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

HUMAN PERFORMANCE 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 Advanced Technologies Group (ATG) in autonomous mode
Pedestrian:	49-year old female, walking a bicycle across Mill Avenue
Date:	March 18, 2018
Time:	9:58 p.m. (MST)
NTSB #:	**HWY18MH010**

B. HUMAN PERFORMANCE GROUP

Rafael Marshall, Operations and Human Performance Investigator, Group Chairman
NTSB Office of Highway Safety
490 L'Enfant Plaza East, S.W., Washington, DC 20594

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 OPERATIONS AND HUMAN PERFORMANCE INVESTIGATION

The Human Performance investigation focused on the behavioral, medical, operational, and environmental factors associated with the driver of the 2017 Volvo XC90. The actions of the pedestrian are also discussed.

1. Uber ATG Vehicle Operator

At the time of the crash, Uber ATG's autonomous vehicles were routinely occupied by a single vehicle operator (VO).[1] Based on Uber ATG training documents and discussions with Uber ATG staff, the essential tasks of a VO are to drive the vehicle when Uber ATG's Self-Driving System (SDS) is disabled, continuously monitor the safe operation of the vehicle when the SDS is activated, take over control of the vehicle when the SDS surrenders control or performs unsafely, and document the performance of the SDS on a shift-by-shift basis. If the SDS were to perform, or fail to perform, a safe maneuver, it was expected that the VO would take over control of the vehicle from the SDS by either taking control of the steering wheel, braking, accelerating, or pressing the disengage button on the center console.

Uber ATG required VOs to be 21 years old or older, not more than three minor traffic violations within the past 3 years; no major traffic violations within the past 3 years, such as suspensions, cancelations, and revocations; and no 'unacceptable' violations within the past 7 years, such as resisting arrest, reckless driving, and alcohol and drug related charges.[2]

1.1. Driver Background

The 44-year old female vehicle operator held a Class D license, which allowed the operator to drive any vehicle that did not require a motorcycle or commercial license. Her most recent license was issued July 2016 and expired January 2039. Table 1 lists her motor vehicle convictions in the past 10 years. She was 5'7" and weighed 180 pounds.

Table 1. Traffic convictions during the past ten years.

Date	Traffic Conviction
April 2016	Violation of maximum speed limit outside urbanized area
July 2015	Reasonable and prudent speed violation[3]
March 2008	Driving while license suspended/revoked/canceled
March 2008	Operation of vehicle without current registration

NTSB investigators interviewed the VO on April 12, 2018.[4] The VO stated that prior to joining Uber ATG, she drove part-time with Uber. Her personnel file also indicated that she had worked as an online moderator for various social communities since 2012. According to the VO, she was interested in autonomous vehicle technology and applied to be a vehicle operator when Uber ATG began testing autonomous vehicles in Arizona. She was screened twice by a recruiting agency before being interviewed by Uber ATG. During her interview, she was given a basic driving test to determine if she could follow basic driving directions and was not prone to distraction while conversing with passengers. The VO was hired in July 2017. The VO stated to NTSB investigators that she was not working a second job at the time of the crash.

[1] Since the crash, Uber has changed this title to 'mission specialist;" however, the title at the time of the crash will be used throughout the human performance chairman factual and analysis.
[2] Human Performance Attachment - Arizona Adjudication Criteria.
[3] See Arizona Revised Statutes, Title 28, Article 6, Section 701.
[4] Human Performance Attachment - Uber ATG Vehicle Operator Interview.

1.1.1. Training Attended by the VO

Prior to beginning her job, the VO was required to attend a three-week vehicle operator training program. The first week of training occurred at "Ghost Town," which was the moniker given to the Uber ATG facility in Tempe. This training lasted 3 days and familiarized recruits with Uber ATG through an onboarding process.[5] Some recruits were also taken to a local vehicle speedway to train them on vehicle handling dynamics and evaluate them on safe driving skills; however, the VO received this part of the training later in the training program due to time constraints. Finally, recruits were introduced to the self-driving test vehicle (SDV).[6]

The second week of training took place in Pittsburgh, Pennsylvania. Here, the VO was trained on the SDV using a closed course before being taken out on public roads. In both driving situations, Uber ATG introduced scenarios that would test the VOs decision making skills and ability to interact with the vehicle controls. When not behind the wheel, the VO attended classes that taught her about Uber ATG's culture and employment policies, employment software applications, public relation procedures, communicating issues with management and technical support, procedures to follow in case of a crash, and safe driving procedures. All VO recruits were evaluated and tested on 6 categories, with only those who performed at an acceptable level being retained.[7]

The final leg of training was conducted in Tempe, where the VO was paired with a mentor and introduced to Uber ATG's infraction policies, state driving laws, local landmarks, and Uber ATG test routes. The VO stated that she was not allowed to pick up passengers in the SDV with the SDS activated until her training with the mentor was complete. During this time, the VO stated that she was also trained on vehicle handling and dynamics on a test track.

According to the driver, when she was trained, there were two distinct employment paths for VOs – test operations and passenger operations.[8] She was initially trained on passenger operators but was eventually trained on test operations when the two duties were combined. She was on a test operations route at the time of the crash. Additionally, her initial training took place when Uber ATG manned its vehicles with two VOs – a pilot who occupied the driver's seat, and a copilot in the passenger's seat who used a laptop to oversee the vehicle's path, and tagged and annotated issues that arose while in autonomous mode. In October 2017, Uber ATG integrated much of the copilot's functions into the "front seat control application" (FSCA) software, housed on a center-dash mounted tablet computer in the SDV. The FSCA interface was the primary means for the VO to interface with the SDS. Complex functions on the FSCA were locked out once the SDV was in motion, and according to Uber ATG, functions that were available to the VO while the vehicle was in motion only required one to two taps to complete.[9] The VO was trained on the

[5] *Onboarding* describes the process of socializing a recruit into an organization's products, and services, as well as its policies, processes, and culture.
[6] The self-driving vehicle consisted of the Volvo XC90 modified to contain Uber ATG's self-driving-system.
[7] Categories included piloting procedures, copiloting procedures, in-vehicle communication, customer service/professionalism, following instructions, and coachability/attitude. See Human Performance Attachment - Uber ATG Vehicle Operator Duties. Also see Human Performance Attachment - Vehicle Operator Hand and Foot Hovering Procedures.
[8] VOs assigned to passenger operations would pick up passengers and introduce them to the SDVSDV, while test operations would run the SDVSDV through canonical routes and report any issues with the operation of the SDS.
[9] Refer to Section 1.4 for more information about the FSCA.

new tablet interface in October 2017 and began operating the SDV as a single VO in November. Investigators were able to obtain from Uber ATG the training records of the VO involved in the crash. It showed that the VO was up-to-date in all her training.

1.1.2. Uber ATG Infraction Policies

Uber ATG had several policies pertaining to the operation of the SDV by the VO. This included a Tiered Infraction Policy, on which the VO received training and Uber ATG made available through the Uber ATG Employee Resource webpage.[10] The infraction policy was divided into three categories: Critical, Serious, and Negligent.

Critical infractions were defined as "Incidents or behaviors that put people and/or ATG at grave risk or create or risk creating large avoidable costs." These infractions "will usually result in termination."[11] Examples given for this category include:

- Use of drugs/alcohol while operating a vehicle, including prescription medications that impair the operator's ability to safely operate a vehicle
- Any physical mobile device usage/ interaction while the vehicle is in motion
- Willful or reckless negligent driving behavior (e.g., running a red light, causing a crash, being involved in a near miss that could have resulted in significant damage or injury)

Serious infractions were defined as "Incidents or behaviors that put people and/or ATG at serious risk, or risk creating significant avoidable costs." These included moving violations, cell phone usage short of critical (e.g., at stop lights), and carrying on extensive non-work-related conversations over Bluetooth. VOs who engaged in a serious infraction were required to participate in remedial training. Further Infractions within a 90-day period could result in further action, including termination. Uber ATG considered mitigating circumstances, such as VO efforts to avoid a more serious or dangerous outcome. It encouraged VO to self-report infractions, and failure to do so could result in additional action up to and including termination for a first occurrence.

Finally, negligent infractions were incidents or behaviors that could create avoidable costs/ risks. These included a failure to execute proper operator technique or procedures, and minor damage to vehicles or equipment. VOs who committed a negligent infraction were required to attend remedial training. A continued pattern of negligent Infractions could result in additional action, including termination. As with serious infractions, Uber ATG considered the circumstances that precipitated in the negligent infraction and encouraged VOs to self-report infractions. Uber ATG also encouraged VOs to report infractions committed by other VOs. In addition, it was Uber ATG's policy to spot-check logs and in-dash camera footage on a random basis. Uber ATG was unable to supply investigators with documents or logs that revealed if and when spot checks were performed.

1.2. VO Work Schedule and 72-Hour History

[10] Operations Attachment - Uber Tiered Infraction Policy.
[11] Termination may be reconsidered in situations where the operator made a best-effort decision to avoid a more serious or dangerous outcome.

According to Uber ATG, the VO was assigned the 4 p.m. – 2:30 a.m. shift. In the month prior to the crash, the driver worked sporadically, and her work times never matched her assigned shift schedule (See Table 2).

Dates	Work Times	Total (HH:MM)
February 16 - 17, 2018	8:59 p.m. - 3 a.m.	6:01
February 18, 2018	12:44 a.m. - 3:33 a.m.	2:49
February 23 - 24, 2018	10:15 p.m. - 3:30 a.m.	5:15
March 2 - 3, 2018	10:45 p.m. - 3:30 a.m.	4:45
March 4 - 5, 2018	11:15 p.m. - 3:30 a.m.	3:40
March 12 - 13, 2018	11:00 p.m. - 3:00 a.m.	4:00
March 17 - 18, 2018	8:00 p.m. - 2:30 a.m.	6:30
March 18 - 19, 2018	7:30 p.m. - 3:15 a.m.	7:45

Table 3 provides a timeline of the VO's activities in the days prior to the crash, based on Uber ATG records, interviews with the VO, and phone records from her personal phone.[12] The VO also had in her possession a business phone; however, this phone did not contain call and text records for the days leading to the crash. The VO did not work from March 14-16. On March 16, she was scheduled to work, but called in sick after experiencing headaches. The VO stated to investigators that she spent the rest of the day and night in bed drifting in and out of sleep.

On March 17, she awoke around 2:30 p.m., visited her doctor, and arrived at work before 8 p.m. She reviewed notes from the end of shift meeting the night before, performed a check of the assigned SDV, then left the facility around 8:50 p.m. She guided the SDV through an established route for about 3.5 hours before switching to a different established route for the rest of her shift. She completed her shift at 2:30 a.m., performed a diagnostic test on the SDV, and left the Uber ATG facility around 3:15 a.m. She arrived home around 3:30 a.m. and went to bed around 5 a.m.

She stated that she awoke between 11:30 a.m. and 12 p.m. on the morning of March 18, 2018, giving her about 6.5 hours of sleep opportunity. She arranged with her Uber ATG supervisor to arrive later for her shift so that she could visit her father in Tucson. She estimated that she arrived in Tucson around 1:30 p.m. and left before 5 p.m.[13] She arrived at the Uber ATG facility around 7:30 p.m., performed a diagnostic test on the SDV, and left the facility around 9:14 p.m.

[12] Human Performance attachment – Vehicle operator mobile phone records; Human Performance attachment – Uber ATG vehicle operator interview.
[13] The distance from Tempe to Tucson is about 109 miles, which can be driven in a little more than 1.5 hours.

Table 2. Uber ATG vehicle operator's activities leading to the crash, based on Uber ATG records, interviews, and phone records.

Time	Activity	Location	Source
Friday, March 16, 2018			
8:00 a.m. - 12:40 p.m.	seven short outgoing phone calls	N/A	phone records
2:30 p.m.	awoke	home	VO interview
N/A	rested at home all day	home	VO interview
Saturday, February 17, 2018			
2:30 p.m.	awoke	home	VO interview
4:15 p.m.	went to doctor	N/A	VO interview
7:52 p.m.	arrived at work	Uber ATG	VO interview
8:00 p.m.	started shift	Uber ATG	VO interview/Uber ATG
8:50 p.m.	left Uber ATG facility	N/A	VO interview
Sunday, March 18, 2018			
2:30 a.m.	completed shift	Uber ATG	Uber ATG
3:15 a.m.	left Uber ATG facility	Uber ATG	VO interview
3:30 a.m.	arrived home	home	VO interview
5:00 a.m.	went to bed	home	VO interview
11:30 a.m. -12:00 p.m.	awoke	home	VO interview
12:30 p.m.	left for Tucson to visit father	N/A	VO interview
1:30 p.m.	arrived at Tucson	Tucson	VO interview
4:30 - 5:00 p.m.	left Tucson	N/A	VO interview
7:30 p.m.	started shift	Uber ATG	VO interview/Uber ATG
7:35 p.m.	initiated vehicle diagnostics	Uber ATG	VO interview
9:14 p.m.	left Uber ATG facility	N/A	Uber ATG
9:58 p.m.	crash	N/A	N/A

1.3. Event Leading to the Crash

The SDV was equipped with an array of external cameras that functioned as part of the SDS. In addition, the vehicle was equipped with an interior/exterior facing after-market in-dash camera (dashcam). After the crash, Uber ATG provided the Tempe Police Department with the flash drive from the dashcam. A copy of the dashcam video recordings was later provided to NTSB investigators. The Tempe Police also provided the NTSB with a redacted police report on the incident, which described in detail the actions of the VO as recorded by the dashcam, from the time she prepared to leave the Uber ATG facility up to the point that first responders arrived on the scene of the crash.[14] According to the police report, at 9:06 p.m., as the VO waited for the garage door of the Uber ATG facility to open, she picked up a gray bag and removed a cell phone

[14] Highway Attachment Tempe PD Police Report18-32694.

with a black case. She exited the facility and parked in the adjoining lot, where she then focused most of her attention on the center console of the SDV, where an Uber ATG-installed tablet computer was mounted. At 9:17 p.m., the VO appeared to reach toward an item in the lower center console area, near her right knee, out of sight of the dashcam. As shown in figure 1, the SDV was equipped with a slot in the lower console area where a cell phone could be placed, located under the Uber ATG-mounted tablet computer. The vehicle exited the parking lot at 9:19 p.m.

Figure 1. The interior of the accident vehicle, with an exemplar cell phone placed in a slot under the Uber-mounted tablet computer.

From the time the VO exited the parking lot to the time of the crash, the VO frequently glanced down towards the lower center console area. The Tempe Police tabulated the number of glances the VO made towards the lower center console area during a 27-minute window, from 9:31 p.m. to 9:58 p.m. During this timeframe, the VO glanced down at the same spot 204 times, of which 166 instances were when the vehicle was in motion. The Tempe Police estimated that the vehicle was in motion for 21 minutes, 48 seconds, and of that time, the VO's eyes were averted from the roadway was 6 minutes, 47.2 seconds, or approximately 32% of the time.

The NTSB reviewed the final clip of the dashcam recording, which lasted 2:58 minutes and ended immediately after the SDV collided with the pedestrian. The recording showed the SDV, occupied by the VO, navigating an urban environment. The SDV passed a total of 6 signal lights, all of which were green. It also navigated two right hand turns at signalized intersections. Traffic appeared light. The VO was observed looking away from the roadway and towards the lower center console area 22 times.[15] In seven of those occasions, the operator took her gaze away from the forward view for 3 seconds or more. Prior to colliding with the pedestrian, the operator glanced away from the forward view for 5.3 seconds. Based on a frame-by-frame analysis of the same dashcam video clip, the Tempe Police estimated that once the VO returned her gaze to the

[15] Additionally, the vehicle operator looked away from the roadway once to reach for a water bottle located in the driver's side door, and once to drink from the bottle.

roadway, she had 0.5 seconds to perceive and react to the presence of the pedestrian. According to data supplied by Uber ATG of the SDS data, the VO initiated an evasive maneuver with the steering wheel 0.02 seconds prior to impact, and initiated braking 0.72 seconds after impact.

The pedestrian was visible on the video clip for about 2 seconds prior to the collision. Her shoes were the first objects to become visible, followed by the wheel rims of the bicycle she was pushing besides her. About a second before the collision, the pedestrian is seen on the dashcam recording looking over her right shoulder at the vehicle. She appeared to be wearing white shoes, blue jeans, and a dark coat. Her bicycle was red and did not have reflectors on either wheel. A small headlight mounted to the front of the bicycle appeared to be on; however, the beam from the headlight was directed perpendicular to the roadway and was not salient.

1.4. Front Seat Control Application (FSCA)

At the time of the crash, the FSCA software was the primary means for VOs to interact with the SDS.[16] The software was housed in a touch-sensitive tablet computer placed by Uber ATG directly on top of the center infotainment screen, as shown in figure 1. The mount for the tablet computer was hinged to allow access to the infotainment screen if the need arose. FSCA functions requiring multiple inputs could only be used when the vehicle was parked. These included VO log-in procedures and initialization of the SDS prior to a test run. When the SDV was in motion, the FSCA restricted tasks to those that required only one or two taps to complete, such as:

- Tagging an object of interest encountered in the operating environment
- Notifying the engineering team of an on-vehicle issue that needs their attention
- Tagging incidents or infractions
- Tagging when the SDS performs incorrectly

Figures 2 is a screenshot of the FSCA during the crash trip. When the SDS is engaged, as it is in Figure 2, the FSCA showed the route of the SDV in green and "Self-Driving Engaged" appeared on the top of the screen. It shows the selectable icons at the bottom of the FSCA screen. If a VO noticed a specific object of interest to the software developers (e.g., stopped school bus, emergency vehicle, an individual directing traffic) the VO would tap the "Label" icon at the bottom-left of the screen to tag the location and time the object was encountered. If an equipment issue occurred in the SDV, such as a malfunctioning dashcam, the VO would tap the "Ticket" icon at the bottom-center of the screen. If the SDV was involved in an incident or infraction, the VO would tap the "Attn" icon at the bottom-center of the screen. Finally, if the SDS incorrectly reacted to an event that should be within the scope of its capabilities but does not cause a hazardous situation, the VO would select the "Autonomy" icon on the bottom-right of the screen. If a vehicle or system issue occurs, operators were instructed to tag the issue, then either pull over or complete their mission before troubleshooting.

[16] Each SDV was still equipped with the laptop previously assigned to the VO copilot; however, essential VO functions could all be accessed through the FCSA. According to the accident VO, she had used the laptop to initialize the SDV prior to initiating her trip because it was quicker to do so than using the FSCA.

In the event the VO must take control of the SDV from the SDS, or if the SDS self-disengaged after encountering a novel situation, the route color is changed to blue and "Ready To Engage" appears at the top of the screen (Figure 3). The four default icons at the bottom of the screen are replaced for 10 seconds by icons labeled "Critical" and "Autonomy." The "Critical" icon would be selected if the VO had to take control of the SDV due to a potentially hazardous action by the SDS, an incident, or a policy infraction. "Autonomy" would be selected in this case if the SDS performs an incorrect but not immediately hazardous maneuver. The result of selecting this "Autonomy" icon was identical to selecting the "Autonomy" icon at the bottom of the FSCA when the SDS was engaged. After 10 seconds, the default icons reappear, regardless of whether the SDS is reengaged or not.

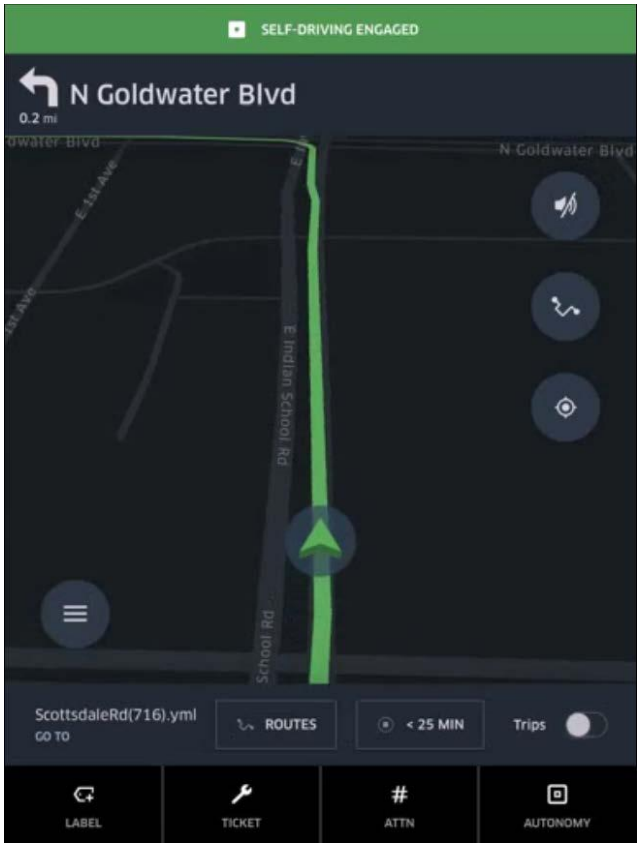

Figure 2. Screen capture of FSCA from the crash SDV. The screen is in night mode. The sound is off, and the map shows turn-by-turn directions. The four options at the bottom of the screen are tapped by the VO during specific situations to tag an event.

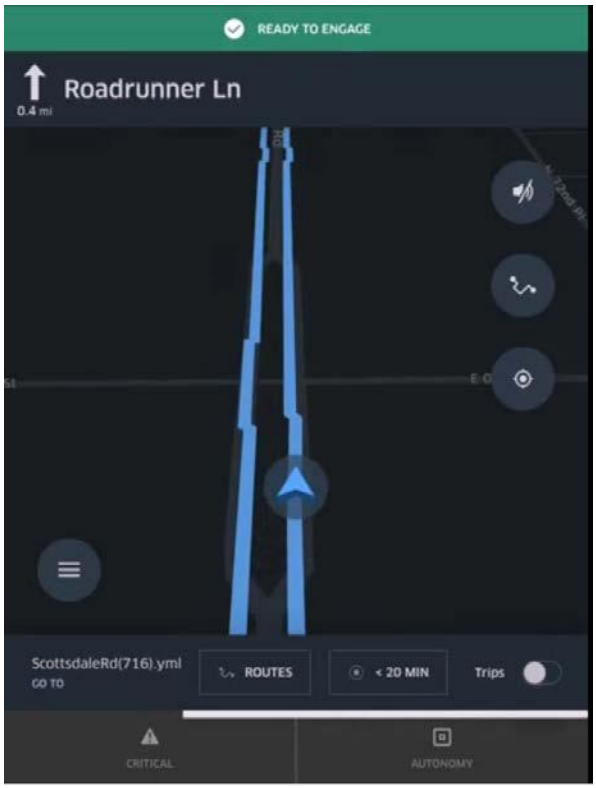

Figure 3. Screen capture of FSCA after the SDS disengaged, about 20 minutes prior to the crash. The screen in on night mode and shows a change in the options selectable by the VO. The sound is off and the map shows turn-by-turn directions.

1.5. Tempe Police Visibility Tests

One March 22, 2018, the Tempe Police Department conducted visibility tests to determine the point at which an alert driver should have been able to detect a pedestrian stepping off the median and into northbound Mills Avenue. The tests were conducted around the same time of night as the crash and under the same lighting conditions. The police used the actual crash vehicle and an actor who was of similar height and build to the pedestrian and wearing the same dark clothing. Based on three test iterations, the driver in the vehicle saw the actor at a minimum of 637.3 feet. The Tempe Police adjusted this distance to account for expected mean value for drivers in a controlled study with a larger population, which yielded a distance of 427 feet. This was further adjusted down to account for driver expectancy, since the test driver was told that he would be looking for a pedestrian, yielding a distance of 213.5 feet. Finally, to obtain the distance at which 85% of drivers should be able to see and identify the pedestrian clearly, the distance was further reduced by 33% to a final distance of 143 feet.[17]

[17] The method used by the Tempe Police was done in accordance to the processes outlined in "Forensic Aspects of Driver Perception and Response," authored by Olson, Dewar, and Farber. The specific method used was the method set forth by Hyzer and Hyzer in Chapter 12 of that publication.

The Tempe Police analyzed the dash cam video and determined that the VOs actual reaction time upon seeing the pedestrian in the roadway was 0.5 seconds. Using the 85th percentile sight distance of 143 feet, the driver's actual reaction time of 0.5 seconds, the vehicle's reported speed of 43.5 mph (63.8 feet/second), and the average drag factor determined from skid testing of 0.92, the Tempe Police determined that had this VO been alert to the roadway ahead, she could have reacted and brought the vehicle to rest 42.6 feet prior to the pedestrian. The Tempe Police also determined that the crash would have been avoidable with a reaction time as high as 1.25 seconds.

The Tempe Police also calculated the walking speed of the pedestrian to be 4.67 feet/second, based on the final frames of the dashcam footage. From the point at which the pedestrian stepped off the curb to the point of impact was about 22 feet, and at a constant walking speed, it would have taken the pedestrian about 4.66 seconds to reach the point of impact. The Tempe Police concluded that "the pedestrian would have been closer to the vehicle's own lane at the time of [VO] perception."

NTSB investigators were permitted to observe the visibility testing take place but were not allowed to take an active role. However, investigators noted that roadway lighting was present on both sides of northbound Mills Avenue. The bulb for the street light closest to the spot where the pedestrian initiated her crossing of northbound Mills Avenue dimmed intermittently before returning to its normal brightness, occasionally producing a shadowed area on the roadway; this shadowed area extended into the left turn lane and part of the left most lane. It could not be determined from available evidence if the shadow were present prior to or at the time of the crash. See the Highway Group Chairman Factual for further information on the lighting at the crash site.

1.6. Vehicle Operator Vigilance / Fatigue

On March 20, 2018, the Tempe Police presented the VO with a search warrant authorizing seizure and search of her cell phones. The Tempe Police conducted a forensic examination of the two phones and found no evidence that the driver was engaged in texting, or was on a phone call, at the time of the crash. The examination did reveal that the VO had three streaming media applications on her personal phone, and one of the same applications on her business phone.[18] Search warrants were prepared and sent to the three service providers. Data obtained from Hulu showed that the account had been continuously streaming video from 9:16 p.m. until 9:59 p.m. (the crash occurred at approximately 9:58 p.m.).

Uber ATG had a policy in place that prohibited phone usage while operating an SDV.[19] VOs were familiarized with the policy during orientation training, the policy was available for viewing online, and there were posters in place in the Tempe facility reminding VOs about the prohibition (see Figure 2). Uber ATG relied on each VO to report on themselves and on other VOs who violate the policy. When Uber ATG received a report, managers reviewed the video recordings to verify that the violation occurred, then meted out the penalty based on the circumstances of the violation. Uber ATG managers also had the option to perform spot checks on VOs by reviewing archival video recordings. According to data supplied to the NTSB by Uber

[18] Her business phone contained the YouTube application, and her personal phone contained the YouTube, Hulu, and Netflix applications.
[19] Human Performance Attachment – Uber ATG mobile phone and driving time policies.

ATG, from April 2017 until February 2018, it had identified 18 VOs who violated its cell phone policy. Nine VOs were sent for remedial training and 9 were fired. Six of the terminations occurred after October, when Uber ATG switched to having one VO in the SDV.[20] Uber ATG's records do not indicate the method by which the violations were identified (i.e., self-report, peer report, or spot check).

Uber ATG did not have a comprehensive policy on vigilance and fatigue.[21] It did have a policy on maximum driving time for VOs. According to the policy, VOs are limited to driving 10 hours following 8 consecutive hours off-duty. VOs are also restricted to 15 hours on-duty following 8 consecutive hours off-duty.[22] These requirements are based on the Federal Regulations that govern property-carrying and passenger-carrying drivers.[23] The policy further stated that Uber ATG believed the maximum driving time was not sustainable, and therefore recommended that the daily driving limit be 8 hours within a 15-hour period, preceded by 8 consecutive hours of off-duty time. A team leader would need to approve any driving time exceeding than 8 hours for two consecutive days. Uber ATG also recommended that VOs take rest breaks of up to 20 minutes for every 2.5 hours of driving; and required that 20-40 minute breaks be taken after a maximum of 4.5 hours of sustained driving.

In September, Uber ATG met with NTSB investigators to discuss several changes that it planned to make to improve safety. First, Uber ATG representatives stated that it had accessed the Federal Motor Carrier Safety Administration's North American Fatigue Management website and planned to use it as a basis for a comprehensive fatigue risk management program. Second, it planned to operate its self-driving vehicles in manual mode, and eventually in autonomous mode, using two VOs to promote alertness and roadway monitoring. Third, it would prohibit personal electronic device (e.g. mobile phone) use by VOs in the driver's seat anytime the vehicle was in operation, even when the vehicle is in the garage or test track. Fourth, it planned to limit VOs to two continuous hours of SDV operations instead of 4.5 hours. Finally, it planned to equip all its SDVs with in-dash cameras that monitored eye gaze to ensure that VOs were attending to the roadway ahead. If a VO gazed away from the forward view for more than a set period of time, the video monitoring system would alert the VO and generate a report to the VO's supervisor. In November 2018, Uber ATG presented the NTSB with updated operational policies reflecting the changes mentioned.

[20] Human Performance Attachment - Uber ATG mobile device policy infractions.
[21] See https://www.nafmp.com for examples of a comprehensive fatigue management policy.
[22] Human Performance Attachment – Uber ATG mobile phone and driving time policies.
[23] 49 *Code of Federal Regulations* 395.

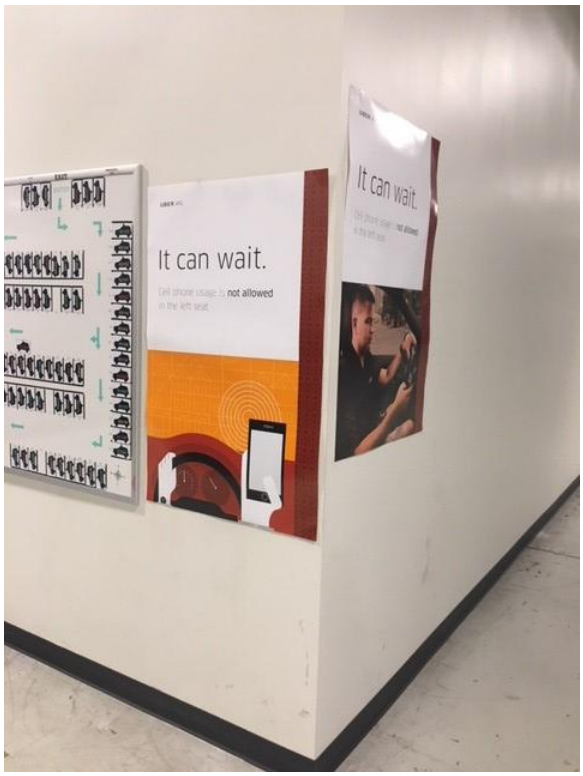

Figure 4. Posters in the vehicle bay of Uber ATG's Tempe facility remining vehicle operators not to use a cell phone while operating an SDV.

1.7. VO Post-Crash Toxicology

The Tempe Police did not collect blood samples from the VO, and the VO was not taken to a hospital after the collision, where a blood sample might have been collected. The VO was evaluated on scene by a trained drug recognition expert and was found not to exhibit signs of substance impairment. According to Uber ATG's drug testing policy, vehicle operators involved in a crash are required to submit for drug and alcohol testing; however, this was not being done. During its September meeting with NTSB investigators, Uber ATG stated that although it had a pre-employment, random, and post-crash drug testing policy, it was not actively conducting the testing allowed for by its policies. It has since enacted drug testing policies and procedures that mirror the federal standards applicable to commercial drivers.[24]

1.8. General Health

NTSB investigators were unable to obtain health information about the VO. Investigators interviewed the driver but were prohibited by her attorney to inquire about her medical history. Nevertheless, video footage of the event prior to and during the crash indicate that medical incapacitation did not play a role in this crash. Despite this, during its September meeting with NTSB investigators, Uber ATG stated that it would begin requiring its VOs to obtain a certificate of fitness from a medical provider before operating a SDV. In November 2018, Uber ATG

[24] See 49 *Code of Federal Regulations* 382 and 392.

provided the NTSB with a confidential policy that required VOs to comply with the federal fitness for duty standards applicable to commercial drivers, including obtaining a Department of Transportation medical certificate from a certified medical examiner.[25]

1.9. Vehicle Detection of the Pedestrian

Investigators met with Uber ATG staff on March 21 for a brief introduction regarding Uber ATG's SDS technology and how it performed prior to the crash. According to Uber ATG, the Volvo XC90 was equipped with its own suite of safety systems, including a forward collision avoidance system ('City Safety') that can detect bicyclists and pedestrians. City Safety was active when the vehicle was not in autonomous mode; however, because Volvo's City Safety system interfered with the ability of Uber ATG's SDS to detect and interpret the roadway environment, Volvo's City Safety was disabled when the vehicle was in autonomous mode. For a detailed description of Uber ATG's autonomous vehicle system, refer to the Vehicle Group Chairman's factual report.

During the March 21 meeting, Uber ATG staff provided investigators with a timeline, based on preliminary data, depicting when the SDS identified the pedestrian and how it reacted to her presence. Uber ATG presented additional information to the NTSB in June that further clarified the timeline. According to Uber ATG, the SDS detected an object 5.6 seconds before the collision. This object was initially classified by the SDS as a vehicle 4.6 seconds before the collision. It was later classified as a bicycle 2.5 seconds before the collision, and the SDS predicted that the bicycle would stay in the left lane. It detected the bicycle within its lane 1.6 seconds before the collision. 'Plan suppression' began 1.3 seconds before the collision, meaning that the SDS suppressed an evasive maneuver because it would have exceeded operational thresholds set by Uber ATG.[26] In the second that followed, the SDS attempted to calculate a trajectory that would avoid a collision with the bicycle but was unable to do so. According to Uber ATG representatives, the SDS emitted an audible chime 0.28 seconds before the crash indicating that the SDV was initiating a controlled stop. The SDS was disengaged by the vehicle operator when she made a steering maneuver 0.03 seconds before the collision.

Investigators requested a demonstration of the vehicle in autonomous mode on public roads; however, due to Uber ATG's self-imposed national moratorium on autonomous testing after

[25] See 49 *Code of Federal Regulations* 391 for more details on fitness for duty health requirements.

[26] According to Uber ATG representatives, because the Uber SDV was a test vehicle, there was a chance that it would falsely detect an object in the roadway and attempt to react to it with hard braking or extreme steering movements. Therefore, Uber ATG programmed their vehicles to suppress actions that may result in abrupt braking or steering executions above a threshold value (maximum acceleration -0.7/+0.3 g's, and maximum jerk +/-0.5 g's). Uber ATG relied on the VO to detect true positives and execute any emergency evasive maneuvers. When the SDS detected a hazard, it would initiate a "plan suppression" to suppress sudden decelerations or steering as it attempts to verify the hazard and calculate an alternative path. If an alternative path was not found after 1 second, the SDS initiated a "continuous trajectory control" stop and emitted an audible chime for the VO to take over. In the case of this crash, the SDS initiated a "plan suppression" 1.3 seconds prior to the crash (probably when the pedestrian entered the SDV's lane), and upon determining that it could not calculate a path that would not exceed its acceleration and steering limits, emitted a chime for the VO to take control of the SDV 0.30 seconds prior to the crash. According to data presented by Uber ATG, the VO disengaged the SDS 0.026 seconds prior to the collision when she initiated a steering maneuver.

the crash, the company could only accommodate this request on its test track. Uber ATG was able to show investigators what appeared on the FSCA when the vehicle was on autonomous mode, as would have been seen by the vehicle operator. When the SDS was engaged, the FSCA showed part of the planned route of the vehicle and the position of the vehicle in that route. No further information was presented to the vehicle operator. The vehicle operator was not shown via the FSCA what the SDS had detected or how it planned to respond to them. Additionally, the vehicle operator could not modify the speed of the vehicle.

NTSB investigators met with Uber ATG representatives again on June 13 and September 25. During these meetings, Uber ATG clarified what it believed occurred on the day of the crash. According to Uber ATG, the SDS did not have the capability to classify an object as a pedestrian unless that object was near a crosswalk. Since the pedestrian crossed in the middle of the street away from a sidewalk, the SDS initially classified her as an unknown object, then as a vehicle, then as a vehicle or a bicycle, and finally as a bicycle. Additionally, because the SDS was unable to correctly classify the pedestrian, it was also unable to predict her path and speed on the roadway. Under both the vehicle and bicycle classifications, the SDS predicted that the object would stay in its travel lane, which was the lane to the left of the SDV. The inability of the SDS to correctly classify the pedestrian as such affected its ability to accurately assign her a trajectory and speed, and as a result, the SDS could not anticipate that the pedestrian could enter the SDV's path of travel.

According to Uber ATG, it has since modified its programming to include jaywalkers among its recognized objects. It has also programmed the SDS to slow in situations where the object cannot be classified with confidence. It has also allowed the SDS to generate trajectories separate from object classification.

2. Pedestrian

2.1. Background

According to the Maricopa County Arizona Office of the Medical Examiner's Report, the pedestrian was a 49-year-old female. She was 5'4" tall and weighed 146 pounds. Her cause of death was multiple blunt force injuries and the manner was described as "accident." The autopsy did not identify any significant natural disease.

Little could be determined about the pedestrian's activities prior to the crash. The pre-hospital care report completed by the Tempe Fire Medical Rescue Department listed the pedestrian as homeless. This was confirmed from conversations with a Tempe Police officer who was familiar with the pedestrian. NTSB investigators attempted to reach the contact person listed on the pedestrian's post-crash treatment records but was unsuccessful. Investigators learned from Uber ATG that the pedestrian had relatives with whom they had settled; however, lawyers representing these relatives refused to cooperate with investigators. Investigators also visited and called homeless shelters in the Mesa and Tempe area to determine if the pedestrian stayed or visited those locations, but received no cooperation from staff. Investigators accessed the pedestrian's Facebook page and sent requests for information to all her friends in the local area; however, none replied to the request. Investigators also reached out to local reporters and law enforcement but were unable obtain verifiable information about the pedestrian's whereabouts prior to the crash.

2.2. Pre-Crash Activities

Because she was homeless, and because there was a lack of cooperation from those who knew her, the NTSB was unable to determine with certainty the pedestrian's activities prior to the crash. Her path in the seconds prior to the crash was recorded by Uber ATG's SDS, which showed the pedestrian stepping from the paved center median pathway and into northbound Mill Avenue when the SDV was 272-feet away (4.3 seconds prior to impact). At this distance, the SDV would have cleared the Red Mountain Freeway underpass. The pedestrian continued to cross the street at a steady pace until impact. The outward facing dash camera in the SDV showed the pedestrian looking over her right shoulder and looking the vehicle about a second prior to impact. It is not known if this was the first time the pedestrian noticed the vehicle, based on available video evidence.

2.3. Pedestrian Post-Crash Toxicology

Investigators met with staff from the Maricopa Medical Examiner's office and requested that they prepare and send blood samples collected from the pedestrian to the Federal Aviation Administration's Bioaeronautical Sciences Research Laboratory for independent analysis. The analysis did not detect alcohol, but detected methamphetamine at 2.126 ug/ml in blood and at 6.0204 ug/g in liver, its metabolite amphetamine at 0.25 ug/ml in blood and 0.517 ug/g in liver. Marijuana's active CNS depressant delta-9-tetrahydrocannabinol (THC) was detected at 0.0076 ug/g in lung but not in blood. Its inactive metabolite 11-nor-9-carboxy-delta-9-tetrahydrocannabinol (THC-COOH) was detected at 0.0031 ug/ml in blood and 0.0027 ug/g in lung. Finally, atropine was detected but not quantified in blood. Methamphetamine is a Schedule II controlled substance that stimulates the central nervous system available by prescription for the treatment of obesity and attention deficit disorder. After a single 12.5 mg oral methamphetamine dose, early blood levels averaged about 0.020 ug/ml and average blood levels in adults using the long acting prescription orally were about 0.032 ug/ml.[27] Methamphetamine is also prepared and used as a street drug, often by snorting, inhaling, or injecting. Generally, levels above 0.2 ug/ml are the result of mis-using methamphetamine to maximize its psychoactive effects. Psychological effects following abuse or misuse range from intense euphoria and rapid flight of ideas to dysphoria, scattered and disorganized thought, intense craving, paranoia, anxiety and irritability, hypervigilance, auditory and tactile hallucinations, and delusions.[28] Methamphetamine metabolites include amphetamine. Postmortem blood methamphetamine and amphetamine levels of 10 adults who died following intravenous methamphetamine overdoses averaged about 13 ug/ml and 0.07 ug/ml respectively.[27]

3. Pertinent State Laws and Executive Orders

[27] d-Methamphetamine. In: Disposition of Toxic Drugs and Chemicals in Man. Ed: Randall C. Baselt. 11th edition. (2017) Biomedical Publications, Seal Beach, CA.
[28] National Highway Traffic Safety Administration, Drugs and Human Performance Fact Sheets -2004, Methamphetamine.

This section describes the Arizona statutes and executive orders that applied to pedestrians crossing at a non-protected section of roadway, as well as those that apply to autonomous vehicle testing and deployment.

3.1. State Statutes on Pedestrian Responsibilities

Arizona Statute gives the right-of-way to a vehicle when a pedestrian crossing a roadway in an area other than a crosswalk. Specifically, *Arizona Revised Statutes* Title 28, Chapter 3, Article 10, Section 793, entitled "Crossing at other than crosswalk" states:

> (A) 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.

3.2. State Statutes on Driver Responsibilities

Arizona Revised Statutes Title 28, Chapter 3, Article 10, Section 794, entitled "Drivers to exercise due care" states:

> 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.

In addition, *Arizona Revised Statutes* Title 28, Chapter 3, Article 16, Section 963, entitled "Image display device; prohibition; exceptions; definition" states:

> 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.

3.3. Executive Order 2015-09

In September 2015, the governor of Arizona authorized Executive Order 2015-09, entitled, "Self-Driving Vehicle Testing in the State of Arizona; Self-Driving Vehicle Oversight Committee." This executive order proclaimed the intent of the state to attract the autonomous vehicle industry to spur economic growth and provide research opportunities to its academic

institutions. To meet this goal, the executive order directed the Department of Transportation, Department of Public Safety, and all other agencies in the state with pertinent regulatory jurisdiction "to undertake any necessary steps to support the testing and operation of self-driving vehicles on public roads within Arizona." Additional rules considered necessary to implement the Executive Order could be promulgated by the Department of Transportation. It specified that pilot programs will take place on the campuses of selected universities in partnership with developers of autonomous vehicles, and that the movement of the autonomous vehicles may be directed by operators with a valid driver's license, "regardless of whether the operator is physically present in the vehicle or is providing direction remotely while the vehicle is operating in self-driving mode." Other restrictions included:

- Vehicles may be operated only by an employee, contractor, or other person designated or otherwise authorized by the entity developing self-driving technology.
- Vehicles shall be monitored and an operator shall have the ability to direct the vehicle's movement if assistance is required.
- The individuals operating vehicles shall be licensed to operate a motor vehicle in the United States.
- The vehicle owner shall submit proof of financial responsibility, in an amount and on a form established by the Director of the Arizona Department of Transportation.

Finally, the Executive Order established a Self-Driving Vehicle Oversight Committee to advise the state on the best methods to advance the testing and operation of self-driving vehicles on public roads. Based upon the results of the autonomous vehicle pilot programs, the committee may propose clarifications or changes to State policies, rules or statutes to facilitate the expanded operation of self-driving vehicles on public roads in Arizona. The Committee shall consist of one or more representatives from the Governor's Office, the Department of Transportation, the Department of Public Safety, the selected universities, and any other pertinent agency. NTSB investigators contacted the Arizona Department of Transportation's representative to the committee a week after the crash to discuss the committee's activities since the executive order was proclaimed. Investigators learned that the committee met twice since the executive order. According to the minutes of the first meeting, the committee reviewed the executive order, elected a chair, listened to a presentation on autonomous vehicles, and took questions and comments from the attending public. The committee's website did not include minutes from the second meeting, however, according to the Arizona Department of Transportation representative, the committee discussed applicable federal guidelines and reviewed the autonomous driving laws enacted by other states. The committee decided that many of those laws stifled innovation and did not substantially increase safety. Further, it felt that as long as the companies were abiding by the executive order and existing statutes, further actions were unnecessary at that time. Investigators inquired if the committee, the Arizona Department of Transportation, or the Arizona Department of Public Safety collected any information from the autonomous driving companies to monitor the safety of their operations. The representative stated that no information was collected.

3.4. Executive Order 2018-04

On March 1, 2018, the governor of Arizona authorized Executive Order 2018-04, entitled, "Advancing Autonomous Vehicle Testing and Operating; Prioritizing Public Safety." The purpose of this executive order was to establish the parameters under which fully autonomous vehicles may operate in Arizona. Prior to operating a fully autonomous vehicle in the state, a company must submit a written statement to the Arizona Department of Transportation acknowledging:

- Unless an exemption or waiver has been granted by the National Highway Traffic Safety Administration, the fully autonomous vehicle is equipped with an automated driving system that is in compliance with all applicable federal law and federal motor vehicle safety standards and bears the required certification label(s) including reference to any exemption granted under applicable federal law
- If a failure of the automated driving system occurs that renders that system unable to perform the entire dynamic driving task relevant to its intended operational design domain, the fully autonomous vehicle will achieve a minimal risk condition.[29]
- The fully autonomous vehicle is capable of complying with all applicable traffic and motor vehicle safety laws and regulations of the State of Arizona, and the person testing or operating the fully autonomous vehicle may be issued a traffic citation or other applicable penalty in the event the vehicle fails to comply with traffic and/or motor vehicle laws
- The fully autonomous vehicle meets all applicable certificate, title registration, licensing, and insurance requirements.

This executive order also directs the Arizona Department of Public Safety to create a protocol addressing the education of law enforcement agencies and other first responders regarding interaction with fully autonomous vehicles in emergency and traffic enforcement situations, the collection of contact information for insurance and citation purposes, and any other information needed to ensure the safe operation of fully autonomous vehicles in Arizona.

The executive order directs the Arizona Department of Transportation and Arizona Department of Public Safety to complete a review of relevant regulations and report those that should be modified or should not apply to fully autonomous vehicles. Additionally, it directs the Arizona Department of Transportation to undertake a review of title and registration policies and procedures and make recommendations to ensure that law enforcement and the general public have the necessary pertinent vehicle information in the event of a collision with a fully autonomous vehicle.

4. Emergency Response to the Crash

[29] A minimal risk condition is defined in the Executive Order as: A low-risk operating mode in which a fully autonomous vehicle operating without a human person achieves a reasonably safe state, such as bringing the vehicle to a complete stop, upon experiencing a failure of the vehicle's automated driving system that renders the vehicle unable to perform the entire dynamic driving task.

Tempe Police was notified of the crash at 10:00 p.m. through a 911 call reporting that 'a person with bicycle is laying in the road.' Tempe Police then notified the Tempe Fire Department via the Phoenix Fire Department Records Management System at 10:01 p.m. The Tempe Fire Department responded on scene at 10:08 p.m. with one Engine Unit (E276) and one Medic Unit (M276). Tempe Police responded with eleven units, with their first unit (4E12) arriving on scene at 10:04 p.m. Tempe Fire Department M276 transported the 49-year-old female bicyclist from the scene at 10:16 p.m. arriving at the Scottdale Osborn Medical Center at 10:23 p.m.

5. General Factors

5.1. Global Positioning System Location

Based on Google Maps, the coordinates of the crash were:

Latitude: 33° 43' 66" N

Longitude: 111° 94' 27" W

5.2. Weather

The closest official National Weather Service weather observations to the crash site was from Phoenix Sky Harbor International Airport (KPHX), located approximately 3.8 miles west of the crash site. Data obtained from the Weather Underground website for observation closest to the time of the crash is shown in Table 1.

Table 3. Weather Data from KPHX

Time (PDT)	9:51 p.m.
Temperature	56° F
Dew Point	34° F
Humidity	44%
Pressure	28.7 in
Wind Dir.	WSW
Wind Speed	12 mph
Wind Gust Speed	21 mph
Precipitation	N/A
Events	N/A
Conditions	N/A

5.3. Illumination

According to the United States Naval Observatory, for March 18, civil twilight occurred at 06:09 a.m. and 7:03 p.m. Sunrise occurred at 6:34 a.m., and sunset at 6:38 p.m.

6. List of Attachments

Human Performance Attachment - Arizona Adjudication Criteria

Human Performance Attachment - Uber ATG Vehicle Operator Interview

Human Performance attachment – Vehicle operator mobile phone records

Human Performance Attachment – Uber ATG mobile phone and driving time policies

Human Performance Attachment - Uber ATG Mobile Device Policy infractions

Human Performance Attachment – Uber ATG vehicle operator hand and foot hovering procedures

Human Performance Attachment -Uber ATG Vehicle Operator Duties

END OF INFORMATION

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