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

December 29, 2017

Video Study

NTSB Case Number:
HWY17MH007

A. ACCIDENT

Location:	Baltimore, Maryland
Date:	November 1, 2016
Time:	6:30 a.m.
Vehicle No. 1:	School Bus operated by AAAfordable Transportation LLC ('school bus')
Vehicle No. 2:	Maryland Transit Administration Bus No. 10 ('MTA bus')
Vehicle No. 3:	Ford Mustang ('car')

B. AUTHOR

Dan T. Horak
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 school bus and the speed of the MTA bus. Three security video cameras recorded the moving school bus as it passed through their fields of view, each for a short period of time. These videos made it possible to estimate the speed of the bus at three locations as it traveled east on Frederick Avenue for approximately 900 feet. The school bus traveled the 900 ft. in approximately 12 seconds. Approximately 600 feet east of the end of the 900 ft. segment, the school bus impacted the MTA bus.

The MTA bus was equipped with a March Networks 10-camera video surveillance system. Video from one of the cameras, Camera 8 – Curbside View, was used for estimating the speed of the MTA bus during eight seconds before impact based on pavement markings. Video from Camera 9 – Front View was then used for estimating the speed of the MTA bus and the speed of the school bus during the last half second before impact, and for estimating the impact location on the road.

Figure 1 shows a map of the accident scene. The three security cameras were installed in a store, on a gas station building, and on a church building. The yellow arrows indicate the locations on Frederick Avenue where school bus speed was estimated based on videos from the three security cameras. A short distance past the location where speed was estimated based on the gas station camera video, the school bus impacted the car. Figure 1 shows the school bus - car impact location and the final location of the car. The following sections describe the analysis of the videos in detail.

Figure 1. Map of the Accident Scene

Security Camera Frame Rate Calibration

Since a speed estimate based on a video depends on the frame rate of the video, the frame rates of the three security cameras that recorded the school bus were experimentally calibrated. This was performed by placing a digital stopwatch with 0.01 second resolution in front of a camera and recording a short video. That calibration video

was then analyzed by stepping through it and reading the frame time of each frame as it was displayed on the stopwatch. The calibrated frame rates of the three cameras are specified below.

Store Camera Video

This camera was located inside a store on the northern side of Frederick Avenue. Its resolution was 704x480 and its frame rate was a constant 10 fps. The school bus was visible in the video for about one second. A frame from the video, showing the school bus, is shown in Figure 2. Speed was estimated by measuring the number of frames needed for the school bus to move its bumper-to-bumper length of 35.75 feet. That number was 4.8 frames which resulted in a nominal estimated speed of 74.5 ft/s. When converted to mph and accounting for measurement uncertainties, the estimated speed is 51±1 mph.

Figure 2. Frame from the Store Camera Video

Gas Station Camera Video

This camera was located on a gas station building on the northern side of Frederick Avenue. Its resolution was 352x240 and its frame rate was a constant 30 fps. The school

bus was visible in the video for about 1.2 seconds. A frame from the video is shown in Figure 3. Speed was estimated by measuring the number of frames needed for the school bus to move its bumper-to-bumper length of 35.75 feet. That number was 12.8 frames which resulted in a nominal estimated speed of 83.8 ft/s. When converted to mph and accounting for measurement uncertainties, the estimated speed is 57±1 mph.

This camera also captured a car that was moving east ahead of the school bus. Its estimated speed was 22 mph. It can be seen in the upper left corner in Figure 3. It was assumed that this was the car impacted by the school bus. When the car was impacted, it was out of the field of view of the camera but most of the school bus was still in the camera field of view. Because of the large mass of the bus compared to the mass of the car and limited video resolution, the video does not show any bus speed change or motion indicative of impact. Impact is assumed based on the large speed difference of the two vehicles and the short distance between them.

Figure 3. Frame from Gas Station Camera Video

Church Camera Video

This camera was located on a church building north of Frederick Avenue. Its resolution was 1920x1080 and its frame rate was a constant 30 fps. The school bus was visible in the video for about two seconds. Figure 4 shows a frame from this video. Speed was estimated by measuring the number of frames needed for the school bus to move its

bumper-to-bumper length of 35.75 feet. That number was 15.5 frames which resulted in a nominal estimated speed of 69.2 ft/s. When converted to mph and accounting for measurement uncertainties, the estimated speed is 47±1 mph.

School Bus Motion Summary Based on Security Cameras

As shown in Figure 1, when the speed of the school bus was estimated first, it was 51 mph. Then, during approximately 8 seconds and 650 feet, the school bus accelerated to 57 mph when it reached the gas station. Just east of the gas station it impacted the car and slowed down due to the impact. Its speed was down to 47 mph about 250 feet east of the gas station, three seconds after the impact with the car. There is no security camera based information on the speed of the school bus east of that location.

Impact with the MTA bus happened approximately 600 ft. east of the location where its speed was 47 mph. Cameras installed on the MTA bus provided information on the speeds of both buses at the time of impact, as detailed next.

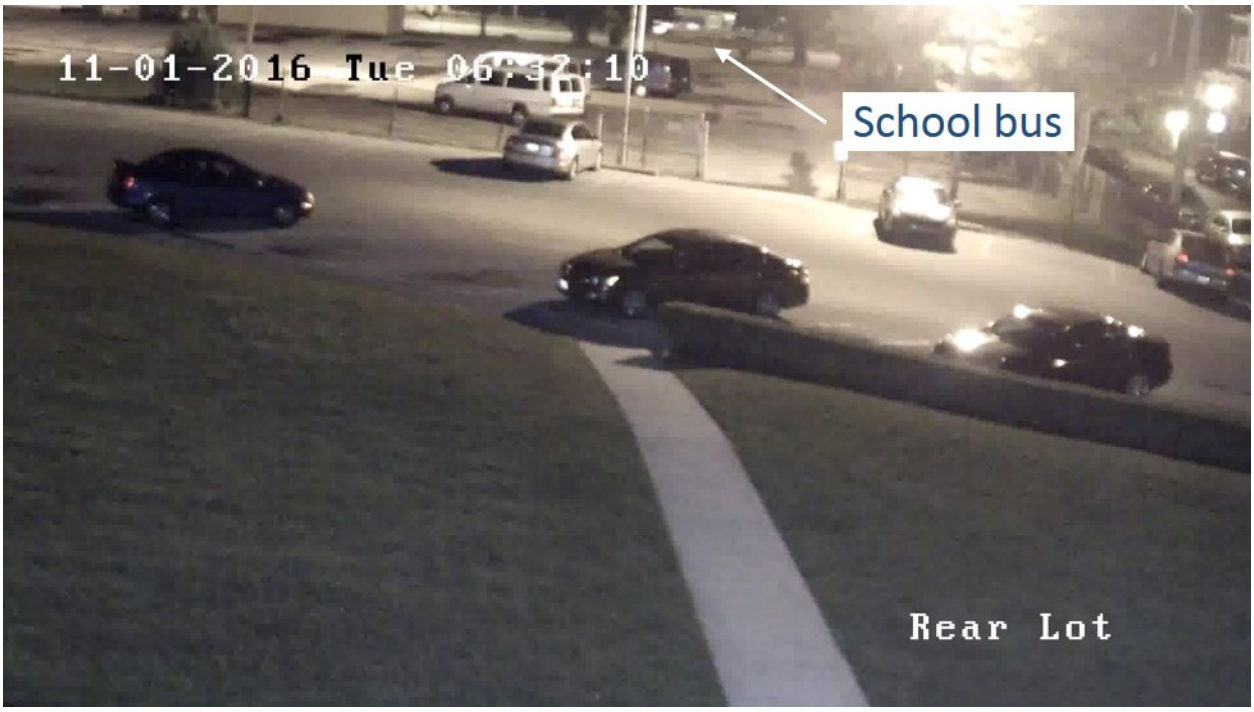

Figure 4. Frame from Church Camera Video

MTA Bus Speed Estimate Based on MTA Bus Cameras 7, 8 and 10

The video from Camera 8 – Curbside View on the MTA bus had resolution of 354x240 and frame rate of 7.5 fps. The MTA bus video frame rates used in the following analyses were those reported by the March Networks video player. The Camera 8 recording lasted up to the point when the MTA bus, which was moving west on Frederick

Avenue, was impacted by the school bus. This video shows that about two seconds before impact, the MTA bus began to turn to the right.

Figure 5 shows a frame from the MTA bus Camera 8 video. The frame shows a Bike Lane pavement marking that is located less than 200 feet east of the final location of the MTA bus. An identical Bike Lane pavement marking is located 482 feet east of the marking seen in Figure 5. The MTA bus traveled this distance in 8 seconds, resulting in an estimated speed of 482/8=60.3 ft/s. When converted to mph and accounting for measurement uncertainties, the estimated speed is 41±1 mph.

A similar process was used to estimate the speed of the MTA bus on shorter road segments that ended west of the Bike Lane pavement marking seen in Figure 5. One estimate was based on Camera 7 – Rear View over a 135 ft. long road segment. A second estimate was based on Camera 10 – Street Side View over a 220 ft. long road segment. Both speed estimates were 43±1 mph.

Figure 5. Frame from MTA Bus Camera 8 Video

MTA Bus Location and Speed Estimates Based on MTA Bus Camera 9

The video from Camera 9 – Front View on the MTA bus had resolution of 354x240 and frame rate of 15 fps. It showed the approaching school bus clearly during the last

half second before impact. The video ended at time of impact. Figure 6 shows a frame from Camera 9 video that was acquired about 0.3 seconds before impact.

The analysis of Camera 9 video consisted of first estimating the locations of the MTA bus at times corresponding to the last eight frames before impact and then estimating the locations of the school bus at these times. With locations and frame times known, it was then possible to estimate the speed of each bus during the last half second before impact and the accurate location of impact. This analysis process required a mathematical model of the camera optics. Its derivation and use are detailed next.

Figure 6. Frame from MTA Bus Camera 9 Video

MTA Bus Camera 9 Model Derivation and Calibration

As seen in Figure 6, Camera 9 video captured details of lane lines, arrow road markings in the two-way center turn lane and a lamp post. These details, all visible in Google Earth, were used as reference points for camera optics calibration.

Camera model parameters are its elevation above ground, its lateral offset from the MTA bus centerline, its roll, pitch and yaw angles with respect to the MTA bus, and the horizontal field of view angle of the camera lens. These six parameters were estimated by varying them iteratively in an analysis program until the mathematical model

of the camera optimally mapped the reference points onto frames from the video at the actual locations of these points in the frames. When optimal mapping accuracy was achieved, the model parameter values were their optimal estimates and the camera was calibrated.

Estimating MTA Bus Locations and Speed Based on MTA Bus Camera 9

The calibrated Camera 9 model made it possible to estimate the locations of the MTA bus at times corresponding to the analyzed Camera 9 video frames. Since the camera was fixed to the bus, it moved when the bus location and orientation were varied. Consequently, iteratively varying the bus location and orientation in an analysis program until there was optimal match between mapped reference points and their images in video frames resulted in optimal estimates of the MTA bus locations. Since the frame rate of the video was known, it was then possible to estimate the speed of the MTA bus. The estimated speed during the last half second before impact was 39±2 mph.

Estimating School Bus Locations and Speed Based on MTA Bus Camera 9

With a calibrated Camera 9 model and estimated locations of the MTA bus, it was possible to estimate the locations and speed of the school bus. As Figure 6 shows, the approaching school bus is visible in frames from the video. To estimate school bus location based on a video frame such as the one in Figure 6, the MTA bus was positioned and oriented in the analysis program at its previously estimated location. A wireframe model of the front of the school bus was constructed that included details of its roof, windshield, headlights and bumper. That wireframe model was then iteratively moved and oriented in an analysis program until the model details optimally coincided with their images in the video frame. The optimal location of the wireframe model was the optimal estimate of the location of the school bus at the time the analyzed video frame was acquired.

Since the frame rate of the video was known, it was then possible to estimate the speed of the school bus. The estimated speed of the school bus during the last half second before impact was 45±2 mph.

With accurately estimated locations of both buses shortly before impact, it was possible to estimate the location on the road at which they first contacted each other. That impact location is marked in Figure 1.

It is evident from the video frame in Figure 6 and from other Camera 9 video frames that the school bus impacted the MTA bus because it did not follow the curve of the roadway. The school bus is seen in the figure entering the MTA bus lane from the two-way center turn lane in which it was shortly before impact. There is no video-based information on when the school bus moved into the two-way center turn lane.

E. CONCLUSIONS

The speed of a school bus that impacted an MTA bus was estimated based on videos acquired by three security cameras. The maximum estimated speed was 57±1 mph. Shortly after that speed was estimated, the school bus impacted a car and its speed at the last location where speed was estimated based on a security camera was 47±1 mph. Approximately 600 ft. east of the last location where speed was estimated based on a security camera, the school bus impacted the MTA bus.

The speed of the school bus shortly before impact was estimated as 45±2 mph. This estimate was based on the MTA bus Front View camera video. The school bus impacted the MTA bus because it did not follow the curving two-way center turn lane in which it was shortly before impact.

The speed of the MTA bus was estimated as 39±1 mph shortly before impact. This estimate was also based on the MTA bus Front View camera video.