**The Intersection of Engineering and Safety Regulation: Transportation Case Studies**

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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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**Abstract**

Over the past couple decades in the United States, there has been a process of deregulation which has weakened the agencies put in place to ensure the safety of the public. Using Actor Network Theory this result is shown through determining the influential actors in a given network—specifically with respect to transportation development. Two cases are presented for study: the Boeing 737 Max 8 crashes and the development of Autonomous Vehicles. In the 737 situations, engineers were forced to create a technological solution to meet a technical specification that hurried the production of the plane. By trading safety, Boeing could produce their new airplane variant sooner, something that engineers had to decide due to the relevant agency not having the resources to properly audit designs. For autonomous vehicles, hurried development exists to be the first to market in a novel and expanding area. People have died as a result of rapid testing that engineers are pressured into conducting. In this space, agencies are not able to keep up with modern technology and thus have not provided adequate regulation to determine safety levels especially with regard to testing. Thus, without a stronger regulatory body, engineers are the ones having to make ethical decisions on safety and are influenced by the larger actors in their networks.

**The Intersection of Engineering and Safety Regulation**

## Introduction

Following a major catastrophic failure, there is often a search for something or someone to blame—one thing that, apparently, if it was different, could have prevented the failure. In reality, however, catastrophic is generally a series of failures. One way safety is ensured, is through regulation and minimum standards. These rules, however, are useless if engineers themselves are employing ethical decision making and are keeping safety in mind in their own work regardless if there is a specification for that task. In the past twenty years, the responsibility of safety has been weighted heavier on the engineering side than the regulation (Herkert, et al., 2020). This shift in balance, is due to faster development.

Autonomous vehicles are one example. Every day, the methodology by which these machines operate changes so quickly. The DARPA Grand Challenge, an event where autonomous vehicles had to traverse a desert on their own, was first held in 2004. Since then, the technology has very rapidly changed, and in that time, there has been very little in terms of safety regulation (DARPA). As a result, it is on engineers to produce safe designs. This is best shown in the recent Boeing 737 Max 8 incidents. The plane was rushed out to meet a new market standard from its competitors (FAA, 2020). By shortcutting the design process, Boeing made quick fix decisions rather than appropriately balancing design changes. Moreover, these quick fixes were also in an effort to meet the FAA's self-certification. Self-certification was a result of the FAA not having the resources to inspect every new aircraft iteration. It also heavily puts the responsibility of ethical decision making on the designers.

So, how do engineers and regulatory bodies interact? What flaws are present and how can errors result? How should regulations and engineering design work to produce ethical and safe designs? By examining current documentation and case studies, some answers could be revealed.

In this paper, a method for analysis is proposed and then applied to case studies. Firstly, the recent and infamous Boeing 737 Max 8 plane crashes are examined using news and government investigations. The other case study is the Autonomous Vehicle industry which is rapidly growing, but has many unanswered questions in terms of safety, as demonstrated through think tank reports and academic discussions.

**STS Framework**

Since the objective is to examine interactions between separate peoples and entities, Actor Network Theory (ANT) is a suitable tool for analysis. The cases presented later are situated in large systems with many moving parts each with their own goals and intents which ANT is intended to examine as that is where challenges to safety arise.  ANT is characterized by studies of humans and non-humans interacting in a network (Yaneva, 2009). The premise is that society and technology are closely intertwined and the borders between actors is where development and events occur. By examining these connections one can extract understanding of why and how certain technological events did or did not occur. Another feature of Actor Network Theory, is the analysis of power dynamics. Naturally, any network is not equally influenced by each member. While ANT cannot necessarily explain why one has a certain amount of influence and another does not, the imbalance is an indication of a point of interest. One can look at the history of this connection and the persistence of its dynamic. This helps reveal underlying assumptions or misconceptions. These interactions could either affirm one’s notion of the network or challenge the imagined design (Tatnall, 2014).

Actors in this case mean an entity, both human and non-human with their own agency and therefore relations with other actors. Humans are an obvious one, but they can also include technologies and organizations. This would also include companies, nonprofits, governments and government entities, etc. This would also mean that actors could also be another network, but a solution to this is the concept of black boxing. Networks or characteristics of actors that are outside the network in question are left as a black box and only the inputs and outputs are considered. Networks on the other hand are formed by the actions of actors. Each actor, working under its own motivation reaches out to other actors and forms interactions. Sometimes those interactions are brief, others are sustained. The enduring ones form the network since the actors end up being reliant on those interactions.

Actor Network Theory is not without its faults. One is that it is only concerned with what did happen. There is no room for investigation into what could have happened or any other what-ifs, only what exists in terms of actors and networks (Shapiro, 1997). Another criticism is in how it reduces the social aspect to a simplified version, which is also its strength. By collapsing all the intricacies of societal and cultural impacts into actor-to-actor connections, a lot of details are lost. Furthermore, the foundational assumption that no dynamics existed before the network makes it difficult and instead are all newly generated by actor interactions. This means that only successful actors and networks are presented. Others who might have been influential but did not become a part of the established network are lost along with their narratives. Thus, Actor Network Theory reflects the “winner’s” history, something that these days is considered a flawed and incomplete perspective (Latour, 2003).

However, for this research paper these criticisms are allowable since the focus is on the relatively modern network and actors. Some of these actors in question are considered the dominating players in their fields and the networks are largely centered around these collective few. The interactions are the subjects of interest since that is where the modern engineer is standing making difficult decisions. The case studies presented next will use those interactions to demonstrate how and where safety is considered in transportation design.

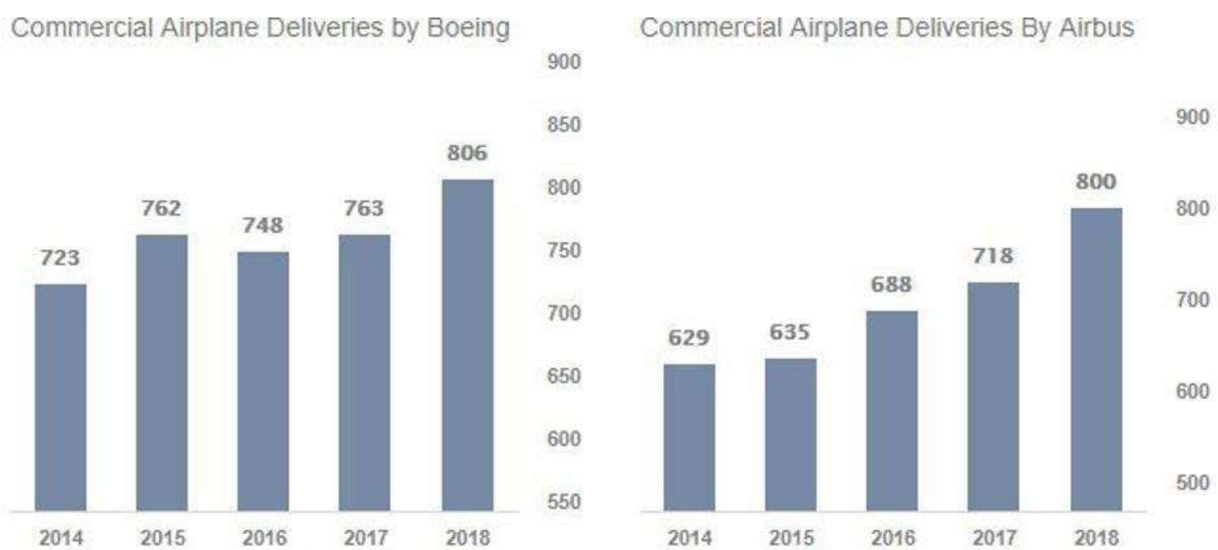
**Relaxed Product Development: Boeing and the 737 Max 8**

One such actor-network is the one in the American civil aviation market centered on Boeing and the FAA. The Federal Aviation Administration (FAA) is the government body, under the Department of Transportation, responsible for handling all civil aircraft management and regulation (DOT, 2018). The FAA manages all US airports and civil air traffic. Moreover, they set and maintain standards for pilot training and certification in addition to aircraft airworthiness. Each new plane that is produced needs to pass through several steps of design review, ground and flight testing, and then maintenance and operational reviews (FAA, 2019). This process is lengthy and requires a lot of manpower due to the narrow expertise required. Thus, a large strain is placed on the FAA. Without any recent significant increase in their budget, the FAA instead has made ways of outsourcing their burdens. One option is having a 3rd party conduct some of the certification process—though the FAA is clear to say that “FAA has never allowed companies to police themselves or self-certify their aircraft.” They also created an option for aircraft that are similarly type rated, i.e., an updated version of a previously certified aircraft, could go through a lighter and therefore an express certification process (Aaron Davis, 2019).

So far, just around the FAA there are its own engineers, pilots, and engineers, 3rd party certifying organizations, the DOT and therefore the rest of the federal government, and then of course the aerospace company in question. Boeing itself. Boeing is made up of many engineers, and designers, builders, managers, executives, etc. all working to design, build and sell their aircraft. Besides the FAA, others that the company interacts with include their contractors and suppliers, and their competitors. Boeing and suppliers are usually long-lasting relationships with Boeing being the buyer for raw materials and parts. Their relation with their main competitor, Airbus, however, is a key part to Boeing's actions as seen in Figure 1 (Team, 2020).

**Figure 1**

Airplane Delivery by Company




Note: This map shows how many airplanes have been delivered each year by Boeing and Airbus. From (Team, 2020)

Combined market share of Boeing and Airbus equals 99% (Duddu, 2020). Each are producing and delivering airplanes at roughly the same rate up to 2018. Thus, Boeing are constantly fighting for market share against Airbus. Their connection is very tightly knit though contentious. This is likely a large reason for the Boeing 737 Max 8 accidents. Boeing and Airbus have the 737 series and the A320 series narrow-body medium-haul jets respectively. These aircraft are each companies' respective best sellers (Hayward, 2020a; Hayward, 2020b). Thus, when Airbus surprised Boeing and released a new version of the A320Neo which dominated the current 737NG in both efficiency and range, Boeing had to react to maintain its market share or risk losing sales to a better plane (Gelles, 2019). Their solution required installing new engines which affected the flight characteristics of the plane. To maintain type rating, the plane has to perform similar to the previous version, but the new engines changed the aerodynamics to break that rule. Boeing instead pushed to fix this mechanically by installing the Maneuvering Characteristics Augmentation System (MCAS). Since it was identified as a flight control system, it did not get listed in manuals or appear in pilot training. Failures in the MCAS led to the deaths of passengers on Lion Air Flight 610 and Ethiopian Airlines Flight 302.

How did a now obvious design failure and flaw get all the way through to production? Because Boeing was surprised by the new plane and had just a few months to propose a competing plane to meet the A320Neo specifications. Thus, existing plans for an entire new plane were scrapped and engineers were tasked with rush designing a new 737. Engineers say they were asked to produce drawings at twice the usual rate. And those drawings ended up being sloppy and "would be fixed later." Looking at the network internal to Boeing, it comprised engineers and designers, builders, management, executives and of course a lot of other support groups that are not relevant to this paper. The decision to update the 737 came from the executives. This decision can be explained as Boeing's shift from an engineering company to a financial one (Herkert et. al, 2020). Previously, top executives had engineering experience, but since the merger with another company, many were replaced with business minded people and shifting the headquarters away from the engineering location in Seattle and placing a new headquarters in Chicago. From the executives the decisions are passed to management and finally the engineers. Due to the high pressure and short timeline, designs were quickly made and remade with any designs requiring pilot training or re-certification to be rejected. More importantly, those engineers that did raise concerns had their thoughts dismissed by management. One engineer did file a formal complaint after the accidents, but did not do so during development since he "feared retaliation" (Kitroeff et. al, 2019a). The interactions between management and their engineers consistently chose profit over safety. And since management holds those engineers' jobs it is difficult for the engineers to refuse or stop development to focus on safety. The change in demands further up the network, flowed down to the engineers and forced them to reconsider their professional ethics.

Regulatory Failure

Another failure in the network is between the FAA and Boeing. Since most planes produced are updated versions of existing aircraft, certification is rare and due to the FAA's limited personnel and resources, the type rating certification process is outsourced. Boeing being the dominant aircraft producer in the US, had a very "cozy" relationship with the FAA (Kitroeff et. al, 2019b). The FAA did a cursory investigation into the MCAS and the 737 Max 8 and then left the rest of the approval process to Boeing even after Boeing made significant changes to the MCAS. Boeing insisted the plane did not need extensive pilot training or simulator training to be considered airworthy. Furthermore, the MCAS failures modes and recovery was not a significant portion of the training pilots did receive even though it was a new system. Boeing's ability to exert influence on the FAA is well demonstrated here.

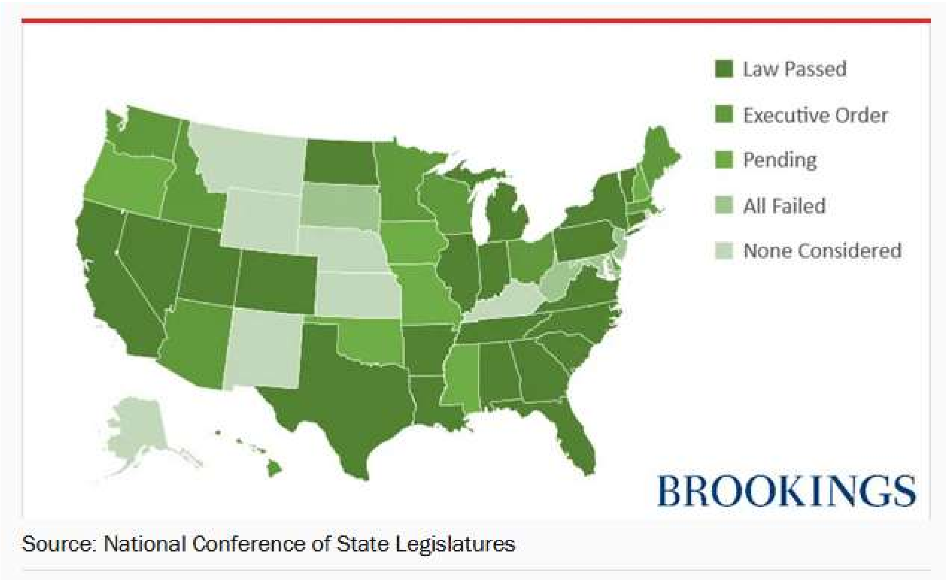
**Regulatory Failures in Novel Fields**

One area that has quickly grown, is the autonomous vehicle space. Autonomous vehicles offer the potential to reduce car crashes, improve traffic flow and efficiency (Anderson et al., 2016). With a fully automated system, users could end up using the travel time in a car for other purposes as the car travels on its own. Other benefits include reduced need for parking and higher mobility for those that cannot or should not drive themselves. Currently though, we are still developing that technology. Some real-world testing has been conducted and has already resulted in two deaths. One occurred when a pedestrian was crossing at a crosswalk at night and was struck by an autonomous car (Pines, 2018). The other was a Tesla car with Autopilot enabled and eventually collided with a highway divider (Green, 2018). In either case, fault is not immediately obvious and is further confused by the fact that the car was in control even though a driver is technically holding the wheel. Other crashes and incidents involving an autonomous car have happened, but in all cases the lack of regulation creates confusion.

Currently, laws exist at a state level with 22 states enacting laws on autonomous vehicles, and 10 others have executive orders placed on autonomous cars as seen in Figure 2 (Karsten and West, 2018).

**Figure 2**

Brookings Institute Survey of Autonomous Vehicle Laws




Note: This map shows the level at which a state has legislatively addressed Autonomous Cars. From (Karsten and West, 2018).

While this is promising, the laws are not consistent and the lack of national legislation makes it confusing to understand and apply laws, especially when it comes to determining liability in crashes. This ambiguity of responsibility needs to be set as the lack of clarity slows down progress and pushes for a technology that has the potential to radically improve the world around us. Currently, this system largely portrays the creators of the technology as the ones responsible for the accidents that occur even though the circumstances are largely the drivers of accidents.

So, using this information as the basis of the network, ANT can be applied. At the root of this technology are the creators. This includes start-up-like businesses developing systems for specialized autonomous transportation such as Perrone Robotics, who are developing local shuttles, to Embark, who are creating autonomous 18-wheelers. Even Uber and Google are creating their own autonomous cars. Then related to them are the car manufacturers who are developing these technologies to be added as features into their cars such as Tesla's Autopilot. These two actor groups are largely chasing the same goals sometimes in the same areas sometimes not. Sometimes partnerships are developed to combine the power and experience of a large car manufacturer with the start-up's technological advantages. A good example is Waymo, a subsidiary of Alphabet Inc who is Google's parent company. Waymo is partnered with several well-known manufacturers, also known as OEMs, such as Nissan-Renault, Volvo, Jaguar Land Rover, and others. Thus, this part of the network sees a lot of activity as information is passed around.

### Government Oversight

The other aspect of this network is the regulatory part. The main actors are the state and federal governments which consist of their legislative and executive branches. Each state government has its own legislature who can enact laws regarding autonomous cars and have transportation administrations to manage or regulate autonomous vehicles. The same thing exists at the federal level, only the actors are Congress and the National Highway Traffic Safety Administration (NHTSA) which is the regulatory body in charge of vehicles. These bodies provide guidance on how to legally interpret situations.

However, as pointed out before, at the state level there is a wide range of regulation and approaches. Most states have placed executive orders that allow the testing of autonomous cars (Dubois and Shinkle, 2020). Most of the laws enacted concern truck platooning which are trucks that are in a formation and automatically travel as a group. Autonomous cars and the larger autonomous vehicles segments are not really addressed. This provides a vacuum of where the default assumption is that responsibility falls onto the creators of the technology and therefore the engineers developing it. At the federal level there has not been any legislation or executive actions on autonomous vehicles. NHTSA has put out a guideline document which in essence outlines the ways developers are expected to prevent accidents which is obviously a good thing (NHTSA). However, the document says completing all these suggestions does not absolve the manufacturer of responsibility for accidents where circumstances are beyond the creators control. Thus, development is stuck on the engineer to determine what is an acceptable level of safety and what would balance financial incentives versus preservation of human life.

The current legal system would be the last member of this network. Their rulings and interpretations can form the basis of how to determine safety levels. Brodsky, however, points out that the current system is not really capable of handling autonomously driven cars (Brodsky, 2016). The current system of contract law would put the liability of accidents on manufacturers through Product Liability—the idea that a flaw in the product would put the creators at fault. A driver is likely to be present and should in theory also be responsible for the safety of the occupants. The courts would have a hard time applying existing ideas and precedents to situations where the man and machine are in such a complex and fast-moving system that it is difficult to point one actor as the one at fault. Thus, the interfaces between drivers, creator, and regulators are very tightly knit going forward.

**Conclusion**

In both cases presented, engineers are increasingly placed in roles of trying to balance safety and financial costs without any baseline regulation available to allow the engineers to ethically create their products. Rushed development without strong oversight is present in both situations and decisions have to be on trading time vs. money vs. safety. Engineers are asked to take on roles that previously governments or agencies would fill, however, as demonstrated by the application of Actor Network Theory, these agencies are no longer the most influential actor in their network meaning they do not have the power to ensure a minimum level of safety. Currently, and possibly going forward, liability will fall to the developers and therefore the engineers to guarantee safety in a system inherently nondeterministic. These engineers will be put into positions to balance safety while progressing the technology forward as the market is ripe and has a high potential and therefore a strong incentive to be the first to achieve success.

This trend has been growing and has the potential to cost more in lives if not addressed. Stronger regulatory bodies is one option. Enforcing and guaranteeing safety would be ideal, though it is a long and politically involved process. Another solution would be to create a stronger culture of ethics within organizations. This could be accomplished through better education of ethics in engineering degrees. Having a strong professional organization in an industry could also create space for ethical decisions if the organization remains independent and maintains the goals of safety. These solutions offer the chance for engineers to make ethical decisions without their own livelihoods under threat and therefore reduce the pressure to continue unethical practices.

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