**NATIONAL TRANSPORTATION SAFETY BOARD**
Office of Research and Engineering
Washington, D.C. 20594

November 22, 2011

# Video Study

**NTSB Case Number:**
**HWY-10-MH-018**

## A. ACCIDENT

| | |
|---|---|
| Location: | Gray Summit, Missouri |
| Date: | August 5, 2010 |
| Time: | 10:11 AM CDT |
| Vehicle No. 1: | 2007 Volvo truck tractor |
| Vehicle No. 2: | 2007 GMC Sierra pickup truck |
| Vehicle No. 3: | 2003 Blue Bird, 71-Passenger School Bus ('Bus No. 1') |
| Vehicle No. 4: | 2001 Blue Bird, 72-Passenger School Bus ('Bus No. 2') |

## B. AUTHOR

Dan T. Horak
NTSB
(202) 314-6664
dan.horak@ntsb.gov

## C. ACCIDENT SUMMARY

On Thursday morning, August 5, 2010, a 2007 Volvo truck tractor operated by a 43-year-old driver was traveling eastbound in the right lane of Interstate 44 (I-44) near milepost 250.6. At about 10:11 a.m. central daylight time, a 2007 GMC Sierra pickup truck operated by a 19-year-old driver struck the rear of the truck tractor as it was stopped in a construction zone.

A 2003 Blue Bird 71-passenger school bus occupied by a 75-year-old driver and 23 passengers was also traveling eastbound in the right lane of I-44 in front of a 2001 Blue Bird 72-passenger school bus occupied by a 38-year-old driver and 31 passengers. After moving into the left lane and back into the right lane, the lead school

bus struck the rear of the pickup truck. The left front of the second school bus then struck the right rear of the lead bus. This collision pushed the pickup truck forward, and it overturned onto the frame rail of the truck tractor. The lead bus came to rest on top of the pickup truck and the truck tractor. The second bus remained engaged with the lead bus.

As a result of the accident, the driver of the pickup truck and one passenger from the lead school bus were killed. Thirty one school bus passengers, the two school bus drivers, and the driver of the truck tractor received injuries ranging from minor to serious.

## D. DETAILS OF INVESTIGATION

Bus No. 2, the 2001 Blue Bird, had a rearward facing camera that recorded on a VHS tape the entire trip, including the impact with Bus No.1. This video was used for estimating five quantities related to this multi-vehicle accident. The estimated quantities were:

(1) Speed of Bus No. 2
(2) Speed of the pickup truck as it was passing Bus. No. 2
(3) Time of pickup truck collision with the truck tractor
(4) Location where Bus No. 2 started turning right
(5) Time between impact of Bus No. 1 and impact of Bus No. 2

### Camera Calibration

Bus No. 2 was equipped with a Gatekeeper video monitoring system manufactured by Gatekeeper Systems, Inc. It consisted of a Gatekeeper Model ACN-1024 VCR unit and an Optex dome camera. The camera was mounted above the front windshield inside the bus, and was pointed rearward to record the passengers.

Using images from the video, bus dimensions provided by the manufacturer and bus dimensions measured by NTSB investigators, it was possible to estimate the camera field of view and the camera location and orientation with respect to the bus. These estimated parameters were used as inputs to a mathematical model of the camera that mapped points in the 3D field of view of the camera onto simulated 2D VCR video frames. The calibrated mathematical camera model placed points inside the bus, such as a corner of a side window, at the same location on a video frame as the real camera did. The camera model was valid whether the points were inside the bus or outside of it and visible through the side or the rear windows.

### Estimating Speed of Bus No. 2

There were two time periods shortly before Bus No. 2 collided with Bus No. 1 when the lateral position of Bus No. 2 in the right lane was constant. Because of the constant lateral position, the white broken lane-dividing line visible through the rear window was passing the same points in the window as the bus was moving. Speed estimation during these periods was relatively simple based on the length and the

spacing of the white line segments and the elapsed time measured by counting video frames. During the last second before impact, Bus No. 2 was turning right so that while the white broken line was visible, it was not passing the same points in the rear window. Speed estimates during this second were based on the calibrated camera model described above.

*Bus No. 2 Speed Estimate between Time 10:18:29 and Time 10:18:36 (30 seconds before collision with Bus No. 1)*

The estimate is based on the broken white lane-dividing line seen in the lower left corner of the right (right as seen in the video, i.e., driver side) rear bus window. Table 1 lists the times when the distant end of the line segment is seen in the corner of the window.

**Table 1** - Data for Time Segment 10:18:29 to 10:18:36

| Line Segment Number | Time (ms) |
|---|---|
| 1 | 8374 |
| 2 | 7907 |
| 3 | 7373 |
| 4 | 6873 |
| 5 | 6439 |
| 6 | 5905 |
| 7 | 5438 |
| 8 | 4971 |
| 9 | 4470 |
| 10 | 4003 |
| 11 | 3503 |
| 12 | 3002 |

The times listed in Table 1 are relative times displayed in a MPEG-2 viewer that was used to step through the DVD copy of the VHS video tape. These times are not the VCR time-stamps seen in the video frames. The MPEG-2 viewer does show 30 frames per time-stamped second, indicating that there were no frames lost during the VHS-to-DVD translation of the video.

The standard for broken lane-dividing lines is a 10 ft line segment followed by a 30 ft gap. This was verified at the accident location using a Google Earth image of the road segment corresponding to Table 1. Figure 1 shows the Google Earth image that includes this segment and a ruler enclosing 14 white lines. The ruler measurement is 550 ft, resulting in a line+gap length estimate of 550/14=39.3 ft which is in close agreement with the 40 ft standard.

Figure 2 shows a plot of the traveled distance vs. the elapsed time. Traveled distance was computed by

$$\text{Traveled Distance} = 39.3 \times (13 - \text{Line Segment Number}) \qquad (1)$$

where Line Segment Number was taken from Table 1. The figure also shows a superimposed constant speed estimate computed via Least Squares. Since the two curves are very close to each other, the speed in the analyzed time segment was constant and the resulting speed estimate of 55.05 mph is very accurate.

**Figure 1** Google Earth Image of the Analyzed Road Segment with a Superimposed 550 ft Ruler

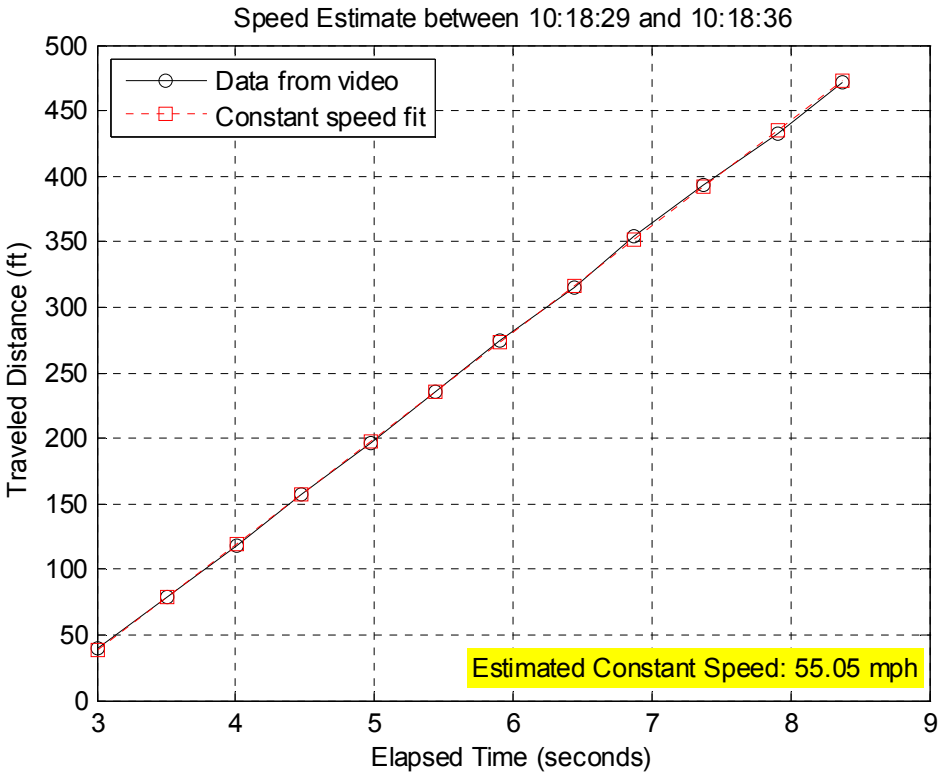


**Figure 2** Bus No. 2 Speed Estimate between 10:18:29 and 10:18:36 (VCR time stamps)

*Bus No. 2 Speed Estimate between Time 10:18:48 and Time 10:18:52 (14 seconds before collision with Bus No. 1)*

The estimate is based on the broken white lane-dividing line seen in the lower left corner of the right (right as seen in the video, i.e., driver side) rear bus window. Table 2 lists the times when the closer end of the line segment is seen in the corner of the window. Note that one of the line segments was skipped because it was not seen clearly enough to be timed accurately.

**Table 2** - Data for Time Segment 10:18:48 to 10:18:52

| Line Segment Number | Time (ms) |
|---|---|
| 1 | 4190 |
| 2 | 3689 |
| 3 | 3089 |
| 4 | skipped |
| 5 | 2121 |
| 6 | 1621 |
| 7 | 1053 |
| 8 | 553 |

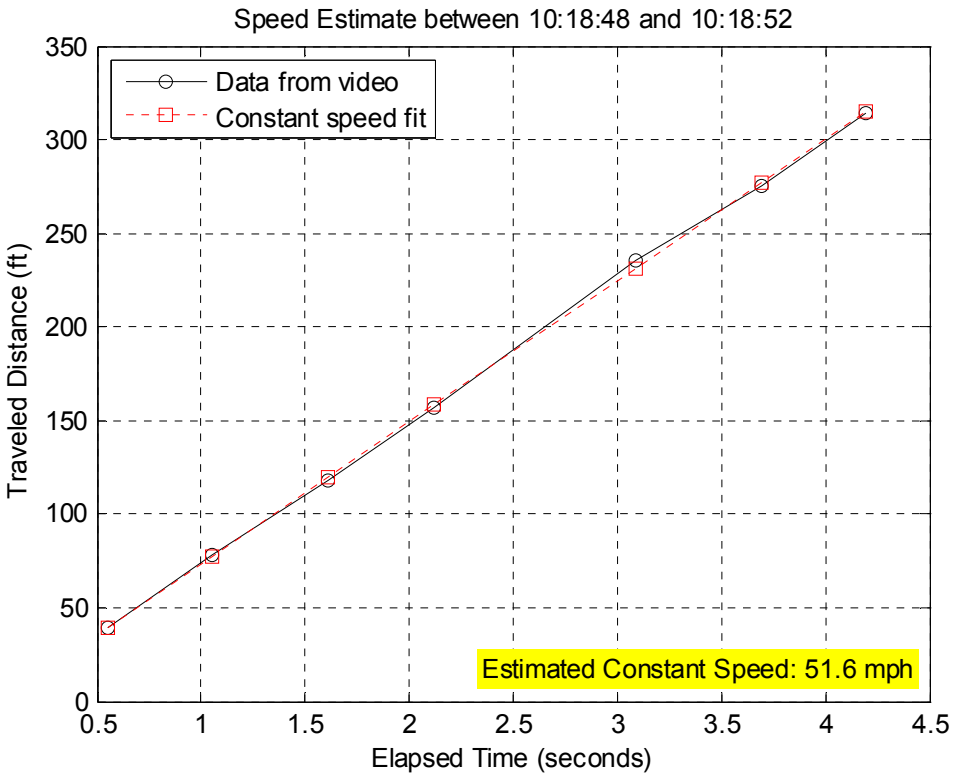


**Figure 3** Bus No. 2 Speed Estimate between 10:18:48 and 10:18:52 (VCR time stamps)

This road segment was analyzed same way as the first segment and details of the speed estimation are shown in Figure 3. The estimated speed was 51.6 mph. Note that the skipped data point did not limit the use of the Least Squares algorithm.

*Bus No. 2 Speed Estimate at Time 10:19:06*

This is the second that ended in collision of Bus No. 2 with Bus No. 1. The speed could not be estimated using the method used above because the bus was not aligned with the lane and, consequently, the broken white lane-dividing line was not passing a constant location in any bus window.

The speed during this second was estimated using the method developed for the 2008 Mexican Hat, UT motorcoach accident (NTSB Case Number: HWY-08-MH012). The camera in Bus No. 2 was calibrated as described above. An interactive computer program was then used to estimate bus locations at which modeled fog lines and a modeled broken lane-dividing line were aligned with the corresponding line images in the video as seen through the bus windows. The lane lines were modeled to match a 24 ft wide road with solid fog lines and a broken lane-dividing line with 10 ft long line segments and 29.3 ft long gaps. The modeled lane-dividing line segments were not

aligned longitudinally with the actual line segments at the accident site. Such alignment was not necessary for the speed estimation method to work.

Alignment was possible at four locations during the analyzed one second of travel. The corresponding VCR frame times were 10:19:06.1667, 10:19:06.4000, 10:19:06.6333 and 10:19:06.9667. Based on the four estimated locations, two sets of three speed estimates were derived. The first set was based on speeds computed individually within each of the three road segments defined by the four locations. These were local speed estimates.

The second set of three estimates was based on the three road segments that started at location No. 1 and ended at locations No. 2, No. 3 and No. 4, respectively. These were average speed estimates over road segments of increasing length. Figure 4 shows the estimated speeds. The speeds are shown at the end of the time segment over which they were estimated. The local speed estimates, marked by circles and interconnected by solid lines, show that the bus went from 43.1 mph down to 42.2 mph and eventually down to 38.1 mph at time of collision. It is possible that the last speed estimate of 38.1 mph reflects a slowdown due to the initial contact between Bus No. 2 and Bus No. 1.

Based on these speed estimates, the deceleration between the first and the second speed estimate locations was 0.16 G and the deceleration between the second and the third speed estimate locations was 0.59 G. It is possible that the deceleration of 0.59 G reflects a contribution from the initial contact between Bus No. 2 and Bus No. 1.

Estimating Speed of the Pickup Truck as It Was Passing Bus No. 2

Bus No. 2 impacted Bus No. 1 at 10:19:07 VCR video recording time. The pickup truck can be seen in the video passing Bus No. 2 at about 10:18:08, 59 seconds before Bus No. 2 impacted Bus No. 1.

Utilizing the broken white lane-dividing line seen through the rear window of Bus No. 2, it was possible to estimate the speed of the bus between 10:17:59 and 10:18:04 as 56.8 mph. It was assumed that this speed remained constant until the pickup truck passed by, i.e., 4 more seconds.

The speed of the pickup truck was estimated utilizing the time it took its length of 241.5 inches to pass the same point in a left side window of the bus. This resulted in a speed estimate of 69.3 mph, 12.5 mph faster than the bus. The accuracy of this estimate is better than ±1.5 mph.

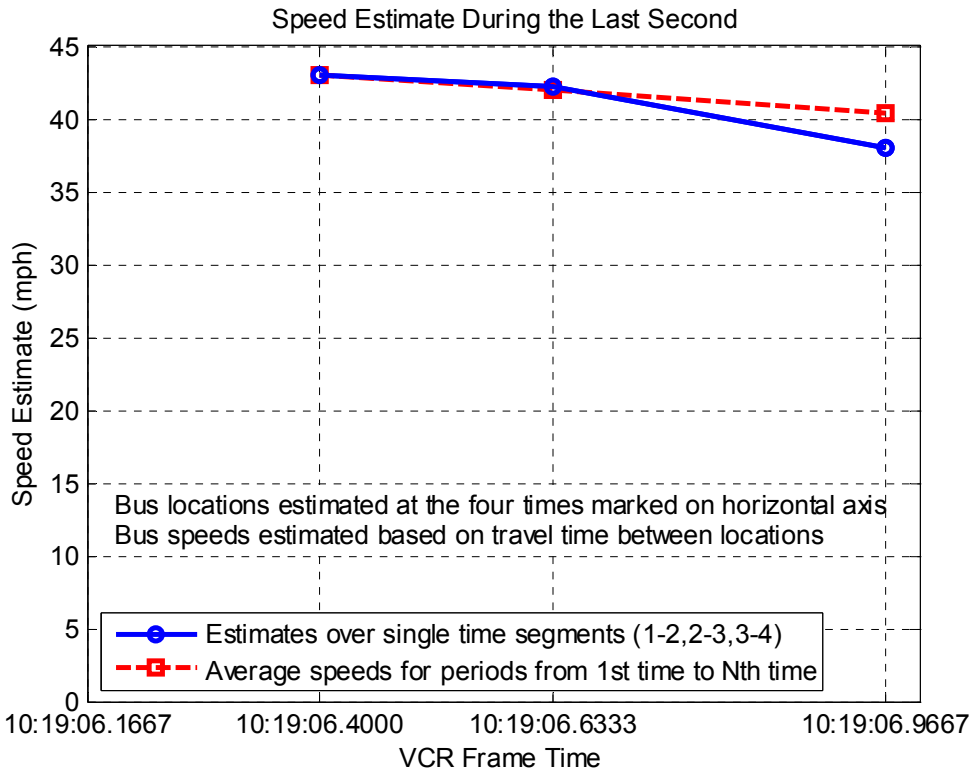


**Figure 4** Bus No. 2 Speed Estimates during the Last Second

Estimating Time of Pickup Truck Collision with the Truck Tractor

Pickup truck speeds are known at three times during the period starting when it passed Bus No. 2.

1. As explained above, 59 seconds before Bus No. 2 impact with Bus No. 1 the speed was 69.3 mph.
2. The speed was 58 mph 5 seconds before the pickup truck impacted the truck tractor (from pickup truck airbag SDM).
3. The speed was 55 mph 1 second before the pickup truck impacted the truck tractor (from pickup truck airbag SDM).

The goal of this analysis was to place upper and lower bounds on the time between the pickup truck impact and Bus No. 2 impact, which required some assumptions about the actions of the pickup truck driver.

At the speed of 69.3 mph, 12.5 mph faster than the bus speed, the pickup truck advanced 18.3 ft each second relative to the bus, a distance close to the length of the pickup truck. If the pickup truck was in the left lane in order to pass the bus, it probably maintained that speed until it advanced several pickup truck lengths ahead of the bus and then returned to the right lane. Then, over some period of time, it reduced its speed to 58 mph.

If the pickup truck was not in the left lane just to pass, then it probably continued at the speed of approximately 69.3 mph in the left lane for some unknown time and then reduced its speed to 58 mph. During that time it also moved to the right lane.

The time difference between the pickup truck impact and Bus No. 2 impact, $\Delta T$, was estimated for several combinations of times $T_1$ and $T_2$, which were defined as follows.

$T_1$ = time period during which the pickup truck continued at 69.3 mph after passing Bus No. 2.

$T_2$ = time period, starting at the end of period $T_1$, during which the pickup truck reduced its speed from 69.3 mph to 58 mph. It is assumed that the speed reduction occurred with constant deceleration.

The values of $T_1$ that were considered for the bus-passing scenario were 3, 5 and 10 seconds, corresponding approximately to 3, 5 and 10 pickup truck lengths. $T_1$ values considered for the scenario where the pickup truck was in the left lane not because it was passing the bus were 20 and 30 seconds.

The considered values of deceleration times $T_2$ were 10 seconds, 20 seconds, 30 seconds and the maximum time that still allowed the pickup truck to decelerate to 58 mph 5 seconds before its impact and then decelerate linearly to 55 mph at 1 second before impact. Note that for each $T_1$ there is a maximum value of $T_2$ that can still meet the accident location constraint. Values of $T_2$ above this maximum result in computed accident locations that are farther than the actual accident location.

An iteration process was used to find a time $T_3$ during which the pickup truck was moving at the constant speed of 58 mph after decelerating to that speed during time period $T_2$. The objective of the iteration was to place the pickup truck at the accident location $T_1+T_2+T_3+5$ seconds after it passed the bus.

The accident location was estimated by integrating the speed of the bus over the 59 seconds mentioned above. Its speed during this 59 second time period was computed by linear interpolation. The speeds used for interpolation were 56.8 mph at 10:18:08, 55.05 mph between 10:18:29 and 10:18:36, 51.6 mph between 10:18:48 and 10:18:52, and the speeds of 43.1 mph, 42.2 mph and 38.1 mph during the last second before impact.

Once $T_3$ was determined by iteration, the time difference between impacts, $\Delta T$, was computed by

$$\Delta T = 59 - (T_1 + T_2 + T_3 + 5) \qquad (2)$$

Tables 3 and 4 list the values of $\Delta T$, the time between pickup truck impact and Bus No. 2 impact, for various values of $T_1$ and $T_2$. In each table, the last value of $T_2$ is the maximum possible, as explained above. The tabulated maximum $T_2$ is the largest

integer number that satisfies the accident location constraint. Five values of $T_1$ were considered and analyzed. However, since the minimum $\Delta T$ occurs when T1=3 seconds and the maximum occurs when $T_1$=30 seconds, only tables corresponding to these extreme cases are included below.

**Table 3** Time between Pickup Truck Impact and Bus No. 2 Impact, $\Delta T$. ($T_1$=3 seconds)

| $T_2$ | $\Delta T$ |
|---|---|
| 10 | 5.9 |
| 20 | 6.9 |
| 30 | 7.9 |
| 40 | 8.9 |
| 41 | 9.0 |

**Table 4** Time between Pickup Truck Impact and Bus No. 2 Impact, $\Delta T$. ($T_1$=30 seconds)

| $T_2$ | $\Delta T$ |
|---|---|
| 10 | 11.2 |
| 12 | 11.4 |

Table 3 shows that the shortest feasible time delay between the pickup truck impact and Bus No. 2 impact is 5.9 seconds and Table 4 shows that the longest feasible time delay is 11.4 seconds. Note that these lower and upper bounds are based only on the video segment recorded 59 seconds before Bus No. 2 impact and assumptions about the speed of the pickup truck.

Estimating the Location where Bus No. 2 Started Turning Right

The motorcoach that was parked on the right shoulder was visible through the right side windows of Bus No. 2 as it passed it. Using video analysis based on the calibrated camera model, it was determined that Bus No. 2 started turning right when its front was 94 ft ahead of the front of the motorcoach (i.e., the bus was already past the motorcoach).

It was assumed that 0.1 seconds passed between the start of steering and the time when Bus No. 2 yawed enough to make the steering effect detectable in the video. This was an estimate based on TruckSim simulations of the steering dynamics of a school bus. In 0.1 seconds, Bus No. 2 traveled about 8 ft along the road. Therefore, it is estimated that the driver of Bus No. 2 started steering to the right when the front of her bus was 94-8=86 ft ahead of the motorcoach and the rear of her bus was 86-35=51 ft ahead of the front of the motorcoach. The time when the driver started steering was 1.9 seconds before it impacted Bus No. 1.

Estimating the Time between Impact of Bus. No. 1 and Impact of Bus No. 2

This time can be estimated two different ways that are independent of each other. One is based on the video from Bus No. 2 during the last few seconds before Bus No. 2 impact. The other is based on the pickup truck impact time estimate derived above and the pickup truck air bag SDM.

It was established above that Bus No. 2 started turning right when its front was 94 ft ahead of the front of the motorcoach. The video shows that this occurred 1.8 seconds before Bus No. 2 impact. It was also assumed above that there was a delay of 0.1 seconds before the effect of steering became visible in the video. If one assumes a short reaction time of 1.5 seconds, a lower limit on the time between the impact of Bus No. 1 and the impact of Bus No. 2 can be estimated as 1.8+0.1+1.5=3.4 seconds.

The second way of estimating the time between the impacts of the two buses is based on the previously estimated time between the impact of the pickup truck and the impact of Bus No. 2. That estimated time was between 5.9 seconds and 11.4 seconds. The pickup truck airbag SDM recorded the Bus No. 1 impact with the pickup truck at 6.0 seconds after the impact of the pickup truck with the truck tractor. When these estimates are combined, Bus No. 2 impact had to occur no later than 11.4-6.0=5.4 seconds after Bus No. 1 impact.

The two estimates, 3.4 seconds and no more than 5.4 seconds, can be combined into one estimated range of between 3.4 seconds and 5.4 seconds

## E. CONCLUSIONS

Bus No. 2 was traveling at a constant speed of 55 mph in the time period between 37 seconds and 30 seconds before collision. It was traveling at a constant speed of 51.6 mph in the time period between 18 seconds and 14 seconds before collision. The accuracy of these speed estimates is better than ±1.5 mph.

During the last second before collision with Bus No. 1, Bus No. 2 slowed down from 43.1 mph at approximately 0.6 seconds before initial contact to 38.1 mph at time of initial contact. The accuracy of these speed estimates is better than ±3 mph. The highest estimated deceleration was 0.59 G, which may include a contribution from the initial contact of the colliding buses.

The pickup truck passed Bus No. 2 at the speed of approximately 69 mph. It happened 59 seconds before Bus No. 2 impacted Bus No. 1.

The driver of Bus No. 2 started steering to the right 1.9 seconds before impacting Bus No. 1. At that time, the rear of Bus No. 2 was 51 ft ahead of the front of the motorcoach that was parked on the shoulder.

The time between the impact of Bus No. 1 and the impact of Bus No. 2 was estimated to be between 3.4 seconds and 5.4 seconds.