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Safety Research Unit

Olgu Sunumu | Case Study

One of the First Fatalities of a Self-Driving Car: Root Cause Analysis of the 2016 Tesla Model S 70D Crash

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Abstract

The recent technological developments have increased the prevalence of automated vehicles and vehicles with Advanced Driver Assistance Systems (ADAS) within the roadway traffic. Consequently, different safety-critical concerns rise for the usage of self-driving vehicles. The present study has investigated a crash between a semi-trailer of a Freightliner Truck and an SAE Level 2 automated Tesla Car. Operated during the autopilot mode engaged, the 40-year-old Tesla Driver hit and traveled under the mid aspect of the semi-trailer without taking any evasive actions prior to the crash and instantly deceased after the initial impact. The contributory factors of Human Error and Equipment Failure have been analyzed using specific tools of the root cause analysis: Five Whys Technique and Barrier Analysis respectively. The analysis has emphasized the importance of situational awareness while driving automated vehicles and showed that safety barrier features of ADAS may fail and should not be over-relied. The potential reasons to over-rely automated systems were discussed, and recommendations that target the safety of automated vehicle drivers have been made.

Keywords: root cause analysis, automated vehicle, case analysis, ADAS, Tesla Model S 70D

Sürücüsüz Araçların İlk Ölümlü Kazalarından Biri: 2016 Tesla S 70D Kazasının Kök Neden Analizi

Öz

Son teknolojik gelişmeler, sürücüsüz araçların ve Gelişmiş Sürücü Destek Sistemleri (ADAS) bulunan araçların karayolu trafiğindeki yaygınlığını artırmıştır. Bunun bir sonucu olarak, sürücüsüz araçların kullanımı için güvenlik açısından kritik endişeler ortaya çıkmaktadır. Bu çalışma, bir TIR kamyonunun römorku ile SAE 2. Seviye otonom Tesla Arabası arasındaki bir çarpışmayı ele almıştır. Oto pilot fonksiyonuyla seyir halinde olan 40 yaşındaki Tesla sürücüsü, çarpışmadan önce herhangi bir kaçınma hareketi yapmadan römorkun orta kısmına tüm hızıyla çarparak römorkun altından geçmiş ve ilk çarpmanın etkisiyle yaşamını yitirmiştir. Kazaya sebebiyet veren İnsan Hatası ve Ekipman Arızası faktörleri, kök neden analizinin belirli araçları kullanılarak analiz edilmiştir. Bunlar sırasıyla Beş Neden Tekniği ve Bariyer Analizidir. Gerçekleştirilen bu analizler, sürücüsüz araçları kullanırken durumsal farkındalığın önemini vurgulamış, ADAS'ın güvenlik bariyeri fonksiyonlarının başarısız olabileceğini ve bu sistemlere gereğinden fazla güvenilmemesi gerektiğini göstermiştir. Sürücüsüz sistemlere aşırı güvenmenin olası nedenleri tartışılmış ve otomatikleştirilmiş araç sürücülerinin güvenliğini hedefleyen önerilerde bulunulmuştur.

Anahtar Kelimeler: kök neden analizi, sürücüsüz araç, vaka analizi, ADAS, Tesla Model S 70D

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One of the First Fatalities of a Self-Driving Car: Root Cause Analysis of the 2016 Tesla Model S 70D Crash

The recent technological developments regarding private vehicles have subsided the human involvement in the driving process, especially with safety-critical control functions such as steering the vehicle or keeping in the lane positioning (NHTSA, 2013). These private vehicles, labeled as autonomous vehicles in general, have been argued to be effective for reducing crashes that are associated with human distraction by some scholars like Fitch, Bowman and Llaneras (2014). Figure 1 depicts the levels of automated cars and explain each level’s main functions, according to Society of Automotive Engineers (SAE, 2016). While self-driving vehicle technology is still advancing, fully autonomous, self-driving cars, which are labeled as Level 4 and Level 5 cars are still not expected to be on the roads until the 2030s (Martínez-Díaz & Soriguera, 2018). Therefore, until the release of autonomous vehicles that do not need any driver input or environment monitoring, automated vehicles that rely on the attention and situational awareness of the human driver (i.e., SAE Level 2 Car) would still be dominant in the highway traffic and transportation system.

Despite the argument that automated cars will promote safety through assistance systems such as side collision warning (SCW) or blind spot detection; interaction of such systems with a human driver does not necessarily guarantee safety. The main reason is that these assistance systems aim at reducing the cognitive load of the driver, which is argued to be just as dangerous as a cognitive overload whilst driving (Johns, Sibi, & Ju, 2014). Therefore, it is important to remark on the significance of driver’s engagement to automated vehicles; so that any unsafe scenario that is caused by a decrement of the vigilance related to cognitive underload could be prevented. A recent paper by McWilliams and Ward (2021) has discussed this issue in detail and emphasized the potential dangers of such cognitive underload can instigate, especially within the domain of automated vehicles. The authors discussed that when engaged in partially automated driving of automated vehicles, the main task of the driver is to monitor the environment to react in response to potential dangers. However, environment monitoring is an undemanding task that requires continuous attention. The monotonous nature of the task, along with the absence of arousal leads drivers to experience cognitive underload. In turn, the cognitive underload instigates drivers to disengage from the driving process and result them to react poorly towards safety-critical emergencies. Therefore, the automated driving assistance features of the automated vehicles can indirectly prevent drivers to detect and react towards hazards, since these assistance features potentially generate cognitive underload for the driver.

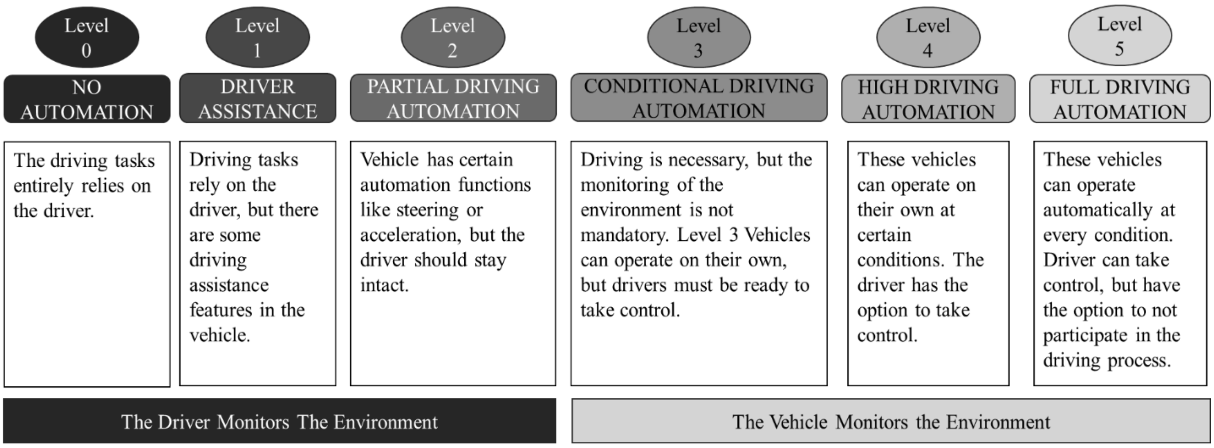

Figure 1. Levels of Automated Cars according to SAE International Standard J3016

Currently, the traffic and transportation system in developed countries has engaged in a transitional period where drivers started to rely more and more on automated vehicles (Reimer, 2014). However, even the highest-level automated vehicle that reduces the driving tasks and cognitive loadings of the driver still relies on the situational awareness and attentiveness of the driver to a degree, especially under safety-critical situations. Therefore, until the era in which fully autonomous, safety-proven cars that do not need any driver input become prevalent, there exists a critical safety problem in this transitional period. A safety problem concerns the lack of situational awareness of drivers due to their cognitive underload.

In this line, the main aim of the present study is to emphasize this existing safety issue through a root cause analysis of an exemplary case. Specifically, the crash in which a Tesla Model S70D car crashed into the semi-trailer of a truck during autopilot will be investigated using two of the root cause analysis toolkits. The scope of the present study is defined so to investigate the main reason as to why did an automated vehicle (i.e., SAE Level 2) involved in a fatal accident. The specific root cause analysis toolkits that are used in this study, namely Five Whys Technique and Barrier Analysis, were selected to reach this end. In simple terms, these analyses present and discuss the main contributors of the accidents for the purpose of revealing the main cause, or in other words the root cause of the crash. This specific crash is critical in the sense that it is one of the first examples of a self-driving vehicle's crash in which a fatality occurs. All the details and information regarding the crash have been retrieved from NHTSA's Special Crash Investigation (SCI) Report (Crash Research & Analysis, Inc., 2018). The following sections will address how the crash took place, investigate the root causes of the crash through the Five Whys Technique and Barrier Analysis technique, and emphasize the potential reasons for the occurrence of the crash.

1.1. The Crash

On May 7, 2016, a driver that operated his Tesla Model S70D using Advanced Driving Assistance System (ADAS) was involved in an underride crash with a semi-trailer that was pulled by a 2014 Freightliner Truck. The crash happened when the Freightliner Truck was attempting to turn left across the travel path of the Tesla. Tesla driver's car traveled under the mid-aspect of the semi-trailer completely, departed from the roadway, and hit other objects before coming to a final rest. The 40-year-old belted male driver of the Tesla received fatal head injuries and pronounced deceased at the crash site. Figure 2 depict the state of the Tesla vehicle at the time when SCI units investigated the crash. The driver of the Freightliner Truck did not receive any injuries during the incident.

Figure 2. Left Front Oblique View (Left) and Left Plane View (Right) of the Tesla at the Time of Investigation (Source: Crash Research & Analysis, Inc., 2018)

The crash occurred within a four-legged intersection in an east/west divided roadway. The weather was clear and the crash took place in the afternoon. The asphalt roadway was dry and the eastbound of the roadway consisted of two lanes. A two-way local roadway-oriented north/south has divided the roadway. A median crossover has supported the intersection. The speed limit of the roadway was 105 km/h (65 m/ph). Prior to the crash, the driver of Tesla was traveling through the right lane of the eastbound roadway and the Freightliner Truck was traveling across the left lane of the westbound roadway, before turning towards the intersection. The sight of the roadway both in perspectives from the Freightliner Truck and the Tesla driver have been provided in Figure 3.

As stated previously, the Tesla driver was using ADAS before the crash took place. Specifically, the driver was traveling with cruise control that is engaged in 119 km/h (73.95 mph). The results of the investigation suggested that the Tesla driver did not make any attempt to avoid the crash, as there was not any brake trail within the crash site, nor any evidence for steering. In other words, the Tesla hit directly to the mid aspect of the semi-trailer, with the full speed that vehicle's cruise control engaged in. The visibility investigation of SCI concluded that visibility was clear both for the Freightliner Truck and the Tesla alike. According to the results of the visibility investigation, the driver of Tesla had approximately 7.25 seconds before reacting to the Freightliner Truck that departed in his travel way, which provides evidence that the driver was distracted right before the crash occurred. Although there was an allegation that the Tesla driver was watching entertainment videos before the crash took place, the investigation of the electronic devices within the Tesla did not provide any conclusive evidence regarding this allegation. For a complete diagram of the primary impact crash and subsequent impact crash, please see Figure 4 and Figure 5.

Figure 3. The Sight of the Roadway from the Perspective of the Freightliner Truck (Left) and of the Tesla (Right) Just Before Turning Left (Source: Crash Research & Analysis, Inc., 2018)

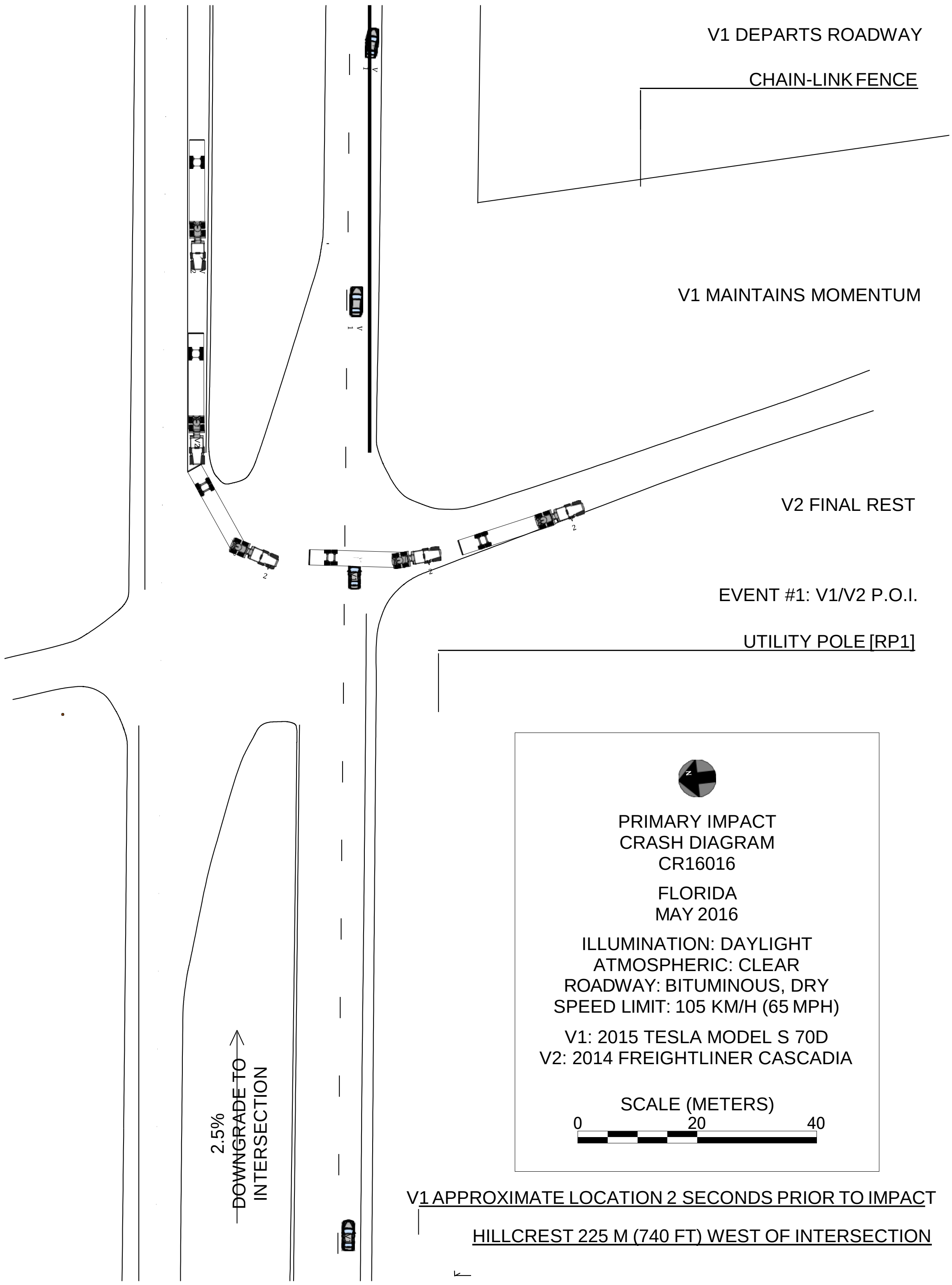

Figure 4. Primary Impact Crash Diagram (Source: Crash Research & Analysis, Inc., 2018)

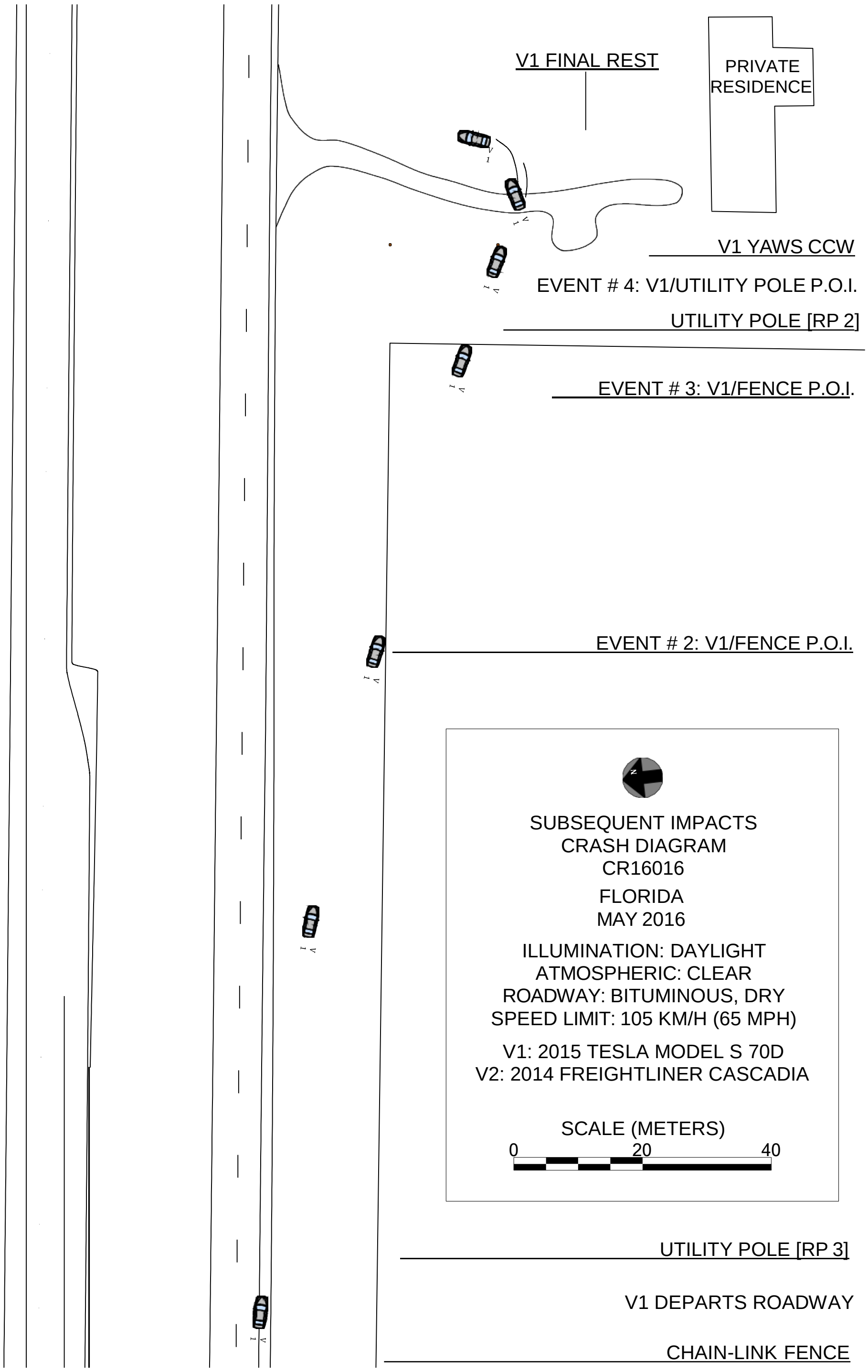

Figure 5. Subsequent Impacts Crash Diagram (Source: Crash Research & Analysis, Inc., 2018)

Overall, the environmental cues of the incident suggest that human error was the central cause of this incident. On the other hand, it is important to note that the driver of Tesla was traveling with the auto steer and Traffic-Aware Cruise Control (TACC) system activated. This suggests an over-reliance on the automated system of Tesla on behalf of the driver. The limitations of emergency safety systems such as Forward Collision Warning (FCW) or Automatic Energy Braking (AEB) could also be discernable in this specific crash. This point was also referred to within the SCI report of the crash, as ADAS is discussed to be failed in this specific incident due to the “overall physical characteristics of the road” and the “cross-path configuration of the involved vehicles’ trajectories” (Crash Research & Analysis, Inc., 2018, *p*. 2). As such, assuming that the crash is based on the Tesla driver's unintentional actions, the decrement of vigilance and lack of situational awareness have mainly contributed to the occurrence and fatality of this crash; both of which could be associated with the over-reliance of ADAS in the Tesla.

2. Root Cause Analysis of the Crash

The extensive report of the Crash Research & Analysis, Inc. (2018) has provided insights and pieces of evidence regarding the environment in which the crash occurred; the possible human errors that took place; and lastly, equipment and assistance system failures. These insights are important in the sense that they build up and describe the framework of the crash. In addition to this framework, further analysis of all the contributory factors using root cause analysis toolkits would provide a wide-scale picture of the crash along with the safety-critical points that should be emphasized.

There are two main enigmas for this crash. Firstly, the Tesla driver did not make any attempt to avoid the crash. Despite there exists an allegation that the driver was distracted by watching a video and the visibility test providing evidence for the driver's distraction before the crash, there is no definitive conclusion with respect to a lack of situational awareness on behalf of the driver. As the driver himself has been pronounced to be deceased, there is no way to reach a certain conclusion regarding the behavior of the Tesla driver right before the crash.

The second aspect is the failure of ADAS, particularly FCW and AEB. These two specific systems detect the moving objects/vehicles with the help of sensors, cameras, and radars that the vehicle possesses. Based on the data logs of Tesla, the ADAS was functional before the crash. Despite they did not respond to the imminent danger, the SCI unit could not find any performance anomalies. Based on this anomaly, the SCI report suggested that the characteristics of the road and cross-path configuration of the relevant vehicles' trajectories could have caused these systems to fail, although there is not a definitive conclusion regarding this incident.

Aside from the Freightliner Truck driver's failure to yield the right of way to the Tesla driver, the causes of the crash revolve around these two aspects. Therefore, a root cause analysis that targets these two aspects, namely human error and equipment failure aspects, would provide further safety-related insights regarding this crash.

2.1. Root Cause Analysis from the Perspective of Human Error

One of the appropriate tool kits of root cause analysis to deeply question the specific causes and symptoms that lead to an incident is the "Five Whys Technique". To put it briefly, the Five Whys Technique's main purpose is to constantly ask the question of "Why" through various layers of cause, which results in the progression of the true root cause of the incident (Ammerman, 1998). When using the Five Whys Technique, it is important to identify the starting point of the analysis. In this specific analysis, the obvious problem is the crash that occurred between a Tesla driver and Freightliner Truck Driver. Therefore, a chart that centralizes this problem and proceeds on asking the question "why" has been provided in Figure 6.

The utilization of the Five Whys Technique on this specific crash eventually emphasizes the point that the Tesla driver was not aware of the danger that disengagement from the vehicle and over-reliance upon ADAS potentially brings. Lack of braking trails and signs of steering on behalf of the Tesla driver suggests that the driver was either fully unaware of the danger or became aware of the situation too late to react.

The next section has investigated the root cause of the crash by investigating the equipment of the Tesla vehicle. Specifically, the equipment failures are identified through the utilization of the Barrier Analysis Technique.

The Tesla and Freightliner Truck have crashed at the intersection, whilst the truck was joining the road by taking a left.

1. Why did the crash occur? Because the driver of the Tesla did not attempt to avoid the crash and hit the semi-trailer directly.

2. Why did the Tesla driver hit the semi-trailer without attempting to avoid? Because the driver failed to see the truck despite clear and unobstructed view on the road and sufficient time to react.

3. Why did the driver failed to see the truck despite clear visibility? Because the driver was **distracted** and lacked situational awareness before the crash occurred.

4. Why did the driver lack situational awareness before crash? Because the auto steering and TACC systems have subsided the driver input necessary for traveling, which resulted with cognitive underload and over-reliance on ADAS.

5. Why did the driver over-relied to ADAS? Because the driver was not sufficiently informed or be aware about the limitations and potential failures of ADAS, which resulted with the low-risk perception during driving.

Figure 6. The Five-Whys Analysis of the Crash between Tesla and Freightliner Truck

2.2. Root Cause Analysis from the Perspective of Equipment Failure

Every adequate system that holds potentially harmful consequences towards vulnerable individuals and objects possesses safety barriers that aim to prevent fatalities and reduce injuries. These safety barriers can sometimes malfunction or be insufficient to resist the potential dangers that the users of the system can potentially face. In such cases, when these dangerous incidents result in a crash or a near miss, a specific toolkit of the root cause analysis, namely barrier analysis, can emphasize which barriers have failed to prevent the occurrence of the incident. Developed by Trost and Nertey (1985), safety barriers have four categories: physical barriers, natural barriers, human action barriers, and administrative barriers. Among these categories, the physical barriers are the most effective barrier type since they aim at preventing the potential hazard directly. Human action barriers and administrative barriers, on the other hand, can be ineffective as they are under the direct influence of human errors and violations. For this study, the safety barriers that should have functioned were identified first. Then these barriers were interpreted and categorized according to the Trost and Nertey's (1985) barrier categories. The summary and groupings of the barriers that are related to this crash could be found in Table 1.

Table 1. ***The Physical, Natural, Human Action and Administrative Barriers That Are Related to the Crash***

Physical Barriers	Natural Barriers	Human Action Barriers	Administrative Barriers
Automated Energy Braking	FCW	Steering or Braking	Speed Limit of 105 km/h (65 mph)
	Driver Disengagement Warning	Controlling the Wheel	
		Maintaining Situational Awareness	

Among the determined barriers, all of them have failed to prevent the crash or even reduce its harmful consequences, which resulted in the worst possible outcome. The list of barriers that have failed and the reason for its failure along with their impact on the crash have been presented in Table 2. Specifically, the first barrier that was involved to avoid the harmful consequences of traffic crashes is the speed limit of the roadway, which was an administrative barrier. At the specific roadway in which the crash took place, the speed limit was 105 km/h (65 mph). This administrative barrier could be considered to be failed since the driver of the Tesla vehicle has determined the vehicle's cruise control speed as 119 km/h (73.95 mph), which is over the speed limit.

While the Tesla driver was excessing the speed limit, the SCI report suggests that he had sufficient time to react to the Freightliner Truck that departed in his travel way (i.e., approximately 7-8 seconds). Based on this evidence, it could be suggested that the Tesla driver has over-relied upon the autonomous features of his vehicle, which led to a deficiency in terms of the driver's situational awareness. Therefore, one of the most important barriers to avoiding the crash, *Maintaining Situational Awareness* during driving, could be argued to be failed, although a definitive conclusion could not be made. Another important barrier is the Driver Disengagement Warning. Within this model of Tesla, the manufacturer has introduced a natural barrier that visually warns the driver when drivers are not putting their hands on the wheel for drivers to takeover the vehicle's control. If the driver continues disengagement, the system will release an auditory warning to takeover, a second audial warning after a certain amount of time, and slow down the vehicle if the takeover still does not take place. The investigation over the autopilot system suggests that the Tesla driver did receive visual and auditory warnings during his trip. However, the data received from the autopilot system suggests that the driver did not receive any warning for disengagement, or a request to takeover 4-5 minutes before the crash took place (Poland, McKay, Bruce, & Becic, 2018). Therefore, the barrier of *Driver Disengagement Warning* has failed to notify the driver over his disengagement. For an in-depth analysis of the autopilot system failures in this crash, please see Poland et al. (2018).

The failure of the Driver Disengagement Warning barrier has led to the natural failure of the other important human action barrier, *Controlling the Wheel*. The evidence regarding the lack of evasive actions suggests that this specific human action barrier has failed, although a definitive conclusion regarding the success of this barrier could not be made. Another barrier that failed at the critical moment when Tesla closed into the Freightliner Truck is the *Forward Collision Warning* (FCW). The Tesla Model S 70D possessed this collision-avoiding safety barrier, which was designed to detect any potential danger or possibility of a crash along the travel pathway using sensors and radars. However, during this specific incident, the FCW have failed to detect the danger coming from the semi-trailer of Freightliner Truck and did not show any warning regarding the potential crash.

Table 2. ***The Barriers of the Crash, the End Result of the Barrier and the Reason for Failure***

What barriers/defenses or controls were in place?	Did the barrier/defense or control work?	Why did the barrier/defense or control fail and what was its impact?
Speed Limit of 105 km/h (65 mph)	No	Because the Tesla driver violated the speed limit and it increased the fatality of the crash.
Driver Disengagement Warning	No	Because sufficient time did not pass for another warning to occur, resulting in the driver to be disengaged with the wheel.
Maintaining Situational Awareness	No	The evidence suggested that driver has little to no situational awareness, due to over-reliance upon ADAS. It prevented the driver to see the Freightliner Truck despite clear visibility.
FCW	No	The system did not work due to “overall physical characteristics of the road” and the “cross-path configuration of the involved vehicles’ trajectories”. The Tesla driver could not be notified regarding the Freightliner Truck on the travel way.
Controlling the Wheel	No	The evidence suggested that driver has no control over the wheel, due to an over-reliance on ADAS. It prevented the Tesla driver to avoid the Freightliner Truck on its travel way.
AEB	No	The system did not work due to “overall physical characteristics of the road” and the “cross-path configuration of the involved vehicles’ trajectories”. The vehicle did not apply any brake and hit directly to the semi-trailer, receiving the impact to its full extent.
Steering or Braking	No	The Tesla driver did not make any attempt to avoid the crash through steering or braking due to a lack of situational awareness, preventing him to avoid the crash.

Just before the exact moment in which the crash occurred, two significant barrier failures are salient, both of which may have reduced the impact of the crash, if not avoided it completely. The first barrier is a human action barrier: *Steering or Braking*. The SCI report has repeatedly emphasized that there was not any evasive action taken by the driver of the Tesla, and the driver hit directly the semi-trailer, with its full cruise control speed. Essentially, failures of other human action barriers, *Maintaining Situational Awareness,* and *Controlling the Wheel* have led to the failure of this final human action barrier. Finally, the last barrier stands as the only physical barrier of this crash, which is the *Automated Energy Braking* (AEB). The AEB system was a specific feature of ADAS that is designed to implement an automated brake when the collision is imminent. However, in this crash, this vital physical barrier has failed to get activated, which resulted in the horrific result.

Figure 7 depicts how the potential danger overcame each and every barrier and lead to the crash. The potential reasons for the failure of barriers were presented in Table 2.

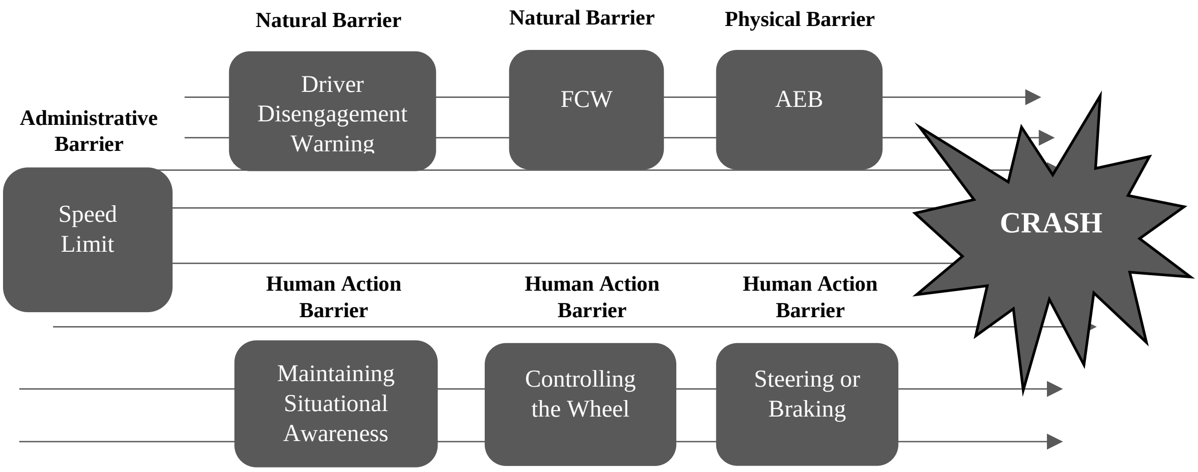

Figure 7. The Failed Barriers of the Crash, Aligned according to Their Chronological Relevance

3. Discussion & Conclusion

Overall, this study has aimed to apply the specific toolkits of the root cause analysis to the crash that occurred between the Tesla Model S 70D and the semi-trailer of a Freightliner Truck. The purpose of the application of root cause analysis to this crash is twofold: First is to establish an in-depth analysis of this exemplary crash based on the extensive report that Crash Research & Analysis, Inc. (2018) has provided. The second was to emphasize the potential equipment failures and potential contributory human errors that lead to fatality in which driving a Level 2 Automated car at the autopilot mode may bring.

As discussed previously, the incident at hand has two major contributory factors that led to its fatality: Human Error and Equipment Failure. In order to investigate the Human Error component thoroughly, a Five Whys Analysis that asks the prior question of "Why did the Freightliner Truck and the Tesla have crashed at the intersection?" has been conducted. Based on the questions and answers, the analysis has determined that the root cause of this crash is the lack of information or awareness of the Tesla driver, regarding the limitations and failures of the ADAS, as well as potential risks of over-relying on autopilot systems. If the driver has been informed better on the limitations of the autopilot feature in terms of safety, he would have been more alert prior to the crash and be situationally aware of the upcoming danger. Therefore, both the manufacturers and state campaigns of automated vehicles should focus on increasing the awareness of people who drive automated vehicles, so that they will not decrement their vigilance due to cognitive underload.

To investigate the role of equipment failure and human-equipment interaction, a safety barrier analysis has been conducted. Based on the analysis, one administrative barrier (i.e., Speed Limit), two natural barriers (i.e., Driver Disengagement Warning and FCW), three human action barriers (i.e., Maintaining Situational Awareness, Controlling the Wheel and Steering or Braking), and finally one physical barrier (i.e., Automated Emergency Brake) have been identified. The analysis has determined that each and every barrier has failed, which led to the worst possible outcome in terms of the fatality of the crash. The analysis essentially shows how human driver input is significant when driving an automated vehicle, especially in terms of suspending the effects of potential equipment failures. In addition, it showed how Driver Disengagement Warning is not a solid safety barrier that guarantees takeover (Poland et al., 2018). The manufacturers of automated vehicles should provide a more reliable barrier that results in a takeover when using ADAS. As a result, until the era in which fully automated vehicles with confirmed safety standards to be released, Level 2 automated drivers must be vigilant and be situationally aware whilst using ADAS, and manufacturers should focus on technological advancements for natural and physical barriers to function under every specific circumstance.

The current root cause analysis that took place in this study is essentially based on the potential risks that over-relying on the automated features of a Level 2 car may bring to the driver. Level 2 is an important transitionary level in which the vehicle monitors the driving environment but still relies on the situational awareness of the driver for safety. In this line, this root cause analysis of this specific case emphasizes the risks of treating Level 2 automated cars as Level 4 or Level 5 vehicles. Considering that Level 4 and Level 5 automated vehicles aim to eliminate human factor in driving operation all together, the automated driving systems should be assured to function under most of the circumstances, especially under safety critical ones. Therefore, the Barrier Analysis that is conducted in this study potentially suggests that the safety barriers that are related to human factors (e.g., S*teering or Braking*) may be absent altogether within the future technologies, which increases the importance of proper functioning of the equipment barriers (e.g., FCW). On the other hand, the Five Whys Analysis for this specific case emphasizes another point that the human driver should be thoroughly informed and be aware of the circumstances in which driving assistance systems can properly function for future technologies.

With the recent advancements in automated vehicle technologies, more and more studies have started to focus on the safety concerns of these automated vehicles (Tafidis, Farah, Brijs, & Pirdavani, 2022). In line with the suggestions of the current study Rukonic, Mwange and Kieffer (2022). have suggested a method to educate drivers with knowledge of ADAS. Another study by Peiris, Newstead, Berecki-Gisolf, Chen and Fildes (2022) discussed how the incompatibility of the road structure with ADAS technologies contributes to the crash rate of the automated vehicles, therefore shadowing the potential safety benefits that ADAS can bring. The current case analysis could also be an example of this situation, as the ADAS system have failed to avoid the crash despite it was functional prior to the crash. A scoping review by Tafidis et al. (2022) discussed that the literature regarding the safety outcomes of automated vehicles are just started to accumulate after 2014. In addition, the existing studies that expects the contribution of the automated technologies to the road safety are not based on real data, but rather on assumptions over the features of the ADAS. Therefore, the comparison of road-safety outcomes between automated driving vehicles (e.g., SAE Level 3 Car) and manual driving vehicles (e.g., SAE Level 0 Car) is still unclear since the research on safety of automated vehicles is still relatively new. Finally, a study by Jenssen, Moen and Johnsen (2019) have argued the safety performance of automated drivers, and presented cases of fatalities (including the current case) related to automated vehicles. The study even reported a pedestrian fatality caused by a SAE Level 3 Uber vehicle, and discussed that automated vehicles need to possess a better "sense of self" that is similar to humans, or else fatalities caused by automated vehicles will only increase. Overall, these studies and reports show how vital it is to receive and interpret data that are related to automated vehicle safety performances or crash statistics. The researchers can only reach towards reliable safety related conclusions regarding the interplay between human factors and automated vehicles, if the data is transparent enough to analyze and interpret.

It is important to note that the results of the root cause analysis of this specific case are, by no means generalizable to other cases, although the main emphasis of the study is valid for most automated vehicles. Rather, this study should be considered as an analysis of a specific case that qualifies as an example for one of the first fatalities that occur within an automated vehicle. On the other hand, the results of the Barrier Analysis that is conducted within this study depend on the interpretation of the researcher. Although Barrier Analysis presents the main categories, the researcher is the one who identifies and categorizes the barriers. In other words, different researchers from different fields could identify different barriers under the categories the Barrier Analysis suggests. Lastly, specific to this case, the deceased status of the Tesla driver has made it difficult to reach definitive conclusions regarding the actions that the driver has engaged in before the crash. Therefore, certain components that are included in this study's root cause analysis (e.g., failure of *Maintaining Situational Awareness*) have been based upon the evidence that the SCI report has provided, although they are not definitive in nature.

To conclude, this specific case analysis has emphasized how important for Level 2 Automated Vehicle Drivers to be vigilant and situationally aware when driving in the Autopilot mode. Case analyses like this crash points out that the developments in automation technologies do not necessarily eliminate human factors in crash involvement. On the contrary, certain human factors like situation awareness and cognitive load gain even further importance within the crashes that involve automated systems. In line with this, the root cause analysis of this specific crash showed that over-reliance upon the assistance systems that automated vehicles provide can bring fatal consequences. Rather, these assistance systems should be backed up with the human drivers' situational awareness and vigilance, as the safety barriers that these systems provide might fail at any given moment.

Ethics Committee Approval Statement

Ethics committee approval is not required since data was not collected from human or animal participants in the relevant study.

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