



**NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF HIGHWAY SAFETY
WASHINGTON, D.C.**

**HIGHWAY FACTORS GROUP CHAIRMAN'S
FACTUAL REPORT**

A. CRASH INFORMATION

Location: Northbound Mill Avenue, approximately 400 feet south of the intersection with Curry Road, in Tempe, Maricopa County, Arizona

Vehicle: 2017 Volvo XC90, being operated by Uber in autonomous mode

Pedestrian: 49-year-old female, walking a bicycle across Mill Avenue

Date: March 18, 2018

Time: 9:58 p.m. Mountain Standard Time (MST)

NTSB #: **HWY18MH010**

B. HIGHWAY FACTORS GROUP

David S. Rayburn Highway Factors Investigator, Group Chairman
NTSB Office of Highway Safety
490 L'Enfant Plaza East, S.W., Washington, DC 20594

Shelly Seyler, P.E.
Deputy Public Works Director
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City of Tempe 200 East Fifth Street
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C. CRASH SUMMARY

For a summary of the crash, refer to the *Crash Summary Report*, which can be found in the NTSB Docket for this investigation.



D. DETAILS OF THE HIGHWAY FACTORS INVESTIGATION

The highway group examined the accident scene, obtained documents describing the traffic metrics, the accident history, the signage prohibiting pedestrian crossings in the accident area, and the specifications of the highway safety lighting in the area. Additionally, legal statutes governing pedestrian movements were examined along with statutes governing vehicle driver responsibility to avoid colliding with pedestrians.

1. Prefatory Data

This accident occurred on North Mill Avenue about 398 feet south of the intersection of Curry Road and approximately 380 feet south of the crosswalk at the intersection. The posted speed limit on North Mill Avenue was 45 mph. **See Figure 1** for a view of the accident area.

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Figure 1 View of impact area on N. Mill Avenue



The GPS coordinates for the accident area are 33 degrees 26 minutes 11.57 seconds north latitude and 111 degrees 56 minutes 33.56 seconds west longitude. The azbilt drawings for this segment of roadway which was last re-aligned in 1991 show that the highway station number for the impact area is approximately 31.+02.¹ The plans indicated a 328.21-foot-long, right-hand curve began approximately 62 feet after the impact area. The curve had a radius of 954.93 feet which is approximately a 6-degree curve. **See Figures 2 and 3 below depicting the after-accident situation map and the impact location in relation to nearby highway safety lighting.**

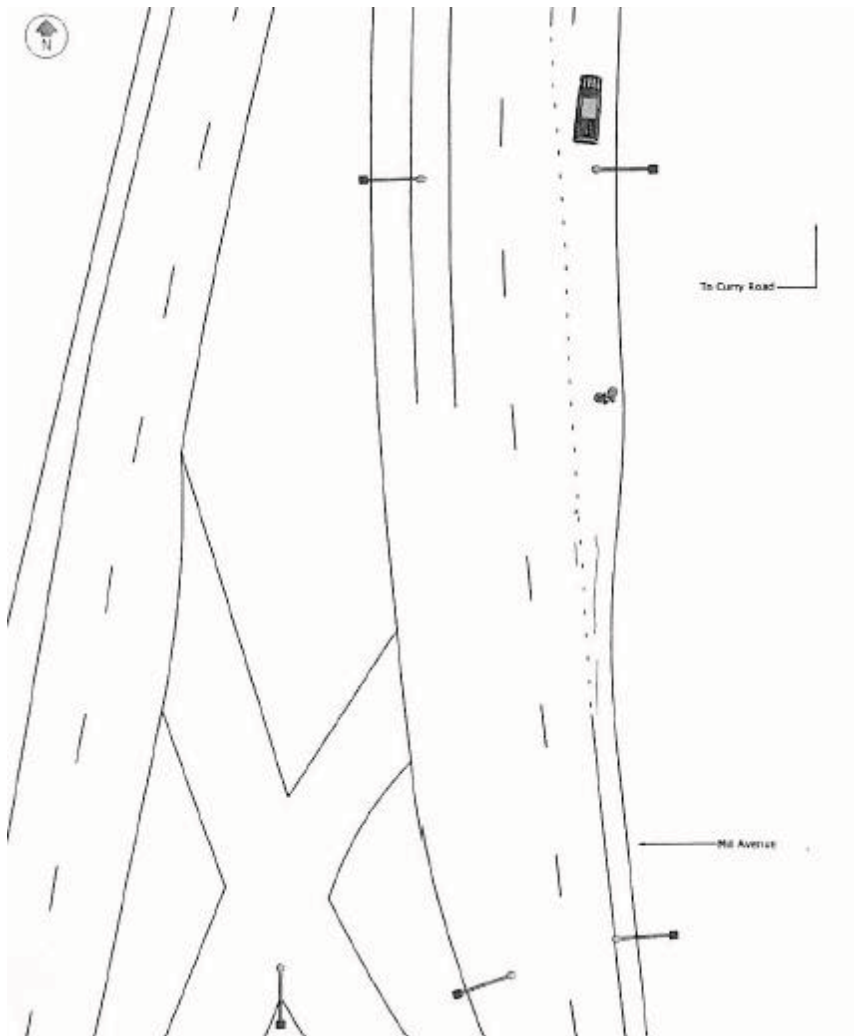


Figure 2 After accident situation map with bicycle and passenger car shown at final positions. (Drawing courtesy of Tempe Police)

¹ Station numbers on highway plans are dimensional reference points for a project.

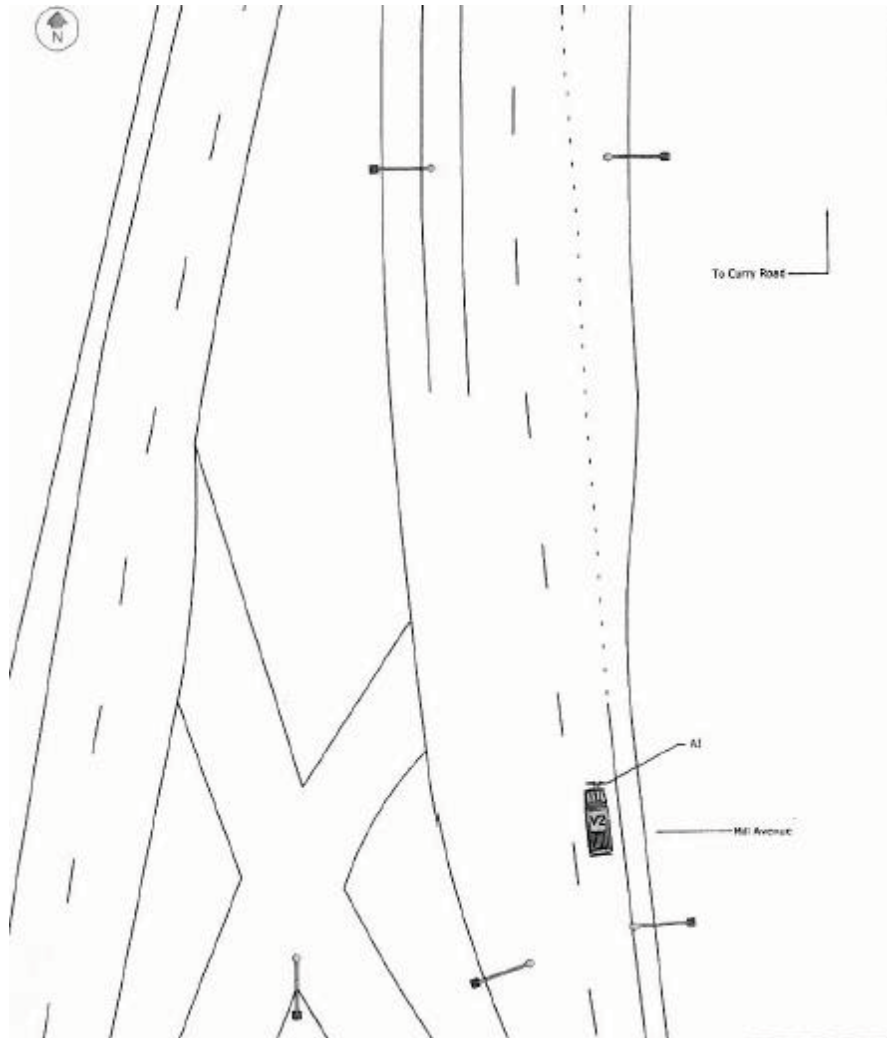


Figure 3 Approximate impact location shown by passenger car and bicycle just north of two street lights. (Drawing courtesy of Tempe Police)

In the crash area N. Mill Avenue consisted of two left-turn lanes, two through lanes, and one bike lane. The crash occurred before the formation of a right-turn lane. There were seven highway safety lighting poles in the area. (See more detailed information on street lights in the Highway Safety Lighting section)

In January 1991 the roadway was aligned to its present configuration and highway safety lighting was installed. Then in August 1995, the median was landscaped, and in 2009 a vertical curb was added to the median and outside lanes and, signage was added to prohibit pedestrian



crossing in the area.² The landscaping in the median area included an X-shaped red-brick configuration. The design gave the appearance of a pathway through the median.

2. Traffic Metrics

North Mill Avenue in Tempe has a functional classification as a principal urban arterial.³ Traffic counts taken after the accident on March 27, 2018 showed that N. Mill Avenue between Curry Road and University Drive had an Average Daily Traffic (ADT) of 16,813 vehicles per day. Counts showed that traffic between 10pm and 11 pm was comprised of 731 vehicles.⁴ Pedestrian counts for this area showed that on Tuesday June 19, 2018, 66 pedestrians and 12 bicyclists crossed N. Mill Avenue during a 24-hour period that was videotaped by a contractor for the City of Tempe Public Works Department. This included the approximate 650-foot distance along N. Mill from Curry road to the Red Mountain Parkway overpass. A musical presentation occurred at at nearby business during the pedestrian counts.

3. Accident History

A search of records by the city of Tempe showed that no other fatal pedestrian crashes had occurred in the accident area in the preceding 10-year-period. The City of Tempe Public works Department queried the Arizona Department of Transportation (AZDOT) accident system for statistics citywide in Tempe involving pedestrian crashes. For the three-year-period 2015-2017, there were a total of 13 fatal pedestrian crashes in Tempe; 10 of those occurred at nighttime. An additional 32 pedestrian crashes during this time period resulted in incapacitating injuries. Eleven of the fatal crashes were like this crash in that they occurred at non-junction related locations.⁵

4. Prohibited Pedestrian Crossing Signage

In 2009, when the Public Works Department was adding vertical curbs on North Mill Avenue, the Tempe Police Department requested they also add signage in the area to prohibit pedestrians from crossing mid-block in this area. **See Figure 4** below for the locations of the signs added to prohibit pedestrians from crossing in the accident area.

² See City of Tempe Public Works Projects 906335, 946552, and work order 42-09 in Highway Attachment, City of Tempe Public Works Department Design Plans

³ The urban principal arterial system serves the major centers of activity of urbanized areas. See section 1.3.4, page 1-10, a policy on Geometric Design of Highways and Streets 6th Edition 2011, American Association of State Highway and Transportation Officials, Washington, D.C.

⁴ See Highway Attachment, Vehicle Traffic Counts for more information.

⁵ See Highway Attachment, Accident History for more details

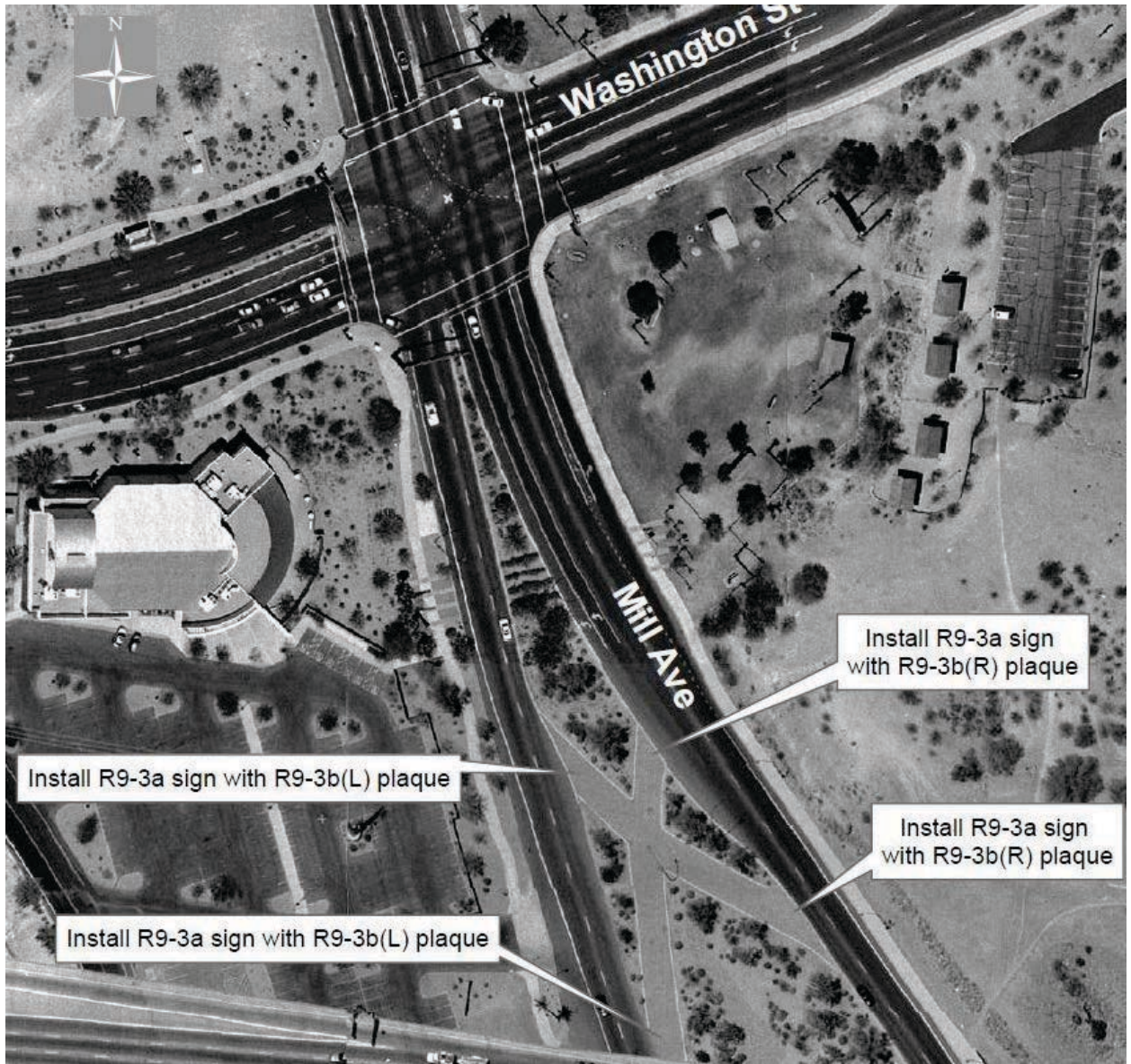


Figure 4 Shows the location of signs prohibiting pedestrians from crossing in the accident area.

After this crash, the City of Tempe added additional double-sided signs to prohibit pedestrian crossings in this area. See Highway Photo 3, which shows the wording on the signs placed in 2009. See Figure 5 below of the sign.



Figure 5 Signs prohibiting pedestrians from crossing South Mill Ave

5. Highway Safety Lighting

Six highway safety lights were installed along North Mill Avenue in the crash area. There were four installations on the right and two installations on the left as a motorist moves northbound on Mill Avenue toward Curry Road. There were additional installations in the landscaped median area. Each lighting fixture was a 250-watt, 240-volt, High Pressure Sodium (HPS) light rated for 30,000-lumen output.⁶ The closest highway safety light to the impact area was fixture No. 39, which was on the right-hand side of the road. Design plans showed it was located at Station No. 30.55 or approximately 47 feet from the impact area at Station No. 31.02. The plans showed the light was installed 33.5 feet right of the roadway centerline on a 32-foot high fixture. The nearest light on the left-hand side of the road was designated on the plans as fixture No. 40. It was located at Highway station No. 30.45, or 57 feet south of the impact area and across the road. This fixture was installed 36.5 feet left of the N. Mill Avenue centerline. The Tempe Police indicated that all of the lights were working except for the farthest light on the left from the impact area. The plans designated this fixture as No. 42. It was located at highway Station No. 32+60, or 158 feet north

⁶ See Highway Attachment, Highway Safety Lighting Specifications and Photometric Performance for more detailed information.



of the impact area and across the roadway in the median. This fixture was installed 36.5 feet left of the N. Mill Avenue centerline. See Figure 6 for design plan locations.

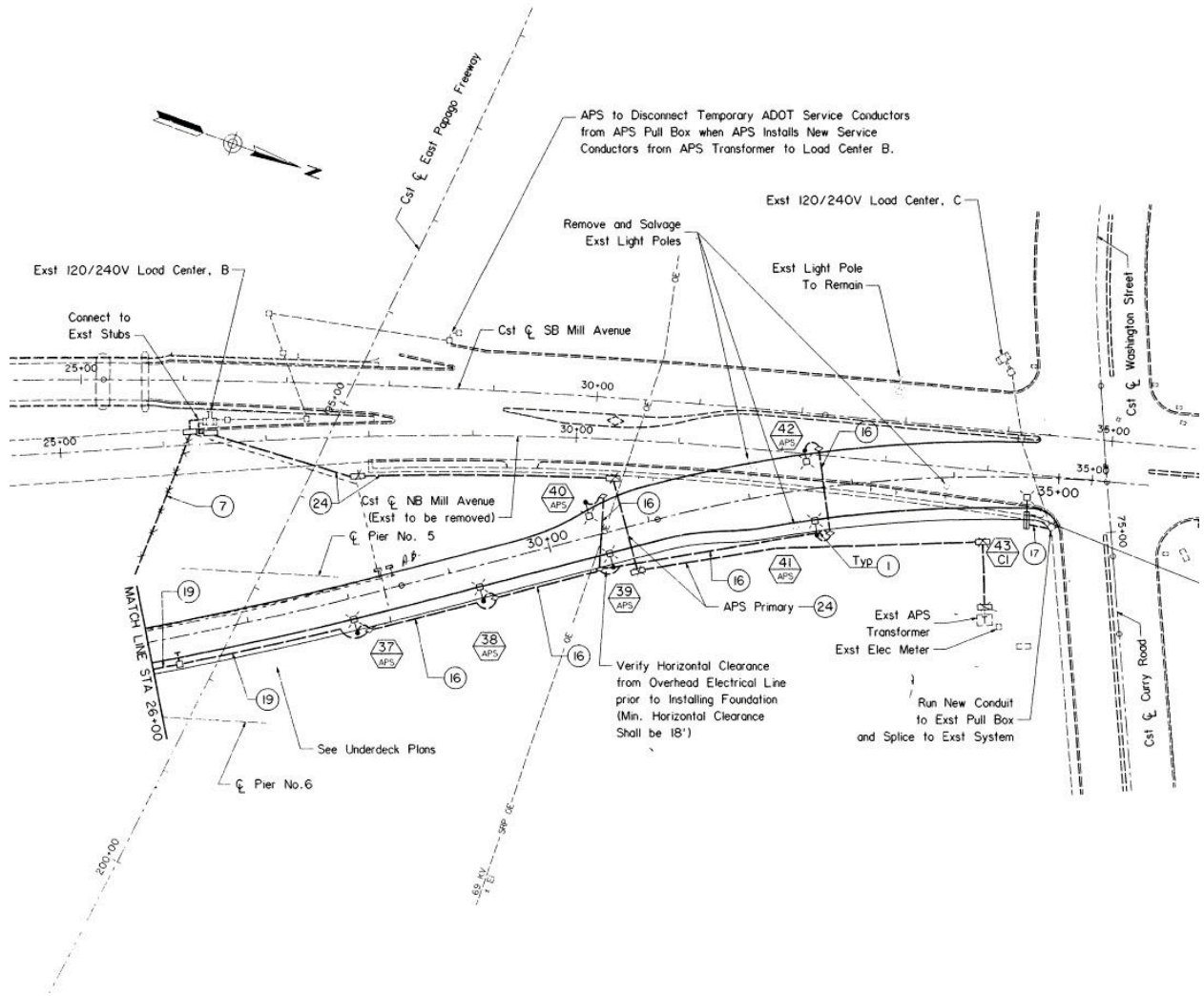


Figure 6 Lighting Fixture locations

Additionally, beginning in the fall of 2017, the City of Tempe began replacing HPS lighting fixtures with LED streetlights in the city, citing increased visibility of pedestrians and cyclists along with substantial cost savings and reduced carbon emissions.⁷

6. Legal Statutes Governing Pedestrian Movements and Driver Responsibility

⁷ See Highway Attachment, 2016 PowerPoint Presentation to the Tempe City Council LED Streetlights



Arizona Statute 28-793 Crossing at Other Than a Crosswalk, provides the following:

- A. Pedestrian crossing a roadway at any point other than within a marked crosswalk or within an unmarked crosswalk at an intersection shall yield the right-of-way to all vehicles on the roadway.
- B. A pedestrian crossing a roadway at a point where a pedestrian tunnel or overhead pedestrian crossing has been provided shall yield the right-of-way to all vehicles on the roadway.
- C. Between adjacent intersections at which traffic control signals are in operation, pedestrians shall not cross at any place except in a marked crosswalk.

28-794 – Drivers to Exercise Due Care

Notwithstanding the provisions of this chapter every driver of a vehicle shall:

- 1. Exercise due care to avoid colliding with any pedestrian on any roadway
- 2. Give warning by sounding the horn when necessary.
- 3. Exercise proper precaution on observing a child or a confused or incapacitated person on a roadway.

28-963 – Image Display Device; Prohibition; Exceptions; Definition

A person shall not view a broadcast television image or a visual image from an image display device while that person is driving a motor vehicle and the motor vehicle is in motion on a public roadway or on an off-highway vehicle trail as defined in 28-1171.

7. Testing and Research

This section provides information about the accident location, air bag control module EDR, speed evaluation, nighttime visibility, pavement friction, and video evaluation of the pedestrian's walking speed. Also an avoidability evaluation was performed by Tempe PD using the information gathered during testing and research.

Since there were no marks at the initial impact point Tempe PD used the video file from the Uber vehicle's forward facing dashcam to triangulate to common points visible on the video file. With this information there were able to determine that the center of the Volvos front bumper was 22.5 feet from (south of) the solid white pavement stripe ending for the bicycle lane and five feet to the left of the pavement stripe when the impact occurred.



Evaluation of the Electronic Data Recorder (EDR) associated with the air bag control module on the Volvo by Tempe PD showed that the Uber/Volvo was traveling at 43.5 mph at impact. Additionally, Tempe PD evaluated the Uber/Volvo vehicle speed using the distance the pedestrian was thrown and a separate evaluation from the distance the bicycle traveled after impact. The pedestrian traveled 74.92 feet after impact, and the bicycle came to rest 105.25 feet after impact. Tempe PD used the Searle minimum throw formula for pedestrian impacts which indicated the pedestrian was struck by a vehicle traveling 32-39 mph. Using the sliding formula for the bicycle they determine the impact speed to be 39 mph. Both methodologies were consistent with the air bag EDR module recordings.

Nighttime Visibility testing was conducted by Tempe PD on March 22, 2018 about 10 p.m. with the NTSB observing the testing. A police officer pedestrian of approximately the same height as the victim wearing dark clothing was positioned at two locations near the impact area, holding the bicycle on her left side as was seen in the accident video footage. In the first test the pedestrian was located laterally even with the left edge of the number one lane or left-hand lane. In the second test the pedestrian and bicycle were positioned at the lane line separating the left-hand and right-hand lanes, which was closer to the actual impact location. The third test was performed in the second position with the pedestrian marching in place to create movement. A Tempe police officer drove the accident vehicle, the Uber/Volve during the visibility testing. He drove at 5 mph and stopped when he could see the pedestrian. The distances were measured with a lidar device three times for each test.

In the first test the pedestrian was visible to the driver at 637.7 feet away. In test two the pedestrian was visible to the test driver at 812.3 feet, and in the third test the pedestrian was visible from 818.3 feet away.

On June 27, 2018 the NTSB performed similar visibility testing by using pedestrian test subject in dark clothing positioned in the left hand lane. The testing was conducted from 637 feet away at 10 pm at night. The pedestrian was visible to an observer when the observer was 637 feet south of the impact area on N. Mill road.

Next, skid testing was performed by Tempe PD with the accident vehicle at the accident location traveling at 40 mph. Five tests indicated the average drag factor for the accident site was 0.92 longitudinal g's.

Next, the shortest or most conservative distance was used to evaluate avoidability. The first step in the process was to adjust the visibility to account for driver expectancy and statistical variability.⁸ The 637.3 feet was multiplied by 0.67 to adjust the value to the expected mean value for drivers in a controlled study with a large population, which yielded a distance of 426.99 feet. This distance was then multiplied by 0.5 to adjust for driver expectancy since the test driver knew he would be looking for a pedestrian. The value was reduced to 213.5 feet and was then reduced

⁸ The text "Forensic Aspects of Driver Perception and Response," Olson, Dewar, and Farber was used to evaluate visibility. Chapter 12 by Hyzer and Hyzer was used to lower the visibility distances.



by 33 % to provide a value that 85 percent of drivers should be able to see and identify the pedestrian clearly. This gave a final visibility distance of 143.04 feet.

The video shows that the driver is looking forward at 0.50 seconds before impact and Uber/Volvo information suggests the driver moved the steering wheel at 0.02 seconds before impact. So, the quickest response time would be 0.5 seconds and according to the text, response times can vary between .6 to 1.25 seconds.

Tempe PD's evaluation showed that a driver traveling at 43.5 mph with a visibility distance of 143 feet and a reaction time of 0.5 seconds could stop on the pavement at the accident scene 42.61 feet prior to where the impact occurred. With a reaction time of 1.25 seconds the Uber/Volvo vehicle could have slowed to 12 mph giving the pedestrian time to move out of the way. The pedestrian's walking speed was calculated at 4.67 feet per second or 3.18 mph from the frames in the forward-facing video. The impact location was 43.5 feet from the roads west curb indicating the pedestrian entered the road at 9.3 seconds before impact.

Further evaluation shows that at the 143 feet visibility distance from impact the Uber/Volvo traveling at 43.5 mph/63.77 feet per second was 2.24 seconds from impact. At this time value the pedestrian was traveling at 4.47 feet per second or was 10.47 feet from impact. Since the right-hand lane was 13.65 feet wide and the impact was 5 feet from the curb it can be seen that the pedestrian was only 1.82 feet out of the Uber/Volvo's lane when the Uber vehicle was 143 feet from impact.⁹

E. DOCKET MATERIAL

The following attachments and photographs are included in the docket for this investigation:

LIST OF ATTACHMENTS

Highway Attachment – City of Tempe Public Works Department Design Plans

Highway Attachment – Vehicle Traffic Counts and Accident History

Highway Attachment – Highway Safety Lighting Specifications

⁹ See Tempe Police Report Case number 18-32694: https://www.tempe.gov/government/police/records#To_obtain_a_Copy_of_a_Police_Report:



Highway Attachment – 2016 Power Point Presentation to Tempe City Council on LED Lights

LIST OF PHOTOGRAPHS

Highway Photo 1 – View of the pedestrian’s travel path into the median separating North and South Mill Avenue. Note the concrete sidewalk changes to a dirt path where the shadow of the overhead bridge begins.

Highway Photo 2 – Continued view of the pedestrian’s path in the median toward N. Mill Avenue. Note the sign facing outward in the left side of the photo that prohibits pedestrians from crossing S. Mill Avenue into the median area.

Highway Photo 3 – Close-up view of the wording on the sign.

Highway Photo 4 – View of the Uber vehicle’s approach path to the accident area.

Highway photo 5 – Pedestrian’s path through the landscaped median to where she crossed into N. Mill Avenue.

Highway Photo 6 – View of where the pedestrian exited the median to cross N. Mill Avenue. Note the sign prohibiting pedestrian crossing in the area is facing the opposite direction. Tempe Public Works will be adding double side signs so the pedestrians coming into the area from under the bridge will have additional signs to guide them to the crosswalk at Washington St./ Curry Road.

Highway Photo 7 – View to the pedestrian’s right where the Uber vehicle approached from.

Highway Photo 8 – View looking to the west at N. Mill Avenue, showing the median area and S. Mill Avenue. In the bottom of the photo are two squares on the side walk marking the location of the drainage inlets. The impact occurred nearest the inlet on the left in the photo, approximately 5 feet west of the solid white bicycle lane line.

Highway Photo 9 – Additional view of North Mill Avenue looking west where the impact occurred in the right-hand lane perpendicular to the drainage inlet on the left in the photo.

Highway Photo 10 – Area where the pedestrian entered North Mill Avenue walking east, moving toward the drainage inlets on the far-right side of the photo.

Highway Photo 11 – (Photos 11-20) Courtesy of Tempe Police Department. This photo depicts just north of the impact area with medical debris and the victims clothing in the right-hand lane and the bicycle laying where the right turn lane begins.

Highway Photo 12 – Additional view of the accident scene the night of the accident.



Highway Photo 13 – View of postcrash scratches in the pavement, smear marks from the victims clothing, and medical debris along with the bicycle in the right background of the photo.

Highway Photo 14 – Closer view of the victims clothing smears in the right-hand lane next to the dashed white line and the bicycle laying in the right-hand turn lane next to the curb.

Highway Photo 15 – View of the victims clothing with medical debris in the right-hand lane followed by the bicycle and then the Uber vehicle in the right-hand turn lane.

Highway Photo 16 – Close-up view of the black and orange bicycle the pedestrian was walking across the road at impact.

Highway Photo 17 – View of Uber vehicle at final position following the impact.

Highway Photo 18 – View of the damage from the impact on the right front of the Uber/Volvo.

Highway Photo 19 – View of the impact area at bottom of the photo and 5 feet to the left of the solid white bicycle lane line. In the background police evidence tags are placed by markings and debris areas.

Highway Photo 20 – View showing bicycle matched up to the damaged areas on the Uber/Volvo

END OF INFORMATION

David S. Rayburn
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