Transportation Safety Board determined[4] that the probable cause of this accident was the failure of the Nebraska Department of Roads to recognize and correct the hazardous condition in the work zone created by the irregular geometry of the roadway, the narrow lane widths, and the speed limit. Contributing to the accident was the accident bus driver's inability to maintain the bus within the lane due to the perceived or actual threat of a frontal collision with the approaching eastbound motorcoach and the accident bus driver's unfamiliarity with the accident vehicle. Contributing to the severity of the accident was the failure of the traffic barrier system to redirect the accident vehicle.

REFERENCES

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[1] Simulation Model Non-linear, SIMON Simulations Model, Version 1, Engineering Dynamics Corporation, April 2002

[2] Engineering Dynamics Corporation, Beaverton, OR

[3] See Vehicle Dynamics Simulation Study, Lawrence E Jackson, May 12, 2003, Project ID 53605, Item 182

[4] See the NTSB report, when available, and the simulations at http://www.ntsb.gov/events/2004/Omaha/omaha_ani.htm