NATIONAL TRANSPORTATION SAFETY BOARD

Vehicle Performance Division
Washington, D.C. 20594

August 8, 2017

Vehicle Dynamics Study

By Shane K. Lack

1.0 Event Summary

Location:	US-Alt 27, Milepost 29, near Williston, Levy County, Florida
Operator #1:	Private operator
Vehicle #1:	2015 Tesla Model S 70D
Operator #2:	Okemah Express, LLC Palm Harbor, FL
Vehicle #2:	2014 Freightliner Cascadia truck-tractor in combination with a 2003 Utility 3000R refrigerated semitrailer.
Date:	May 7, 2016
Time:	Approximately 4:36 P.M. Eastern Daylight Saving Time (EDST)
NTSB Number:	HWY16FH018

2.0 Crash Summary

See NTSB docket HWY16FH018, Crash Summary; and for more detail see the Technical Reconstruction Group Chairman's Factual Report.

3.0 Simulation Purpose

Sight line analysis using AASHTO methodology [1] in combination with roadway design data, on-scene measurements, and vehicle performance data downloaded from the car [2] determined that the car crested a rise in the roadway and was visible to the truck driver approximately 10.4 sec (1135 feet)

before the impact [3]. Data downloaded from the car, witness testimony and the physical evidence found on the roadway indicated the car was traveling in the right-hand lane at a constant speed of about 74 mph from the time it crested the hill until the collision [3]. While precise information on the car's motion prior to the crash was available, there was limited information on the truck's motion. This simulation study looks at what can be reasonably determined about the movement of the truck prior to the collision.

The limited information on the truck's motion include: the truck's position at impact (which was established from damages found on the trailer and evidence marking the point of impact on the roadway) and the testimony of a witness that was traveling behind the truck. In this study, simulation is used to evaluate the witness' statement and determine if the description of the accident is consistent with the physical evidence, with data from the literature on tractor-trailer acceleration and cornering capabilities [4-6], and with the motion of the car. The value of simulating the movement of the truck is to establish a reasonable time for the turning movement to corroborate the witness account that the car was visible to the truck driver at the beginning of the turn.

The objective of the simulation study was not to precisely estimate the position time history of the truck, but to estimate ranges of vehicle motions that were consistent with the witness' description and the physical data. Key aspects of the simulations are described below.

4.0 Witness Account

A driver traveling behind the truck on westbound US-27A witnessed the accident. This witness reported that the truck was stopped or nearly stopped in the left turn lane of westbound US-27A when he first noticed it, and that the car had begun to crest the hill prior to the truck beginning its turn. The witness further reported being able to observe the car for several seconds prior to his view of the car being blocked by the left turning truck and reported that he thought the driver in the passenger vehicle would need to slow down to avoid a collision with the truck. As the witness approached the intersection he reported hearing the crash and seeing the passenger vehicle emerge from underneath the trailer and then depart the roadway. The witness then slowed down and made a U-turn in the same intersection where the truck had turned. The witness indicated that he (the witness) was traveling about 60 mph prior to slowing to make the U-turn.

5.0 Simulation Methods

The software used to simulate the motion of the vehicles in the study was PC-Crash [7]. PC-Crash is vehicle dynamics software that is fully capable of modeling two and three-dimensional motions of tractor-semitrailers and automobiles to a level of detail required for this analysis. In this study, simulation offered several key advantages over kinematic analysis. These advantages include: monitoring of lateral accelerations, estimates of off-tracking by the trailer, and visual estimates of sight lines.

Since position time history data was not available for the truck a series of simulations were conducted to estimate the possible range of the truck's motion. Data used in the simulation study include: the

witness testimony, data on tractor-trailer acceleration rates and cornering capabilities, survey data of the roadway and the physical evidence on the road [3] , and the electronic data indicating the speed of the car prior to the collision [2]. The characterization of the data used in the study is shown in Table 1.

Table 1 Data Sources.

Data type	Parameter	reference	comment
Car crests hill approximately 10.4 seconds prior to the collision.		Ref [3]	
Truck Data	Overall Length combination = 73 feet Tractor wheelbase = 16.2 feet Trailer wheelbase = 39.8 feet	Ref [8] and laser scan data measurements taken by NTSB	
Tractor-Trailer combination weight	Combination weight (empty) = 30,166 lbs to 33166 lbs. Possible loading conditions: 1/2 Load = 17,800 lbs Full load = 36,000 lbs 20 palates = 20,000 lbs	Data received from Vehicle Group Chairman based on manufacturers data and possible loading condition.	Tractor was not weighed. Weight estimated between 16,000 and 19,000 lbs.
Truck longitudinal acceleration rates used in study	0.035 to 0.1 g	Ref [4] and [5]	Based on trucks equipped with automatic transmissions. Truck weights: 30,902 lbs to 66,465 lbs

5.1 Modeling the Car's Motion in the Simulations

In the simulations, the car was modeled traveling in the right lane of eastbound US-27A at a constant 74 mph up to the point of impact. The simulation was not extended post impact with the trailer. Data downloaded from the car indicated that the car was traveling at a constant speed of about 74 mph for more than a minute prior to the collision. Physical data found on the roadway and the witness testimony indicated that the car was traveling in the right-hand lane of westbound US-27A prior to the collision.

5.2 Modeling the Motion of Witness Vehicle

In the simulations the witness vehicle was modeled at speeds of 60 and 65 mph and was placed so as to reach the beginning of left turn lane of westbound US-27A approximately 1 second after the impact. This is consistent with the statement of the witness, who indicated he was driving about 60 mph when he first observed the truck and that he turned around in the intersection where the truck was turning following the collision.

5.3 Maximum Lateral Acceleration

In the simulations, lateral accelerations above 0.25 g lasted for less than 0.75 seconds unless otherwise noted. This range is based on the evaluation of data from over 90 left turn driving maneuvers obtained from a naturalistic driving study conducted with refrigerated trucks involving vehicle-to-vehicle technology [6]. This naturalistic driving study data indicated that lateral acceleration rates above 0.25 g typically lasted for less than 0.75 seconds. The short duration of these peak accelerations would be consistent with the driver reducing the lateral acceleration (by reducing his throttle or steering, or by braking) when the lateral acceleration above 0.25 g was reached.

5.4 Simulations

More than one hundred individual simulations were performed to evaluate the influence of different parameters or different time histories of parameters. Results from six representative simulations are provided in some detail in this study. These simulations indicate the overall range of results obtained. Simulation Runs #1 through #5 were selected to indicate the range of potential scenarios generally having the shortest time available for the driver of the car to react to the truck entering the eastbound travel lanes. Simulation Run #6 represents a possible scenario indicating the longest time available for the driver of the car to react to the truck entering the eastbound travel lanes. The line of sight time and time-to-contact estimates for all simulations conducted in the study fell within ranges indicated by simulation Runs #5 and #6 described in the next sections.

6.0 Results

6.1 Truck Path

The path of the truck used in the simulation (Figures 1 and 2) is the path which minimized the distance traveled while matching angle of the trailer in the roadway when the collision occurred. It was identified through an interactive approach.

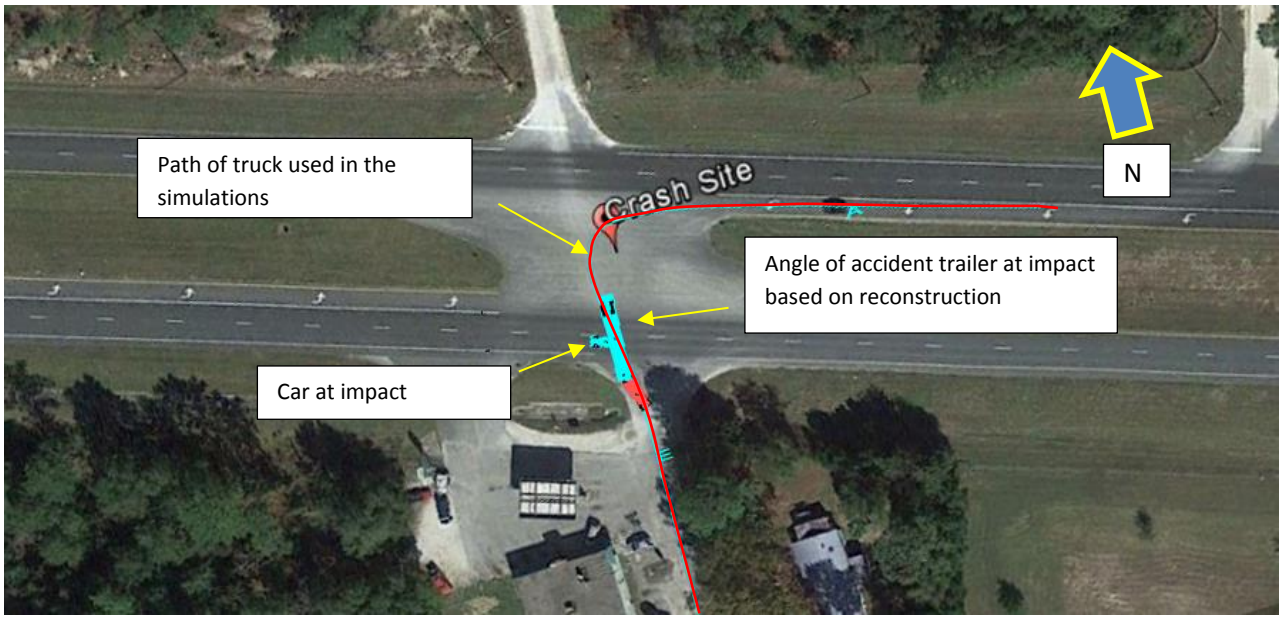

Figure 1 – The red line indicates the path of the truck used in the study. The angle of the trailer shown in figure is the approximate angle of the accident trailer at impact based on the damages to the trailer.

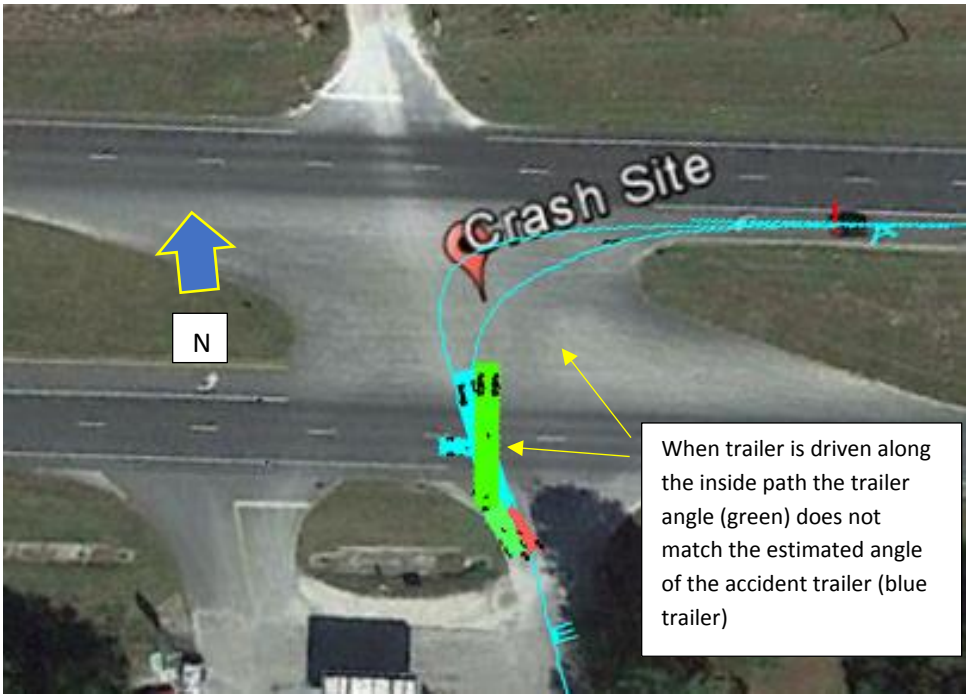

Figure 2 – When the truck was driven along paths "inside" of the path used in the study the trailer did not align properly with position of the accident trailer at impact. In the diagram the green trailer represents the position of the trailer at impact when driven along the inside path. The blue trailer represents the position of the trailer at impact based on the reconstruction.

6.2 Estimation of the Maximum Speed of the Truck through the Turn

The estimates of the maximum speed of the truck through the turn are shown in Figure 3. These speeds were estimated by driving the truck through the turn at the maximum lateral acceleration threshold. As indicated by the figure, the simulations indicate that the maximum speed of the truck was limited to less than about 13 mph through a large portion of the turn in order match the restriction on lateral acceleration. At a speed of 13 mph the truck driver could have brought the truck to a stop with moderate braking when the tractor was approximately 25 feet from the eastbound travel lanes.

Figure 3 - Due to the radius the turn the speed of the truck was limited through portions of the curve. The truck's maximum speeds through portions of the turn are noted in the figure.

6.3 Line of Sight and Time-to-Contact Analysis

To evaluate the sight lines and time-to-contact (TTC) the truck was driven through the turn over a range of different acceleration rates and initial velocities using the PC-Crash software. The results of a small sample of the simulations conducted as part of this study are described in Tables 2 through 4. Simulation Runs #1 through #5 demonstrate how the sight line times and TTC estimates approach limits (Tables 2 and 4) as the truck travels more quickly through the turn. These limits are primarily a result of the limitations on the truck's speed imposed by the maximum lateral acceleration threshold and the radius of the turn (see Figure 3). The tables also contains the results of Run #6 which was used to estimate the lower bound of the sight line times.

Table 2 provides a basic description of the simulation and sight line estimates. Table 3 describes the position of the truck in the left-hand turn lane when the car crests the hill for each of the simulations in Table 2. As indicated by the data in Table 3, the position of the truck in the simulations as the car crests the hill matches the witness's general description that the truck was in the left turn lane stopped or traveling slowly prior to the car cresting the hill. Table 4 contains the results of the TTC analysis for several of the simulations.

The column labeled “Witness Line of Sight Time” in Table 2 is the estimated time the witness would have had to observe the car prior to his view being blocked by the left turning truck. The column labeled “Truck Driver Line of Sight Time” in Table 2 is the estimated time the truck driver would have had to observe the car prior to reaching a point 25 feet from the edge of the road at which point the speed of the truck was limited to less than 13 mph (by the radius of the turn) and the truck driver could have stopped by applying moderate braking before entering the eastbound lanes. As indicated by the data in the Table, the witness and truck driver line of sight times do not increase significantly between Runs #4 and #5 even though the maximum acceleration almost doubles. The reason for this limit is discussed later in the report.

When the simulations begin, the truck is completely in the left turn lane of westbound US-27A with front of the truck at the end of the left turn lane. In simulation Runs #1 through #4 the truck is accelerated at the maximum rate unless it exceeds the lateral acceleration threshold. A plot of the accelerations and speed versus time for Run #4 is shown in Figure 4. In Run #5 (Figure 5) the truck is initially traveling 14 mph and then brakes to slow in the tightest part of the turn and then accelerates at up to the maximum acceleration rate. Because the truck is cornering at close to the lateral acceleration limits, this simulation maximizes the speed of the truck through the turn and as it approaches the eastbound lanes. In Run #6 (see Figure 6) the truck is forward with only the trailer wheels in the left turn lane of westbound US-27A when the car crests the hill. This is estimated to be the farthest forward the truck could be and still match the witness’ description that the truck was in the left turn lane of westbound US-27A when the car crested the hill. This produces the lowest estimates of sight line times because the truck is more forward and traveling at a higher speed (12-13 mph). In the simulation braking does not occur until the truck enters the eastbound lanes.

Table 2 – Sample data from sight line estimates.

Run #	Initial speed (mph)	Maximum acceleration (g)	Witness Line of Sight Time* (sec)	Truck Driver Line of Sight Time** (sec)	Speed of truck at impact (mph)
1	0	0.035 g	5.6	5.1	13.4
2	0	0.05 g	6.3	5.4	15.8
3	5	0.035 g	5.8	5.2	14.1
4	5	0.05 g	6.8	5.8	15.9
5	14	0.10 g	6.8	5.6	18.1
6	13	Braking only	3.2	3.0	3

*Terminates when truck obscures line of sight of witness

**Terminates when front of tractor reaches point 25 ft from left edge of travel lanes

Table 3 – Position and speed of the truck when car becomes visible. (10.4 seconds prior to the collision.)

Run #	Initial speed (mph)	Max acceleration (g)	Speed of truck when car Crests the hill (mph)	Position of truck when the car crests the hill (10.4 seconds prior collision)
#1	0	0.035	7.1	Rear 1/2 of trailer in left turn lane of westbound US-27 A. Front 1/2 of trailer forward of the end of the left turn lane of US-27A.
#2	0	0.05	6.9	Trailer 3/4 in left turn lane in left turn lane of westbound US-27A. Tractor and 1/4 of trailer forward of the end of the left turn lane of US-27A.
#3	5	0.035	8.0	Rear 1/2 of trailer in left turn lane of US-27A. Front 1/2 of trailer forward of the end of the left turn lane of US-27A.
#4	5	0.05	7.7	Trailer completely in left turn lane of westbound US-27A. Tractor is forward of the end of the left turn lane of US-27A.
#5	14	0.10	14	Tractor and trailer completely in left turn lane of westbound US-27A
#6	13	Braking Only	13	Trailer wheels only in the left turn lane. This is probably the furthest forward the truck could be based on the witness description. Speed of truck near maximum for this part of turn results in smallest driver and witness sight line estimates.

Table 4 – Time to contact (TTC) at key Points.

Run #	Initial speed (mph)	Max acceleration (g)	Time–to-Contact (TTC)	
			Front of tractor is approximately parallel with the left edge of the left turn lane of eastbound US-27A (sec)	Front of tractor first crosses into the eastbound travel lanes of US-27A from the median (sec)
#1	0	0.035	4.5	3.9
#2	0	0.05	4.0	3.5
#3	5	0.035	4.4	3.7
#4	5	0.05	4.0	3.5
#5	14	0.10	3.9	3.4
#6	13	Braking only	7.0	6.2

Figures 4 and 5 below illustrate how the radius of the curve affects the speed of the truck. Even though the truck in Run #5 enters the turn at a much higher speed (14 mph vs 5 mph) the speed of the truck in both simulations is approximately the same from about 6 seconds TTC until about 2 seconds TTC due to the limits on the speed imposed by the maximum lateral acceleration resulting from the speed and the radius of the turn. The truck collision speeds in the simulations are only slightly different (18.1 mph vs 16.9) since the maximum acceleration is only applied over the last 2 seconds. Because the speed of the truck in both simulations is limited by the turn radius for much of the last six seconds prior to the collision, the distance the truck travels is approximately the same in both simulations. The fact that the trucks travel approximately same distance over the last several seconds results in similar sight distance measurements and TTC for both simulations.

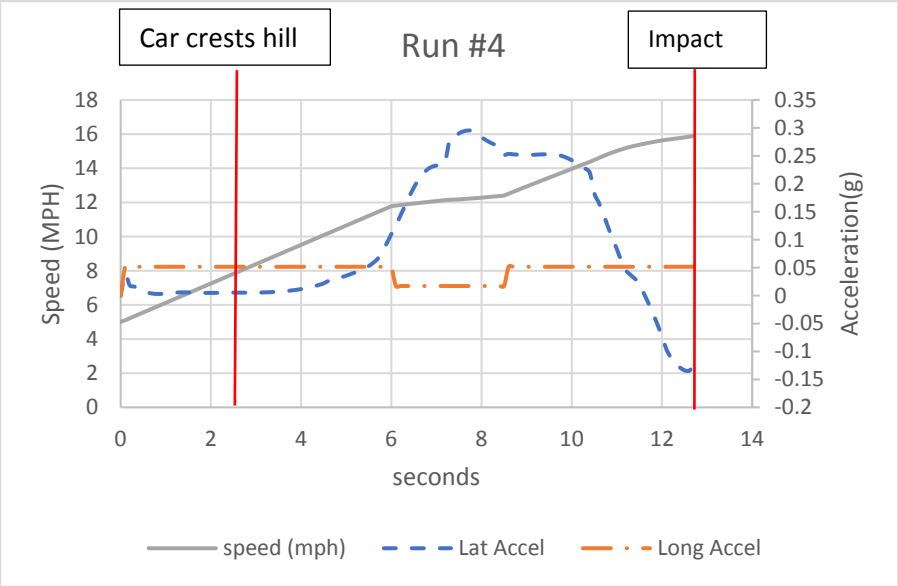

Figure 4 – Plot diagram of the truck's speed and acceleration time for Run #4.

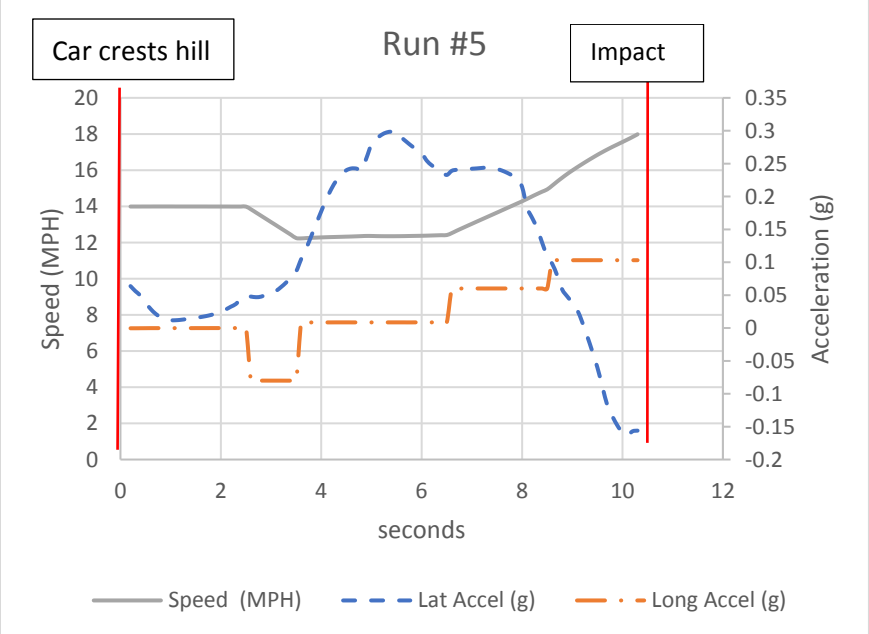

Figure 5 – Plot diagram of the truck's speed and acceleration versus time for simulation Run #5.

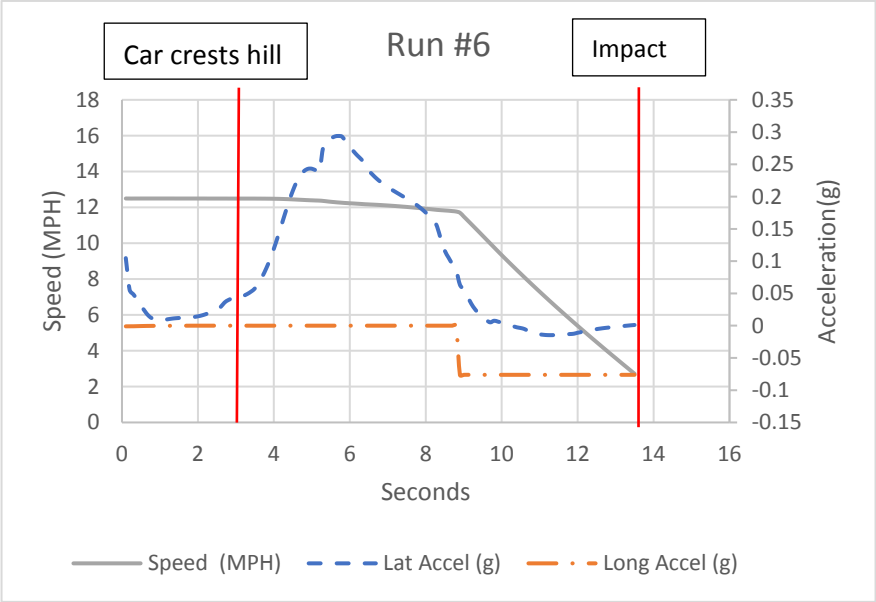

Figure 6 – Plot diagram of the truck's speed and acceleration versus time for simulation Run #6.

7.0 Discussion of Line of Sight Evaluations

7.1 Evaluation of the Witness' Line of Sight

The results of the simulations in Tables 2 and 3 support that the witness could have had a clear line of sight to the car for between 3.2 to 6.8 seconds prior to his view being blocked by the left turning truck. This is consistent with the witness's description that he observed the car for several seconds prior to the collision.

7.2 Evaluation of the Truck Driver's Line of Sight

The results of the simulations in Table 2 support that the driver of the truck would have had a line of sight to the car for about 3.0 to 5.8 seconds prior to reaching a point 25 feet from the edge of the road. At this point (25 feet from the road) the simulations indicate the speed of the truck would have been less than about 13 mph (due to the radius of the turn) and the driver of the truck could have applied

moderate braking and stopped the truck prior to entering the eastbound travel lanes of US-27A. If the truck driver chose to continue across the road at this point (25 feet from the edge of the road), and accelerated at a moderate pace (0.05 g) it would have taken him approximately 6.2 seconds to clear the intersection.

8.0 Evaluation of the Truck's Approach to the Eastbound Lanes.

The approximate orientation and speed of the truck as it approached the left edge of the eastbound travel lanes based on the simulations is shown in Figure 7.

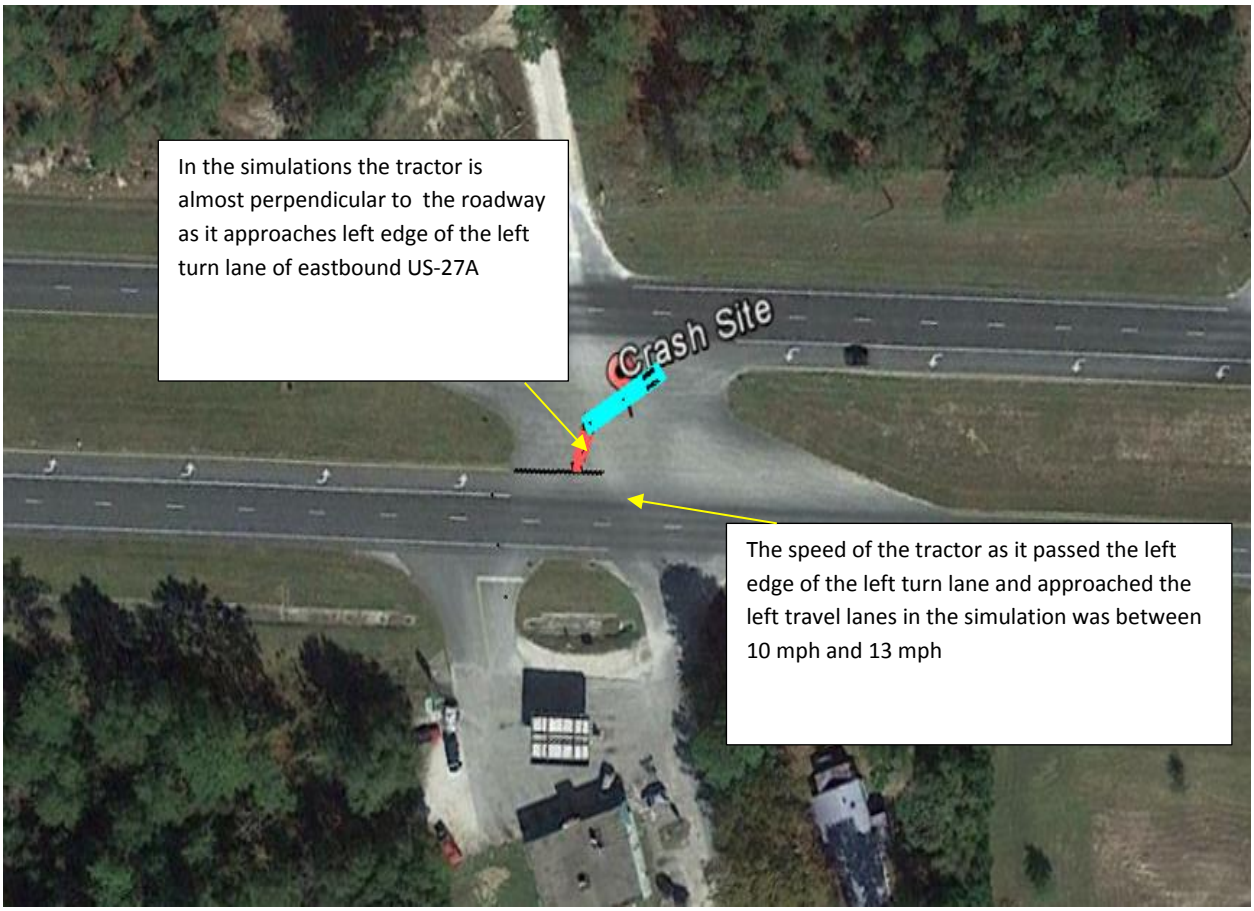

Figure 7- Approximate orientation and speed of the truck as it approached the eastbound in the simulations.

The estimates of minimum TTC as the truck approached the eastbound lanes travel lanes of US-27A are shown in Table 5.

Table 5

Description	***Minimum Time-to-Contact (TTC)***
Front of tractor is approximately parallel with the left edge of the left turn lane of eastbound US-27A	*3.9 s*
Front of tractor first crosses into the eastbound travel lanes from the median	*3.4 s*

A review of literature on perception/reaction times [ref 9-16] found that most drivers (85 to 95 percent in studies in which percentile information was provided) responded within 2.2 seconds in an emergency situation in which the collision hazard was clearly identifiable and appeared almost directly in front of the driver.

9.0 Summary

In this study simulation was used to evaluate the witness' statement and determine if his description of the accident was consistent with the physical evidence, with data in the literature on tractor-trailer accelerations and cornering capabilities, and with the recorded motion of the car.

The results of the simulations support that the witness statement is consistent with the other information gathered in the course of the investigation. The results of the study also support that the truck driver would have had a line of sight to the car for at least several seconds, giving him the opportunity to stop prior to entering the eastbound lanes. The study also indicates that the car driver had at least 3.4 seconds to react to the front of the tractor crossing into the eastbound travel lanes.

References:

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