Development of Autonomous Vehicle Technology: The Relationship Between Innovation and Legislation

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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

According to the National Highway Traffic Safety Administration (NHTSA), human error is a major factor in 94 percent of fatal crashes in the United states (NHTSA, 2019). Autonomous Vehicle (AV) technology has emerged as a potential way to reduce these fatalities that occur in situations such as distracted, drunk, and drowsy driving. Other than safety, AVs will allow for productive use of time during a commute or a road trip. This translates to immense savings considering the 46.9 billion hours United States citizens spend driving each year (Griffin, 2018). Other economic implications include the destruction and displacement of jobs. According to 2014 Census data, more than 4.4 million U.S. citizens over 16 years old work as professional drivers (ibid). Automakers increase the reality of these implications through their rapid innovation of AV technology. This is pressuring action from the United States government which is historically time intensive. The time pressure and the variety of automotive companies and government bodies create a complicated relationship for AV technology. Analysis of the government and industry relationships will help characterize the future of AVs and provide insight into its safe and responsible development.

Innovation and Legislation of Autonomous Vehicle Technology

The development of AV technology will be described through Hughes' technological momentum framework. This framework defines a pattern of how technological systems evolve and expand over time (Hughes, 1987). The pattern of evolution is a combination of phases including invention, development, innovation, transfer, and competition, growth, and consolidation. A technological system does not follow these phases in order as they often overlap and backtrack. A system can make multiple iterations of invention, development, and innovation before moving to transfer. Hughes claims that as technological systems become larger through growth and consolidation, they acquire momentum. When a system becomes large and mature, its use in society is challenging to control.

Technological systems have system builders to support their growth and development. Their role involves solving critical problems and responding to reverse salients. Hughes defines reverse salients as, “components in the system that have fallen behind or are out of phase with the others” (Hughes, 1987, p. 73). For AV technology, automakers are a key system builder. Automakers will need to develop or change technical components of their AVs especially with the introduction of new legislation. The developments can create reverse salients if previously optimal components become outdated. On the other hand, government and other regulatory bodies will also play a role as a system builder. The decisions and policies made will impact the innovative limits of automakers.

The evolutionary phase of a technological system can be recognized by understanding the phases’ key characteristics. The invention phase typically involves radical inventions, meaning that they do not become components of existing technological systems. This can include similar inventions that did not develop into innovations. An invention moves into development by embodying the economic, political, and social characteristics needed to function in the system. This is achieved by gradually increasing the complexity of constructed test environments until they closely resemble the real world. At this point, the technological system can explore investments and handle failures on a smaller scale. The innovation phase clearly reveals the technologically complex system. For example, it often defines the combination of component systems of manufacturing, sales, and service facilities. Transfer occurs when the system adapts to characteristics that allow it to survive in a particular time or place. The process of adapting to these characteristics ends in what Hughes defines as technological style. This refers to the social construction of the technology. Lastly the growth, consolidation, and competition phase is where the system gains the most momentum. The system usually endures reverse salients, gains interest from corporations or government, and makes improvements through conservative inventions during this phase. As the system grows, the persistence of acquired system characteristics becomes more embedded (Hughes, 1987).

Applying technological momentum to AV technology will help define its current phase of evolution with respect to the technological system. With the momentum of AV technology, it is crucial for the key system builders and stakeholders to consider the implications of its integration into society. As integration increases, the corresponding increase in momentum can make the use of AV technology difficult to change.

Case Context

The development of AV technology is often categorized in terms of automation levels developed by the Society of Automotive Engineers. These levels are summarized in Table 1 and range from “No Automation” at level zero to “Full Automation” at level five. This translates from a driver performing all of the tasks at level zero to the vehicle being able to perform all driving functions at level five. The middle level 3 requires the driver to be ready to take control of the vehicle if notified, but they do not need to monitor the environment (NHTSA, 2017).

Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
No Automation Zero autonomy; the driver performs all driving tasks.	Driver Assistance Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Partial Automation Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Conditional Automation Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	High Automation The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	Full Automation The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Table 1: Society of Automotive Engineers Automation Levels (Adapted from NHTSA).

Level 1 AV technologies already exist today and there are over 44 companies developing their own versions of AVs at various levels (Griffin, 2018). Tesla and Google are two companies that highlight the fast pace in development as they are both working on level 5 autonomous vehicles (ibid). This emphasizes how automakers will play a major role in determining the impact and magnitude of AVs if they enter the market on a large scale. The impacts depend on factors such as the level of automation and business models including whether AVs will be owned, rented, or shared (Marletto, 2019). The availability of this technology to consumers, however, is conditional on state and federal laws permitting it. In contrast to the rapid innovation in the industry, the regulation of AV technology is substantially slower.

The U.S. federal government has discussed several topics in regard to their role in AV technology development. One of the challenging decisions is the impact of regulation on innovation. The NHTSA, an agency of the U.S. Department of Transportation (DOT), has proposed a non-regulatory approach to advance the integration of AV technology into the transportation system. The NHTSA outlines a “Voluntary Safety Self-Assessment” for those within the industry of autonomous vehicles to demonstrate the safety of their AV technology to the public. The assessment is meant to show the public that industry is considering safety aspects of their technology, collaborating with the DOT, promoting self-establishment of industry safety norms, and building public trust through transparent testing (NHTSA, 2017).

The non-regulatory standard introduced by the NHTSA is not what the automotive industry wants in terms of policy. The industry is concerned with being able to circulate AVs into the market and they need standards in order to make markets possible. The "Self-Driving coalition for safer streets" was created by automakers including Ford, Google, Lyft, Uber, and Volvo to promote clear national regulation. The coalition also acts as a collective industry force to advocate for the safety of autonomous vehicles to both lawmakers and the public (Marletto, 2019). Overall, although the NHTSA recommendations are helpful to consider, they do not offer a prompt timeline that will unify manufacturer legal obligations across the national market (Griffin, 2018).

In terms of federal and state power, a shift of responsibilities to the federal level is promoted for consistency reasons. The House Committee on Energy and Commerce has expressed that variance across states may create barriers or slow investment in AV technology. This was promoted in the "SELF DRIVE Act" in the House, and later the "AV START Act" in the Senate (Geistfeld, 2018). It was determined that federal laws created must preempt conflicting laws at the state and local level. A balance between federal and state laws may be found by bringing the laws that the majority of states already hold to the federal level (ibid). The increase in federal responsibility highlights the importance of understanding their priorities regarding AVs.

Research Question and Methods

The research question informed by the previous discussion is: How will the relationship between the federal government and the automotive industry impact the safe development of autonomous vehicles in the United States? This is important to address now considering the safety, economic, and other implications will depend on how these stakeholders approach the integration of AVs into society.

Focusing on the federal level, the NHTSA was selected to represent the government's perspective. The NHTSA's automated vehicle guidance policy documents from the years 2016, 2017, and 2018 provided the data. These documents outline the NHTSA's framework for the safe integration of autonomous vehicles into the transportation system. Their relationship to industry was analyzed with data from a combination of white papers focusing on the safety of AVs. The white papers were from Ford, Waymo, and one co-authored by companies including BMW, Audi, and Volkswagen. Ford is an American automaker currently developing a Level 4 AV (Ford, 2018). Waymo, in contrast, is a technology company under Google developing a Level 5 AV (Waymo, 2018). The co-authored paper represents a generalized view from multiple companies and was published in 2019. Overall, the variety of automakers creates a well-rounded perspective how the automotive industry view safety of AVs.

The data was analyzed using the quantitative content analysis method of co-occurrence networks through the open source software KH encoder. The co-occurrence networks are made up of nodes and edges. The nodes represent the most frequent words within each document. The edges connecting two nodes represent a strong similarity relationship between the words measured by the Jaccard coefficient. This measurement looks at the intersection of sentences that include both words compared to the union of all of the sentences with either word or both. The pair of words will have a higher Jaccard coefficient if they appear more often together than not (Higuchi, 2016). This method was chosen as it is able to analyze the most frequent words and their relationships to each other.

Different co-occurrence networks were created to analyze the relationships within and between documents. The co-occurrence networks for within a document are color-coded by groupings of related words and edges. This simplifies recognition of themes and priorities. The size of the nodes is indicative of the overall frequency of the word in the document. The co-occurrence networks of multiple documents have word and document nodes that facilitate comparing and contrasting. The edges that connect a word to two documents describe the similarities while the edges from word to one document reveal the differences. The results were interpreted based on the visual co-occurrence networks generated and the context of the documents that the network corresponds. They were also discussed through the lens of the technological momentum framework and Hughes' phases of evolution.

Results

Analyzing the co-occurrence networks of paired, frequent words indicated that the NHTSA's current framework allows the automotive industry to have a high degree of influence over the future of autonomous vehicles in the United States. This is highlighted in the shift from planning regulatory tools from the NHTSA's initial policy in 2016 to supporting voluntary guidance in 2017 and 2018. From the industry perspective, their focus in the development of AV technology is continued testing, validation and customer experience. The impact of this relationship between NHTSA and the automotive industry is that the testing methods and scenarios standardized within the industry itself may be a major factor in determining how AV technology will be developed and integrated in the future. These standards will be influenced by the motivations of the automotive industry and may not take into account other economic, social, or political considerations. Analyzing these other considerations could be the focus of the NHTSA in the future.

Priority and Relationships of NHTSA (2017-2018)

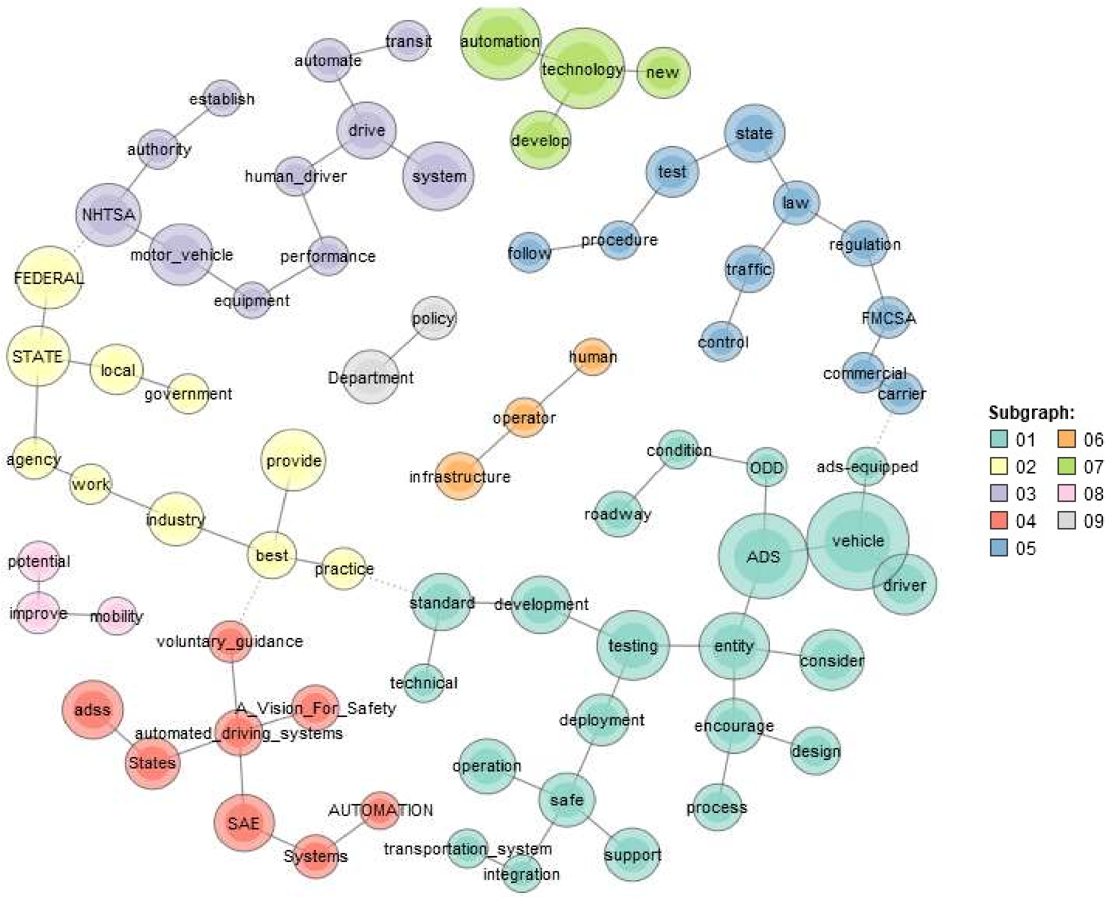

Figure 1: NHTSA co-occurrence network (2017-2018)

The above co-occurrence network in Figure 1 combines the 2017 and 2018 documents by the NHTSA since the 2018 release builds upon the 2017 release. The NHTSA's role and their perspective on the automotive industry's responsibility emerges in group or subgraph one. A central node in this subgraph is "entity" which refers to the automotive industry or those "designing ADSs [automated driving systems] for use on public roadways in the United states"

(DOT, 17, p. 2). The NHTSA is clear on their role to support and encourage the automotive industry to test and develop safe standards. Subgraph one branches to groups two and five which represent the connections between levels of government. This suggests regulation at the federal, state, and local levels will stem from the testing and development done by the entities. Without testing results to prove safety of innovations, regulations and standards will not be made. In terms of technological momentum, standardization will be needed in the future to facilitate transfer and growth.

Currently, Figure 1 shows characteristics of both development and innovation phases. The testing, design, and safe group one indicates development. The innovation phase is quantified most in the grouping with "infrastructure" in subgraph six and "commercial" in subgraph five. This relates to combining component systems, preparing the infrastructure, and creating additional commercial uses of AVs. Notably, the infrastructure grouping is not connected to the automotive industry represented in subgraph one. This disconnect can impede transfer of AVs into society as the technology must function within roadway conditions.

NHTSA Relationship over Time (2016 to 2018)

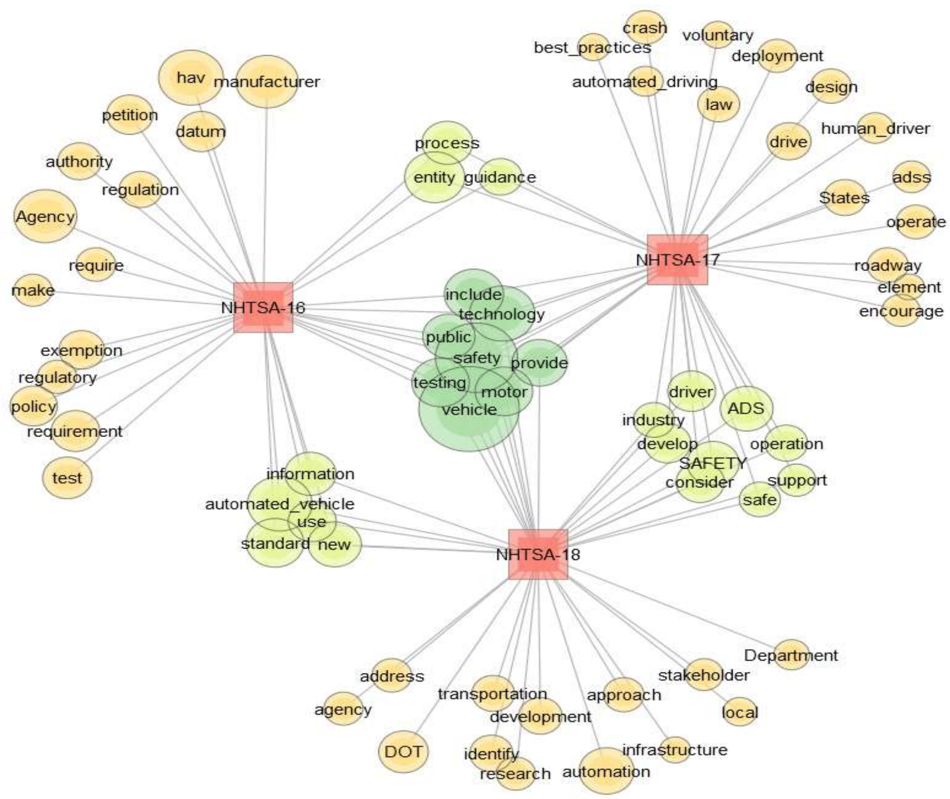

Figure 2: NHTSA over time co-occurrence network

The co-occurrence network in Figure 2 shows the connections between the NHTSA documents over time. The red blocks correspond to one policy document. The darker green center signifies the strongest concepts that are consistent throughout the three documents. The shared frequent words of safety, testing, technology, and public were not particularly surprising. The more shocking aspect is that these were the only constants. The focus on safety reveals the unchanging priority of the NHTSA despite changes made in their role. The 2016 policy put the NHTSA in an active position to implement modern regulatory tools for helping AV development. This greatly contrasts their current voluntary framework in order to remain flexible to new AV innovations.

As previously mentioned, the NHTSA can be characterized within the development and innovation phases. The focus only on safety, however, reveals a lack of embodying all of the economic, political, and social characteristics needed for development. The current automotive transportation system is highly integrated and consolidated into society. Any adaptation and transfer of AV technology will need to consider these other characteristics and their impacts on the current transportation system. In addition, Hughes labels legislation and market as critical factor to transfer of technology. (Hughes, 1987) Therefore, the NHTSA will likely need to create substantial laws regarding these characteristics in the future.

Priority and Relationships of the Automotive Industry (2018 to 2019)

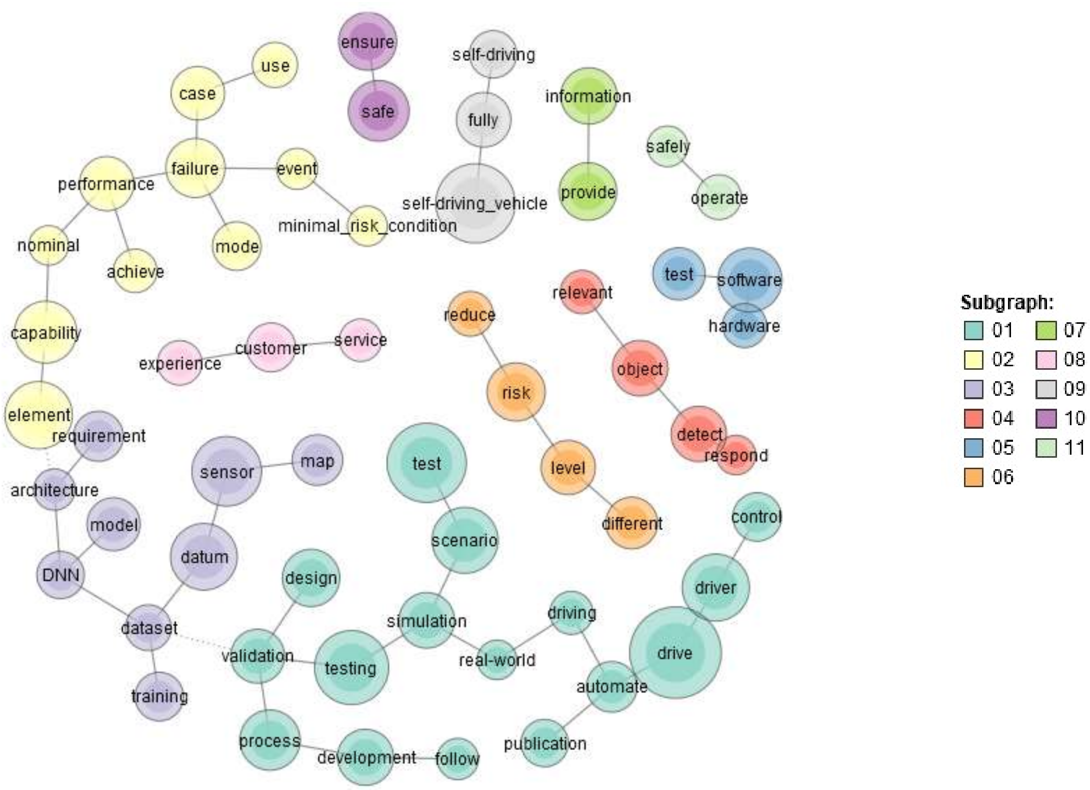

Figure 3: Industry co-occurrence network

The co-occurrence network in Figure 3 shows the co-correspondence of frequent words in the automotive industry white papers. The network creates 11 distinct groups with groups one to three representing the largest. Those three groups strongly emphasize the focus of testing in the automotive industry which relates to the development phase of technological evolution. One of the key activities is to validate the technology using increasingly complex test environments. This relates to describing the risk levels in group six and how their technology detects and responds to objects in group four.

The automotive industry aims to prove the safety of their technology through describing their testing and technology to the public. More specifically, although, is proving safety to potential customers. The customer is referenced in group eight, but it is disconnected from the safety and performance groupings. This contrasts to the NHTSA documents which link safety, public, and technology together. Therefore, a key difference in the automotive industry is their goal to sell to customers in the United States and potentially in other nations. While public safety is a top priority of the NHTSA, proving safety to customers is a different version of this priority in the automotive industry. Selling to customers aligns with going through the innovation and transfer evolutionary phases. Moving forward with these phases will require the automotive industry to focus on sales and the system characteristics needed for survival in multiple nations.

Connection between NHTSA and Automotive Industry

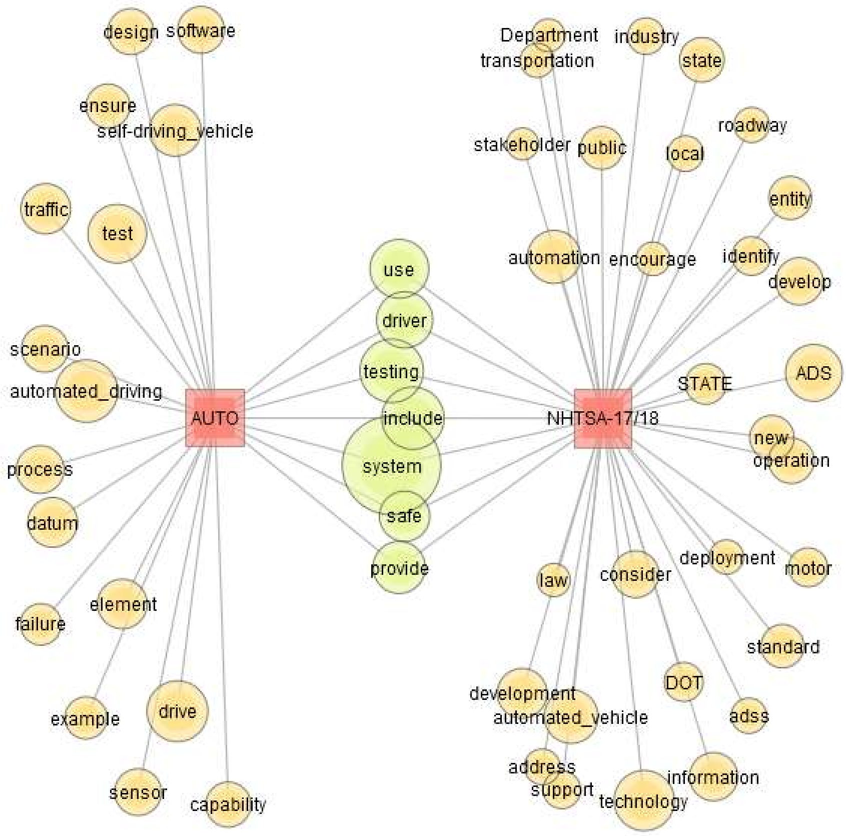

Figure 4: NHTSA and Industry co-occurrence network

The final co-occurrence network of Figure 4 exemplifies the relationship between the NHTSA's current policy in node "NHTSA-17/18" and the general automotive industry in node "AUTO". Similarly, to the NHTSA documents over time, the main similarities are testing, safe, and safety. The nodes to the individual documents reveal disconnect in their motivation behind these similarities. For the automotive industry, their motivation with testing is to prove the "capability" of their system. The ability to convey safety will be needed not only for the AVs to go to market, but to also be well received by customers. On the other hand, the perspective of safety for the NHTSA is driven by the "public." The top priority of the public is followed by standard creation and impact of deployment. The goals of the NHTSA may not be met given the voluntary nature of their policy. Instead, the automotive industry can define the safe development of AVs to their vision without mandatory evaluation. However, this points to more regulatory action taken by the NHTSA after the industry sharing its innovations. This timeline can create additional reverse salients if the new laws will immediately outdate the released innovations. To avoid these reverse salients, it is important for both the NHTSA and automakers to understand each other's priorities and limitations.

Discussion

The results provided a characterization of the NHTSA and automotive industry and their relationship to each other within a complex technological system. It was determined that the NHTSA allows for the industry to maintain a high level of influence. This means progress in the current work of the industry can largely define the developmental changes to the system. However, the strength of the influence should be considered on a broader level as well. There are other stakeholders within the technological system, such as the public, that can 'check' the influence of the automotive industry. In terms of the technological momentum framework, the NHTSA and automotive industry documents generally describe characteristics within the development and innovation. The overall technological system can continue to go through iterations of invention, development, and innovation, or it may move to transfer at any point. In consideration of transfer, a critical factor to take into account is the public's sense of safety and acceptance of the technology. In this case, the NHTSA is encouraging the automotive industry to demonstrate their technology is safe to the public, but it is not required. If the NHTSA does not initially create laws, public disapproval of certain technological features may be the main reverse salient to emerge in the future.

The characterization of the relationship between government agencies and industry can be applied to various other cases. A similar case today is the relationship between the federal Aviation Administration (FAA) and the use of Unmanned Aerial Systems (UAS) or drones. The increase in innovation with drones has prompted the FAA to make new regulations based on recreational and commercial use. The FAA is concerned with the safe integration of drones into the National Air Space which parallels the NHTSA's concern with AV integration into the transportation system. For both organizations, safety remains a top priority as decisions are made to further the development of their respective systems. (DOT, 2019) On a broader scale, it is important to understand how different system builders interact, their priorities, and their limitations as it will impact the growth and future characteristics of the system.

This analysis is limited as it simplifies the technological system of autonomous vehicles to just the relationship between the NHTSA and the automotive industry as described by select documents. The transportation system and potential integrations with AV technology require changes of artifacts and cooperation between various other organizations. These other changes and stakeholders can influence the NHTSA and automotive industry, but their impacts are not included. In addition, there was a small number of documents analyzed. The focus was on the guidelines posted by the NHTSA, but further research into other actions of the NHTSA may provide more accurate implications with the automotive industry.

In future research, something I would do differently is having a more organized documentation while doing research and analysis. This includes going through data to trying different methods of analysis. In this case, I needed to read through longer documents of text. I often found that I had to go back to what I previously read which wasted time. I realized I need to have a well-defined plan for taking notes on the documents to minimize time spent rereading.

This research will advance my engineering practice especially as I move into the workforce. The quantitative aspect with text analysis or text mining is something I have not done before and it has a variety of applications that may apply to future work projects. On a non-technical level, this research has reinforced my learning in the importance of understanding the relationships between key stakeholders and their values as it can greatly influence a system.

Conclusion

Characterizing the relationship between the NHTSA and the automotive industry revealed the complexity of working within a technological system and the implications of a stakeholder's actions and priorities on its development. The NHTSA described working together with the automotive industry as, "critical for helping policymakers understand the capabilities and limitations of these new technologies, while ensuring that the private sector understands the priorities of policymakers and the issues they face" (DOT, 2018, p.26). The ability to have this understanding is a key aspect in the relationship between innovation and legislation. Future work can explore the complex relationships between the key stakeholders and system builders of other technological systems that will need to be integrated. That will help determine implications on society beyond just transportation.

References

American Vision for Safer Transportation through Advancement of Revolutionary Technologies Act: report of the Committee on Commerce, Science, and Transportation on S. 1885 (2017).

Ford. (2018). *A Matter of Trust: Ford's Approach to Developing Self-Driving Vehicles*. https://media.ford.com/content/dam/fordmedia/pdf/Ford_AV_LLC_FINAL_HR_2.pdf

Geistfeld, M. A. (2018). The Regulatory Sweet Spot for Autonomous Vehicles. *Wake Forest Law Review*, *53*(2), 337–364.

Griffin, M. L. (2018). Steering (or not) Through the Social and Legal Implications of Autonomous Vehicles. *Journal of Business, Entrepreneurship and the Law*, *11*(1), 81-114.

Hicks, D. J. (2018). The Safety of Autonomous Vehicles: Lessons from Philosophy of Science. *IEEE Technology and Society Magazine*, *37*(1), 62–69. doi: 10.1109/mts.2018.2795123

Higuchi, K. (2016). KH Coder 3 Reference Manual. http://khcoder.net/en/manual_en_v3.pdf

Hughes, T. P. (1987). The Evolution of Large Technological Systems. In Bijker, W., Hughes, T. & Pinch, T (Eds.) *The Social Construction of Technological Systems* (50-82). Cambridge, MA: MIT Press.

Ili, S., Albers, A. and Miller, S. (2010), Open innovation in the automotive industry. *R&D Management*, 40,: 246-255. doi:10.1111/j.1467-9310.2010.00595.x

Marletto, G. (2019). Who will drive the transition to self-driving? A socio-technical analysis of the future impact of automated vehicles. *Technological Forecasting and Social Change*, *139*, 221–234. doi: 10.1016/j.techfore.2018.10.023

National Highway Traffic Safety Administration (2017). *Automated Driving Systems 2.0- A Vision for Safety.* Washington, D.C.

U.S. Department of Transportation, & National Highway Traffic Safety Transportation Administration (2016). *federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety.* https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/federal_automated_vehicles_policy.pdf

U.S. Department of Transportation (DOT) (2017). *federal Motor Vehicle Safety Standards; V2V Communications*. Washington, D.C.

U.S. Department of Transportation (2018). *Preparing for the Future of Transportation: Automated Vehicles 3.0.* https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf

U.S. Department of Transportation (2019, December 26). *Press Release – U.S. Department of Transportation Issues Proposed Rule on Remote ID for Drones.* federal Aviation Administration. https://www.faa.gov/news/press_releases/news_story.cfm?newsId=24534

Waymo. (2018). *Waymo Safety Report: On the Road to Fully Self-Driving*. https://storage.googleapis.com/sdc-prod/v1/safety-report/Safety%20Report%202018.pdf

Wood, W et al. (2019) *Safety First for Automated Driving*. https://www.aptiv.com/docs/default-source/white-papers/safety-first-for-automated-driving-aptiv-white-paper.pdf