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

March 21, 2016

Video Study

NTSB Case Number:
HWY15FH010

A. ACCIDENT

Location:	Houston, Texas
Date:	September 15, 2015
Time:	7:03 a.m.
Vehicle No. 1:	2008 IC Integrated CE school bus
Vehicle No. 2:	2003 Buick LeSabre passenger car ('accident car')

B. AUTHOR

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NTSB

C. ACCIDENT SUMMARY

For a summary of the accident, refer to the *Crash Summary Report* in the docket for this investigation.

D. DETAILS OF INVESTIGATION

The purpose of this study was to estimate the speed of the accident car, the angle with which it impacted the school bus, and the speed of the school bus. The bus was equipped with seven video cameras. Two cameras were rear-facing and aimed at occupants. One camera was aimed at the loading door. Two cameras were mounted near the lateral centerline of the bus, one recording the road ahead and one the road behind the bus. Two externally-mounted rear-facing cameras were mounted near the front of the bus, about nine feet above ground, one on the left side and one on the right side. They recorded traffic in the lanes left and right of the school bus.

Most of the information used in this study came from the video recorded by the externally-mounted rear-facing camera on the left side of the school bus that was traveling in the second lane. It captured the impacting accident car that was traveling in the third lane, left of the school bus.

The video system on the bus was supplied by Safety Vision, LLC, and its SafetyView video player software was used to play the recorded videos. SafetyView was generating time stamps for the frames in the video, but they were incorrect. For example, it showed some adjacent frames as spaced by 0.199 seconds and other adjacent frames spaced by 0.004 seconds. However, the time stamp differences between frames separated by ten frame-to-frame sampling times always summed up to 0.1 seconds. This indicated that the frame rate was a constant 10 fps but the time stamps were incorrect. Viewing the motion of vehicles in the video also confirmed that the frame rate was constant.

SafetyView could export frames from the video in bmp format with the resolution of 720x480 pixels. The exported frames had significant barrel distortion because of the wide angle of view of the camera. This distortion was corrected mathematically and the corrected frames were used for analysis of vehicle motions.

Figure 1 shows a frame from the video after the barrel distortion was corrected. It shows the accident car crossing from the third lane into the second lane, toward the school bus, 0.8 seconds before it impacted the left side of the bus.

Figure 1 Frame from the Video Used for Vehicle Motion Analysis

Estimating Speed of the School Bus

The video clearly showed the broken white lane lines on the highway. The standard length of the white segments is 10 ft and the standard space between the white segments is 30 ft long. This results in a pattern that repeats every 40 ft. Google Earth measurements showed that the broken lane lines at the location of the accident were accurate. Measurements going back 800 ft from the location of the car-to-bus impact indicated that the 40 ft pattern lengths were accurate to within less than 1% whether measured over one or over multiple solid white segments.

The locations of the school bus were estimated over 480 ft that ended just before the impact location based on the solid white line segments seen in the video frames. Seven locations were considered, corresponding to seven video frames spaced by ten video frame intervals from each other. This eliminated the need to use the incorrect video time stamps because the spacing by ten frame intervals guaranteed spacing of one second between adjacent analyzed video frames. The estimated speed of the bus was 55.4±1 mph.

Estimating Speed of the Accident Car

The accident car was clearly visible in the video for about ten seconds before it impacted the school bus. Its location along the road had to be estimated based on video frames acquired with the camera that was on the school bus which was ahead of the car and was moving. When the car was close to the bus, shortly before the impact, the location of the car with respect to the broken lane lines could be estimated accurately. At earlier times, when the car was far behind the bus, the accuracy was lower. The speed of the car was estimated over four seconds prior to impact. During these four seconds, the video allowed accurate location estimation of the car. The estimated speed of the accident car was 69±1 mph.

The speed recorded by the accident car air bag module was 70 mph five seconds before impact and 68 mph just before impact. The agreement between the video-based speed and the air bag module speed is very good. It provides validation that the car speed was indeed between 68 mph and 70 mph. Furthermore, it also validates the constant 10 fps frame rate of the video, eliminating the confusion caused by the incorrect time stamps. Consequently, it also validates the 55.4±1 mph school bus speed estimate that relies on the accuracy of the 10 fps frame rate.

Estimating the Car-to-Bus Impact Angle

At the time the impact occurred, the school bus was traveling in the second lane (counted from right) and the accident car was traveling in the third lane. The video shows that during the last two seconds before impact, the accident car moved laterally to right, crossed from the third lane into the second lane, and impacted the bus. The car-to-bus impact angle can be estimated by $tan^{-1}(V_y/V_x)$, where V_y and V_x are the lateral and the longitudinal speeds of the car, respectively.

The camera was mounted on the school bus with significant yaw angle with respect to its longitudinal axis of the bus, and with significant roll and pitch angles with respect to ground. This resulted in the third lane in the video frames being more than twice as wide as the fourth lane, i.e., the image was very nonlinear in the lateral (across the lanes) direction. This optical effect was unrelated and in addition to the barrel distortion of the images, which was corrected earlier in the analysis.

A model of camera optics was developed so that the lateral location of the car with respect to the lane lines could be accurately estimated in the presence of the nonlinearity. The parameters of the model were the elevation of the camera above ground, its roll, pitch and yaw angles with respect to the bus, and the field of view angle of the camera. These five parameters were estimated in an iterative process where they were varied until the solid segments of the broken lane lines were accurately mapped onto video frames at the locations of their images in the frames.

Once a camera model was available, longitudinal lines spaced laterally by one foot were superimposed on frames from the video so that the area to the left and to the right of the lane line between the second and the third lanes was calibrated laterally in one foot increments. The superimposed lines were at the elevation corresponding to the elevation of the accident car headlights. These superimposed lines allowed the estimation of the lateral location of the right edge of the right front headlight of the accident car relative to the lanes. The rate of change of the lateral location was the estimate of the lateral speed of the accident car.

The lateral speed of the accident car was estimated over a 1.1 second long time interval ending at impact time. This process resulted in estimated lateral speed of the accident car of 2.3±0.25 mph, which translates to estimated car-to-bus impact angle of 1.9º±0.2º.

E. <u>CONCLUSIONS</u>

Speeds of a school bus and of a car that collided on a highway were estimated based on video acquired by a camera installed on the bus. The school bus was traveling at the estimated speed of 55.4±1 mph and the car at the estimated speed of 69±1 mph. The angle with which the car impacted the school bus was estimated as 1.9º±0.2º.