Analyzing Automation Failures in the Aviation Industry

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

As businesses grow to meet higher consumer demands, managers are always looking to either decrease costs of production or increase production efficiency, thus saving time and increasing output and profits (Gilkey, 2010). When Henry Ford revolutionized the manufacturing industry with his automation of the assembly line, a spark was ignited in industries all over the world. Businesses soon realized that machines could take over repetitive tasks that were primarily conducted by unskilled workers. Automated machines grew in popularity as they require a one-time cost of installation with routine maintenance along with no training costs that are necessary with human workers. It began with simple machines that were essentially automated electric drills used by large-scale manufacturers on their assembly lines. Automation has since evolved into complicated machines that can assemble tiny silicon chips that power smartphones and software that can use tools to perform medical surgeries (Edwards, 2021).

The rise of automation has not come without controversies. Ever since the first jobs were replaced by machines, there has been growing concern about future rises in unemployment due to automation. Over the past few decades, these concerns have been answered by pointing out that automation has only taken over unskilled labor and that it has in effect created new avenues for employment in research and development. However, as automated technology evolves further, there is genuine evidence that a large portion of jobs will be lost to machines. Driving trucks is the most common occupation in 29 out of the 50 states in the United States (Bui, 2015). There is an unprecedented amount of research being conducted on autonomous driving that could potentially wipe out the entire occupation (Shepardson & Jin, 2022).

As automation grows more popular, businesses begin to explore where they could reduce costs even within automated machines. Labor shortages around the world caused by the

COVID-19 pandemic have caused a global push toward investments in automated machines (Deczynski, 2021). With increased research into automated technology coupled with ever-increasing demand, there appears to be a widespread belief that simply introducing automation into an environment will speed up targeted processes and produce output faster. This approach to automated technology ignores the fact that there are rarely any examples of factories or workplaces with identical processes. Even factories that produce the same output have small differences that must be considered when designing automated machines. Employing machines without considering the environment they will be operating is considered an improper implementation. Improper implementations of automation, such as that in the Boeing 737 MAX aircraft, can not only lead to future costs for better implementation but could lead to disastrous results. It can be very beneficial to study the compatibility of a piece of technology with the environment it will serve. The research will focus on analyzing real-life cases where automation failed to achieve its intended purpose and led to costly and sometimes fatal results.

Breaking Down the Characteristics of Infrastructure

With the rise of technology, specifically autonomous software and machinery, there has been much discussion about how it can help businesses increase output while lowering production costs (Assembly Automation, 2009). However, much of the talk about automation glosses over the importance of the design and implementation of automation in a workplace. To study the properties of automation, this paper will view automation as a form of infrastructure. *The Ethnography of Infrastructure* by Susan Leigh Star provides nine characteristics of infrastructure that can be used to study how effective a piece of infrastructure is in performing its intended job and enhancing its environment (Star, 1999). This paper will concern itself with four of the most important characteristics that pertain to automation: (1) embeddedness, (2) links with conventions of practice, (3) embodiment of standards, and (4) visible when broken.

Embeddedness is the property of technology where it is sunk into other structures or the overall process of production, such that there are no distinguishing subcomponents of the technology. It can be described as one large system. This would allow the automation technology to conform itself seamlessly to the environment that it has been injected into (Sheridan, Vámos, & Aida, 1983). Designing automation technology to fit into a production process not only speeds up production but also reduces or eliminates the costs of refitting the surrounding factors to adjust to the new addition. In general, the benefits of customizing automation technology outweigh the costs of going that extra step. Having links to conventional practice is a similar idea to embeddedness where the technology emulates the societal or technical norms. Essentially, the same process is followed but it is now automated. Following conventional practice ensures that there is transparency in the system. Even though the process is automated, the people working alongside it and the supervisors overseeing it still know what the machinery is doing under the hood. The only difference is that the software will now be performing those tasks and the stakeholders will know the inner workings of that process. Sticking to the convention also reduces the time and other resources spent on training the employees in operating and working alongside the automation technology. Deviating from set routines can be especially difficult to adjust for older workers, who can get caught in a digital divide and may be viewed as underperforming when it is automation that gets in the way of them carrying out their tasks (Jæger, 2004). Embeddedness and links to convention allow for the smooth integration of automation into a system of operations.

The embodiment of standards refers to having technology follow certain standards that have already been put in place by society. Infrastructure functions best when it aligns with scientific standards, such as measurement units depending on the location, or aesthetic and functionality standards, such as the positioning of knobs and levers. In 1999, the Mars Climate Orbiter launched by NASA crashed into Mars because the altitude control system was designed with imperial measurements while the navigation system was designed using metric units (Harish, 2021). This catastrophe that cost NASA $125 million could have been avoided if the entire project used scientific standards for measurement. Star also argues that infrastructure becomes visible when it breaks down. When it is fully operational, it works in the background transparently but sticks out during outages. This characteristic may have a negative connotation but in fact, it is beneficial for the stakeholders. If a piece of technology, especially software, breaks down but does not have the ability to inform its surroundings, the technology might run with a fault without anyone noticing. Its ability to become visible allows the operators to figure out the issue and make the repairs as fast as possible. If the previous three characteristics are also part of the technology, it will be easy to find the fault due to the implemented transparency in the system. Following standards and ensuring visibility upon failures minimizes outage times when technology inevitably breaks down at some point.

Choosing not to implement the aforementioned characteristics of infrastructure can lead to delays in the adoption of the technology and failures in the overall process. The notion that the introduction of more technology will solve any problem in question is outdated and it is apparent that implementation is important for successful results. This becomes more important in high-stakes industries such as the healthcare industry where poor implementation can lead to negative unintended consequences (Harrison, Koppel, & Bar-Lev, 2007). The four characteristics expressed by Star clearly explain why injecting automation into a process is not simply a plug-and-chug problem and requires deep insight into the environment being manipulated.

Case Context

When the Wright brothers performed the first successful airplane flight, it was believed to be the pinnacle of human achievement but that flight was only the beginning. In the coming years, engineers kept adding new upgrades, such as altimeters and anemometers, to the airplane making it increasingly easier for pilots to maneuver the high skies (Little, 2019). With the rising demand for commercial flights in the 1950s, there was a serious need for automation technology that could assist pilots during long flights across oceans. The demand was especially heightened by a series of crashes in the 1960s caused due to pilots losing control of the aircraft due to speeding over the limit, stalling, and excessive bank angles. Automation technology began with simple mechanical devices such as compasses and gauges and evolved into electrical devices that could give pilots information about fuel consumption and estimated times to the final destination (Chialastri, 2012). The most recent evolution of automation in aviation is decision-making software that can process the input from environmental variables and make real-time decisions that impact how the aircraft is operating (Noyes, 2017). This greatly reduced room for human error as the automated system can make calculated decisions without any human biases and pilots are only required to take control when the autopilot system fails and airplanes must be directed manually.

After airline companies realized the benefits of automation in aviation, they welcomed it with open arms. Older airplanes utilized cables that ran from the cockpit to the wings of the airplane, which would move as the pilot manually moved a steering stick in the cockpit. With newer aircraft, there is a computer that registers the pilot’s steering and conveys those instructions to a computer near the wings of the plane, that moves the wings accordingly. The reduction of hundreds of pounds of cables from the aircraft saves airlines millions of dollars in fuel consumption (Holloway, 2017). Automation technology also helps stabilize the airplane such that it stays optimally placed in a jet stream to use as little fuel as necessary to stay on course. With easier controls and the aircraft being able to control itself for a significant amount of flight time, airlines are able to certify and hire pilots faster compared to hiring pilots that would fly the planes manually.

These advantages have led to extraordinarily quick adoption of automation into the aviation industry but they have also brought along some issues that accompany utilizing machines to reduce costs. One of the main concerns with automation is the overwhelming amount of information that is being processed by the automation system. An image of the modern airplane cockpit would clearly show the hundreds of gauges and buttons that are at the pilots' disposal. These may not be an issue when the system is operational but during emergency situations, there is simply too much on the dashboard for pilots to manage (Dave, 2011). Heavy reliance on the autopilot leading to quicker certifications for pilots can be catastrophic if the system were to fail. Another issue is the overreliance on the autopilot system which leaves too many points of failure in the system. As the number of planes in the air increases, there are more parameters that need to be accounted for. If the autopilot controls almost every aspect of the flight, its failure could be too overwhelming for the pilots to recover from (Funk & Lyall, 2000). This also leads to complacency with pilots delegating work to autopilot and losing the skills required to act during emergencies. Furthermore, there is a disparity between the engineers who design autopilot systems and the pilots. Pilots' opinions are rarely asked for when designing the automation which can lead to problems if the system does not conform to general procedures that pilots follow (Turner, 2017).

Research Questions and Methods

The issues addressed above will be explored by asking the question: Why do airplanes crash even with reliable automation technology onboard and how these failures could have been avoided? The research will be performed through case studies of events when the failure of autopilot aboard the flight was cited as the primary reason for a crash or an emergency situation. Information will be gathered primarily through investigation reports and new articles that performed a thorough analysis of the crashes and provided a detailed summary. The cases to be studied will be the two Boeing 737 MAX crashes, Air France Flight 447 crashing, the crash of First Air Flight 6500, and the crash of Turkish Airlines Flight 1951. This research considers automation as a piece of infrastructure aboard the aircraft. In searching for possible solutions and ways to avoid these failures, the case studies will try to identify where Star's characteristics of infrastructure can be applied to the automated technology to improve the technology or help the pilots avoid emergencies. Each of these cases will be studied by asking the following questions:

1. What is the context surrounding the airplane, airlines, and the automation aboard the airplane?
2. What was the technical issue or bug that caused the crash?
3. How did the pilots onboard the aircraft react to the situation?
4. What was the end result of the incident?
5. How do Star's characteristics of infrastructure be applied to the case?

Each case study will also provide a suggestion for how the automation technology could be improved and how the crash may have been avoided.

Results

Airplanes in the air today are marvels of human engineering and when their design is dissected into individual systems, one can realize how complex the process of making humans fly can be. It has become glaringly evident that it is the complexity of these airplanes that makes it so difficult to find a single point of failure that led to the crash. Every crash involves some combination of technological failure, human error, and weather conditions. After almost every crash in the past two decades, there is a blame game that ensues where neither the airline company nor the airplane manufacturer wants to take responsibility until the black box, which records the plane's final moments, is recovered. Even after an image of the crash has been created with the black box recording, there is always room for interpretation of who is to blame. For this research, the analysis of the crashes focused on the technological failure as well as any human error that may have contributed to the crash.

Boeing 737 Max Crashes

In the commercial aviation industry, there is fierce competition between the two largest suppliers of airplanes, Boeing and Airbus. Forecasts for 2016 predicted that the market share for single-aisle airplanes would be 45% Airbus and 43% Boeing (Morris, 2016). When Airbus announced the A320neo, an updated version of their best-selling commercial model A320, Boeing was faced with a large loss in market share. Airbus proclaimed that the new model was equipped with a larger engine that could be 14% more fuel-efficient and would require little to no pilot retraining and orders for new Airbus planes skyrocketed (Goold, 2017). Boeing's best-selling commercial plane, the 737, was too low to the ground for a larger engine to fit under the wing. To work around the problem, engineers at Boeing decided to move the engine farther up the wing so it would be slightly above the wings and this model was called the 737 Max. Boeing also claimed that this model would not require pilot retraining and soon the 737 Max became the highest ordered airplane by airlines around the world. However, due to the engine being higher up on the wing, when the airplane was at full throttle like during takeoff, the nose of the plane would point too far upward, which could lead to a stall, where the plane begins to start losing altitude. To counter this problem, Boeing installed a software called the Maneuvering Characteristics Augmentation System (MCAS) that would automatically push the plane down if it was flying at too high of an angle. Boeing understood that pilot retraining would cost airlines a significant amount of time and money, decreasing their potential sales, so they assured airlines that the 737 Max was essentially the same as its predecessor, and many pilots only received a two-hour training on iPads before flying it for the first time (Kitroeff et al., 2019).

On October 29, 2018, Lion Air Flight 610, a 737 Max, took off from Jakarta, Indonesia to its destination at Pangkal Pinang, Indonesia. Black box recordings from the flight were able to construct an image of the plane's final moments in the air. When the airplane took off in full thrust, the MCAS took control by pushing the nose of the plane down due to its high angle of flight. The pilots used their judgment to pull the nose upward and the MCAS kept fighting back by pushing the nose down. The pilots were not aware of the new software and could not find out how to turn it off in the quick reference handbook. For the next few minutes, the aircraft kept losing altitude, most likely due to the struggle between the automation and the pilots and software receiving incorrect sensor data. Only twelve minutes after takeoff, the plane crashed into the Java Sea, killing all 189 people on board (Bellamy, 2019).

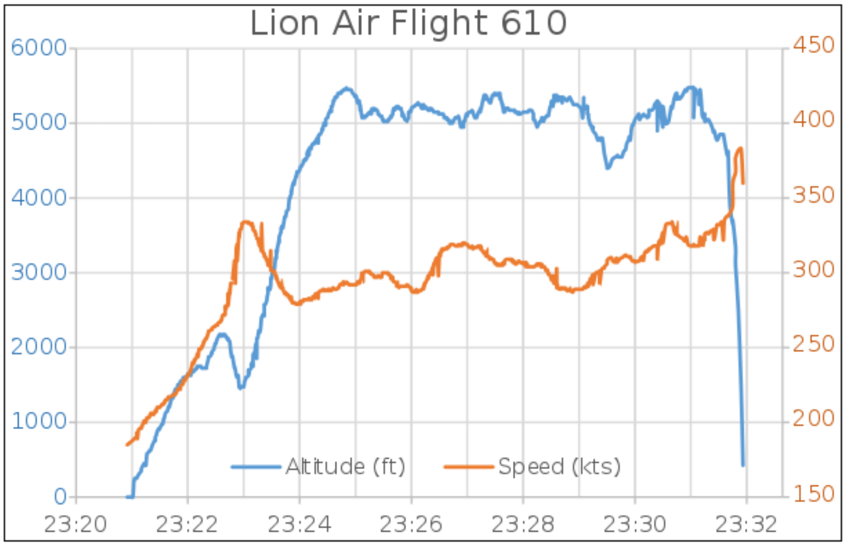

Figure 1. Lion Air Flight 610's speed and altitude chart (Shrivastava, 2020).

On March 10, 2019, Ethiopian Airlines Flight 302 took off from Addis Ababa International Airport. The pilots faced the same problem with the MCAS pushing the nose of the plane down while the pilots kept trying to pull the plane up. In this case, the pilots were able to successfully turn off the MCAS. However, the airplane was already in a downward trajectory with a significant vertical speed and the pilots were not able to regain control. The airplane crashed six minutes after takeoff, killing all 157 people on board. Immediately after these two crashes, Boeing aggressively defended their airplane design and cited pilot incompetence as the primary cause of the accident while Lion Air blamed Boeing for supplying them with faulty airplanes. However, with the evidence uncovered through flight records and black box recordings, it has become evident that Boeing placed maximizing their sales above customer safety by not disclosing the details about the MCAS. Firstly, the pilots were neither trained for nor were they aware that the MCAS would automatically push the nose of the plane down during takeoff. This violates the MCAS's links to conventions of practice where the pilots are properly trained for new software and are taught how to turn off the automation in case of failures. There is also no precedent for the autopilot altering the angle of attack on a plane which further calls for proper pilot training. Links to conventions ensure that there is transparency in the system such that even though tasks are automated, the humans working around the software are aware of what is happening under the hood. Secondly, the MCAS was not properly embedded into the overall autopilot system. Although it was invisible to the pilots, its actions were clearly out of the norm and clearly exceeded the amount of control that most autopilot technology has over an aircraft. By implementing a rough solution to the engine pushing the nose too high, Boeing tried to save on initial costs but paid for it through money paid out for wrongful death settlements to the victims. Both of these crashes could have been avoided if Boeing had been more transparent about the MCAS and invested in pilot training instead of sacrificing passenger safety.

First Air Flight 6500

Planes that are flying far away from the North or South poles can solely rely on their compasses that are calibrated with the magnetic north. However, when flying close to the north pole, pilots have to keep adjusting their compasses as the disparity between the magnetic north and true north is significantly higher closer to the north pole. Another technology to consider is that First Air Flight 6500 was using the Instrument Landing System (ILS) (FAA, 2019). Using this technology, the airplane would intercept a localizer signal from the airport and the autopilot system onboard would guide the airplane to land exactly on the runway that was instructed to land on.

On August 20, 2011, First Air flight 6500, a Boeing 737-200, was flying from Yellowknife, Northwest Territories to Resolute Bay, Nunavut, Canada. This flight was very close to the north pole so the pilots were required to constantly adjust their compasses to align with true north instead of magnetic north. For the majority of the flight, the aircraft was operated using HDG HOLD, which is the regular version of autopilot that simply guides the plane to the provided coordinates. During descent, the aircraft was switched to the Instrument Landing System (ILS) because of low visibility. When the aircraft was close enough to the destination airport, the localizer signal was intercepted and the plane began making a left turn towards the airport. Just before the left turn had been completely executed, the captain inadvertently bumped the control column with enough force to cause the autopilot to partially disengage and revert to the regular cruising HDG HOLD autopilot (Transportation Safety Board of Canada, 2011). Since the left turn was never fully executed, the plane was one degree off the course to the runway, which became worse due to winds in the area, and due to low visibility, the pilots were not able to manually see that they were off course. Both pilots believed that the ILS was active and that they have made a complete left turn and there was no indication from the aircraft that the other type of autopilot was in control. When the aircraft began to descend onto the runway, the pilots realized that they were off course and moving too fast for a landing. Rules state the aircraft must be 3 miles from the runway to execute a go-around, meaning that the aircraft lifts up, goes around the runway, and tries landing again (Landsberg, 2016). Unfortunately, the pilots were too busy trying to figure out how they had deviated away from the runway and trying to get back on course that they missed the 3-mile minimum. The pilots were still suffering low visibility and the plane crashed into a hill under cloud cover one mile east of the Resolute Bay airport, killing twelve of the fifteen people aboard the flight.

It can be very easy to portray this incident as pilot error or pilot incompetence but there has to be some deeper analysis into why the pilots felt a false sense of security until it was too late to save the plane. The two types of automation technologies aboard the airplane serve their own purposes but there was no indication of which autopilot was in control of the flight. This incident is a violation of Star's characteristic of infrastructure which states that technology must be visible when it is broken. Although there was no malfunction in the system during the flight, there should have been some warning from the ILS when the left turn was aborted before the HDG HOLD took control. Pilots need to be made aware when maneuvers are fully executed and which system is operating the plane at any given moment. This crash could have been avoided by the pilots acting slightly faster to being off course and more importantly by the autopilot technology being more communicative with the pilots.

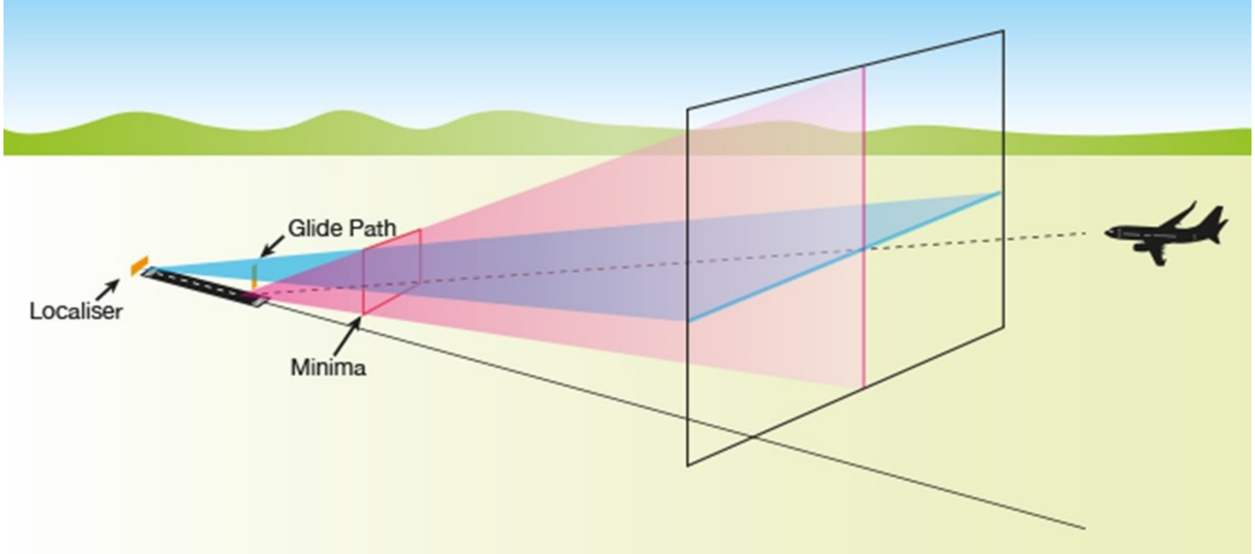

Figure 2. The Instrument Landing System (Mark, 2018)

Turkish Airlines Flight 1951

On February 25, 2009, Turkish Airlines flight 1951, a Boeing 737-800 was scheduled to fly from Istanbul, Turkey to the Amsterdam Schiphol Airport. Around halfway through the flight, the captain's radio altimeter, the instrument that measures altitude, sounds an alarm as it is showing a false reading of eight feet below sea level, which is impossible. The false reading also causes the landing gear alarm to sound because the plane believes it is on the ground and is informing the pilots to deploy the landing gear (Dutch Safety Board, 2009). Unbeknownst to the pilots, the faulty altimeter had caused the autopilot of the aircraft to change to “Retard/Flare” mode at 1000 feet altitude. This mode is only activated in the final phase of landing below 27 feet. The aircraft uses the ILS to guide itself to the runway indicated by air traffic control and at 500 feet above the ground, the pilots begin going through the landing checklist. They suddenly realize that the speed of the aircraft is dangerously low and it won’t make it to the runway. They increase the engine power but the autothrottle mechanism has idled the engines, meaning they were effectively turned off. The captain takes manual control and the pilots deactivate the autothrottle but somehow leave the throttles at idle. The captain pushes the nose down to gain more speed and the engine throttles now turn to maximum power but the plane has lost too much altitude to make a difference. The aircraft crash-landed 1.5 kilometers away from the runway. Due to the plane being in a neutral position, it was not a nosedive and it did not catch fire but the aircraft broke into three pieces on impact. Of the 135 occupants of the airplane, nine were killed including all three pilots on board.

When the black box recordings, which also record all the sensor data that the autopilot uses, were analyzed, it was realized that the autopilot followed the localizer signal during landing but the autothrottle idled the engines due to the incorrect altitude indication. The pilots believed that the plane was slowing to capture the landing path from the localizer but instead it was coming to a complete stop. This is another case of automation technology not being visible when it is broken. Although to the autopilot it was functioning properly, there should have been some indication to the pilots that the “Retard/Flare” had been turned on. If the pilots had known the faulty altitude readings would trigger the engines to turn idle, they would have taken manual control earlier in their flight and could have guided the airplane safely to the runway. One of the most dangerous aspects of automation is when it is not able to communicate with its surroundings about malfunctions. If it keeps working under faulty conditions, there could be disastrous consequences. This scenario also violates Star's characteristic of links to conventions of practice. It is widely understood that when there is crucial technology in play, there must also be backups in case of technology failures. In this case, there should have been a backup altimeter or perhaps two altimeters that the autopilot could compare to ensure that the readings were accurate. The result of this crash should prompt airplane designers to more thoroughly test their automation technology. This crash could have been avoided if the autopilot had been designed with better software that would indicate to pilots when important decisions prompted by mechanical devices were executed.

Figure 3. The aftermath of the Turkish Airlines Flight 1951 crash (Dutch Safety Board, 2009).

Air France Flight 447

The Airbus A330 is designed to be flown by a crew of two pilots and the cockpit is designed such that each pilot has a side stick on their side to maneuver the aircraft. However, the controls are not synchronized. If one of the pilots pushes the plane up, while the other pushes it down, the actions will cancel out so communication is essential. Airbus claims that sidesticks allow pilots to have a free hand to easily access the control board. Boeing planes, on the other hand, have large, synchronized control yokes, which are similar to steering wheels, for each pilot in the cockpit with the belief that the yoke retains more general flying skills and maintains coordination between the pilot and copilot (Aircraft Technic, 2020). Another issue with the A330 was that only a slight motion on the side stick could turn the plane from a neutral position to full throttle upward and this small movement could easily be triggered accidentally.

Figure 4. A control yoke (left) and a sidestick (right) (Aircraft Technic, 2020).

On June 1, 2009, Air France Flight 447, an Airbus A330, was scheduled to fly from Rio de Janeiro, Brazil to Paris, France. The 13-hour flight exceeded the maximum 10 hours permitted by Air France’s regulations for pilots to operate an aircraft without a break so the flight had a crew of three pilots. During the flight, the aircraft encountered a thunderstorm and the pilots noticed that the plane was being hit with ice crystals so they turned on the anti-icing system to counter the issue. The ice crystals caused the airspeed indicators to malfunction and the autopilot disengaged causing the auto-thrust to turn off (BEA, 2012). The pilots were forced to take manual control during a thunderstorm. One of the pilots pulled the sidestick back causing the nose of the plane to point up. This led to stalling and there was a stall warning indicated in the cockpit. The pilot did not realize that he had caused the nose to point up and the co-pilot was also oblivious since his side stick was not linked to his colleague's. The pilots kept trying to figure out why the plane was losing altitude while still having 100% engine power. When they realized that one of the sidesticks had been held slightly back, the plane was already in a nosedive into the ocean. The plane crashed into the Atlantic Ocean with all 228 passengers and crew on board.

After all the data from this crash was analyzed, Airbus's cockpit design was heavily criticized but they aggressively defended their design claiming this to be an isolated incident. However, through the lens of Star's characteristics of infrastructure, this appears to be a violation of the embodiment of standards. Flying an aircraft is a tenuous task, especially on a 13-hour flight where the pilots have to be communicating well. The unsynced sidesticks do not allow both pilots to feel each other's actions when controlling the airplane. This can easily disrupt the coordination between two pilots trying to rescue an aircraft from a thunderstorm. The unsynchronised sidesticks also violate the characteristic of embeddedness. Technology should blend with its surroundings without hindering the activities that it was designed for. In this case, even though the sidesticks were aesthetically embedded into the cockpit design, they were a hindrance in the emergency situation when the airplane stalled and went into a nosedive. Synced sidesticks would have alerted one of the pilots that it was an unknown human error that was pushing the nose of the plane upward and could have saved the plane from crashing.

Flight(s)	**Model of the plane**	**Automation Failure**	**Result of crash**	**Star's characteristics of infrastructure violated**
Lion Air Flight 610, Ethiopian Airlines Flight 302	Boeing 737 MAX	The MCAS system kept pushing the nose of the plane down during takeoff	A total of 346 people died in both crashes	Links to conventions of practice, Embeddedness
First Air Flight 6500	Boeing 737-200	Pilots confused about which autopilot (cruise or landing) was in control	12 of the 15 occupants died	Visible when broken
Turkish Airlines Flight 1951	Boeing 737-800	Autopilot turned off engine due to a faulty altimeter reading	9 people killed including all 3 pilots	Links to conventions of practice, Visible when broken
Air France Flight 447	Airbus A330	Sidestick design/operation confused the pilots	228 passengers and crew died	Embodiment of standards, Embeddedness

Table 1. Summary of the results (Created by Gandhi, 2022).

Discussion

Analyzing any kind of infrastructure through Star's characteristics of infrastructure can be very helpful in identifying future points of failure in the system. This analysis can be applied to more orthodox forms of infrastructure, such as highways and buildings, as well as more subtle forms of infrastructure, such as software. There are a plethora of cases to study in other industries that can provide insight into why and how automation fails. For example, in 2013, the Affordable Care Act was one of the biggest initiatives taken on by the Obama administration.

When the ACA's website crashed mere two hours after launching, the White House suffered backlash for not providing proper avenues to learn more about the ACA. A lack of integration, visibility, and testing left the website unable to handle the millions of users trying to access its information (Andrews & Werner, 2013). Analyzing such cases also provides a framework for how a piece of technology is designed. Star's characteristics of infrastructure are best applied before the technology is built and during the design phase. Creating a foolproof design that does not succumb to the usual pitfalls studied earlier significantly reduces the points of failure.

One of the largest issues with studying plane crashes is the lack of information that is available immediately after a crash. As time passes, information erodes away and investigations must be performed quickly. The added aspect of the loss of innocent lives also means that sentiments are running high and can influence how the available information is interpreted. In the cases studied for this research, investigators were fortunate enough to recover the black box recordings necessary to piece together the circumstances that led to the crashes. However, this is not always a guarantee. For example, Malaysian Airlines Flight 370 disappeared over the South China Sea in 2014 after it was lost from air traffic control radar screens (MacLeod, Winter, & Gray, 2014). To this day, only small pieces of the wreckage have been recovered with no conclusive evidence on how the plane disappeared and where it crashed has been found. There are many such crashes where the circumstances leading to the crash are blurred and with time, it has become impossible to know what truly occurred.

This research focused primarily on the technological aspects of the crashes. There is a human aspect involved in these incidents that was not fully addressed here. For further analysis of these cases, I can study how pilots are trained for emergencies and whether the pilots in these crashes acted in parallel to their training. If their actions are in line with their training, it may imply that new training modules need to be developed that draw scenarios from real airplane crashes. If their actions were not in line with their training, there needs to be further analysis into whether instinct or strict protocol should be followed during emergencies. With the number of people that travel through the air every day, training modules for pilots must be designed to best train them for the worst-case scenarios.

Studying failures of automation provides me with a new lens through which technology can be viewed. Before studying Star's characteristics of infrastructure, my development process for software began with an idea and pivoted straight to writing code and testing the logic within it. Now, I see the pitfalls in development processes that I did not observe before. Usability, integration, and visibility are some of the most important aspects of technology that are often overlooked. When working on projects in my professional career, I will have a unique perspective that can spot the potential shortcomings of technology before they lead to future problems.

Conclusion

Researching failures of technology in aviation shows that even though flying is statistically the safest way to travel, many improvements can be made to make it safer (Ferro, 2018). Firstly, government agencies, such as the FAA, need to monitor the introduction of new technology in aviation. Large corporations, such as Boeing, will always think from a business point of view, where money rules all. Boeing faced minimal legal consequences, other than a $2.5 billion settlement paid out mainly to the airlines (Chokshi, 2022). Governments around the world have to ensure that commercial airlines are buying safe airplanes. Secondly, pilot training needs to be improved to facilitate greater preparation for emergency situations, especially scenarios when automation is to fail. There also need to be rules stating that pilots have to be retrained for new airplanes, even if the new airplane is only slightly different from its predecessor. Lastly, all pieces of automation that are approved for installation on airplanes must be thoroughly tested, meaning that the new technology must be put through every emergency scenario possible.

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