TECHNOLOGY DEVELOPMENT UNDER UNCERTAINTY: ASSESSING THE IMPACTS OF COVID-19 ON AUTONOMOUS VEHICLE DEVELOPMENT

By

John Parcell

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ABSTRACT

TECHNOLOGY DEVELOPMENT UNDER UNCERTAINTY: ASSESSING THE IMPACTS OF COVID-19 ON AUTONOMOUS VEHICLE DEVELOPMENT

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The introduction of new, transformative technologies into societies has the potential to change nearly all aspects of contemporary life. Existing literature has focused on the presumed benefits that this technology will have for communities using data from community surveys, simulated models, and small pilot programs. However, there is little written about how a large-scale disruption, such as a pandemic, may slow down or accelerate the development of new technology. This dissertation explores how a pandemic influences the speed of the deployment of new technology and the decision-making associated with those processes. Phase one of this research explores how this pandemic impacted technology deployment using key stakeholder interviews completed with individuals associated with the development process of NAIAS 2020 autonomous shuttles. Phase two of this research used the interview data to create a survey tool for a Delphi Study to gain consensus among international autonomous vehicle experts using surveys to determine the extent to which the pandemic response policies benefitted or hindered the technology development process. The findings of the dissertation indicate that the pandemic hindered technology development, however, the development process is long-term, and this topic should be revisited in the coming decade. The legacies of this event will provide guidance that will shape policy formation for managing the impacts of large-scale disruptions.

This dissertation is dedicated to my wonderful wife, Elizabeth and to my parents. Without her I would not have been able to finish this program or apply in the first place. Without them, I would not have the ambition I do now.

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Chapter 1: Introduction

The introduction of new, transformative technologies into society has the potential to change nearly all aspects of contemporary life. One example of a new technology leading the way for a revolution in mobility services is the introduction of autonomous vehicles (AVs). There are different scales of AV development taking place simultaneously across the globe, involving stakeholders from a variety of disciplines. The development process can take decades, and likely will require a significant amount of design and testing before fully autonomous vehicles can take the road. Uncertainty among the stakeholders can have an unknown effect on the development process and the decision-making of the associated parties.

Existing literature has focused on the presumed benefits that AVs will have for communities using data from community surveys, simulated models, and small pilot programs (Bansal & Kockelman, 2018; Fraedrich et al., 2019). In order to gain further insights about how AVs will impact real time traffic developers require pilot programs use to monitor how they function and to understand consumer preferences (Cohen et al., 2018; Stoiber et al., 2019). In order to realize the societal benefits associated with AVs a lengthy development process including high levels of stakeholder participation, funding, and time is required. However, development of new technologies can be sensitive to disruptions, and there is little written about how a large-scale disruption, such as a pandemic, may impact the development process.

1.1 Background

In late-2019 the emergence of COVID-19 began in the Wuhan Province of China, eventually spreading across the world (Cucinotta & Vanelli, 2020). The World Health Organization declared this strain of coronavirus (formally named SARS-CoV-2) a global pandemic on March 11, 2020 (Coronavirus Disease 2019 (COVID-19): Situation Summary, 2020). Following this declaration countries around the world had to make decisions regarding travel and gatherings with the intention of ensuring their populations’ safety. These decisions are focused on restricting the contact between potentially infected people to contain the spread of infection. The consequences of governments placing restrictions on large populations across the world makes the COVID-19 a uniquely unstudied disruption.

Pandemic response included the cancellation or postponement of large-scale events across the world. This includes events focused on deployment of new technologies, including annual auto-shows in Beijing, China; Geneva, Switzerland; New York City, United States; and Detroit, United States. These events rely on diverse, international attendees and global exposure to justify the investment in holding the multi-week events. Furthermore, decisions that mandate long-term quarantines, or limit travel could limit inventiveness, restrict access to resources in the workplace, and even make it more difficult for people to communicate with one another.

1.2 Autonomous Vehicles

I chose autonomous vehicles as the technology of focus for this study due to promised benefits associated with their adoption, including increased traffic flow, energy reduction, safety, and more (Bahamonde-Birke et al., 2018; Taeihagh & Lim, 2019; Yang, 2016). The process of adopting AVs on a widespread scale is unique because it must be beneficial for the industry innovators as well as the population to make the transition easier (Wadud et al., 2016). These benefits include increased regulation, safety, and reducing the burden of the driver. The problem is that there are concerns over the extent of what the benefits may be once AVs begin to infiltrate public traffic systems on a widespread scale (Bahamonde-Birke et al., 2018; Taeihagh & Lim, 2019).

The benefits of increased adoption are that there will be more data to analyze to review existing regulations. For the automotive industry increased demand and based on the sale of AVs will increase the number of AVs on public roadways (Wen et al., 2019). For industries to fully optimize the benefits that they may gather from selling AVs there must be an external regulatory framework in place to help communities adopt new technologies (Taeihagh & Lim, 2019). The more that individuals ride in AVs the more feedback they can provide to industry professionals so that they can adjust to work together to ease the transition period (Wen et al., 2019).

Some benefits will impact society at the community level, such as overall road safety and traffic patterns (Ruggeri et al., 2018). Existing literature indicates that the direct effects of increased road safety will be positive for society (Bahamonde-Birke et al., 2018). Different cultures have different opinions of how AVs will impact overall driver safety. However, the United Kingdom suggests that the highest level of benefits is related to keeping people safe (Taeihagh & Lim, 2019).

Individual benefits of AV adoption generally focus on the reduction of the burden for the driver both cognitively and physically (Singleton, 2019; Wadud et al., 2016). The lack of a physical vehicle operator means that there is the potential for riders to increase their productivity while travelling and that more groups of people will have access to new mobility solutions (Singleton, 2019). The assumptions of potential users are important for understanding validating potential policy solutions to help increase adoption (Singleton, 2019). This data helps industries refine their products with user feedback to increase the provision of services over time as well (Wen et al., 2019).

1.3 Research Questions and Anticipated Findings

Due to this ongoing pandemic I analyze the impact that decision-making will have on the outcome of in the face of a pandemic technological development. This research has two research goals to explore these impacts:

1. Uncover the early impacts that the onset of the COVID-19 pandemic will have on the deployment of new technology, particularly those that are intended for public use.
2. Explore how various stakeholders and public officials can work to mitigate the negative effects that disruptions can have on the technology development process.

This paper uses the 2020 North American International Auto Show (NAIAS) as a starting point for the first phase of the study in order to explore the larger technology development process of AVs. This event was chosen as a framing device because it encapsulates the development process for new technologies from the inception phase to the testing phase. Additionally, there is a diverse group of stakeholders involved in the development of AVs associated with the event that could be contacted to participate in data-gathering. The event is unique because the anticipated attendance of 800,000 includes international attendees who may be affected by COVID-19. NAIAS also anticipated showcasing public-use, on-road autonomous vehicle demonstrations until event officials postponed the 2020 event until 2021. This study is unique because it will examine how the COVID-19 outbreak limits the development process due to travel restrictions, lack of airline services, increased spread of the virus, and elimination of a demonstration platform in real time.

The second phase of the study It is anticipated that the findings from this event will demonstrate how pandemics interrupt technology deployment using the COVID-19 and the 2020 NAIAS as a starting point. It is hopeful that the data gathered from this study can be translated to the development of new technologies under uncertainties on a global scale. The legacies of this event will provide guidance that can shape policy formation for managing the impacts of future large-scale disruptions. This also includes ways use new technologies to help mitigate the negative effects associated with the event. This research will be relevant for helping public officials prepare for what may happen to the development of new technology during an on-going pandemic.

Chapter 2: Literature Review

The purpose of the literature review is to examine two concepts related to this study:

1. Policies intended to mitigate the effects of a pandemic.
2. The development process of new technologies.

The third section of this literature review is composed of four case studies of pandemics and a discussion of how they have impacted the development of technologies. The intention of this section is to tie together the concepts listed above. These case studies will also help frame how this research will fit into the existing literature.

The literature review section of this research paper provides background information on two main research goals. First, the rationale for implementing different response policies for handling a large-scale public health crisis, such as the COVID-19 pandemic, will be evaluated. The Covid-19 pandemic has generated global change; thus decision-makers are responsible for identifying solutions to the problem. When responding to a global pandemic the focus shifts to not only how policymakers can contain the virus, but what negative ethical and economic effects are associated with these policies.

The second section of the literature review discusses how new technologies are developed. These steps range from the formation of the individual idea through the final deployment. This section provides a theoretical framework showing how technology is developed in order to examine areas where pandemic response policies may interrupt each stage of development.

The third section ties together sections 2.1 and 2.2 by providing historical case studies that demonstrate how technology and pandemics have interacted over time. There is little recommended for ways to study policymaking during large disruptions and historical context will help increase understanding of how these concepts are intertwined. Finally, the last section is a synthesis of the literature sources for each section, including a table showing how specific pandemic response policies impact the different stages of development.

2.1 Decision-Making Frameworks for Pandemics

A pandemic may be classified as a crisis because the existing resources, laws, and policies in place may not be sufficient to deal with the effects of the situation (Bryson, 1981). The declaration of a pandemic will indicate large changes that should occur regarding how a society is forced to operate (Kassens-Noor, 2019). Pandemics also occur at unpredictable times and the chemical composition and mode of replication varies for each individual virus (Gelderblom, 1996). Individual crises are not well understood and thus neither are the ways to respond to pandemics.

The process of deciding which type of policy to implement in response to a pandemic includes assessing numerous variables, such as who is affected and what the policy ultimately impacts. These variables mean each policy can have a varying degree of how successfully it can "flatten the curve", or slow down the rate of infection (Matrajt & Leung, 2020). Implementation threshold and community compliance are factors that further complicate planning efforts and have the potential to entirely de-rail mitigation strategies (Davey et al., 2008). Not all responses can be the same and in order to understand the repercussions of a decision there must be an evaluation framework.

Unfortunately, a uniform framework cannot be used because problems can vary based on the amount of change they can create and the knowledge of the situation by the decision-makers (Braybrooke & Lindblom, 1963). Before we can establish a way to evaluate decisions, careful attention should be spent determining the effects of the problem at hand. Braybrooke and Lindblom (1963) outline four types of decisions that account for these variables:

1. Decisions that generate small changes that are made with knowledge of the situation.
2. Decisions that generate large changes that are made with knowledge of the situation.
3. Decisions that generate small change that are made with little knowledge of the situation.
4. Decisions that generate large changes that are poorly understood.

Pandemics fall into the fourth category described by Braybrooke and Lindblom (1963) because of their high degree of unpredictability and variability of viral composition (Gelderblom, 1996). There is limited theory generated for how to plan for circumstances of uncertainty and there are few decision-making frameworks on how to respond to these crises (Kassens-Noor, 2019). This section highlights possible response policies that have been developed over time to slow the spread of a pandemic including what they are, what variables are associated with the spatial-controlled policy, who it impacts, and potential shortcomings. The policies discussed in detail in this section are as follows:

1. *Self-Quarantine*: Self-quarantine is a voluntary measure where individuals may place themselves in quarantine if they believe they are infected or have come into contact with an infected person until proper testing may be completed (Hollingsworth et al., 2011; Oshitani, 2006; Zhao & Feng, 2020).
2. *Travel Constraints*: Travel constraints refer to the limitation of flights, trains, or other public transit methods to eliminate inter- and intra-population contact (Bonaccorsi et al., 2020; Chinazzi et al., 2020; Falk & Hagsten, 2020).
3. *Location Closures*: Local closure is the systematic closure of potentially high-risk transmission locations, such as restaurants, schools, and retail shopping centers (Chin et al., 2020; Markel et al., 2007; World Health Organization Writing Group, 2012).

4. *Cap on Gatherings*: Limiting gatherings refers to the cancellation of large gatherings, even if they are located outside. For instance, religious pilgrimages, concerts, and other venues where people may be in close contact (Quadri, 2020; Steffen et al., 2012; Tam et al., 2012).
5. *Shelter in Place*: Shelter in place, or community quarantine, policies are a stricter version of self-quarantine. This policy refers to when entire communities may be encouraged to stay at home, rather than just those who are infected (Kelso et al., 2009; Markel et al., 2007; Spitale, 2020).
6. *Complete House Arrest*: Complete house arrest refers to a mandatory stay at home order where people are not allowed to leave their homes except for emergencies. At this phase there may be fines or surveillance mechanisms in place for enforcement (Cook & Cohen, 2008; Marais & Sorrell, 2020; Zurayk, 2020).

2.1.1 Self Quarantine and Social Distancing

The first strategy to mitigate the effects of a pandemic is to implement preventative measures to reduce the contact between members of the community (Hollingsworth et al., 2011). Isolation may occur in two ways: individuals removing themselves if they are believed to be symptomatic and individuals removing themselves if they have come into contact with an infected individual, but who do not yet have symptoms (Oshitani, 2006). There are proven studies that show isolation and social distancing are an effective preventative measure against a virus in the early phases of its introduction (Agusto, 2013; Kelso et al., 2009; Matrajt & Leung, 2020). However, there remains little research available about how to determine the timing and duration of these measures and the data to support implementing long-term isolation policies remain weak (Baum et al., 2009). This section covers the different types of self-quarantine that may be implemented rapidly during a pandemic and the shortcomings related to the policies.

The variables associated with deciding which of the two isolation policies to adopt include the timing of its adoption, which members of the population must be included, and the duration of the isolation policy. Intrapopulation interventions perform better than interventions between various communities if the response is rapid (Wang et al., 2012). If the response is not fast enough then more restrictive isolation techniques must be adopted to cut off contact between potentially infected individuals and their coworkers or classmates (Halloran et al., 2008). Finally, the duration of the policy must be established to ensure the spread is contained. The USA national pandemic plan dictates that 12-weeks is the recommended maximum duration of this type of intervention, however, in severe instances this may need to be extended to eliminate potential second waves (Hollingsworth et al., 2011). Each of these variables may continually be changing due to the movement of people within the community but once the spread of the virus is determined then the intensity of the intervention can be determined through policy solutions.

Strategies on isolation can affect individuals, groups, and entire communities through patient isolation or voluntary isolation of all community members (Wang et al., 2012). Since it is difficult to ensure compliance with all community members it is suggested that isolation may work best in combination with other pandemic mitigation strategies (Wu et al., 2006). On the macro-level the best strategy is social isolation of all groups within the community while treating the individuals who are infected throughout the whole community (Davey et al., 2008). In combination with isolation policies, individual workplaces that carry out essential tasks can participate in work-place isolation as well by staggering arrival times and encouraging that workplaces bring in 50% of their employees at a time (Halloran et al., 2008; Marshall et al., 2009; Zhao & Feng, 2020). Staggering when restrictions are lifted for everyone can help avoid second waves of infection by slowly building up immunity for the community as a whole (Zhao & Feng, 2020).

Self-quarantine and social distancing measures may be included in contemporary planning practices to mitigate pandemics, but the logistics of implementing them continue to be a challenge (Markel et al., 2007). Shortcomings related to isolation policies include economic, governmental, and success-related concerns (Andradóttir et al., 2011). Poorer residents are less likely to agree to participate in voluntary isolation because of a lack of long-term job security and familial resources (Baum et al., 2009). If the government mandates isolation in a more severe manner than voluntary isolation then trust in the government and community may erode if they do not ensure that plans are made for delivering essential provisions to the community (Aledort et al., 2007; Baum et al., 2006; Olivera-La Rosa et al., 2020; Wu et al., 2006). Furthermore, social isolation does not always result in long-lasting success or immunity to the pandemic and once controls are lifted there is the potential for a second wave of the virus (Hollingsworth et al., 2011; Kelso et al., 2009; Zhao & Feng, 2020). Social isolation is one of the least restrictive measures of intrapersonal interventions. However, the low long-term success rate and these concerns indicate a level of risk with mandating this policy.

2.1.2 Constraints on Travel

While social isolation may be an early choice for a mitigation strategy for intra-population containment, once the infection spreads outside of specific geographic confines inter-population solutions must be implemented. Similar to social isolation, constraints on travel is a policy that should be implemented early to reduce the spread across geographic boundaries (Wang et al., 2012). Research shows that new viral strains can move rapidly across the globe due to increased efficiency and volume in transportation technology, such as airline travel (Brownstein et al., 2006). Travel restrictions have a beneficial effect in stopping this rapid movement and potentially total incidence (Camitz & Liljeros, 2006). However, similarly to social isolation, there are variables that must be addressed before implementing policy solutions.

Determining when to introduce travel restraints and if they should be combined with other mitigation policies must be decided when implementing this strategy. The timing of limiting regional or international travel early on during a period of sickness will strongly reduce the probability of viral strains being introduced to new communities (Brownstein et al., 2006). However, unlike intra-population containment strategies inter-population strategies are less affected by late response times because they are not as closely tied to the socio-economic intricacies of isolating groups within a community (Wang et al., 2012). Combining these tactics, and isolating travelers after their introduction to a new location, increases the effectiveness of this strategy (Falk & Hagsten, 2020; World Health Organization Writing Group, 2012). The addition of travel constraint policies provides a secondary layer of mitigating the widespread spread of infection. However, there are still shortcomings with this strategy in the increasingly globalized world (Bajardi et al., 2011).

Travel restrictions are the most beneficial to implement for municipalities that see large numbers of travelers or ones that have a higher fiscal capacity (Bonaccorsi et al., 2020; Falk & Hagsten, 2020). Municipalities that rely on connectivity and mobility for their economy will be more directly impacted by a travel restriction policy (Bonaccorsi et al., 2020). However, in larger nations this may vary to some extent since the travel restrictions will impact populations that depend on long distance travel for resources that are necessary for living (Kraemer et al., 2020). This indicates that larger nations need to restrict travel across their country similarly to how smaller nations would restrict travelers from outside of their country. The effect of travel restrictions is evident during the COVID-19 pandemic when the distribution of the spread matched mobility data from within the country (Kraemer et al., 2020).

The effectiveness of implementing a travel ban can be undermined by the social, constitutional, and logistical consequences of such a drastic measure (Brownstein et al., 2006). For instance, in some countries, limiting travel is considered unconstitutional and cannot be mandated by the government and furthermore essential professions must be exempt from even the loosest travel restriction recommendations (Camitz & Liljeros, 2006). Travel bans for extended periods of time may cause further social unrest as well. During the Ebola outbreak in West Africa the short travel bans only postponed the spread of Ebola across regions by a few extra weeks (Poletto et al., 2014). Furthermore, in the case of COVID-19, by the time the travel ban took effect in and out of Wuhan, China the virus had already spread through other cities in China and did not effectively contain the spread (Chinazzi et al., 2020). Policymakers must decide if they must risk the anger of their citizens in the supposed good of public health and if this decision does not happen fast enough travel constraints will be ineffective regardless.

2.1.3 Constraints on Location

A further restriction of limiting gatherings within communities is to close specific public locations. Examples of locations may include highly frequented public places such as schools, public parks and amenities, gyms and entertainment venues (World Health Organization Writing Group, 2012). In the instance that infections are still able to spread despite minor closures further measures must be implemented, including closing larger venues such as churches and even public municipal meetings (World Health Organization Writing Group, 2012). In the event of such school closures this non-pharmaceutical intervention may be advertised as a partial form of mandatory quarantine for some members of the community (Effler et al., 2010). Using these tactics in pandemic planning comes with considerable risk if careful enough consideration is not taken to prepare the community for the negative effects associated with the closures (Cauchemez et al., 2009; Halloran et al., 2008).

Two common types of location closures that often happen in conjunction are public gathering events and schools (Markel et al., 2007). The closure of schools (public, private, and daycares) has been proven to be highly effective in limiting the excess death rate during pandemics since students are able to stay at home and eliminate community contact (Halloran et al., 2008; Markel et al., 2007). School closings are especially effective if there is no pre-existing immunity since they eliminate a regular meeting platform for members of families across the whole community (Gojovic et al., 2009). Additionally, in many instances community members indicate that they are in favor of closing schools to deal with levels of student and staff absences that may already be caused naturally by the pandemic (Chin et al., 2020; Johnson et al., 2008). These studies provide evidence that pre-emptive closures can help to mitigate the negative effects of pandemic response strategies since policy makers are able to strategically designate the parameters of their policies (Cauchemez et al., 2009; Gemmetto et al., 2014).

Once the parameters of the location closure policy are determined the policy really impacts student populations, stopping the regular contact of large groups of the population. As discussed above, school children are some of the most likely to be impacted by the closure of their schools (Chin et al., 2020). Parents who have school-aged children will be the next group impacted by this if countries do not offer childcare subsidies (Chin et al., 2020). Depending on the extent of location closures communities will experience small businesses being the first section of the economy that is impacted by the policies. Small businesses are financially fragile compared to larger corporations or franchises and are likely to lose the most business if they must close for any period of time (Bartik et al., 2020).

Mitigating the potential negatives of closures of specific locations is difficult across different communities due to their varying socio-economic compositions. For example, school closures are more difficult for low-income households who may face economic strain if the closure lasts for long periods of time (Cauchemez et al., 2009). Furthermore, the closure of special education programs can create a gap of specialized educational and physical activity platforms for families in need (Yarımkaya & Esentürk, 2020). The location of the community where closures occur is also important for determining how they should be implemented. Rural communities have greater success with closing public spaces because group contacts are less frequent in areas with smaller populations (World Health Organization Writing Group, 2012). Despite the economic burden deciding when to extend community closures is a crucial part of maintaining their success. Once mandatory closures are relaxed to any extent their effects stop, so policymakers must carefully choose when they decide to re-open their communities (Cauchemez et al., 2009).

2.1.4 Put a Cap on Gatherings

A stricter response than closing public gathering places is putting a cap on mass gatherings (MGs) to limit the number of people that are at a specific site simultaneously. This is more difficult to manage because the definition of a mass gathering can vary based on the event and the group of attendees can differ greatly (Memish et al., 2012). Little consensus exists on the attendance of a gathering for it to be considered a MG, varying anywhere from approximately 1,000 to 25,000 people (Memish et al., 2012). The World Health Organization (WHO) defines MGs as any occasion that brings in so many people that it puts a strain on the existing planning and response resources of the host venue (Tam et al., 2012). Since no singular solution exists for how to respond to the spread of disease at a MG the WHO definition is the most appropriate to examine how to plan for MGs since it already implies that there will be a strain on local resources (Steffen et al., 2012). This section covers what features of MGs can lead to the spread of sickness and what planning efforts can be made to prevent that.

Despite these concerns with MGs as a hub for global travelers there are preventative planning measures in place to mitigate threats to public health. Preparatory actions for host communities to take for MGs include contingency planning, increasing communication bandwidth, training, and providing adequate staff and equipment (Lim et al., 2010). Increases in technology have enhanced the effectiveness of these planning measures by providing more rapid responses for on-site testing and increased surveillance and tracking systems of travelers who test positively (Haworth et al., 2010). This also includes providing medicine on site in the instance that travelers or members of the host community fall ill (Memish et al., 2012; Tam et al., 2012). Refining these preventative measures over time also requires on-going development and consultation with the local community to ensure that they are culturally appropriate, particularly for communities that host religious pilgrimages (Khan et al., 2010; Massey et al., 2009).

The problem with planning a MG during a potential pandemic is that there is no precise way to determine how they may amplify the spread of sickness or where the sickness originates (Steffen et al., 2012). Additionally, the spread of the virus could occur two ways: from the travelers into the host community and from the host community to the travelers, which consequently may spread it in their home communities (Tam et al., 2012). Careful surveillance of where the virus originates from during a MG is important for tracking how viruses spread globally. However, this may be increasingly more difficult for periods of high travel like religious pilgrimages that occur during holidays because there is already a global increase in air and land travel (Haworth et al., 2010; Khan et al., 2010). This holiday traveling can lead to a second peak that may occur far after the travelers return to their local communities depending on the incubation period of the viral strain (Shi et al., 2010).

Preventative planning may help to mitigate some hazardous effects of holding a MG during a pandemic situation. However, there are additional variables such as duration and type of event, crowd size, and mobility that may make holding any MG a potential risk (Steffen et al., 2012). The average demographic of the crowd may significantly impact viral transmission as well. For instance, a population of predominantly elderly visitors at an event such as the Hajj may have a much higher number of fatalities than an event such as a sporting event (Quadri, 2020; Steffen et al., 2012). Policymakers must use this information to postpone, cancel, or carefully screen MGs if a new virus like COVID-19 emerges in the months leading up to the event (Quadri, 2020; Tam et al., 2012). While some MGs have annual expectations of how they will operate based on lessons learned over decades of holding the event there is always the potential for a new disruption to make cancellation the safest choice (Memish et al., 2012).

2.1.5 Shelter in Place

An increasingly intense intra-population mitigation strategy is to enforce a mandatory "shelter in place" order to isolate households from one another. Shelter in place can be implemented in two ways: complete isolation of ill persons and complete community-wide quarantine (Markel et al., 2007). Unlike self-quarantine, these shelter in place orders have the potential to impact communities as a whole rather than only individuals and they are assumed to be mandatory in nature (Markel et al., 2007). This policy can vary from location to location, even within the United States. Prior to COVID-19, eighteen (37%) states have the ability to mandate the closure of academic institutions and businesses during outbreaks and 15 (31%) states have the legal ability to mandate quarantine for their residents (Holmberg et al., 2006). Unfortunately, because this is a more severe strategy for isolation this policy is subject to the same shortcomings and vulnerabilities as the previous strategies.

The level of mandatory quarantine depends on how severely the rate of infection has spread. If measures are implemented early in a pandemic then smaller, local level interventions may be all that is needed to stop active clusters of diseases from spreading (Kelso et al., 2009; Spitale, 2020). However, more people may need to be included in this level of intervention if there is an actual risk that a disease is spreading at the global level (Spitale, 2020). The broader these mandatory quarantine policies are the more people within each community they will impact. Once the pandemic reaches global spread every level of society will be impacted by the effects of the pandemic, and this will include response policies until the spread of the disease is controlled (Shields et al., 2020).

The WHO recommends that when people become symptomatic quarantine should take place, however, forcing this on the population may ultimately become impossible to manage (Shields et al., 2020; World Health Organization Writing Group, 2012). Mandatory shelter-in-place orders can be seen as draconian by some groups of the population and states may worry that implementing them could be interpreted as a negative impact on personal freedom (Kelso et al., 2009). States that have the ability to legally close businesses must also provide financial support for individuals who have lost income (Braunack-Mayer et al., 2010; Holmberg et al., 2006). Additionally, rapidly implementing quarantine when it is the most effective can create civil unrest if the policy is implemented before the public is able to be informed about why the mandates are being put into effect (Braunack-Mayer et al., 2010; Spitale, 2020).

The use of a community-wide quarantine has the potential to substantially reduce the risk of an arrival of a pandemic or at minimum provide time to introduce new pharmaceutical interventions (Nishiura et al., 2009; Rosenfeld et al., 2009). When implemented rapidly and for the appropriate amount of time these rigorous measures will help communities avoid the worst-case scenario of a pandemic (Kelso et al., 2009). According to modeling completed by Kelso et al. (2009) and the WHO (2012) this could mean containing the disease by 90% to potentially 98%. Unfortunately, the timing of these measures is particularly sensitive and there is the potential for significant error with this strategy. Despite its potential for high levels of success, sheltering-in-place represents more significant concerns than other intra-personal containment policies due to its severity.

2.1.6 Complete House Arrest

Complete house arrest is the most restrictive measure for keeping people isolated during a pandemic in an effort to control the spread of a disease (Cook & Cohen, 2008). This policy is an aggressive response for state decision makers to choose because mandatory quarantine must also be followed community-wide, even at hospitals or nursing homes where patients who fall ill receive care (Cook & Cohen, 2008). However, house arrest has the potential to be the most effective response policy by severely slowing the pace of transmission and greatly limiting the number of patients who need to be sent to hospitals for treatment (Ciuriak & Fay, n.d.). The problem with a policy that is restrictive is that the number of variables greatly increases from household to household, particularly that the conditions of homes and amenities may vary which complicates how effective this policy can be (Orset, 2018). In instances where complete house arrest is the only way to stop the spread of the virus the policies must carefully detail how to enforce the policy and how to manage the consequences (Atangana, 2020; Zurayk, 2020).

Once the duration of the house arrest is established there must be a framework in place to enforce the order. People are less likely to comply with longer quarantine policies (greater than seven days) than they are for shorter quarantine policies (less than seven days) and thus there must be a way to monitor if people violate the order (Orset, 2018). Neighborhood surveillance cameras are a way to improve the likelihood of catching people who violate the orders; however, this is not a punishment mechanism (Lipsitch et al., 2011). Some countries have implemented a fine system for visitors in addition to a short prison sentence (Cook & Cohen, 2008). Enforcing penalties creates a problem for nations concerned with infringing on civil liberties (Braunack-Mayer et al., 2010). Alternatively, other countries like Singapore have implemented stricter penalties for violating quarantine. Residents who violate quarantine once are provided internet-connected cameras so that the person can report their health status or even are electronically monitored through tracking bracelets to enforce house arrest (Cook & Cohen, 2008).

Prolonged house arrest with proper enforcement mechanisms can eliminate pandemics within local settings (Marais & Sorrell, 2020). However, each individual within the community may be impacted by the house arrest policies in a different way. Small households are more likely to slow down the outbreak during a total stay at home policy because there are fewer variables associated with the individuals within the home (Sjödin et al., 2020). Larger households, public housing, and households who have individuals who must go out in public will need a longer lock down period and may be more negatively affected by the house arrest policy (Sjödin et al., 2020). Additionally, this may have less of an impact on wealthier communities compared to low-income communities where people do not have the monetary resources to stay at home (Zurayk, 2020). Negative impacts may also be exacerbated in food deserts where people need to rely on transit for food or lack access to healthy food options (Zurayk, 2020).

Similar to the other policies listed above a complete house arrest order has significant criticisms that make it difficult to continue for long periods of time. Once the timeline and the enforcement mechanism are established then there must be adequate provisions in place to set up home offices and keep people comfortable in their home with adequate medical provisions or food (Bastos & Cajueiro, 2020). Ultimately, regardless of the difficulties with enforcing such a severe policy there are legal mandates for doing so. According to international law the protection of public health is a legitimate reason to limit human rights in severe circumstances and public health is an inherent right that must be protected (Abeyratne', 2006). If implementing a complete house arrest policy is the only way to stop the spread of illness during a pandemic it must be considered once the appropriate safeguards are in place and policymakers can ensure that the pros outweigh the cons.

2.2 Technology Development Process

Technology development is the process of developing new knowledge, design and manufacturing processes, and eventually a final product (Cooper, 2006). This four-stage process intends to set the foundation for future corporations to build from moving forward (Cooper, 2006). The development process generally contains the following steps, although they may vary from project to project:

1. Inception: The generation of a new idea (Cooper, 2006).
2. Design: Creation of an outline for the product and process meant to fulfill the end goal (De Wagter et al., 2018).

3. Testing: Evaluation of the new technology in the field to ensure that the product works (Winkle et al., 2018).
4. Deployment: Distribution of a new product or process for widespread use (Chen et al., 2016).

This section discusses each one of these steps in detail, including the variables and stakeholders that should be involved throughout the duration of the process.

2.2.1 Inception

The development of new technologies starts with the generation of a new idea (Cooper, 2006). This first phase, the inception (vision) phase, is necessary to build the foundation of a new project and determine the amount of financial and research resources needed to follow through on the idea (Cooper, 2006). This section will discuss how existing resources can generate new ideas in two ways: first, utilizing existing research to improve technologies, and second, combining existing technologies with new ideas to build off of their current capabilities (Gonzalez-Salazar et al., 2016; X. Wang et al., 2012). This includes beginning initial research from the same literature sources, laws, and regulations that currently exist to outline the conceptual framework for new technologies to operate in (Simmons et al., 2015). Once this foundation is established the technology road mapping can begin to move the plan forward (Cooper, 2006).

Once the theoretical framework is established a review of the capabilities of existing technology and how it may be improved must be conducted. On a macro level this can include modifying an entire concept, such as how drones and unmanned aerial vehicles (UAVs) have evolved from commercial aerial vehicles (Li et al., 2018). Similarly, autonomous vehicles are evolving from existing motor vehicles, although the overall product also requires technology to allow for the vehicle to think for and navigate itself (Fadlullah et al., 2017). Evolution like this requires stakeholders who develop learning algorithms, censors, and cameras to collaborate on how their technologies lead to the creation of a new overall product (Fadlullah et al., 2017; Gonzalez-Salazar et al., 2016). The advancement of production services and individual technology components have the potential to help facilitate the inception of new technologies through collaboration (Szalavetz, 2019).

The final phase of the inception stage is to identify the end goal for the development process and how the research process must be shaped to meet that goal (W. Chen & Xu, 2010; X. Wang et al., 2012). The research process includes recognizing the areas of research and markets that will be affected by the final deployment (Maloney et al., 2020). Identifying potential secondary effects of deploying new technologies must occur during the inception phase in order to minimize any negative distributive outcomes that occur during development (Huenteler et al., 2016). Once the stakeholders are identified, the roadmap for development is completed, the end goal is identified, and proper safeguards are in place then the development process can proceed past the inception phase.

2.2.2 Design

Following the inception phase the next step is to build off the ideas in the first step and begin to design the technology to meet the end goals (De Wagter et al., 2018). If the new technology is based off existing technologies, then the design may be improved from what currently exists. New designs can improve inefficiencies with previous designs or can be adapted to include new programming or machine components (De Wagter et al., 2018; B. Wang et al., 2016). However, this is a process that requires researchers and developers to get feedback to ensure that the design is feasible (Matthew-Maich et al., 2016). The feedback process must be set up to allow a smooth exchange of information to keep the design process efficient and the stakeholders involved (Wen et al., 2019).

The design process is further shaped by needing to focus on the human element of products to improve usability upon deployment (Cárdenas et al., 2020). Involving users during the early stages of development and understanding how people will interact with the technology has the potential to save time and costs at the end of the design stages (Tremoulet et al., 2020). The rationale behind this human-centered design is that technology can be changed more easily during the beginning stages of development than human users can be upon final deployment (Cárdenas et al., 2020). In the case of AVs and other mobility services this includes having to focus on design factors for the world where these services will operate (Harrow et al., 2018).

The final stage of designing a product before entering the testing phase is receiving feedback from potential users to make more adjustments and improve the product (Gil et al., 2015). Gathering feedback can be accomplished without needing to use the technology in a lab setting. Potential users can provide feedback through focus groups and interviews that provide data for researchers to build upon (Tremoulet et al., 2020). These datasets can isolate design variables that are important to the users that will be necessary for testing in the future (Kato et al., 2015; Stone, 2004; B. Wang et al., 2016). The results from these feedback sessions are a starting point for this phase of development. There will be more research efforts needed during the testing phase that will produce more data to support full deployment (Tremoulet et al., 2020).

2.2.3 Testing

The penultimate phase of development is testing the new technology in the field to ensure that the product works as initially planned. Testing the system requirements builds confidence for both the manufacturer and the public (Winkle et al., 2018). Testing can be completed for both individual pieces of new technology and on the final product as a whole (Ziegler et al., 2014). Over time testing generates theory for how technology should operate under ideal conditions and provides an opportunity for new technology to be compared to the accepted norm (Hadsell et al., 2009). Once the full product is ready to be tested in the field different teams can begin isolating factors to advance different areas of the field prior to the deployment phase (Mersky & Samaras, 2016; Ziegler et al., 2014).

Testing can occur in two phases: lab testing and testing in the field. Testing in lab settings allows for safe development because the technology is operating in situations where all variables can be controlled other than those being tested (Winkle et al., 2018). Lab testing in some instances can rely on modeling and demonstrations that use computer simulations to show how the technology would function based on existing data (Elkins et al., 2010; Markkula et al., 2018). Modelling software has improved to the point where virtual testing can include new variables like human interaction by using real recordings of something like road traffic and pedestrian crosswalks (Markkula et al., 2018). However, lab testing can also include physical demonstrations. For autonomous vehicles an example of lab testing includes using air tunnels so that data can be gathered to determine if the design of the vehicle's body can hold up in real world scenarios (Lyu et al., 2018). However, lab testing can only go as far as simulating the real-world scenarios and eliminating any remaining concerns before real-world testing (Lyu et al., 2018).

The autonomous vehicle programs at the 2020 NAIAS event fall under the field-testing category of technology development. Once testing in the real world begins there are more variables that must be accounted for. Even if preliminary lab tests indicate that a new technology is ready for human interaction there is no guarantee that this will be held up throughout the deployment (Markkula et al., 2018). People must be involved in the real-world testing because all people use technology in a different way and at a different level of efficiency (Mersky & Samaras, 2016; Ziegler et al., 2014). Unfortunately, gathering large amounts of people together for long periods of interaction for the entire duration of the testing phase is not likely to be possible (Stoiber et al., 2019). This shortcoming is especially true for AVs, which researchers state may need to be tested for millions of miles over several years before accepting that they are safe to deploy (Kalra & Paddock, 2016). Real-world testing is necessary where there is a need for a new variation of testing procedures that can be used to assess how ready technology is for deployment in a more efficient manner (Kalra & Paddock, 2016; Mersky & Samaras, 2016).

2.2.4 Deployment

The final phase of new technology development is the deployment of the technology for widespread use and adoption. At this phase most of the design and testing work has been completed, however, there is still work to be done to optimize the deployment (Chen et al., 2016). Deployment involves a new level of stakeholders that have been minimally involved thus far. This includes bringing in firms to spread the new technology into the appropriate market through advertising and awareness campaigns (Narasimhan et al., 2006). Advocacy groups also can play an important role in the diffusion of new technologies by influencing groups of people to use new technologies that meet their needs (Kim & Urpelainen, 2013).

The involvement of these groups also requires that the proper frameworks are in place from a regulatory and infrastructural viewpoint. The infrastructure frameworks include the secondary technologies that are needed to promote adoption (Chen et al., 2016). For example, electric vehicles require that charging infrastructure is in place before they can be used for long-range travel (Chen et al., 2016). Different countries and even states within the United States have different regulatory requirements that impact deployment of technologies as well (Fischlein et al., 2010). To an extent, the success of a deployment ultimately depends on the socio-political context of a specific location (Fischlein et al., 2010). These variables indicate that, despite the work put into the development process, there may be unforeseen challenges in the final stages.

The deployment phase potentially can take years to completely fulfill depending on the extent of the deployment and the economic resources needed to do so (Xia, 2011). Beyond regulatory uncertainty and lack of appropriate infrastructure there are more factors that can potentially impede deployment. Readiness, on behalf of the users, may resurface as a problem if the developers failed to gather enough input during the design process (Xia, 2011). Furthermore, market competition between teams that are in a race to finish their development processes at the same time potentially may further complicate how successful deployment is (Xia, 2011). The development process is meant to streamline the delivery of advances in new technologies, however, there are problems that may come up at any phase due to the amount of time, monetary resources, and stakeholders involved throughout the entire process.

2.3 Impact of Pandemics on Technology

This section examines how technology has played a role, either positively or negatively, during a pandemic. This includes examining how improvements in technology have helped to proliferate the spread of infection or reach new geographic areas, increase monitoring for infected individuals, and improve the speed of communication across populations. The three pandemics and associated technologies discussed in this section are:

1. The Spanish Flu (1918-1920) and steam locomotives.
2. Severe Acute Respiratory Syndrome (2003) and thermal and video surveillance.
3. Middle East Respiratory Syndrome (2012) and Web 2.0 technologies.

4. Covid-19 (2019-present) and mobility solutions.

2.3.1 Spanish Flu (1918-1920)

The Spanish Flu (1918 influenza pandemic) is one of the most severe pandemics to spread across the globe. The pandemic, caused by the spread of an H1N1 virus, caused the death of approximately 670,000 Americans and over 100 million people worldwide in three waves from 1918 through 1920 (Chandra et al., 2013; Jodelet et al., 2020). The spread of the virus vastly increased because of urbanization and the dispersion of military troops throughout the world (Ammon, 2001; Chandra et al., 2013). The rapid deployment of new mobility services facilitated the spread of infection during the time period when the virus first emerged (Jodelet et al., 2020). The unexpected spread the Spanish Flu into new global regions through long-range road transportation vessels indicates a lack of identifying potential negative secondary effects during the inception phase of steam locomotive development (Ayoola, 2011; Huenteler et al., 2016).

The Spanish Flu spread to many new countries through ports in coastal cities. Passengers and crew who were infected then spread the virus to locations in Africa and Asia that were located far away from the point of origin for the virus (Ohadike, 1991; Patterson & Pyle, 1991). Advancements in steamship technology greatly increased the chance of coastal spread by moving people from port to port more rapidly if the virus is still present or incubating in travelers lungs (Patterson & Pyle, 1991). The rapid spread of disease is an example of a negative distributive outcome during the development of steamships is a secondary effect of achieving faster travel (Huenteler et al., 2016). Some communities attempted to account for this by implementing quarantine periods for travelers, but the varied time of implementation and duration of quarantine created room for error (Bajardi et al., 2011; Hollingsworth et al., 2011; Ohadike, 1991).

Unfortunately, the increase in ship capacity and travel speed led to large number of influenza carriers to move around port cities before they were aware of how broadly the disease was spreading (Ohadike, 1991).

The installation of necessary travel infrastructure, such as railroad lines, that made transcontinental travel possible also further facilitated the movement of people to remote regions of the world (Chen et al., 2016; Patterson & Pyle, 1991). Furthermore, the existing railroad infrastructure allowed for more advanced locomotives to be placed on existing routes and increase the efficiency of the existing system (Patterson & Pyle, 1991). The problem occurred in places in isolated rural communities, such as the Ozarks in the United States, who experienced spikes in cases because the development of their railroad infrastructure coincided with the first phase of the Spanish Flu (Dicke, 2015). Other global factors, like wartime disruption, migrant populations, and the European conquest of Africa may have increased travel, but the development of faster modes of transportations without any safeguards for protecting the host regions led to an increased spread of the Spanish Flu (Ayoola, 2011; Ohadike, 1991; Trilla et al., 2008).

2.3.2 Severe Acute Respiratory Syndrome (SARS) (2003-Present)

Severe Acute Respiratory Syndrome (SARS) is a respiratory disease that appeared in China during 2003. The illness spread to a total of 32 countries across the globe, eventually infecting approximately 8,000 people and resulting in over 900 casualties, mostly in China (Tan & Enderwick, 2006). SARS is one of the first modern day examples of how the increased availability of international travel has challenged the world's ability to slow down the spread of a pandemic (Hung et al., 2018). However, while globalization increases the likelihood of infectious diseases spreading across boundaries, emerging technologies can create new ways for how pandemics may be contained (Smith, 2006).

Traditional border screening measures had a difficult time stopping travelers who were infected with SARS from traveling from country to country. Increased travel for tourism creates additional challenges for individually screening out potentially infected travelers because diseases that have long incubation periods may go undetected (Hung et al., 2018). The onset of SARS helped to encourage the design and deployment of new, more efficient thermal scanners to update border screening protocol and help regions avoid issuing travel constraints or other more severe pandemic response policies (Bell, 2004; Tan & Enderwick, 2006). The infrared thermal scanners were designed to scan large numbers of people at a time into airports and ports to identify travelers who have elevated temperatures to test them for infections (Bell, 2004). The development of this novel technology intended to solve the problem of needing to screen more people in a shorter number of time that traditional screening measures could not accomplish (Bell, 2004).

During the SARS pandemic updated communications and survey technology helped reduce paper waste and keep essential workers safe (VanDenKerkhof, 2003). Essential workers that need to leave their residences for essential work, such as working in hospitals, can use smart devices outfitted with SARS screening procedures to more accurately identify potentially infected workers (Tan & Enderwick, 2006; VanDenKerkhof et al., 2003). Online SARS screening surveys went through the inception phase of development as a result of needing to find a way to overcome the shortcomings of traditional paper screening surveys for hospital personnel (VanDenKerkhof et al., 2003). Paper surveys are limited because they cannot constantly reflect the most up-to-date information and they require contact of shared materials such as pens and paper forms for review (VenDenKerkhof et al., 2003). The deployment of these new online screening technologies benefitted from SARS because they were rapidly developed to accommodate a constantly changing situation.

2.3.3 Middle East Respiratory Syndrome (MERS) (2012-Present)

Middle East Respiratory Syndrome (MERS) is a zoonotic viral disease first identified in Saudi Arabia in 2012 (Iqbal et al., 2019; Pascal et al., 2015). In the years following the identification of the first case over 1,800 cases have been reported in humans in 22 countries in the Middle East Region, Africa, Europe, Asia, and North America (Iqbal et al., 2019; Pascal et al., 2015). Like SARS, MERS is a respiratory disease, however, the mortality rate is higher at 30%, which increases the urgency for making decisions to slow the spread (Iqbal et al., 2019). Communicating with the public through a technology that is widely available, like cellular phones, about the threats of viruses and how they may be transmitted can accomplish slowing the spread (Fung et al., 2013; Yamin et al., 2018). However, even with mobile devices relevant information is still difficult to get to the public in a timely manner (Oh et al., 2020). This problem has created an opportunity to enhance existing technologies with new applications to improve their efficiency since the base technology is already widely distributed to the public.

The development that has helped to solve this problem is social media applications, web 2.0 technologies that display user-generated content, that people can download on cellular devices (Lee & Choi, 2018; Tang et al., 2018). The proliferation of these applications has given public health authorities the opportunity think of creative ways to spread information related to health crises (Lee & Choi, 2018; Tang et al., 2018). The number of adults using social media regularly has made this possible. The number of adult users has exploded from 2005 to 2015 (from 7% to 65% in the United States alone) and the public has been able to gain access to important information more quickly than ever before (Lee & Choi, 2018; Tang et al., 2018). During rapidly changing events the public could proactively check social media for real-time updates since tech developers designed ways to get the data to the public faster (Lee & Choi, 2018). Recognizing how new social media applications can be deployed to anyone with a mobile device or internet access has also helped policy makers and epidemiologists discover what questions the public may have and even analyze how people are reacting to pandemic response policies (Fung et al., 2013; Seo & Shin, 2017).

Despite the benefits of using social media applications for spreading information during pandemics there are concerns, particularly because they were mobilized for public health purposes so rapidly there was minimal time for testing the effectiveness. While social media has developed into an effective tool it may not be the best way for public health agencies to send out complex information(Oh et al., 2020). Research indicates that people are more likely to go to social media when they are afraid or angry about an issue than to educate themselves (Oh et al., 2020). During the MERS outbreaks social media data indicate that some countries experienced higher levels of worry during the pandemic due to how frequently citizens were exposed to information regarding infections near them on social media (Ro et al., 2017). If the public reacts negatively while reading social media posts then there is the potential that they may lead to unsuccessful communication between the posters and the public and there may be community unrest or a lack of following public health guidelines (Oh et al., 2020). The benefits of using social media applications is that it fills a need for public health agencies to react quickly and the core technology associated with using them is already available, and thus they may be deployed rapidly. However, data seemingly indicates that without the testing and design phase of development the eventual deployment may not successfully meet the developer's initial goals.

2.3.4 SARS-CoV-2 (COVID-19) (2019-Present)

SARS-CoV-2, later named COVID-19 by the World Health Organization, first started to appear in 2019 in Wuhan, China (Aloi et al., 2020). The initial reporting of a cluster of pneumonia cases was discovered to be COVID-19 in January of 2020, which has spread so rapidly that the World Health Organization officially declared COVID-19 to be a global pandemic on March 11, 2020 (Aloi et al., 2020). Initial evidence has suggested that municipal responses to containing the spread of COVID-19 centered on slowing the spread for specific geographies rather than controlling the overall size of the global pandemic (Espinoza et al., 2020). Decision-makers first accomplished limiting the spread by implementing location closure and travel restriction policies for all non-essential travel (Aloi et al., 2020). The drastic reduction in travel has an impact on the deployment of various modes of transportation; however, it also may lead to an opportunity for developing new technologies.

The initial travel restriction policies resulted in a large decrease in vehicles miles driven and days driven per week in municipalities that introduced these measures (Stavrinos et al., 2020). A case study in Santander, Spain indicates that after the order of complete house arrest the amount of vehicular traffic fell by as much as 78% in the first three weeks alone (Aloi et al., 2020). Public transportation declined even more drastically in Santander, seeing a 93% drop in usage (Aloi et al., 2020). More individuals chose to travel by private car given that there is less potential of exposure in privately owned vehicles (Beck & Hensher, 2020; Hensher, 2020). This disproportionately affects lower-income populations who do not own private vehicles and rely on public transportation for essential travel (Bonaccorsi et al., 2020). The decline in public transit usage limits the ability for alternative mobility solutions, such as ride-hailing and even autonomous shuttles, to be deployed without limitations due to COVID-19 response policies (Bonaccorsi et al., 2020; Ceder, 2020; Hensher, 2020).

COVID-19 may be significantly limiting the current deployment of new mobility solutions; however, it is also creating an opportunity for the development of new technology beginning at the inception and design phases. The decline of travel has subsequently led to a decline in emissions and air pollution from vehicular travel, opening potential discussions for how to re-examine ways to keep emissions low when normal traffic levels resume (Liu et al., 2020). Furthermore, during this time when manufacturing is slowed down manufacturers can shift their focus to re-designing existing vehicles to include new smart technologies (Yamani et al., 2020; Zeng et al., 2020). New types of robotics and artificial intelligence applications have been modified during COVID-19 to eliminate human-to-human contact, disinfect public spaces, or screening people for temperature spikes to help identify infections (Zeng et al., 2020). With additional time to plan, these technologies can be implemented to optimize smart mobility solutions after the uncertain time of COVID-19 (Ceder, 2020; Zeng et al., 2020).

2.4 Synthesis of the Literature

The analysis of the literature revealed that there are both positive and negative effects for the various stages of technology development due to the implementation of potential pandemic response policies. Table 1 below shows the relationship between the stages of development and the response policies and the assumed effect that between the two. The relationships are categorized by having an upward arrow (↑) to indicate a positive effect and a downward arrow (↓) to indicate a negative effect. The boxes that do not contain any information indicates that I did not uncover any link between the two items during the literature review.

The literature indicates that the pandemic response policies have the most effect on the deployment stage of development. Shelter in place policies also impact the most stages of technology development, impacting all stages except for the inception phase. One notable discovery is that the literature does not indicate that there are seemingly no effects that come from location closure policies. Some effects may not be narrowly categorized as a result of an individual policy, but some responses broadly affect all areas of development. Some of the pandemic response policies also may have similar impacts on different stages of development, such as self-quarantine restricting stakeholders working together and cap on gathering policies preventing advocacy groups and stakeholders from meeting. Finally, only two relationships that both had more than one effect were travel constraint policies on the testing phase and cap on gathering restrictions on the design phase.

Table 1: The Effects of Pandemic Response Policies on the Stages of Technology Development (Literature Review Data)

		Stages of Technology Development			
		Inception	**Design**	**Testing**	**Deployment**
Policy Responses to Pandemics	**Self-Quarantine (Social Distancing)**	↓*: Multiple stakeholders must work together and become familiar with each other. ↓: Different stakeholders cannot be together to work on shared components of AVs.			↓: Advocacy groups cannot support deployment through face-to-face contact.

Table 1 (cont'd)

	Travel Constraints			↑: AVs can drive in local traffic if only inter-population constraints are implemented.	↓: A lack of traveling will slow interaction with AV specific infrastructure.
	Location Closures				
	Cap on Gatherings		↓: Transit studies need to involve humans present for feedback. ↑: Well-designed systems can rely on digital communications.		↓: Advocacy groups and stakeholders cannot meet.
	Shelter in Place		↓: The design of new vehicle technology requires that it is human friendly.	↓: Public transit will decline as people travel less.	↓: Workers will need to leave their homes to install infrastructure for AVs.
	Complete House Arrest			↓: Teams cannot meet to collaborate and deploy shuttles.	↓: Workers will need to leave their homes to install infrastructure for AVs.

Table 1 (cont'd)

	All: Areas of Deployment Broadly Affected by All Pandemic Responses	↑: New policy is based off available existing research. ↑: Scoping new technology can be done virtually.	↑: Aesthetic design can be shared digitally for improvement.	↑: Testing can occur on private tracks for safe development.	↓: The regulatory atmosphere must all for deployment pre-pandemic or it will be delayed.

*This table represents the findings from the literature review(italics) and key stakeholder interviews.
*The "↑" arrow indicates a positive effect that the pandemic response policy would have on that phase of technology development.
*The "↓" arrow indicates a negative effect that the pandemic response policy would have on that phase of technology development.

Chapter 3: Methodology

The methodology section of this dissertation includes the framework of how I conducted the study. This includes a discussion of how the research tools are created, distributed, and analyzed. The first section of this methodology includes an overview of gathering relevant literature in order to create a framework for the overall research project. Second, I describe the process of the recruitment of interviewees associated with the NAIAS testing process to participate in the key stakeholder interviews. In the second section I also include the development of the survey tool and coding of the interview data. Finally, the methodology describes the design of the second phase of data collection, a Delphi Study.

3.1 Literature Review

The literature review includes peer-reviewed articles from Web of Science, an online database, that are relevant to the research topic. Topic searches were completed for each of the decision-making frameworks and design implementation phases. The search results were then refined to only include social science articles so that the most relevant articles were reviewed. Additionally, case studies are included in the literature from previous pandemics (including the Spanish Flu, SARS, MERS, and COVID-19) to demonstrate how pandemics have had an impact on technology and mobility from a historical perspective.

3.2 Phase One: Key Stakeholder Interviews

In order to explore how this pandemic impacted technology deployment at the event key stakeholder interviews were completed with individuals who participated in planning NAIAS 2020. This includes State of Michigan employees who worked on establishing the AV demonstrations within NAIAS and those who directly worked on the planning processes of the event. Interviews were also completed with the providers of the AV pilot programs that would be showcased at the event to explore how the pandemic interrupted their services and what safeguards may be put in place to protect the users.

3.2.1 NAIAS 2020

This dissertation uses the 2020 North American International Auto Show (NAIAS) as a starting point to explore how a pandemic can impact the deployment of new technology. I chose the NAIAS event for the emphasis on innovative mobility technology and the events international exposure. The COVID-2019 pandemic is an unforeseen disruption that augmented global circumstances in the months prior to the event due to travel and gathering restrictions. These circumstances make this event a unique case study for examining the impacts of the pandemic on deploying new technology and the policies put in place leading up to the event to mitigate these impacts.

The North American International Auto Show (NAIAS) began in 1899 when two electric and two steam powered cars were displayed to exhibit the burgeoning age of automobiles in Detroit, Michigan (*North American International Auto Show*, n.d.). The 2020 NAIAS anticipated opening in June for the first time in an effort to expand the show into an outside space and increase the number of exhibits. The show's timeframe initially took place from June 7th, 2020 until June 20th, 2020. This two-week period includes single day events such as the Gallery, Press Preview, AutoMobili-D, Charity Preview, Industry Preview, and a multi-day public show from June 13th-20th, 2020.

The NAIAS attracts an average of approximately 800,000 attendees throughout the course of the event (*North American International Auto Show*, n.d.). The attendance of the different single-day events varies. In 2019, the Gallery, the most exclusive event for luxury vehicles, totaled 500 employee representatives, and the less-exclusive single-day events had attendance totals of 4,568 (Press Preview), 10,572 (Charity Preview), and 35,185 (Industry Preview) (*750,000+ Celebrate the Future of the Mobility Industry at 2019 NAIAS*, 2019). A majority of attendees come from the public event show that takes place over the second half of the event. Journalists from 60 distinct countries were in attendance for the entire event, along with 200 companies and brands at the AutoMobili-D challenge, and executives, designers, and developers from 1,679 companies and attendees from 26 distinct countries at the Industry Preview alone (*750,000+ Celebrate the Future of the Mobility Industry at 2019 NAIAS*, 2019). At the end of the event generates a total economic impact of $430 million for the region (*750,000+ Celebrate the Future of the Mobility Industry at 2019 NAIAS*, 2019).

A new facet of the 2020 NAIAS is the introduction of the 2020 Michigan Mobility Challenge, an initiative developed by the Michigan Governor's Office, the Michigan Department of Transportation (MDOT), and the Michigan Economic Development Corporation (MEDC). The purpose of this program is to incentivize industry innovators to propose new technological developments that can help transform mobility using autonomous vehicles to address transportation gaps for seniors, veterans, and people with disabilities (*MDOT - NAIAS 2020 Mobility Challenge*, n.d.). Five winners were chosen from the program and were awarded a total of approximately $5.4 million dollars for the development of their pilot programs. In total the winners donated three 15-passenger automated shuttles, a fixed route 15-passenger shuttle that has technology to allow for passengers with mobility restraints to board, 10 robo-taxis, two 3-D printed shuttles, and two 10-passenger shuttles that are fully electric in the downtown and a level-four autonomous shuttle for attendees that arrive at the Detroit Metro Airport (*NAIAS Congratulates Five Michigan Mobility Challenge Participants*, n.d., Szczesny, 2019).

The Detroit Auto Dealers Association cancelled the 2020 NAIAS event less than three months prior to the originally planned start date on March 28, 2020 (*2020 North American International Auto Show Cancels,* n.d.). The announcement came after the TCF Center announced their selection as a site for a temporary field hospital for the Federal Emergency Management Agency (FEMA) to assist with the State's COVID-19 response (*2020 North American International Auto Show Cancels*, n.d.). The immediate announcement from NAIAS officials is that the event would be postponed an entire year to similar dates in June of 2021 and the programming will be a continuation from the 2020 event (Johncox, MacDonald, & Kelly, 2020).

3.2.2 The Interview Guide

The main portion of data gathering for this phase of the study is key stakeholder interviews with individuals involved in the event planning process. The purpose of these semi-structured interviews is to gather first-hand data on the how the development process was disrupted by COVID-19. Semi-structured interviews were chosen to gain an in-depth understanding of how the stakeholders perceived the planning process (Silverman & Patterson, 2015). This includes a selection of grand tour and probe questions that would help to uncover themes relevant to the study, starting with a discussion regarding the NAIAS event and then furthering the conversation to cover AV development and the pandemic as a whole. The probe questions are valuable because they provide the participants opportunities to respond to the intricacies of their, or their organizations, specific role in the planning process (Adams, 2015). The open-ended nature of the questions additionally allows the participants to be candid in ways that they may not be in a focus group setting and provides more context than a qualitative survey (Adams, 2015).

I developed an interview protocol to guide the expert interviews and to ensure continuity throughout all the interviews used in the data gathering process (Silverman & Patterson, 2015). This tool assisted with focusing on relevant themes to the study based on the questions that were selected (Silverman & Patterson, 2015). The interview guide consisted of four elements: the informed consent, the introductory questions, the thematic questions, and the closing segment. The informed consent included covering a written statement that outlined the focus of the research and the steps taken to ensure the protection of the human participants. The thematic section contains two segments: probing questions and grand tour questions. The closing segment allowed the interviewees to respond to any questions or statements in further detail. The interview guide is located in Appendix A.

I initially submitted the interview tool for IRB approval at Michigan State University on February 6th, 2020 and given MSU Study ID number 4041. The MSU IRB determined the initial study to be exempt on February 20th, 2020. I completed the first interview on March 9th, 2020, one day prior to the first confirmed case of COVID-19 in Michigan (Oosting, 2020). As the details of the pandemic evolved I submitted a revised interview guide on March 17th, March 24th, and April 10th, 2020 to more adequately address the evolving disruption. I completed the final interview on June 15th, 2020.

The target population for the event planning phase is the professionals from state agencies involved in AV deployment, Michigan Mobility Challenge winning team members, and members of the NAIAS planning team. To identify the initial participants for the interview phase the key contacts that were listed on the Michigan Mobility Challenge press release were contacted to see if they were interested in being interviewed. From there, I implemented a snowball sampling method so that the original contacts could assist in identifying other individuals involved in this process so that they could be asked for an interview as well (Handcock & Gile, 2011). These professionals are from the Michigan Economic Development Corporation, Michigan Department of Transportation, and Michigan's Governor's Office. A list of the interviewees' affiliation, date of contact, and interview dates are included in Appendix B.

For the purpose of recruiting potential interviewees, I first established a sample population target size. Examples of common sample sizes for qualitative interviews may be 20 to 30 respondents; however, literature has determined that this is a moving target, with some authors suggesting a range of anywhere from five to 50 (Mason, 2010). Interviews were completed until representatives from all involved stakeholders had the opportunity to participate in the study to ensure all viewpoints are represented. Additionally, the interview guide underwent revisions over time to be more relevant as the pandemic evolved and to review existing questions to ensure that they were measuring what they are intended to measure (Müller, 2015). Ultimately a total of 25 key stakeholders were interviewed during the data gathering period, shown in Appendix B. The interviewees can be grouped into five categories: private stakeholders such as consultants (9), representatives of state government entities (8), representatives for NAIAS (4), local government entities (2), and non-profit organizations (2).

3.2.3 Coding Interview Data

The interview responses were transcribed by the researcher using an online application. Once I compiled the data the process of disassembling the data into related groups started through a coding process to uncover themes related to the research questions (Castleberry & Nolen, 2018). I chose a thematic analysis as the coding technique to uncover the underlying meanings within the text by first open coding the data (Silverman & Patterson, 2015). In the open coding process the lines of data from the interviews were grouped together to form relevant groups, capturing the meaning conveyed by the interview participants (Silverman & Patterson, 2015). Second, I completed a focused coding process on the codes that were created in step one, organizing them further into specific themes to be further analyzed. Once the themes were identified from the focused coding process the data could be reported to examine how the responses related to the initial research question. A list of the focused codes can be found in Appendix C.

3.3 Phase Two: Delphi Study

The second phase of the study uses a Delphi Study in an attempt to gather consensus on if COVID-19 has benefitted or hindered the deployment of autonomous vehicles. The literature review and the key stakeholder interviews provided initial insights into how public policy responses to Covid-19 have impacted the four stages of autonomous vehicle development by placing the data into Tables 1 and 8. I selected the Delphi Study for phase 2 of the research as it is an accepted method to build consensus among experts on the data (Jeon et al., 2014). The data provided for review come from phase one of the study and asks the experts if the pandemic will benefit or hinder the deployment of new technology.

3.3.1 The Survey Tool

The Delphi Study uses a survey tool that is distributed to experts in the field in order to collect their opinions on the first phase of the study. The survey questionnaire is developed using the data shown in Table 8 generated from the literature review and key stakeholder interviews. The questionnaire asked the panel of experts to review the data provided in each cell based on the initial assumption that it either benefits or hinders the development of new technology. Each question in the questionnaire then asked the experts if they believed that the pandemic response policy benefitted or hindered development based on the included data.

The survey questionnaire is separated into four categories based on the stage of technology development: inception, design, testing, and deployment. Likert Scale questions were used for every question in the survey and the experts were presented with five options to choose from. Potential responses are that the pandemic response greatly benefitted, benefitted, neither benefited nor hindered, hindered, or greatly hindered that stage of development. I chose this question format so that the experts could choose both the type of effect and the extent of that effect. Additionally, each question had an open-ended section after the Likert Scale so that the experts had the opportunity to provide rationale for why they chose their response and include any potential data points that were not included in the original table. The Delphi Study survey questionnaire also included Table 8 so the participants could review it while they responded to questions.

I initially submitted the survey questionnaire for IRB approval at Michigan State University on July 27, 2020 and given MSU Study ID number 4891. The IRB Review Board determined the questionnaire to be exempt on July 28, 2020. At this stage I adapted the questionnaire into an electronic format using Qualtrics Survey Software so that it could be distributed via email. I updated the Qualtrics online survey in between each survey to include the responses from the previous round of surveys. The framework for the Delphi Study is located in Appendix D.

3.3.2 Selection of Experts

The study requires that the experts that are chosen for the Delphi Study are knowledgeable in technology development and in the deployment of autonomous vehicles (Rådestad et al., 2013). Potential respondents were identified by searching for authors who have published works in the field of autonomous vehicle development or who work in research programs at universities. Furthermore, I invited international experts because COVID-19 is a global pandemic, and it is important to gather viewpoints from experts who have had varying experiences based on their country's pandemic response. Following a review of existing literature, the respondents were chosen broadly based on their expertise and geographic locations (Keeney et al., 2006; Rådestad et al., 2013). All participants were given a consent form prior to participating so that they could maintain their anonymity throughout the Delphi Study process (Jeon et al., 2015; Rådestad et al., 2013).

The first round of requests to participate were sent to potential respondents on August 3, 2020. To increase the response rate, I applied for funding through the Graduate School, College of Agriculture and Natural Resources, and the School of Planning, Design, and Construction at Michigan State University. On August 25, 2020 Michigan State University awarded the funding through the previously mentioned sources to provide each respondent who completes all three phases of the Delphi Study electronic gift cards totaling 20 dollars. I sent a five-dollar electronic gift card to respondents after the completion of the first and second rounds of the study and a final ten-dollar electronic gift card at the completion of the data gathering period.

3.3.3 The Delphi Study Process

To begin the process, after the identification of potential respondents, the experts were informed about the study via email correspondence and invited to participate in the study (Jirwe et al., 2009; McKenna, 1994). I sent the first round of questionnaires to the potential respondents on August 3rd, 2020 asking them to review the data table and respond to the questions about each specific cell in the table. They were also directed to respond to open-ended questions. The open-ended-questions allowed the respondents to provide input on the questions and add or remove statements that they believed were valuable in linking pandemic response strategies to technology development.

The existing literature on conducting Delphi Studies is vague on what percentage of agreement there should be to achieve consensus (Jeon et al., 2015; Rådestad et al., 2013). A proportion of responses for this study is set at a minimum of 70% to indicate the participant consensus, meaning that at least 70% of total respondents believed that the pandemic response would have the same effect on development. This number is selected to ensure that there is minimal variation in agreement among the experts. I sent a reminder email to the respondents to ensure that all potential respondents had an opportunity to participate before analyzing the data from phase 1. After the maximum number of responses were gathered I analyzed the data to determine what areas had the levels of highest agreement (Rådestad et al., 2013).

After the collection and analysis of the data for the first round the feedback from the open-ended questions was included in the data table originally presented to the experts. The second-round survey included a notation regarding the questions where the experts had reached consensus since they were removed from the questionnaire. I then sent the questionnaire and data table to the respondents asking them to review the updated data table and respond to the same Likert Scale questions as before to determine if the additional feedback has caused the experts to reconsider their original response. I repeated the same process after the second round of responses and the table and updated responses that had reached consensus were sent out to the respondents to answer the remaining questions a final time. I included an open-ended question at the end of the final questionnaire to allow the experts an opportunity for final feedback.

3.3.4 Analysis of the Delphi Study

The Delphi Study yielded both quantitative and qualitative data through a combination of the Likert Scale questions and the open-ended component. I placed the Likert Scale data into Tables 10, 12, and 14. The number of responses for each choice on the Likert Scale was divided by the total number of responses for each question in the survey so that the percentage of each answer could be calculated for every question. If the percentage for a specific response met the 70% threshold than the response met consensus among the experts according to the study's requirements and thus did not necessitate respondents to review the question in next round of consultation. The data in Table 10, 12, and 14 are a quantitative visualization of how the respondents believed that the pandemic response policies affected the various stages of technology development.

I completed a coding process on the qualitative response data from the open-ended response portion in each phase of the Delphi Study. The coding process determined if the responses were indicative of a positive or negative effect on technology development. After the coding process the statements from the respondents were placed into the framework provided in Table 8 so that the respondents could read the responses during the next phase of the Delphi Study. In phase 2 and 3 of the study the respondents were asked to review the updated tables that included the open-ended response data and again respond to the Likert Scale questions to see if their interpretation of how the pandemic impacts technology development had changed. A combination of the Likert Scale and qualitative data can explain how respondents changed their answers over time and provide a rationale for why some respondents selected a specific answer.

Chapter 4: Interview Data and Analysis

It is anticipated that the decisions made in planning NAIAS 2020 will demonstrate how pandemics interrupt technology deployment. The first phase of this study examines how the legacies of this event will provide guidance that will shape policy formation for managing the impacts of large-scale disruptions. This includes an analysis of the timeline of decisions made by relevant stakeholders and emergent themes from the key stakeholder interviews. The combination of data will cover the planning process and its after-effects in their entirety.

4.1 Timeline of the COVID-19 Pandemic and Planning for NAIAS 2020

In order to properly frame the timeline of events surrounding the auto show I completed a comprehensive review of policy decisions related to pandemic response to initially determine what impact they may have had on NAIAS 2020. Tracking this information creates a timeline of how organizations associated with the show have been reacting to the pandemic on a broad scale. The effects and legacies of these policy decisions will define how the pandemic impacts the preparations for deploying new technologies. The policy decisions below are from the months leading up to the event and immediately after the cancellation of NAIAS, which coincides with the completion of the interviews. This list in Table 2 below includes gathering press releases from NAIAS officials, the State of Michigan, the federal government, local transportation departments, automotive industries, and other large-scale auto shows.

Table 2: The Effects and Legacies of COVID-19 Response Policies

DATE	STAKEHOLDER	POLICY	EFFECT	LEGACY
February 17, 2020	Auto China Show, Beijing Municipal People's Government	Based on spread of COVID-19 the Beijing Municipal People's Government recommended people avoid large events and declared a public health emergency for the province.	The Auto China Show (starting April 21st ,2020) had to postpone the event indefinitely because the health restrictions made it impossible to hold the large event.	The cancellation came only two months before the event would take place and a month before NAIAS's postponement. This provided a framework for NAIAS to follow as they prepared to cancel.
February 28, 2020	Geneva International Motor Show	Three days before the event the event's Federal Council cancelled the auto show after the Swiss government banned gatherings of 1,000 or more.	The gathering ban came out after the construction of the event space so there was no time for event planners to modify the event space to meet new public health requirements or install safeguards in the event space.	The ban of gatherings ended 3 days before the initial start date of the Geneva event (March 15th, 2020). This case study helps NAIAS officials look at decision-making under high uncertainty in a small window of time.
March 10, 2020	New York International Auto Show	The NYIAS (April 8th, 2020) announced postponement until August of 2020 to protect the attendees and partners from public health risks. In a follow-up move NYIAS postponed until 2021 because caps on gathering and travel bans are still in effect.	The event's anticipated impact for 2020 was $330 million of revenue and over 1 million attendees. The pandemic response policies would decrease the financial impact and attendance of the event.	The NYIAS event was the first event in America to cancel. This provides the most realistic model for NAIAS to follow while making decisions on whether to cancel. Especially because both New York and Michigan were home to epicenters of the pandemic in April.

Table 2 (cont'd)

March 13, 2020	President Donald Trump	Beginning on March 13, 2020 the United States is banning entry to travelers coming from 26 European countries.	While this ban does not apply to legal U.S. Citizens, it does prohibit entry into the country for a majority of European countries.	There will be a delay in exposure at the NAIAS event for any potential non-American attendees.
March 13, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-5 to ban all events and assemblages in shared spaces of over 250 people.	This ban forces the temporary postponement of events and gatherings throughout the state until April 5th, 2020.	NAIAS anticipates roughly 750,000 attendees over the course of two weeks. Any limitation on assemblages will greatly limit how many people can attend the event.
March 16, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-11 to ban all events and assemblages in shared spaces of over 50 people.	This ban further restricts the postponement of events and gatherings throughout the state until April 5th, 2020.	NAIAS anticipates roughly 750,000 attendees over the course of two weeks. Any limitation on assemblages will greatly limit how many people can attend the event.
March 16, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-9 to temporarily close theaters, bars, and casinos, and limit restaurants to carry-out and delivery only.	Locally owned businesses and establishments that fall under this umbrella may suffer from lack of revenue if they are unable to provide their goods or services.	NAIAS 2019 reported an economic impact of $430 million to the Detroit regional economy. Even if AV pilots did operate, their function would be changing, and people would not go to recreational amenities. This may cause the immediate regional impact of AV pilots to be stunted.

Table 2 (cont'd)

March 16, 2020	Detroit Transportation Corporation	The Detroit People Mover has accelerated cleaning opportunities and eliminated routes to the TCF Center.	The restriction of routes will hinder mobility throughout downtown Detroit and put an increased emphasis on cleaning.	At the request of the TCF Center this stop will be bypassed. If this continues it will limit exposure for NAIAS through conventional transit means. The increased cleaning will create guidelines to sanitize public spaces.
March 17, 2020	Detroit Department of Transportation	DDOT suspended routes because of driver shortages due to public health concerns.	Cancellations of bus routes limit mobility options for the city. **UPDATE:** Service resumed on March 18, 2020 following a new deal that includes waiving fares and cleaning buses.	Autonomous vehicles at NAIAS are intended to operate within the mobility infrastructure of Detroit. However, disruption of services for existing transportation will impact the effectiveness of demonstrations.
March 18, 2020	Ford Motor Company	Ford halted North American production to thoroughly clean the plants for the month of March 2020.	Halting the production of Ford's plants due to pandemic conditions will create restrictions for the operating power of the Brand.	The production related actions are being caused by the travel and contact restrictions. This will impact the ability of the Detroit-based manufacturer to focus on their NAIAS exhibition and potentially limit their deliverables for the event.

Table 2 (cont'd)

March 18, 2020	General Motors Co. (GM)	GM halted North American production due to market conditions to thoroughly clean the plants for the month of March 2020.	Halting the production of GM's plants due to pandemic conditions will create restrictions for the operating power of the Brand.	The production related actions are being caused by the travel and contact restrictions. This will impact the ability of the Detroit-based manufacturer to focus on their NAIAS exhibition and potentially limit their deliverables for the event.
March 18, 2020	President Donald Trump	In a mutual agreement the border between Canada and America will be temporarily closed to non-essential traffic.	The restriction of travel will create a barrier for potential movement between the two countries.	The travel ban would prohibit Canadian workers coming to manufacturing plants in Detroit and potential NAIAS attendees from coming in from Canada.
March 20, 2020	Governor Gretchen Whitmer (MI), Governor Mike DeWine (OH)	Governors from Michigan and Ohio call on the federal government to ensure the automotive industry and associated jobs are supported by the federal government.	COVID-19 threatens to negatively impact the industry through rapid economic deceleration.	The pandemic has created uncertainty with the funding for AV development due to the economic strain placed on the automotive industry. Stakeholders indicated that from NAIAS 2020 to NAIAS 2021 the funding for testing pilots may be interrupted.

Table 2 (cont'd)

March 23, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-21 directing non-critical businesses to temporarily close and all Michiganders to stay home or 6-feet away from each other.	This order directs residents to stay in their homes or practice social distancing until April 13, 2020 unless they are a part of critical work forces necessary to sustain or protect human life.	The stay at home order, if extended, could potentially lead to a NAIAS event that is unable to have any attendees at all. Furthermore, even professional attendees would not be permitted to attend since the event is a non-critical event.
March 23, 2020	SMART	The regional transit provider started offering free fares on routes initially on March 17th. Beginning on March 23rd they altered the schedule due to a drop in rides and began a nightly cleaning using antibacterial products.	The limited transit and increase in cleaning changes the programming that goes into operating local transit options.	The elimination of fees will create a gap in funding. However, the increased CDC cleaning recommendations will create a path moving forward for how to clean public transit shuttles during pandemics.
March 23, 2020	Indian Trails	The Indian Trails motor coach service has suspended operations for the Michigan AirRide shuttle and purchased 1,900 gallons of disinfectant.	This shuttle route takes people to the Detroit Metro Airport, limiting options for how people can come into Detroit.	This order will hinder cross regional mobility services and access to the DTW airport terminals. The cleaning recommendations will set guidelines for how to clean high-touch areas on buses.
March 25, 2020	MDOT	MDOT Research Administration transitions to working remotely.	To prevent the spread of COVID-19 the research administration has begun working remotely, stopping face-to-face contact.	Lack of face-to-face contract and increase of telecommuting will create difficulties for MDOT planning processes leading up to NAIAS.

Table 2 (cont'd)

March 28, 2020	NAIAS, FEMA	NAIAS officials cancelled the 2020 event due to the TCF Center signing a contract with FEMA to convert the center into a temporary field hospital.	The event will be postponed to June of 2021. More than 100 centers nationwide were converted to field hospitals and this is where FEMA chose Detroit for a 6-month contract. This decision directly led to NAIAS cancelling the event.	The contracts, funds, and planning processes for the 2020 show will be pushed back an entire year. The effects will matriculate to all stakeholders involved and the platform for exposure is eliminated for 2020.
March 28, 2020	MI National Guard	Over 20 members of the Michigan National Guard have been designated to support FEMA in transitioning the TCF Center into a field hospital.	The site will be converted to hold 1,000 beds and accept their first patients on April 10th, 2020. This gives the event center less than 2 weeks to convert.	The cancellation may impact the event center the most. In this instance, the TCF Center is mandatorily shut down for 6 months.
March 28, 2020	Governor Gretchen Whitmer (MI) and President Donald Trump	President Trump approves Governor Whitmer's request for a major disaster declaration.	The Major Disaster Declaration in Michigan allows for the state to be eligible to receive FEMA programming and emergency aid.	This funding is the final portion of the conversion of the TCF Center to a field hospital. The event center is officially secured as the field hospital.
March 29, 2020	Detroit Q-Line	The Q-Line in Detroit is suspending service beginning on March 29th due to lack of demand for transit along the Woodward Corridor.	The decision to pause this service will be important for helping to protect the health and safety of the customers. The Q-Line will not operate until safety measures are implemented.	The AV shuttles at NAIAS are intended to work with existing transit, and any decline in mobility options will slow down how AVs are used in the downtown.

Table 2 (cont'd)

April 1, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-33 which declares an official state of disaster and expands the scope of protection for Michigan families.	The Executive Order expands the state of the emergency and disaster so that funds may be reallocated to prepare for mitigating the effects of the virus.	This Executive Order is indicative that policy is focused on the pandemic, rather than AV development. This is representative of a potential hindrance for overall deployment as mentioned by the interviewees.
April 9, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-42 extending the prior "Stay Home, Stay Safe" order until April 30th.	No assemblages of any people are allowed in Michigan until the end of April. This limits gatherings and travel to protect people.	The stay at home order prevents in-person work on AV development since it is a non-critical business. All work must be completed virtually while this order is in effect.
May 6, 2020	Governor Gretchen Whitmer (MI)	Governor Whitmer signed Executive Order 2020-75, which allows public bodies to conduct remote public meetings.	This Executive Order enabled public bodies to work and create policy decisions using remote meeting technologies.	There is a constant need to collaborate with stakeholders in this environment. Online tech services can help the planning process from any location.
May 7, 2020	Governor Gretchen Whitmer (MI)	Governor Gretchen Whitmer signed Executive Order 2020-77, which extends the Stay Home, Stay Safe mandate, but allows auto workers to return to work.	This Executive Order assists Michigan automakers to resume manufacturing activities despite the stay-at-home order.	This helps automakers resume production, continue work on developing AVs, and avoid losing potential sales due to lack of products.

Table 2 (cont'd)

July 29, 2020	Governor Gretchen Whitmer (MI)	Governor Gretchen Whitmer signed Executive Order 2020-160, limiting indoor gatherings.	This Executive Order limits indoor gatherings to 10 people or less to slow the spread of COVID-19.	If NAIAS officials believe that there is a concern that COVID may disrupt the 2021 event the event space will need to be reorganized to accommodate social distancing guidelines and a cap on gathering policies for the first time.

The pandemic response policies listed above all influence the planning processes and establish the legacies associated with cancelling NAIAS. Some of the policies, such as those enacted by SMART, DDOT, and other transportation providers, do not fit neatly into the framework created in the literature review. These transportation-based policies focus more on sanitation and route efficiency and thus represent a gap in existing pandemic response literature for maintaining cleanliness in publicly shared areas. The other policies in this section fall into the following categories: travel constraints, location closures, cap on gatherings, and a blend between shelter in place and complete house arrest.

The two policies that restricted travel in and out of the United States were made by the federal government on March 13th and March 18th, 2020. These policies, while they may not impact United States residents immediately, do have a large impact on NAIAS. The event relies on visitors from other countries for increased exposures and with these restrictions in place indefinitely there will be less diversity at the event and the autonomous shuttles to the airport will be severely limited. The legacy of this policy for NAIAS is that the event program may need to find ways to get individuals and businesses more involved if they are unable to travel to the show, especially if there are data gathering measures associated with the show (such as the AV pilots).

The policies that were made by the state government of Michigan relating to location closures effectively limited the urban cores of Michigan. One of the earliest and broadest location closure policies came from Governor Gretchen Whitmer (MI) and temporarily closed all theaters, bars, casinos, and restaurants throughout Michigan. This policy essentially closed all recreational businesses in Michigan to limit the spread of COVID-19, but at the expense of limiting destinations that people would be traveling to with the NAIAS autonomous shuttles.

Another instance of location closures in Michigan came from the private sector when General Motors Co. and Ford Motor Company closed their production plants to deep clean the facilities for the safety of their employees. These location closures may eventually impact AV development more than most other policies because they severely limit the manufacturing and operation of the vehicles.

The most severe policies enacted in Michigan in the COVID-19 pandemic to date are the stay at home orders enacted by Governor Gretchen Whitmer on April 9th, 2020 (Executive Order 2020-42) and May 7th, 2020 (Executive Order 2020-77). These orders are a blend of the shelter in place policies and the complete house arrest policies described in Sections 2.1.5 and 2.1.6. Executive Order 2020-42 recommends that people do not leave their home except for emergencies for three weeks with violations being punishable by either jail time or a fine pursuant to the Michigan Emergency Management Act (Brook & Culler, 2020). A stay at home policy this severe means that people will not be able to work on the event planning or AV development in face-to-face settings and that people will not be using AVs for transportation since intra-community travel stops nearly completely.

A culmination of all the policies from the State of Michigan and Governor Gretchen Whitmer were put into the *MI Safe Start* plan to re-open the state based on if the state meets safety criteria. The *MI Safe Start* plan has six phases of re-opening based on:

1. Uncontrolled Growth,
2. Persistent Spread,
3. Flattening,
4. Improving,
5. Containing, and

6. Post-Pandemic (Whitmer, 2020).

The safety practices permitted in the plan vary in severity for each phase, however, they are still strict enough at phase 5 that NAIAS would not be permitted. The only phase of the plan where NAIAS could feasibly operate is “Post-Pandemic”, where large events are permitted, and community spread is no longer a threat. The safe start plan may put the 2021 event in jeopardy as well if the risk of spread remains a concern or no vaccine is approved for widespread distribution.

4.2 Stakeholder Interviews

The following section discusses the findings from the key-stakeholder interviews after I completed an iterative coding process to identify recurring themes between the stakeholders. I broke the analysis down into six sections starting with the characteristics of the respondents and of NAIAS as a platform to provide a framework for the interviews. Next, the impacts the pandemic has had on both the planning process and postponement of NAIAS 2020 are discussed. Finally, potential methods for contingency planning and safeguards for preparing for holding the event in 2021 are discussed.

4.2.1 Characteristics of Respondents

Common themes that emerged in the framing questions are that most of the respondents have attended NAIAS as a visitor or as a worker and they display deep familiarity with the event, how it functions, and the planning processes. The interviewees also demonstrated a great deal of familiarity with autonomous vehicles. A total of 16 interviewees (64%) responded that they have ridden in autonomous vehicles either for enjoyment or for their work. However, the results of their rides in autonomous vehicles are mixed. Some respondents enjoyed the rides and found them very practical, while others experienced negative side effects (like motion sickness) from the ride.

4.2.2 Characteristics of NAIAS

The first question asked interviewees how the 2020 NAIAS event related to autonomous vehicle development and what they learned during the planning process of the event. The interviewees expressed that testing the AV pilots are important for public and industry professionals alike. The respondents expressed optimism prior to the pandemic that the event would have positive long-term impacts on AV development. However, the respondents indicated that the pandemic response policies from the state and federal government greatly inhibited these potential benefits.

The interviewees indicated that having the pilots are beneficial because they allow for a unique opportunity for AVs to mix with real human traffic and other modes of mobility, gain rare access to picking up passengers at the airport, and provide a deeper, critical look at how the vehicles operate on a real road. Using pilot shuttles will allow for a smoother rollout than simply introducing AVs onto public roads because the pilots are pre-programmed to follow a specific route downtown and human drivers are aware of their presence before their deployment. Autonomous vehicles, at this stage of development, still have room for improvement in the technology and the pilot will be helpful in finding areas for improvement. Ultimately, the opportunity to have pilot shuttles on the road at NAIAS is a chance to “bring awareness” and “enroll new industry members in recognizing autonomous concepts” (Interviewee 8- 4/2/20; Interviewee 11- 4/8/20).

The most important part of having these pilots at a large event like NAIAS is that there is an opportunity to find repeat users for the AV shuttles from out of town event attendees who rely on some form of public transportation. The extended duration of the event also provides ample opportunity for the general public to incorporate AV shuttles into their daily routines. The attendees at the first week of NAIAS (the Press Preview, Industry Preview, and AutoMobili-D) are generally tech-savvy and industry professionals who are looking to advance the automotive industry. The second week of the event (the public show) is useful for testing purposes because it gathers users who have a deep interest in automobiles and may provide feedback on the intricacies of the vehicles. Event officials planned for pilots to operate downtown for the entire duration of the event providing ample opportunities for feedback on how the vehicles performed at their mobility functions in a dense urban setting. One interviewee thought of this as an opportunity to actually "embrace the city" for the first time with NAIAS (Interviewee 22- 6/2/20).

The variety of users and the potential of finding repeat users would have made the NAIAS pilots incredibly valuable for gathering rider feedback. The State of Michigan agencies that facilitated the pilot programs for NAIAS planned on using a survey tool to gather input from the riders to create widely available data for all AV developers. The developers are meant to work together, and if "they can all be successful, that is going to move the industry forward" (Interviewee 16- 4/29/20). Interviewees identified shared success as creating awareness through exposure, enabling further research and development, and educating the public through field testing. There is a belief that the data from the NAIAS pilots will be a catalyst for both future policymaking and the long-term development of AVs.

The effects that the COVID-19 response policies will ultimately have on the NAIAS event will be negatively impacting the development of these publicly used AVs. NAIAS initially planned on hosting "thousands of people from around the world", however, the travel bans from the U.S. Federal Government banning European visitors (March 13th) and Canadian visitors (March 18th) effectively eliminated NAIAS as an international platform (Interviewee 13-4/10/20). Furthermore, the mobility restrictions imposed by DDOT, SMART, the Detroit People Mover, and Detroit Q-Line means that, even if the AV shuttles were tested without NAIAS, they would not be able to be tested in conjunction with other modes of mobility or human travelers.

Table 3: Quotes from Responses to the Question "What have you learned about autonomous vehicle adoption and deployment in Michigan through the 2020 NAIAS?"

Question	Synthesis of Data	Exemplary Quote
What have you learned about autonomous vehicle adoption and deployment in Michigan through the 2020 NAIAS?	A definitive positive of having the AV shuttles is that it helps the public understand what the technology is capable of currently.	"So, it (NAIAS) brings awareness for sure."- Interviewee 8 (April 2, 2020)
	The shuttles involve various industry stakeholders and ultimately will help all further autonomy for mobility solutions on a broad scale.	"That I think it makes a really unique opportunity to kind of inform and enroll the industry in an autonomous concept."- Interviewee 11 (April 8, 2020)
	The largest benefit for NAIAS is that it is a large platform and the event itself draws in people from across the world. The test group at NAIAS is incredibly large and diverse.	"So, it was good to be able to just enable research and development. So, and it's also just a massive, you know, platform for exposure, the Auto Show, thousands of people from around the world."- Interviewee 13 (April 10, 2020)
	The benefit of having a long event is that there can be specific events specifically designated to helping inform attendees about new technologies.	"They're skeptical about AVs and the AutoMobili-D event helps, you know, it gets people to be more comfortable with these things."- Interviewee 14 (April 9, 2020)

Table 3 (cont'd)

	Even if people are unable to ride in AVs at the event, they can speak to people close to them who did ride in them. This leads to an even further spread of awareness.	"I think the opportunity here is that more members of the general public attend, and you know, that creates this ripple effect once you've ridden in one and you see how the vehicle responds to potential collisions or to any other hazards or weather, then you can go home and tell your friends and family."- Interviewee 21 (May 21, 2020)
	Another benefit for AV testing at the time is that the plan is to fold them into the fabric of the downtown and tie them into existing transportation networks.	"To really, you know, embrace the city that was one of the main things. Finally, being able to go outside with our show let us (NAIAS) be able to embrace the city, because the city I feel was finally in a place where we could do that."- Interviewee 22 (June 2, 2020)

*Quotes in the table are edited to enhance readability.

4.2.3 Impacts on the Planning Process

Throughout the interview collection process, policies began to come out in response to COVID-19 that threatened the cancellation of large events like NAIAS. To gauge the impact of the pandemic and pandemic response policies on the event the interviewees were first asked how COVID-19 impacted the planning process in the months leading up to the event. This question intends to gather relevant information on how the pandemic impacted the processes of deploying functioning AVs and holding the event. The responses regarding disruptions to the planning process may be separated into the following categories: the impact on NAIAS as an event, managing uncertainties to plan for the ultimate end goals, and managing unanticipated changes and changing regulatory frameworks to compensate for the pandemic. Additionally, the lessons learned from this planning process can be used to create safeguards for planning future events.

When the first recorded cases of COVID-19 appeared in early December, NAIAS officials only had 6 months of time to examine how the pandemic may impact the 2020 event. NAIAS is an incredibly large event and thus requires a large investment of time, volunteers, and resources to successfully run the event. Planning to set-up the event venues requires a significant amount of time and permitting just to ensure that the TCF Center can accommodate for large crowds. However, the current layout of the event is not anticipated to be filled to capacity because social distancing policies are impossible to maintain in a tight space due to increased "percentages of how much open space has to be within" the event center (Interviewee 22-6/2/20). Increased distance between attendees will force event organizers to modify the layout of the event and fewer numbers of attendees will be able to be in one space at once. Ultimately, limiting the number of attendees at the event will lessen NAIAS' ability to demonstrate new technologies. As COVID-19 continued to spread, the decision to cancel the event became the center of the planning process as policies shifted towards slowing the spread of COVID-19.

The interviewees overwhelmingly stated that the main goal for having autonomous vehicles at the 2020 event is to familiarize people with technology prior to deployment since most of the inception and design phases were completed prior to the event. Several interviewees noted that the planning process cannot be stopped in the months leading up to the event in case the event is able to go on as planned at the risk of falling behind. However, as the COVID-19 situation became increasingly complicated around the world more uncertainties began to emerge in the planning process. The respondents associated with State Municipal Entities noted that as COVID-19 progressed all possible scenarios must be planned for, including cancellation, since it is hard to determine how sensitive the event is to potential disruptions until they occur.

Adjustments are necessary as new data appear to help eliminate some level of uncertainty when making decisions.

The most significant obstacle to the AV development process during the pandemic is that the regulatory focus for many policy makers will be COVID-19 responses rather than mobilizing AVs. The pandemic affects all systems, not just those surrounding NAIAS. The pandemic response policies, such as travel restrictions, social distancing, and stay-at-home orders make it more difficult to accomplish goals related to development when stakeholders cannot be in the same location as one another. Creating policies that distance groups of people creates an increasingly large need to rely on technology to communicate during the crisis and collaborate in a constantly changing environment. However, several respondents brought attention to the potential role that AVs may play in response to the pandemic. An increased emphasis on eliminating person-to-person contact means that AVs can be used for spraying disinfectant, delivering food or medicine, or taking sick people to appointments so long as regulations are made to enable them.

Table 4: Quotes from Responses to the Question "Broadly, how did the coronavirus (COVID-19) affect the planning processes of NAIAS?"

Question	Synthesis of Data	Exemplary Quote
Broadly, how did the coronavirus (COVID-19) affect the planning processes of NAIAS?	Stopping the planning process pre-emptively means that if the event does happen the planners will not be prepared. It is better to have everything in place no matter what.	"We can't stop the planning, because if this is able to happen, it needs to happen. So, I think it's really just made us refine our plans and do a lot more 'what if' scenarios."- Interviewee 4 (March 24, 2020)

Table 4 (cont'd)

	This demonstrates the financial and time investments put into developing the AV pilots throughout the first phases of technology development. The AV shuttles for NAIAS were highly specialized in their tasks, and because the disruption struck in the testing phase (stage 3 of development) the planning shifted from deployment to salvaging the existing work in order to not lose any investments.	"We (technology developers) are really in the implementation phase, the acceptance, kind of testing phase where the companies that we had under contract were ready to deploy. We had all our operational stuff, from an infrastructure perspective, ready to go. It just forced us to look at how do we not lose all the effort? And all the investment that we've made in the contracts up to this point, it's kind of changed our mentality to, Okay, how do we salvage all the hard work that's been done?"- Interviewee 15 (April 20, 2020)
	This concern shows how many decision-making stakeholders are involved. During disruptions there may be stakeholders not directly involved in the development process who can influence the process.	"We're waiting to hear the final orders. Governor's a little busy right now, she's the final authority on that. But, so of course, everyone's just on hold like us is in the middle of development. It's on hold."- Interviewee 18 (May 8, 2020)

*Quotes in the table are edited to enhance readability.

4.2.4 Impacts of Postponing NAIAS

Once cancellation of the event became a concern more interviewees discussed the ramifications of postponing or cancelling NAIAS. The interview guide included two questions regarding cancelling or postponing NAIAS to separate the impacts of the pandemic into categories: perception and deployment of AVs. The responses from the interviewees included information on both the pandemic response and event cancellation. Perception refers to how the public views autonomous transportation considering the risks presented by the pandemic. Deployment refers to what perceived benefits or hindrances the interviewees believe the pandemic may have on the deployment of AVs out for public use.

A recurring theme regarding perception is that hands-on experience can change how people accept technologies, particularly technologies that no one currently has access to. There is an inherent skepticism with the unfamiliar, especially since there is a gap between industry professionals and the public in understanding what AV technologies are capable of. Skepticism is increased during the pandemic because people will be more concerned about pandemic related issues and avoiding large gatherings. There is even a concern that the long-lasting effects of COVID-19 will result in "significantly lower attendance at large events like that (NAIAIS) probably for the next two or three years", significantly hindering developers' ability to gather data from the public (Interviewee 11- 4/8/20). Public transportation may see an even longer decline in ridership since some populations may not want to share public transportation vehicles because the public does not have the opportunity to control when, or how, they are sanitized.

The most significant problem with changing people's perception during this time is that the pandemic creates a delay in exposure to testing vehicles. Information regarding advancements in AVs generally is disseminated through traditional news outlets, however, the pandemic has dominated the news cycle and has taken away media attention from AV development. Furthermore, prior to the cancellation, the interviewees expressed a growing concern that a smaller NAIAS event (limited by COVID response policies) would limit inventiveness and decrease the flow of information to visitors. Education helps to bridge the gap between the public and professionals, and the additional year will delay the opportunity for educational opportunity unless something is done to increase educational programming during the period of cancellation.

Concerns with how the general public perceives AVs directly impacts the testing and deployment phases of AVs (and AV pilots). An increased focus needs to be put on public health and sanitation must be scheduled on a more frequent basis for public vehicles. Hiring cleaners for vehicles could be “priceless” to keep vehicles sanitized, however, moving vehicles to a common area to be cleaned creates an economic problem because trips are being made without moving passengers and thus not generating income (Interviewee 5- 3/30/20). The delay from COVID-19 creates an opportunity to improve and include new technologies that can clean AVs without requiring a common cleaning site or cleaning staff. The limited time available for transit providers to react to the pandemic, has relegated some services to using household items like “shower curtains around drivers to limit transmission” because no other alternatives were available to them (Interviewee 17- 5/8/20). Technological innovation has some lengthy steps, but this delay has opened a window of opportunity to help alleviate newly discovered concerns for whenever the next disruption occurs.

There is some consensus that not having the 2020 NAIAS event has not severely hurt deployment prospects, however, it still represents a missed opportunity for data gathering. Testing, particularly field testing, can be rare and some type of feedback is necessary for final products. Having fully functional AV shuttles at NAIAS represents a unique opportunity to test accessibility that may not occur in a general development setting. However, there are also interviewees that do not believe that testing should come from events in the first place because it can be “really dangerous” and letting people ride in autonomous vehicles requires a “rigorous and very carefully thought out development and testing program” (Interviewee 11- 4/8/20). Even without NAIAS there are still opportunities to test vehicles and the development process will continue for AVs.

Ultimately, cancelling the 2020 NAIAS event will not impact the eventual deployment of AVs, but it will be a significant missed opportunity for the testing phase of development. Testing helps shape policy for eventual deployment of new technologies, but the testing phase itself may be misleading for some riders because it is not available to them long-term. One interviewee associated with a local municipality recognized this concern for their city, indicating that "it is hard for anyone (residents) to rely on the transportation service (shuttles) that is up and running for two weeks and then gone" (Interviewee 24- 6/5/20). Ultimately, deploying AVs will eventually depend on levels of urbanization, economic assets, and the inclusion of important local stakeholders more than it will a testing pilot. In the years following the pandemic the priority for manufacturing and research will go back to focusing on AV development because they represent a large step in technological innovation, regardless of their involvement at the 2020 NAIAS event.

Table 5: Quotes from Responses to the Questions "What impacts will this decision to postpone have on the perception of AVs for Michigan communities?" and "What impacts will this decision to postpone have on the deployment of AVs for Michigan communities?"

Question	Synthesis of Data	Exemplary Quote
What impacts will this decision to postpone have on the perception of AVs for Michigan communities?	The hands-on aspect of using the AVs at NAIAS is a unique testing opportunity where users can provide real feedback.	"Now you're bringing a technology to the forefront that they can get on and use and evaluate and provide great feedback even."- Interviewee 2 (March 10, 2020)
	Interviewees expressed some skepticism that the public would be highly accepting of the new technology to start.	"So, it's already a tentative kind of public acceptance of the new technology." - Interviewee 5 (March 30, 2020)
	"Autonomous vehicles" is a term that many people are unfamiliar with. Once people can hear the word and associate it with a real technology then they can build a sense of familiarity with the technology.	"I think anytime that we can educate people about what the words are that we're using, and what they mean and then relate those to, you know, physically being able to see a system or touch a system I think helps, right?" - Interviewee 7 (April 2, 2020)

Table 5 (cont'd)

	There is an indication from some interviewees that this may not be a short-term disruption. A lack of trust surrounding large events or MGs will limit the effectiveness of using pilots at trade shows.	"There's no denying that by postponing it, it will postpone any exposure. I do think that we're going to see significantly lower attendance at large events like that probably for the next two or three years. So, you will have an impact because of that." - Interviewee 11 (April 8, 2020)
What impacts will this decision to postpone have on the deployment of AVs for Michigan communities?	The technology development process of AVs is like other types of technological advances. If people do not understand the technology, they need an opportunity to feel and touch the product through field testing. However, there's an informational component and exchange of knowledge necessary as well.	"Cell phones went through the same technology and things as they progress through, if people need, people will adapt, and people will get a better understanding and a better adoption of it, if we bring it to them where they can touch and feel and actually understand how the systems are working, and be able to engage and ask questions. And they start to correlate it to their personal life, right, the benefits that they get, just like we did with cell phones." - Interviewee 2 (March 10, 2020)
	The technological development process is lengthy, and has been especially for AVs. Missing one event for testing will not be detrimental to their overall deployment, however, it still is a missed opportunity.	"Deployment is multi-dimensional and complex. And that was true long before any of us had heard the word COVID. So, if you go back a few years, there were these extraordinary, you know, predictions about how the whole auto industry was going to be transformed by automated technologies. And, you know, it's been a crawl, not a run." - Interviewee 12 (April 9, 2020)
	The industry still has one singular goal: deploying fully functioning AVs, regardless of the timeline.	"The development process will still continue on. So, it won't have any impact to the industry one way or the other by the postponement." - Interviewee 13 (April 10, 2020)

Table 5 (cont'd)

	This represents an opportunity and a detriment to overall AV development. The opportunity is that technology can be greatly improved and there are new opportunities to outfit vehicles with new updates. The detriment is that even if changes are made to autonomous mobility solutions there are now limited opportunities to use them in real life testing scenarios.	"The upside is that you have a year, and a year in the tech world right now is huge. It is really pretty remarkable; the upside is that technology continues to change. It can only make things better in terms of what's available to utilize in that project moving forward. I think there's an upside. The downside is that real life testing doesn't get to happen. And I think there are things that you've learned from real life testing that you don't learn in the laboratory." - Interviewee 25 (June 15, 2020)

*Quotes in the table are edited to enhance readability.

4.2.5 Contingency Planning

The announcement to cancel NAIAS came on March 28th, 2020. At the same time NAIAS announced that there would be no further events scheduled for 2020 at this time and that the main event would take place in June 2021 due to the 6-month contract that FEMA has in place with the TCF Center. Having functioning AV pilots is directly tied to the decision to hold the event in the summer since autonomous vehicles are unable to drive in inclement weather conditions. This information itself indicates that the technology will not be developed enough to be deployed in locations that experience inclement weather for extended periods of time. Establishing a rescheduled date immediately helps NAIAS staff and affiliated stakeholders to salvage their planning efforts to be implemented at a time that should promise a similar level of attendees, layout, and weather conditions. The one-year layoff also ensures that the event planners can take time to put in proper precautions if COVID-19 concerns remain. This includes installing new touchless features, safety plans for mass gatherings, and re-planning event spaces to accommodate large gatherings.

Most interviewees expressed the need to simulate a face-to-face experience in lieu of the event and that online services make that more feasible and affordable than ever. However, there are potential drawbacks to using online webinars and showcases for transferring knowledge in a re-imagined format. The online programming would not allow for user feedback as effectively for autonomous vehicles because videos "cannot simulate true autonomy" (Interviewee 11- 4/8/20; Interviewee 14- April 9, 2020). Online programming could potentially assume some functions (such as fundraising or sharing information), but ultimately the impact would not be the same as if the testing and design phases of development were completed in a face-to-face setting.

Table 6: Quotes from Responses to the Questions "Why was June 2021 chosen for the future of the show?" and "Between now and next year's show will there be any online programming available?"

Question	Synthesis of Data	Exemplary Quote
Why was June 2021 chosen for the future of the show?	There were no other options to have the event planned and functioning during the same year (2020). The TCF Center agreed on a 6-month contract with FEMA for the event space and that eliminated the ability to have the event inside and outside.	"There was no plan to postpone it. As soon as we found the field hospital thing, we started looking well, we started looking, you know, can we do this later in the year and just with the current Convention Center and the fact that the convention center that FEMA contracts with for six months. Okay. And so that everything, we were there's nothing available. Okay, where could we have both it in and outside, you know, the way it was supposed to be."- Interviewee 22 (June 2, 2020)

Table 6 (cont'd)

	CES (the Consumer Electronics Show) is currently planning for a 2021 date and in order to keep up with this competing event NAIAS will as well.	"I mean, I saw CES that they're going to make January happen in 2021."- Interviewee 24 (June 5, 2020)
Between now and next year's show will there be any online programming available?	Online programming does not possess the same qualities as physical in terms of assessing the acceptance of a new type of technology.	"I think that that experience of being in a familiar car and having it doing things by itself, because you have the point of comparison of having been in the car driver to that, I think that is a is a really, really critical part of introducing people and maybe even assessing their, their acceptance of that technology and you can't do that."- Interviewee 14 (April 9, 2020)
	The technology associated with virtual meetings can help include people in showcases, despite pandemic response policies that limit contact.	"I think there may be significant potential value in doing some kind of a virtual autonomous mobility experience with various participants, there's so much you can do now with animation and, and, you know, virtual meetings and webinars." -Interviewee 21 (May 21, 2020)

*Quotes in the table are edited to enhance readability.

4.2.6 Creating Safeguards

The cancellation of the 2020 NAIAS created an opportunity for its stakeholders to examine how they can use the COVID-19 pandemic as a learning opportunity to create safeguards for mitigating the effects of future disruptions. The interviewees revealed that, at the core of the planning and development process, the most important theme that needs to be the focus of future planning efforts is enabling frequent and substantive communications between all stakeholders. Respondents from all five affiliations interviewed stated that stakeholders from different areas of expertise are necessary to build connections between different experts in areas related to regulation, policy, and technological development. Successful technological development requires common ground to be established through this communication so that a foundation is established in the event of another great disruption.

COVID-19 showed how to use these communications to form policy based on best practices for mitigating these disruptions. One respondent indicated that the planning process for the 2020 event has created the need for “emergency planning on a scale that we [the stakeholders] have never tried to implement before” (Interviewee 25- 6/15/20). These best practices for mitigating disruptions can be based on existing policy. However, COVID-19 also generated new ideas to include in future planning efforts. In the case of autonomous vehicles and publicly shared technologies this has manifested itself by placing a new emphasis on sanitation plans and using new technologies to the advantage of the stakeholders.

In the case of technology development, mitigation policies can also focus on how existing technologies can be used to create solutions during a disruption or how policy can help further the technology development process. From a policy perspective, legislation can help open options for the testing phase of technology deployment in private settings during a disruption. Michigan has accomplished this by having open testing policies for AVs, which has allowed the state to experiment with smaller AV shuttles to “take the human out of the equation and implement that technology” (Interviewee 8- 4/6/20). Additionally, there is an opportunity to explore using various new technologies in transit that “could apply support for the prevention of infectious diseases being spread” (Interviewee 3- 3/24/20). Existing companies that provide transit and ridesharing services through policy also can help with the overall deployment of new technologies.

Table 7: Quotes from Responses to the Question "How can policymakers and involved stakeholders work together to create safeguards for mitigating the effects of disruptions?"

Question	Synthesis of Data	Exemplary Quotes
How can policymakers and involved stakeholders work together to create safeguards for mitigating the effects of disruptions?	One way to create safeguards is to find a way for the technology being developed to be used to mitigate the effects of disruptions. This way, no time is lost during the design or testing phases during the disruption.	"So, another hurdle the industries in the public sector are facing, and what's interesting is, I'm now looking at different startups that could apply could support for the prevention of infectious diseases being spread, you know, via transit."- Interviewee 3 (March 24, 2020)
	The COVID-19 Pandemic has created an opportunity to include sanitation technologies in future "best practices" for pandemic response policies. Even if current technologies cannot be used for this pandemic, the inception phase of future technologies can utilize data from this disruption.	"And also on the vehicle, there may either be some new things that we weren't going to include, whether that's specific anti-microbial coating, or, you know, maybe there's a EKG monitor or a temperature sensor inside the vehicle, which is quite advanced. So, it'd be hard to get done soon."- Interviewee 3 (March 24, 2020)
	The important stakeholders to involve in the planning process are the policymakers, developers, and officials that were directly affected by the pandemic. Keeping open lines of communication, even after the disruption, can be important for recognizing best practices for future disruptions.	"I mean, we already have emergency operating centers, we already have all of the constructs in place, but we don't always have the right people at the table making these decisions. So having a post-mortem with the actual stakeholders that were most affected, to come together, with those people that can actually solve the issues and plan for it would make a lot more sense than what we typically see."- Interviewee 10 (April 6, 2020)
	If the development of technology can provide a benefit during the pandemic then the inception and design (intellectual) and testing and deployment (regulatory) environments should be established to allow for the development of that technology during the disruption.	"Bottom line is we believe people will be safer with this technology. If we believe as we do, that our law is advantageous for people developing what they need to do, then we should we should say, this is what we offer in terms of a regulatory environment."- Interviewee 16 (April 29, 2020)

Table 7 (cont'd)

	An open line of communication is important among stakeholders to achieve success. There needs to be trust established between all the involved parties.	"I think the biggest obstacle about success is always about understanding that there's a trust and trusting somebody and working on the same goal."- Interviewee 19 (May 11, 2020)
	The group of professionals have not done emergency planning on a scale like this. This creates an opportunity for implementing safety policies at future NAIAS events, like what is done at other MGs (the Hajj).	"I think what we've learned from COVID-19 is disaster planning, or emergency planning, on a scale that we have never tried to implement before."- Interviewee 25 (June 15, 2020)

*Quotes in the table are edited to enhance readability.

4.3 Synthesis of the Interview Data

Following the completion of the key stakeholder interviews I collected and coded the data from the open-ended responses as either positive or negative effects. I updated Table 8 to include the data from the open-ended responses, showing the effects of pandemic response policies on stages of technology deployment including data from the literature review and interviews. A total of 43 effects were added to the table, an increase of 25 from the literature review data. Thirty-six of the effects represented a negative impact on the stages of technology development, and 7 of the effects represented a positive impact.

Self-quarantine (4 negative effects and 2 positive effects) and travel constraints (7 negative and 2 positive) policies share similar themes. Both policies separate people and interrupt how individuals normally interact with one another in public. Self-quarantine does not allow people to meet in-person continually over periods of time, which is generally necessary for the design and testing phases. Travel constraints impact how public transportation is supposed to function because there will be less human interaction on public vehicles or between drivers and riders. However, the positive effects for both policies emphasize how technology can help people separate in ways that were previously not possible, including digital communication and using smaller, single-person AVs for transportation if they are available.

Location closures (5 negative) and cap on gathering (3 negative) policies both share similar effects as well. Ultimately, these policies threaten to either limit or eliminate the NAIAS platform, which eliminates the opportunity to test the pilots. The event will not be needed to test the pilots, but limits on the attendees or using only the public as a testing audience would limit the exposure to the AV pilots. From a work-based perspective the location closure policies may marginalize some stakeholders who cannot participate as effectively via web platforms and closures of production assemblies will negatively impact the construction of the AV pilots. These policies affect commuting patterns as well by changing the locations that people can travel to and potentially limiting how many people can ride on large public transit vehicles. Disruptions in how people live in their day-to-day lives will potentially skew AV shuttle data because the NAIAS pilot programs were supposed to benefit from operating around human operated vehicles.

Shelter in place (3 negative and 1 positive) and complete house arrest (7 negative and 1 positive) policies create similar effects on the inception and deployment phase. The positive effects for each policy on the inception phase are that the development process can start, and collaboration can be achieved if people communicate frequently online. During the deployment phase, there were concerns that these policies would not be effective for some workers, particularly because AVs will require people to leave their homes and clean public vehicles routinely. These policies also disrupt the testing phase because there will be a lack of people on the streets, and it is impossible to simulate pedestrians. Gathering data on how AVs will function will be difficult because AVs will only be used for medical trips or emergencies.

The last section of Table 8 covers the broad impacts that the pandemic has on specific stages of technology development. In this section the inception, design, and testing phases have similar negative effects, that digital programming cannot simulate reality in a way that allows for honest feedback. Without this on-road testing the deployment will be negatively affected because regulation for AVs requires the testing data. Regulatory obstacles may be more difficult to overcome anyway since pandemic relief regulation may take the forefront for policymakers. The one positive effect listed in this final section is that AVs can be improved from a technological standpoint since improvements in technology can happen rapidly.

Table 8: The Effects of Pandemic Response Policies on the Stages of Technology Development (Literature Review and Interview Data)

		Stages of Technology Development			
		Inception	**Design**	**Testing**	**Deployment**
Policy Responses to Pandemics	**Self-Quarantine (Social Distancing)**	↓*: Multiple stakeholders must work together and become familiar with each other. ↓: Different stakeholders cannot be together to work on shared components of AVs. ↑*: *The high levels of communication are necessary for AV pilots can already happen digitally.*	↓: *Design must be continually adjusted to reflect social distancing requirements.*	↓: *Testing requires diverse stakeholders be in attendance without restrictions.* ↓: *Social distancing limits the ability to put operators or handlers on AVs.*	↓: Advocacy groups cannot support deployment through face-to-face contact. ↑: *AVs can be used for new services to help enforce social distancing.* ↓: *It is difficult to separate operators and passengers in vehicles designed pre-pandemic.*

Table 8 (cont'd)

	Travel Constraints	↓: *If existing transportation services are changed it will augment how AV pilots are intended to function.* ↓: *AV pilots must be functional to provide valuable data.*	↑: *2020 NAIAS demos follow a specific route for programming that already exists.*	↑: AVs can drive in local traffic if only inter-population constraints are implemented. ↑: Lab tests can simulate reality. ↓: *Human drivers will interact with AVs less frequently.* ↓: *Pilots are temporary and not reliable during a disruption.* ↓: *AVs will lose the ability to interact with human travelers.*	↓: A lack of traveling will slow interaction with AV specific infrastructure. ↓: *Delay in exposure.* ↓: *Public transit will decline.* ↑: *Single-passenger AVs will be more useful.*
	Location Closures	↓: *Workplace closures will be difficult to manage if some stakeholders cannot participate equally.*	↓: *2020 NAIAS needs to use multiple venues to meet full capacity.*	↓: *Plant closures stopped production of shuttles at various stages of completeness.*	↓: *Closure of city offices will disrupt issuing permits.* ↓: *The NAIAS platform will be eliminated.*

Table 8 (cont'd)

	Cap on Gatherings	↓: *NAIAS averages 750,000 attendees and limitations will alter its impact.*	↓: Transit studies need to involve humans present for feedback. ↑: Well-designed systems can rely on digital communications.	↓: *There may be concerns for being on large shared vehicles.*	↓: Advocacy groups and stakeholders cannot meet. ↓: *The event will be limited.*
	Shelter in Place	↑: *The development process can continue if people work from home.*	↓: The design of new vehicle technology requires that it is human friendly.	↓: Public transit will decline as people travel less. ↓: *Urban areas will see transit impacted the most, which is where NAIAS takes place.* ↓: *Pedestrians are needed for testing and cannot be simulated.*	↓: Workers will need to leave their homes to install infrastructure for AVs. ↓: *Workers will need to leave their homes more to clean AVs.*

Table 8 (cont'd)

	Complete House Arrest	↓: *Some stakeholders may not be able to enable their workers to work virtually full time.* ↑: *Collaboration can be achieved if all stakeholders enter online meetings.*	↓: *The focus of policy will be centered on homes, not AVs.* ↓: *Focus on the news will not be educating people on AVs.*	↓: Teams cannot meet to collaborate and deploy shuttles. ↓: *Limited movement means there will be no repeat users.*	↓: Workers will need to leave their homes to install infrastructure for AVs. ↓: *Workers will need to leave their homes more to clean AVs.* ↓: *Lack of workers will impact funding for automotive companies.* ↓: *AVs will be limited to only medical trips, not gathering data.*
	All: Areas of Deployment Broadly Affected by All Pandemic Responses	↑: New policy is based off available existing research. ↑: Scoping new technology can be done virtually. ↓: *Limit inventiveness.* ↓: *Sharing ideas online is less familiar than face-to-face contact.*	↑: Aesthetic design can be shared digitally for improvement. ↓: *Online programming makes it harder to get feedback from people.* ↓: *Videos cannot simulate auto.* ↑: *Delays with NAIAS can be a chance to improve technology.*	↑: Testing can occur on private tracks for safe development. ↓: *Feedback is necessary for pilots to be improved through testing.* ↓: *Online programming doesn't allow real on-road testing.*	↓: The regulatory atmosphere must allow for deployment pre-pandemic or it will be delayed. ↓: *Regulations will not focus on AV deployment until post-pandemic.*

*This table represents the findings from the literature review and key stakeholder interviews. The statements from existing literature are in plain font. The statements from the stakeholder interviews are in italics.
*The "↑" arrow indicates a positive effect that the pandemic response policy would have on that phase of technology development.
*The "↓" arrow indicates a negative effect that the pandemic response policy would have on that phase of technology development.

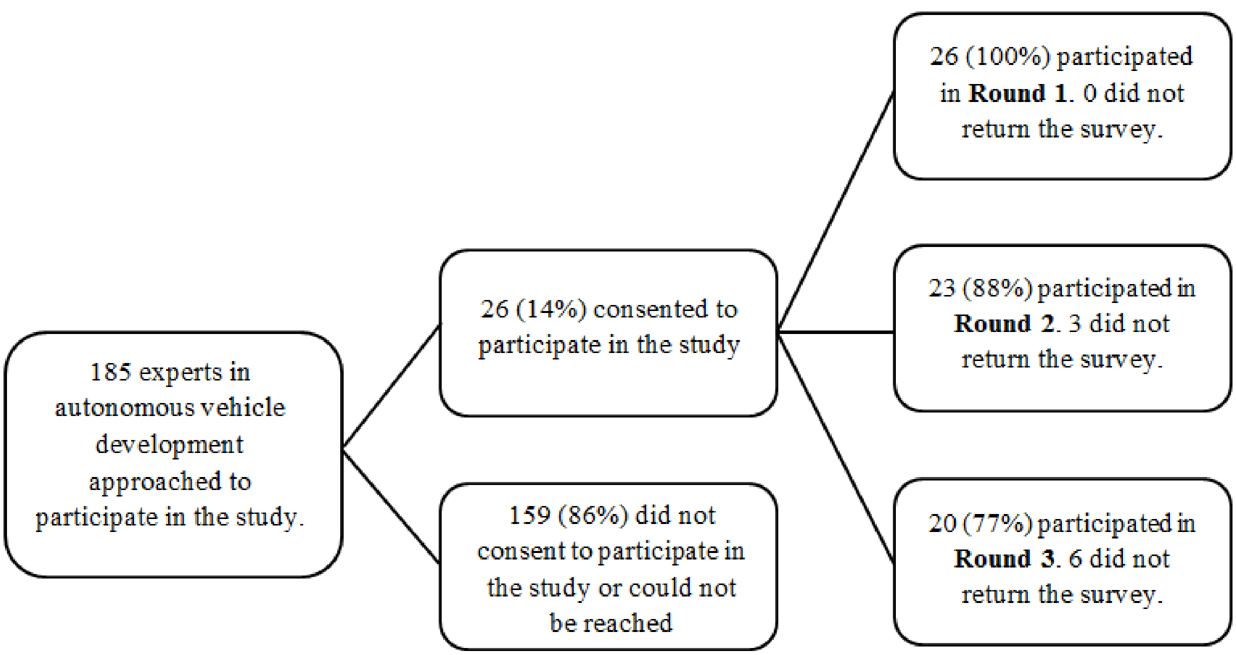
Chapter 5: Delphi Study Data and Analysis

I started the three-phase Delphi Study after completing the synthesis for the interview data. After the data analysis I included the open-ended responses in the table for review in subsequent rounds of the survey for additional review from the respondents. This section analyzes the responses from the survey tool for each round of the Delphi Study.

5.1 Delphi Study: Respondents

Invitations to participate in the Delphi Study were sent to 185 potential participants via e-mail from August 3rd to September 10th, 2020. The participants were gathered from a pool of experts on autonomous vehicle development that were identified from articles in peer-reviewed academic journals and university-based autonomous vehicle research groups. Twenty-six individuals completed the survey questionnaire, all of whom signed the consent form agreement to complete all three phases of the study (Appendix E, Figure 1).

Figure 1: Number of Delphi Study Participants in Each Round



The largest group of respondents by age is 40-49 years old (9), followed closely by 30-39 years old (7). Together these two groups accounted for a total of 61.5% of all study participants. The remaining age groups for the participants are 18-29 (2), 50-59 (3), 60-69 (1), and 70 and older (4). A large majority of respondents indicated that they are affiliated with higher-educational institutions (16). Other affiliations of the respondents are private entities (3), non-profit organizations (3), other (3: student, research center, and retired), and a government entity (1). Ultimately, the 26 respondents came from six countries: the United States of America (17), Canada (4), Australia (2), Italy (1), the Netherlands (1), and Singapore (1).

5.2 Delphi Study: Phase One

The first phase of the Delphi Study ended on September 17th, 2020 and the data were placed into Table 10 below to see if any statements reached consensus among the experts. In the first round only one of the questions met the 70% level of agreement required to achieve consensus: 73.1% (19) of the respondents believed that complete house arrest policies "greatly hinders" the deployment phase of technology development. The next highest category for all categories included was a tie between eleven that all achieved a level of consensus of 53.8% (14).

The results from phase one indicate that, in total, the participants believe that pandemic response policies "hinder" the development of autonomous vehicles at each stage of the development process. A complete count of all responses shows that the testing (50%) and design phases (47.1%) are the most likely to be hindered by the pandemic because they require more constant collaboration and people to be in the same location to complete work. In the open answer response portion, the participants added 28 responses that were coded as negative effects, shown in Table 15 at the end of this chapter. The negative responses for the inception and design phases relate to how pandemic response policies limit contact, prevent data gathering, and restrict access to resources that may only be available in physical workspaces. The responses for the testing and design phase are centered mostly on a decreased demand for traveling and an unwillingness for people to use shared, public vehicles.

The answers that received the lowest number of responses in both the Likert Scale and open-ended responses for all categories are “greatly benefit” and “benefit”. Only ten open ended responses were coded as positive effects for AV development, compared to 28 negative effects. The positive effects for the inception and testing phases primarily rely on having people work from home or communicate with online tools. For the testing and deployment phase, public roads could be easier for AV pilots to navigate on because they will be less congested or only used by essential workers. The development phase had the most respondents select positive responses, indicating that the pandemic response policies will have the most negative impact on the earlier phases of AV development and once AVs are deployed they can fulfill some beneficial roles during a pandemic.

The participants were also asked to what extent the pandemic impacted AV development on a broad scale. These responses in Table 9 matched the overall responses from the respondents gathered by adding up the aggregate of all responses. When asked about the overall impact on AV development 57.7% responded that it would hinder development, compared to 45.1% stating “hinder” in the aggregate responses. The responses indicate that the participants believe that the pandemic will have a greater impact on AV development than it has had on their personal lives. In terms of personal impact, Table 9 below shows the largest group of respondents (46.2%) indicated that the pandemic has neither had a positive or negative impact. This may be attributed to the increased ability for participants to work from home if their work has allowed them to.

Table 9: The Overall Impact of COVID-19 on AV Development and Personally on the Survey Respondents (Phase 1)

AV Development			Respondents		
	Number	Percentage		Number	Percentage
Greatly Benefit	0	0.0%	Greatly Positive Impact	0	0.0%
Benefit	3	11.5%	Positive Impact	1	3.8%
Neither	6	23.1%	Neither	12	46.2%
Hinder	15	57.7%	Negative Impact	9	34.6%
Greatly Hinder	2	7.7%	Greatly Negative Impact	4	15.4%
Totals:	**26**	**100.0%**	**Totals:**	**26**	**100.0%**

Table 10: Responses from the First Round Survey of the Delphi Study

	Self-Quarantine		Travel Constraints		Location Closure		Cap on Gatherings		Shelter in Place		House Arrest		Totals	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Inception														
Greatly Benefit	1	3.8%	1	3.8%	1	3.8%	1	3.8%	1	3.8%	1	3.8%	6	3.8%
Benefit	1	3.8%	1	3.8%	0	0.0%	1	3.8%	2	7.7%	0	0.0%	5	3.2%
Neither	9	34.6%	9	34.6%	9	34.6%	11	42.3%	10	38.5%	7	26.9%	55	35.3%
Hinder	12	46.2%	13	50.0%	14	53.8%	11	42.3%	9	34.6%	9	34.6%	68	43.6%
Greatly Hinder	3	11.5%	2	7.7%	2	7.7%	2	7.7%	4	15.4%	9	34.6%	22	14.1%
Totals:	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**156**	**100%**
Design														
Greatly Benefit	1	3.8%	2	7.7%	2	7.7%	1	3.8%	1	3.8%	1	3.8%	8	5.1%
Benefit	0	0.0%	2	7.7%	0	0.0%	1	3.8%	1	3.8%	1	3.8%	5	3.2%
Neither	10	38.5%	10	38.5%	7	26.9%	11	42.3%	7	26.9%	7	26.9%	52	33.3%
Hinder	14	53.8%	11	42.3%	14	53.8%	11	42.3%	14	53.8%	14	53.8%	78	50.0%
Greatly Hinder	1	3.8%	1	3.8%	3	11.5%	2	7.7%	3	11.5%	3	11.5%	13	8.3%
Totals:	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**156**	**100%**
Testing														
Greatly Benefit	1	3.8%	2	7.7%	1	4.0%	1	3.8%	1	3.8%	1	3.8%	7	4.5%
Benefit	1	3.8%	1	3.8%	3	12.0%	2	7.7%	3	11.5%	1	3.8%	11	7.1%
Neither	6	23.1%	6	23.1%	2	8.0%	7	26.9%	2	7.7%	2	7.7%	25	16.1%
Hinder	14	53.8%	11	42.3%	12	48.0%	14	53.8%	14	53.8%	8	30.8%	73	47.1%
Greatly Hinder	4	15.4%	6	23.1%	7	28.0%	2	7.7%	6	23.1%	14	53.8%	39	25.2%
Totals:	**26**	**100%**	**26**	**100%**	**25**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**155**	**100%**

Table 10 (cont'd)

Deployment														
Greatly Benefit	1	3.8%	2	7.7%	1	3.8%	2	7.7%	2	7.7%	1	3.8%	9	5.8%
Benefit	3	11.5%	3	11.5%	2	7.7%	2	7.7%	0	0.0%	1	3.8%	11	7.1%
Neither	8	30.8%	4	15.4%	4	15.4%	9	34.6%	3	11.5%	3	11.5%	31	19.9%
Hinder	10	38.5%	12	46.2%	14	53.8%	11	42.3%	14	53.8%	2	7.7%	63	40.4%
Greatly Hinder	4	15.4%	5	19.2%	5	19.2%	2	7.7%	7	26.9%	19	73.1%	42	26.9%
Totals:	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**26**	**100%**	**156**	**100%**
Totals:	**104**		**104**		**103**		**104**		**104**		**104**		**623**	

5.3 Delphi Study: Phase Two

The second phase of the Delphi Study ended on October 7th, 2020 and I subsequently entered the data into Table 12 below to see what items achieved a 70% level of consensus. In addition to the single item from phase 1 (complete house arrest *greatly hinders* the deployment phase) the following two questions achieved consensus in phase 2:

- Travel constraints *hinder* the testing phase of development (73.9%).
- Complete house arrest *greatly hinders* the testing phase of development (73.9%).

Shelter in place policies *hindering* the testing phase (65.2%) came the next closest to achieving consensus. In phase 2 the respondents were given the ability to discuss if they disagreed with the statements that met consensus in phase 1. One respondent disagreed with the consensus from the first phase (shown in Table 10) and stated that they disagreed with the view of deployment presented "without the broader societal view", indicating that deployment of AVs goes beyond the pandemic (Respondent 8- 8/22/20).

The inception phase and the design phase changed the most from the first phase to the second phase of the Delphi Study. Each phase saw changes in the response that received the most responses for the following pandemic policies: self-quarantine, cap on gatherings, and complete house arrest (Table 12). Responses for self-quarantine both trended towards *neither benefit nor hinder* the inception and testing phases after *hinder* received a majority of responses in the first phase. Complete house arrest saw a change towards *neither* for the inception phase, however, for the design phase eight more respondents selected *greatly hinder* in phase 2 than phase 1. Only one respondent filled in the open-ended portion for this question so the only input for the large change is that the respondent believes that if "important stakeholders are the ones affected this phase [design] will be hindered" (Respondent 26- 10/5/20).

Throughout the entire survey in phase 2 the most selected response in 15 out of 23 total categories is *hinder*. However, the number of categories where *hinder* received the most selections, or tied for the most selections, is still lower than the 21 categories it led in phase 1. However, despite this decline the most popularly selected category for all four phases of development remained that pandemic response policies in total *hinder* development. When asked about how the pandemic effects AV development in total the results from phase 2 (Table 11) again showed that 81.8% of respondents believed that the pandemic would *hinder* development overall, an increase of 24.1% from phase 1. However, the amount of time that the pandemic will hinder development is disputed. Respondent 7 (9/21/20) wrote in the open-ended portion of the survey that they expect “COVID-19 to hinder the development in the short-term", however, there is optimism that the effects will not hinder the overall development and deployment of AVs.

In the period from the completion of Phase 1 of the Delphi Study to the completion of Phase 2 of the Delphi Study (9/17/20 through 10/7/20) 26.3% respondents changed their responses, indicating that the pandemic had a negative impact on them personally. The increase in respondents selecting negative impact coincided with a 20.1% decline in respondents that stated that the pandemic had neither a positive nor negative effect on their personal life. This may be attributed to increased stress from the fall 2020 semester starting at universities throughout most of the United States since 16 respondents are affiliated with higher education institutions and 1 is a student.

Table 11: The Overall Impact of COVID-19 on AV Development and Personally on the Survey Respondents (Phase 2)

AV Development			Respondents		
	Number	Percentage		Number	Percentage
Greatly Benefit	0	0.0% (+0.0%)	Greatly Positive Impact	0	0.0% (+0.0%)

Table 11 (cont'd)

Benefit	0	0.0% (-11.5%)	Positive Impact	1	4.3% (+0.5%)
Neither	3	13.6% (-9.5%)	Neither	6	26.1% (-20.1%)
Hinder	17	81.8% (+24.1%)	Negative Impact	14	60.9% (+26.3%)
Greatly Hinder	1	4.5% (-3.2%)	Greatly Negative Impact	2	8.7% (-6.7%)
Totals:	**22**	**100.0%**	**Totals:**	**23**	**100.0%**

*The data within parentheses indicates the percent change from the results of Round 1 (Table 9) of the Delphi Study.

Table 12: Responses from the Second Round Survey of the Delphi Study

	Self-Quarantine		Travel Constraints		Location Closure		Cap on Gatherings		Shelter in Place		House Arrest		Totals	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Inception														
Greatly Benefit	1	4.5%	1	4.3%	1	4.3%	1	4.3%	1	4.5%	1	4.3%	6	4.4%
Benefit	0	0.0%	0	0.0%	0	0.0%	0	0.0%	1	4.5%	2	8.7%	3	2.2%
Neither	11	50.0%	5	21.7%	6	26.1%	7	30.4%	10	45.5%	9	39.1%	48	35.3%
Hinder	10	45.5%	10	43.5%	11	47.8%	14	60.9%	9	40.9%	4	17.4%	58	42.6%
Greatly Hinder	0	0.0%	7	30.4%	5	21.7%	1	4.3%	1	4.5%	7	30.4%	21	15.4%
Totals:	**22**	**100%**	**23**	**100%**	**23**	**100%**	**23**	**100%**	**22**	**100%**	**23**	**100%**	**136**	**100%**
Design														
Greatly Benefit	1	4.3%	1	4.3%	1	4.3%	1	4.3%	1	4.3%	1	4.3%	6	4.3%
Benefit	0	0.0%	2	8.7%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	2	1.4%
Neither	14	60.9%	6	26.1%	4	17.4%	13	56.5%	5	21.7%	5	21.7%	47	34.1%
Hinder	7	30.4%	11	47.8%	12	52.2%	5	21.7%	11	47.8%	6	26.1%	52	37.7%
Greatly Hinder	1	4.3%	3	13.0%	6	26.1%	4	17.4%	6	26.1%	11	47.8%	31	22.5%
Totals:	**23**	**100%**	**23**	**100%**	**23**	**100%**	**23**	**100%**	**23**	**100%**	**23**	**100%**	**138**	**100%**
Testing														
Greatly Benefit	1	4.3%	1	4.3%	1	4.3%	1	4.5%	1	4.3%	1	4.3%	6	4.4%
Benefit	0	0.0%	0	0.0%	1	4.3%	1	4.5%	0	0.0%	0	0.0%	2	1.5%
Neither	5	21.7%	0	0.0%	2	8.7%	6	27.3%	2	8.7%	1	4.3%	16	11.7%
Hinder	9	39.1%	17	73.9%	13	56.5%	12	54.5%	15	65.2%	4	17.4%	70	51.1%
Greatly Hinder	8	34.8%	5	21.7%	6	26.1%	2	9.1%	5	21.7%	17	73.9%	43	31.4%
Totals:	**23**	**100%**	**23**	**100%**	**23**	**100%**	**22**	**100%**	**23**	**100%**	**23**	**100%**	**137**	**100%**

Table 12 (cont'd)

Deployment														
Greatly Benefit	1	4.8%	1	4.3%	1	4.3%	1	4.3%	1	4.3%	The Respondents Reached Consensus in Round 1		5	4.4%
Benefit	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%			0	0.0%
Neither	6	28.6%	3	13.0%	3	13.0%	6	26.1%	2	8.7%			20	17.7%
Hinder	8	38.1%	11	47.8%	10	43.5%	11	47.8%	9	39.1%			49	43.4%
Greatly Hinder	6	28.6%	8	34.8%	9	39.1%	5	21.7%	11	47.8%			39	34.5%
Totals:	**21**	**100%**	**23**	**100%**	**23**	**100%**	**23**	**100%**	**23**	**100%**			**113**	**100%**
Totals:	**89**		**92**		**92**		**91**		**91**		**69**		**524**	

5.4 Delphi Study: Phase Three

The final phase of the Delphi Study ended on October 14^{th}, 2020 when 20 respondents finished completing their survey. Upon completion of the final phase no more questions met consensus among the respondents. The statements that gathered the highest amount of consensus did not meet the 70% threshold required by the methodology of this study. The statements that "complete house arrest *greatly hinders* the design phase" and "shelter in place *hinders* the testing phase" received 13 responses out of a total of 20 possible (65%). A total of 8 categories had a different category receive the highest number of responses from phase 2 to phase 3, compared to 7 from phase 1 to phase 2.

Two respondents took the opportunity to voice their disagreement to the statements that met consensus presented in Table 12. One respondent indicated that the extent that travel constraint and complete house arrest policies can hinder the testing phase is dependent on if a member of the testing team is subjected to the policies (Respondent 26- 10/7/20). The other respondent had a much broader view of why they disagreed with the pandemic hindering AV development. Ultimately, their sentiment is that if the people and environment needed to develop AVs is protected from negative health effects then the development process can continue. Technology can be used for good in society, and the development process can continue so long as there are people to work towards an end goal, or as the respondent responded, "dead people do not develop technology" (Respondent 8- 10/8/20).

The eight questions that had a change in the largest number of respondents mostly trended towards the respondents believing that the pandemic response policies hindered development even more than in phase 2 (Table 14). The one response that trended more towards *neither* instead of *hinder* is the travel constraint policies on the design phase. Respondent 25

(10/9/20) indicated that the design phase may not be as adversely impacted because this phase can "mostly still be done at home." The testing phase did not have any changes in which questions gathered the most responses from the respondents.

More respondents in Phase 3 selected *benefit* than they did in phase 2 (22 responses in phase 3 compared to 7 in phase 2). However, despite the increase in *benefit* responses *hinder* remained the category with the most responses for all four stages of development. Although, *greatly hinder* tied *hinder* for the most responses for the deployment stage in phase 3. This data is reflected in Table 13, where a large majority of respondents indicated that they believed that the pandemic would *hinder* the overall development of AVs. Respondent 20 (10/7/20) indicated that the more negative impact may occur for overall development because the "sum of constraints will be worse than the constraints individually considered."

Table 13: The Overall Impact of COVID-19 on AV Development and Personally on the Survey Respondents (Phase 3)

AV Development			Respondents		
	Number	Percentage		Number	Percentage
Greatly Benefit	0	0.0% (+0.0%)	Greatly Positive Impact	0	0.0% (+0.0%)
Benefit	2	10.5% (+10.5%)	Positive Impact	1	5.0% (+0.5%)
Neither	0	0.0% (-14.3%)	Neither	4	20.0% (+2.7%)
Hinder	15	78.9% (-2.1%)	Negative Impact	13	65.0% (+1.4%)
Greatly Hinder	2	10.5% (+5.7%)	Greatly Negative Impact	2	10.0% (-0.9%)
Totals:	**19**	**100.0%**	**Totals:**	**20**	**100.0%**

*The data within parentheses indicates the percent change from the results of Phase 2 (Table 11) of the Delphi Study.

Table 14: Responses from the Third Round Survey of the Delphi Study

	Self-Quarantine		Travel Constraints		Location Closure		Cap on Gatherings		Shelter in Place		House Arrest		Totals	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Inception														
Greatly Benefit	1	5.0%	1	5.0%	1	5.0%	1	5.0%	1	5.0%	1	5.0%	6	5.0%
Benefit	2	10.0%	0	0.0%	0	0.0%	0	0.0%	2	10.0%	2	10.0%	6	5.0%
Neither	10	50.0%	3	15.0%	3	15.0%	5	25.0%	5	25.0%	4	20.0%	30	25.0%
Hinder	7	35.0%	7	35.0%	12	60.0%	10	50.0%	7	35.0%	5	25.0%	48	40.0%
Greatly Hinder	0	0.0%	9	45.0%	4	20.0%	4	20.0%	5	25.0%	8	40.0%	30	25.0%
Totals:	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**120**	**100%**
Design														
Greatly Benefit	1	5.0%	1	5.0%	1	5.0%	1	5.0%	1	5.0%	1	5.0%	6	5.0%
Benefit	3	15.0%	3	15.0%	1	5.0%	0	0.0%	0	0.0%	1	5.0%	8	6.7%
Neither	7	35.0%	7	35.0%	6	30.0%	6	30.0%	3	15.0%	2	10.0%	31	25.8%
Hinder	9	45.0%	7	35.0%	11	55.0%	12	60.0%	9	45.0%	3	15.0%	51	42.5%
Greatly Hinder	0	0.0%	2	10.0%	1	5.0%	1	5.0%	7	35.0%	13	65.0%	24	20.%
Totals:	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**120**	**100%**
Testing														
Greatly Benefit	1	5.0%	The Respondents Reached Consensus in Round 2		1	5.0%	1	5.0%	1	5.0%	The Respondents Reached Consensus in Round 2		4	5.0%
Benefit	1	5.0%			2	10.0%	1	5.0%	1	5.0%			5	6.3%
Neither	5	25.0%			5	25.0%	5	25.0%	1	5.0%			16	20.0%
Hinder	7	35.0%			8	40.0%	10	50.0%	13	65.0%			38	47.5%
Greatly Hinder	6	30.0%			4	20.0%	3	15.0%	4	20.0%			17	21.3%
Totals:	**20**	**100%**			**20**	**100%**	**20**	**100%**	**20**	**100%**			**80**	**100%**

Table 14 (cont'd)

Deployment														
Greatly Benefit	1	5.0%	1	5.0%	1	5.0%	1	5.0%	1	5.0%	The Respondents Reached Consensus in Round 1		5	5.0%
Benefit	2	10.0%	0	0.0%	1	5.0%	0	0.0%	0	0.0%			3	3.0%
Neither	4	20.0%	2	10.0%	3	15.0%	3	15.0%	2	10.0%			14	14.0%
Hinder	12	60.0%	10	50.0%	5	25.0%	7	35.0%	5	25.0%			39	39.0%
Greatly Hinder	1	5.0%	7	35.0%	10	50.0%	9	45.0%	12	60.0%			39	39.0%
Totals:	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**100%**	**20**	**1.0%**			**100**	**100%**
Totals:	**80**		**60**		**80**		**80**		**80**		**40**		**420**	

5.5 Synthesis of the Delphi Study Data

Following the completion of the key stakeholder interviews I collected and coded the data from the open-ended response portion of the surveys as either positive or negative effects. Table 15 (below) represents all the potential effects of pandemic response policies on the stages of technology development that have been gathered from the literature, key stakeholder interviews, and the Delphi Study. The open-ended responses from all three phases of the Delphi Study yielded a total of 67 effects (19 positive and 48 negative) that have been placed in Table 15.

The positive effects for the inception and design phases primarily focus on people being able to work from home during the disruption. This includes using technology, such as online meeting tools, to meet people virtually and work from home. Respondent 23 (10/15/20) noted that working from home is more possible than any time before 2020, and respondent 1 (9/10/20) followed up on this by writing that working from home will help design proceed similarly to pre-COVID paces. The positives for the testing phase come from the location closure, cap on gathering, and shelter in place policies. These effects relate to developers taking advantage of less congestion on the roadways to jumpstart testing on public roads without needing to be concerned about the public. Ultimately, the final deployment of AVs is "more long-term than the pandemic" and stakeholders must find a way to work through the development process during the disruption (Respondent 23- 10/8/20).

The most negative effects gathered from the Delphi Study are related to the inception phase of development (15 total). The focus of the negative effects for this phase is that the pandemic response policies make it more difficult for people to meet each other, collaborate, and generate inspiration for new ideas in virtual settings. Respondent 25 (9/28/20) stated that "social gatherings are where ideas are generated", and without an annual platform like NAIAS there will be a gap where industry professionals miss out on collaborating with one another. The hinderances for the design phase also relate to stunting people's creativity and eliminating the ability for people to gather in labs and manufacturing facilities where "design needs to take place" (Respondent 11- 10/4/20). One additional concern for the design process is that "reduced or delayed funding is a threat to the design process" (Respondent 1- 9/30/20).

While the hindrances for the inception and design phase focus on people not being able to meet one another the testing and development phases require people to ride on AVs to be successful. Testing requires people experiencing AVs because lab tests are only simulated and thus "do not generate the same level of confidence" (Respondent 25- 9/15/20). Location closure policies have a particularly negative effect on testing and deployment because these phases are dependent on specific locations being open and operational, such as testing tracks and pick-up/drop-off points for AVs. Another recurring theme for these phases is that the pandemic will create a concern for getting into shared vehicles. Respondent 25 (9/15/20) went as far as saying that "people will not be willing to use AVs at all."

Ultimately, the respondents in the Delphi Study believe that the pandemic response policies *hinder* the development of AVs. The leading category of total responses shown in Tables 10, 12, and 14 indicates that the largest group of respondents for each phase of development selected *hinder* as their answer. There are some policies, such as complete house arrest, anticipated to have a more severe effect on development. In fact, *greatly hinder* was the only other response category to tie *hinder* for the most responses for a single phase (Table 14). A majority of respondents also selected *hinder* when asked about how the pandemic impacts overall technology development (shown in Tables 9, 11, and 13).

Table 15: The Effects of Pandemic Response Policies on the Stages of Technology Development (Literature Review, Interview, and Delphi Study Data)

		Stages of Technology Development			
		Inception	**Design**	**Testing**	**Deployment**
Policy Responses to Pandemics	**Self-Quarantine (Social Distancing)**	↓*: Multiple stakeholders must work together and build familiarity. ↓: Different stakeholders cannot be together to work on shared components of AVs. ↑*: *The high levels of communication are necessary for AV pilots can already happen digitally.* ↓*: The uncertainty about policy responses makes it difficult to plan. ↓: Digital meetings may not be as productive of face-to-face meetings since stakeholders cannot meet. ↑: The inception phase is long as gradual, so there will not be a significant impact.	↓: *Design must be continually adjusted to reflect social distancing requirements.* ↑: Work from home is proven to work quite well and this will help design proceed similar to pre-COVID paces. ↑: If professionals on the design team worked from home, they could already have their equipment at home.	↓: *Testing requires diverse stakeholders to be in attendance without restrictions.* ↓: *Social distancing limits the ability to put operators or handlers on AVs.* ↓: Researchers need to conduct live and virtual simulations in parallel. ↓: If this only effects some members of the testing team it will be difficult to get teams together at the same time. ↓: Researchers need to conduct live and virtual simulations in parallel, which becomes more difficult if people need to isolate.	↓: Advocacy groups cannot support deployment through face-to-face contact. ↑: *AVs can be used for new services to help enforce social distancing.* ↓: *It is difficult to separate operators and passengers in vehicles designed pre-pandemic.* ↓: AV deployment models that involve ridesharing could not function. ↑: Deployment is more long-term than the pandemic, and AVs can take over different functions (like remote delivery) following the pandemic. ↓: People will not want shared vehicles or public AVs since enclosed spaces are

Table 15 (cont'd)

		↑: New online tools let people work from afar and can accelerate ideas and save travel time. ↑*: Working from home is more possible than before 2020. ↑: The inception phase is long, and thus quarantine may not happen for the entire duration of the phase. ↑: This is not a severe pandemic response and a majority of people should be working still. ↓: Problems caused by the pandemic, like inability to provide basic services, will take the focus off developing AVs.			potentially areas to spread the virus. ↓: Lingering memories from the pandemic will erode trust in using AVs.

Table 15 (cont'd)

	Travel Constraints	↓: *If existing transportation services are changed it will augment how AV pilots are intended to function.* ↓: *AV pilots must be functional to provide valuable data.* ↓: Less people traveling means that there will be a lack of use case studies for people to examine in real time. ↓: Fewer overall trips mean that it will be difficult to prove how AVs can work in congested settings. ↓: Face to face connection will be important for introducing stakeholders. ↓: Less people will travel because of economic hardship caused by the pandemic. ↓: Moving AVs to	↑: *2020 NAIAS demos follow a specific route for programming that already exists.* ↑: If collaborative tools are improved the design process can be improved from remote places. ↓: It will be a negative if people from different locations need to meet.	↑: AVs can drive in local traffic if only inter-population constraints are implemented. ↑: Lab tests can simulate reality. ↓: *Human drivers will interact with AVs less frequently.* ↓: *Pilots are temporary and not reliable during a disruption.* ↓: *AVs will lose the ability to interact with human travelers.* ↓: Lab simulations are limited and do not generate the same level of confidence. ↓: This means safety drives cannot even be on pilots.	↓: A lack of traveling will slow interaction with AV specific infrastructure. ↓: *Delay in exposure.* ↓: *Public transit will decline.* ↑: *Single-passenger AVs will be more useful.* ↓: People are less likely to use rideshare or public AVs because there will be no social travel. ↓: Deployment requires moving people and vehicles to new locations.

Table 15 (cont'd)

	Travel Constraints (cont'd)	different regions or municipalities may be difficult if they are subject to travel constraints. ↓: If fewer trips are needed people will not be able to visualize how AVs function in congested settings.			

Table 15 (cont'd)

	Location Closures	↓: *Workplace closures will be difficult to manage if some stakeholders cannot participate equally.* ↓: The hindrance will come from not being able to experiment in real settings. ↓: "Tinkering" will be more difficult with only at-home supplies. ↓: If offices and workplaces are closed people may struggle to start the inception phase.	↓: *2020 NAIAS need to use multiple venues to meet full capacity.* ↓: If research labs or critical resources are closed it will negatively impact design. ↓: Design needs to take place in labs and manufacturing facilities. ↑: Exemptions can be granted if the work is essential. ↓: If labs, tracks, or resources are closed it will slow down the design pace.	↓: *Plant closures stopped production of shuttles at various stages of completeness.* ↓: Long term closures and plant closures will hinder AV pilots. ↓: Testing is location-specific and if locations are closed the trust in shared vehicles will drop. ↓: Trust in using public and shared vehicles will drop based on these restrictions. ↑: An initial benefit could be testing AVs on roads that are less congested. ↑: Lighter congestion could get the testing jumpstarted on public roadways.	↓: *Closure of city offices will disrupt issuing permits.* ↓: *The NAIAS platform will be eliminated.* ↓: If places are closed people will have less motivation to travel, reducing the demand for special mobility services. ↓: Deployment can be dependent on location (pick up/drop off points, stations, etc.). ↓: People will not use AVs if there is nowhere to go.

Table 15 (cont'd)

	Cap on Gatherings	↓: *NAIAS averages 750,000 attendees and limitations will alter its impact.* ↓: NAIAS is an inspiring event, and its cancellation will have some hindrance on overall inception. ↓: Social gatherings are where ideas are generated.	↓: Transit studies need to involve humans present for feedback. ↑: Well-designed systems can rely on digital communications. ↓: Reduced or delayed funding is a threat to the design process. ↑: Design does not require people to be together in large groups.	↓: *There may be concerns for being on large shared vehicles.* ↓: Conferences and stakeholder interaction is essential for enabling AV development, without networks like this the testing will be slowed. ↑: The size of the cap may not be prohibitive if it is still reasonable. ↓: There will be more concern for people getting into cars together during testing. ↓: Conferences and interaction among stakeholders enable development and without normal social networks the pace of testing will slow down.	↓: Advocacy groups and stakeholders cannot meet. ↓: *The event will be limited.* ↓: Interest in sharing vehicles will be limited.

Table 15 (cont'd)

	Shelter in Place	↑: *The development process can continue if people work from home.* ↑: There are non-public courses that could be used for looking at the technology. ↓: These shelter in place policies mean that spontaneous ideation is less likely to happen organically.	↓: The design of new vehicle technology requires that it is human friendly. ↓: Hampers the design team from meeting in real life.	↓: Public transit will decline as people travel less. ↓: *Urban areas will see transit impacted the most, which is where NAIAS takes place.* ↓: *Pedestrians are needed for testing and cannot be simulated.* ↑: Roads will be less congested and thus early stage testing of AVs can be completed on more open public roads. ↓: Testing requires people to experience AVs.	↓: Workers will need to leave their homes to install infrastructure for AVs. ↓: *Workers will need to leave their homes more to clean AVs.* ↓: People will not be willing to use AVs at all. ↓: Supplied cleaning items on AVs may not be a feasible sanitation option.

Table 15 (cont'd)

	Complete House Arrest	↓: *Some stakeholders may not be able to enable their workers to work virtually full time.* ↑: *Collaboration can be achieved if all stakeholders enter online meetings.* ↑: Companies can allow employees to work from home. ↑: People are still able to meet online.	↓: *The focus of policy will be centered on homes, not AVs.* ↓: *Focus on the news will not be educating people on AVs.* ↓: Draconian measures like this would negatively impact people's creativity. ↓: Working from home restricts access to tools and materials. ↓: If important stakeholders are the ones affected this phase will be hindered. ↓: Design is a multi-person process and limiting face-to-face interaction will be constraining.	↓: Teams cannot meet to collaborate and deploy shuttles. ↓: *Limited movement means there will be no repeat users.*	↓: Workers will need to leave their homes to install infrastructure for AVs. ↓: *Workers will need to leave their homes more to clean AVs.* ↓: *Lack of workers will impact funding for automotive companies.* ↓: *AVs will be limited to only medical trips, not gathering data.* ↑: If essential workers were allowed to leave this would benefit deployment so they could use the AVs.

Table 15 (cont'd)

	All: Areas of Deployment Broadly Affected by All Pandemic Responses	↑: New policy is based off available existing research. ↑: Scoping new technology can be done virtually. ↓: *Restrictions limit inventiveness.* ↓: *Sharing ideas online is less familiar for some people than face-to-face contact.*	↑: Aesthetic design can be shared digitally for improvement. ↓: *Online programming makes it harder to get feedback from people.* ↓: *Videos cannot simulate autonomy.* ↑: *Delays with NAIAS can be a chance to improve technology without feedback.* ↓: The pandemic could limit funding in this stage of development.	↑: Testing can occur on private tracks for safe development. ↓: *Feedback is necessary for pilots to be improved through testing.* ↓: *Online programming doesn't allow real on-road testing.*	↓: The regulatory atmosphere must all for deployment pre-pandemic or it will be delayed. ↓: *Regulations will not focus on AV deployment until post-pandemic.*

*This table represents the findings from the literature review and key stakeholder interviews. The statements from existing literature are in plain font. The statements from the stakeholder interviews are in *italics*.
*The "↑" arrow indicates a positive effect that the pandemic response policy would have on that phase of technology development.
*The "↓" arrow indicates a negative effect that the pandemic response policy would have on that phase of technology development.
*Text that is underlined came from the open-ended responses from the experts included in the first round of the Delphi Study.
*Text that is in blue font and **bold** came from the open-ended responses from the experts included in the second round of the Delphi Study.

Chapter 6: Policy Recommendations, Shortcomings, and Future Research

The final chapter of this dissertation provides answers for the research questions and policy recommendations based on the analysis. The policy recommendations discuss ways to use AVs to help mitigate the effects of a pandemic and ways to continue the development process with the best interest of public health in mind. Additionally, the final chapter discusses the potential limitations in the dissertation. The chapter concludes with identifying potential future research directions for this project.

The research goal throughout the course of the project remained identifying how the ongoing COVID-19 pandemic has impacted the development of new technology. The original research goals stated in Section 1.3 are as follows:

1. Uncover the impacts that the COVID-19 pandemic will have on the deployment of new technologies, particularly those that are intended for public use.
2. Explore how various stakeholders and public officials can work to mitigate the negative effects that disruptions can have on the technology development process.

Sections 6.1 and 6.2 respectively discuss how key stakeholders and technology experts view policy decision on how to contain Covid-19 impact technology development using the case of autonomous vehicles.

6.1 Impacts of Pandemics on Technology Development

The data from the key stakeholder interviews and the Delphi Study showed that the COVID-19 pandemic, and pandemic response policies broadly, hinder the development of AVs. Table 15 represents the compilation of the data from all phases of the research: the literature review, the interviews, and the Delphi Study. I added a total of 110 effects to Table 15 through the qualitative data gathered from the interviewees and Delphi Study respondents, and of those effects 84 (76%) indicated a negative change. This data indicates that there is a belief that technology development will be impacted negatively by decisions made in response to the pandemic. Furthermore, the data from the Delphi Study indicates that the more constraint the policies imposes the greater the hindrance for technology development.

The first phase of the study yielded a significant amount of discussion on the challenges of the regulatory environment caused by the pandemic. COVID-19 will take the regulatory spotlight off AV development, making it more difficult to move towards deployment. Another realization that came from the interview data is the role how important the access to on-road testing plays in the development of new technologies. AVs, specifically, require on-road testing to gather data on how the technology interacts with human operators. Location closure policies and travel constraints will create a gap in time where developers will not have access to large testing populations or the ability to receive input on publicly used vehicles. In the long term, the lost opportunities for stakeholder meetings and on-road testing due to COVID-19 should hinder all phases of development leading up to the deployment of AVs due to increasingly strict pandemic response policies.

An additional hindrance for traditional AV development is that the teams that develop AVs may need to change to work more effectively during the pandemic. This could include moving stakeholders or resources to areas that are closer geographically so that travel constraint policies are not as impactful or adding new, diverse members to the development teams. Interviewee 25 (June 15, 2020) hinted at needing new types of experts on AV development teams, specifically those who are well-versed in emergency planning or working through disruptions. The COVID-19 pandemic has provided an indication to AV developers that the process will not go smoothly from inception to deployment, and thus their teams must be equally as flexible and well-equipped to handle disruptions.

The second phase of the study, the Delphi Study, saw experts come to consensus on three out of 24 statements. The three responses that came to consensus refer only to the testing phase (2) and deployment phase (1), and two of those responses refer to the question asked regarding complete house arrest policies. The phases of development that reached consensus focus only on the time when the technology has been created and will be used in a real-time setting. That two phases (inception and design) that did not have any responses meet consensus could be explained by there being different experiences among the respondents of how positively or negatively they view working remotely or from a home environment. One notable response from the Delphi Study is that a majority of respondents replied that the pandemic will *hinder* AV development overall in each round of questioning regardless of what questions reached consensus.

The responses may also vary based on where the respondents are in the world and how well their country or region has controlled the pandemic. The pandemic thus may affect the global research and development network for AVs disproportionately. For example, if the pandemic is not under control in the United States due to weak pandemic response policies than the research would move to European and Asian countries. This issue arose regionally during the key stakeholder interviews when members of the teams providing AV shuttles for NAIAS were shut down. The AV teams, which contained global stakeholders, were left at a disadvantage for stopping “at a time that they were not designed to stop at” (Interviewee 18- 5/8/20). The greater long-term effect on development could be a global shift in development to new markets depending on how well the host countries have managed the pandemic.

Despite the overall sentiment that the pandemic will hinder development there is a small cohort of respondents that believe the pandemic can improve the development process, particularly in the inception and design stages. These stages of development can utilize existing research and can be completed from home, and thus there is still the ability for people to work. The disruption can provide research teams with new questions that they can use their technologies to solve, expanding the scope of the inception phase. However, the biggest benefit from having pandemic response policies is that people will be protected from potential infection, thus continuing the development process in the long-term since “dead people do not develop technology” (Respondent 8- 10/8/20). Regardless of the impact of the pandemic, and policies that promote long-term public health will benefit the eventual deployment of AVs.

The response data from the interviews indicate that the pandemic will hinder AV development and the responses from the Delphi Study saw experts in the field agree on these statements. However, the data indicate that the ultimate deployment of AVs is a long process, and this question will need to be re-visited in the coming decade. Even if the pandemic does not hinder all phases of development the negative effects have the potential to inevitably delay the ultimate deployment of AVs.

6.2 How can Stakeholders Mitigate Large-Scale Disruptions

The study involved a variety of stakeholders and public officials who have had their work negatively impacted by the COVID-19 pandemic. The data gathered throughout this study can be used to establish best practices and policies for safeguarding the development process from future disruptions. The respondents in this study recommended ways to meet with all involved parties to follow-up after this pandemic and to build on response plans and to use new technology as a tool. Strategies to mitigate the effects of the pandemic may be divided into two categories: preparation (discussed in Section 6.2.1) and innovation (discussed in Section 6.2.2).

6.2.1 Preparation

Preparation policies refer to the policies that may be put in place to help all parties be prepared in the event of a major disruption. This category includes putting safeguards in place to dampen the effects of potential disruptions. Existing literature indicates that preparing for a pandemic means putting an increased emphasis on public health. In terms of AV development focusing on public health should include having all stakeholders have a work from home plan or sanitation plans for manufacturing plants to slow down the spread of infection. A recurring theme from Delphi Study participants is that the inception and design phases of development can continue smoothly if there are resources readily available for people to work remotely. As for sanitation plans, the Ford Motor Company and General Motors Co. halted production on March 18, 2020 (Table 2), and if a sanitation plan was built into their general operating procedure than there would not have been a need to suspend production.

Early in the planning process of NAIAS Interviewee 4 (3/24/20) mentioned that the planning and development process cannot stop regardless of any potential disruptions. The purpose of the preparation policies essentially is finding ways to repurpose existing planning work and to minimize any negative effects. As the pandemic progressed the stakeholders began to realize that COVID-19 represented disaster and emergency planning for everyone, not just planners, on a scale that has been previously unseen (Interviewee 25- 6/15/20). Thus, creating a plan for working during disruptions can help prepare stakeholders so that they can continue working in these situations.

Working during disruptions may be easier thanks to advances in videoconferencing and meeting technologies, as indicated by a recurring theme in the data is that working from home is more possible now than ever. However, it is important that people are aware that they can take advantage of these tools to continue working. The inception and design processes that happen early in development can be completed remotely if there is a plan in place to allow for people to do so. Interviewee 23 (6/23/20) highlighted how difficult the transition to work from home was because it happened so abruptly.

In addition to being prepared for disruptions follow-up is crucial after the disruption passes for ensuring that best practices are up to date. This includes gathering the most affected stakeholders after the disruption ends to solve issues of what went wrong. Including a follow-up session ensures that safety and preparation plans can be updated, is necessary for preparing for future disruptions (Interviewee 10- 4/6/20). There are no all-encompassing safety plans that are guaranteed to be effective for different populations, however, to ensure a return to work for all industries stakeholders must "follow-up to know what safety plan is going to work and know what safety features employers are putting in place" (Interviewee 22- 6/2/20).

6.2.2 Innovation

Innovation policies find ways to use technology for positive purposes during the disruption. In the instance of AVs innovative policies can be used to eliminate contact between potentially infected individuals and essential workers. The concept of using AVs to eliminate contact between transit workers has been discussed earlier in the paper in a quote from Interviewee 17 (5/8/20), who mentioned that shower curtains were being used by bus drivers to separate themselves from passengers. AVs and other new screening technologies can be implemented in the public sphere to greatly reduce the community spread of viruses through technical solutions. Additionally, increasing public trust in these solutions would help alleviate some uncertainty for workers and the general public during a public health emergency.

Respondents for the interview portion of this also begin to speculate how technology could be used to solve problems during a disruption. In this research it was alluded to that following COVID-19 there is an opportunity to view how AVs can help people during pandemics in new and innovative ways. The biggest benefit of fully functional AVs is that they eliminate the need for people to be in the same space as a driver or other members of the public. Single-passenger AVs can help take essential workers to work during pandemic policies that limit the operations of traditional public transit systems. Furthermore, AVs can take infected people to hospitals or to appointments.

Utilizing AVs during the pandemic would ultimately change the roll-out strategy for developers in a changing U.S. auto market. While deploying AVs to move people during pandemics may not be feasible currently, there are other ways to utilize AVs for beneficial purposes. Deployment that is focused on filling a need rather than being developed for the sake of development has the potential to help the general public during time of uncertainty. Two ways that AVs can be updated for innovative uses during a pandemic includes being used for remote tasks and updating the vehicles to increase their cleanliness. AVs that deliver food and that are used for cleaning can see their deployment benefitted because of a pandemic because they can complete tasks without needing people (Interviewee 8- 4/2/20). The pandemic has also created new ways for AVs to be deployed that have previously not been necessary. For instance, using AVs to spray disinfectant in heavily trafficked public areas can help with ensuring cleanliness and making people more comfortable going in public for essential trips. The increased development of technology in addition to the circumstances created by the pandemic creates unique opportunities for applying technical solutions to emerging problems.

The COVID-19 pandemic also has created an opportunity for manufacturers to design AVs with anti-microbial materials or outfit public spaces with technologies that increase public safety during a pandemic. Respondent 3 (3/23/20) mentioned that early into the pandemic in Michigan that companies have started to work on creating “anti-microbial coatings” for the inside of public vehicles to slow the spread of COVID-19. Addressing public health issues, like increasing cleanliness through design, will improve products like AVs during their development process rather than needing to retrofit existing products.

6.3 Limitations of this Research

The limitations of this study may be attributed to the COVID-19 pandemic limiting the access for recruiting participants or restricting the ability for individuals to participate during the data collection. Shortly after the interview process started the State of Michigan issued stay-at-home orders and face-to-face interviews could not be conducted in the field. All interviews throughout the remainder of the data gathering process had to be conducted via the phone and establishing contact with potential interviewees became more difficult because potential respondents intermittently lacked access to their e-mail or work phones. COVID-19 response policies made recruiting individuals for the Delphi Study more difficult as well because potential respondents were either working from home or preparing for their semester of facilitating remote learning if they worked in higher education. Difficulties stemming from COVID-19 may explain the low response rates for the Delphi Study. The on-going pandemic made it more difficult to recruit potential participants, establish trust through a virtual setting, and relay large amounts of information to the Delphi Study participants.

6.3.1 Disadvantages of Autonomous Vehicles

One additional limitation of the research is that it does not explore the negative impacts of adopting AVs, especially during a time of uncertainty. The interview respondents and Delphi Study participants brought up the cost of the development process as a potential area where it may be hindered by the pandemic. Existing literature shows that there are price concerns for individuals who want to own their own personal AV and municipalities facing financial hardship. The pandemic creates additional financial hardship, and the eventual deployment of AVs would largely benefit those who were able to afford the new technology and put some members of the population at a disadvantage. This research may be re-visited when AVs are eventually deployed to explore if the pandemic has exacerbated the exclusion of certain groups from using AVs a mode of transportation.

6.4 Future Research

The COVID-19 pandemic rapidly changes as new information about the virus is discovered, the spread moves to new countries, and pandemic response policies are issued. Thus, the data gathering processes and case study have changed over time as key stakeholders make decisions related to the pandemic. The reliance on a constantly changing situation creates a unique opportunity for future research related to this topic to be revisited later. Future research opportunities should focus primarily on long-term follow-up with stakeholders involved in development to see how the pandemic pushed back the eventual deployment of AVs

The effects of the pandemic on technology development can be theorized from this research. However, first and foremost, AV development is a long process and the effects that COVID-19 has on the process may not be fully realized until five or ten years in the future. Follow-up with key stakeholders will be required in the future to determine how this disruption affected the development process in its entirety. Second, using public forums, like NAIAS, as a platform to gather data and test new technologies may be severely limited in the coming years due to COVID-19. Social distancing guidelines may become required for an undetermined amount of time post-COVID-19 and it is yet to be seen if the stakeholders involved in the development process will be able to gather in person across the globe in the coming year. The impact that COVID-19 will have on the development of AVs may not be realized until long after the pandemic has ended.

APPENDICES

APPENDIX A: Interview Guide

Table 16: Interview Guide

<table>
<tr><th colspan="3">Interview Guide</th></tr>
<tr><td colspan="3">1. Informed Consent</td></tr>
<tr><td colspan="3">RESEARCHER: Hello, thank you very much for taking the time to sit down and interview with me today. I am very happy to get the opportunity to learn about your knowledge and decision making involved with the planning of the 2020 North American International Auto Show in regard to on-going adversity caused by the COVID-19 pandemic.
Before we begin, I would like to first cover this consent form. It discusses the research process, the potential benefits and risks associated with your participation, and the ability for you to opt-out or not answer any question that you do not choose to. Before we begin if you could please sign this, and I will provide you with a copy after the interview is completed.</td></tr>
<tr><td colspan="3">RESEARCHER: The first portion of this interview will cover some framing questions about your involvement with the NAIAS. Then we will transition to some broad thematic questions, of which we may ask some brief follow-up questions to. Following these thematic questions I will conclude with a brief closing question and offer you the opportunity to respond with any questions you had for me or to follow-up on any previous answers.</td></tr>
<tr><td colspan="3">2. Framing Questions</td></tr>
<tr><td colspan="3">Demographics: What is your gender, age, and geographic location?</td></tr>
<tr><td colspan="3">How long have you worked in your current capacity?</td></tr>
<tr><td colspan="3">Is this your first time working on the planning process for the NAIAS?</td></tr>
<tr><td colspan="3">Have you ever ridden in an autonomous vehicle?</td></tr>
<tr><td colspan="3">3. Thematic Questions</td></tr>
<tr><td>Research Goal</td><td>Grand Tour Question</td><td>Probe Questions</td></tr>
<tr><td>Questions about the Auto Show.</td><td>What have you learned about autonomous vehicle adoption and deployment in Michigan through the 2020 NAIAS?</td><td>Please zone in with your answer on event attendees. What can they contribute to deploying new technologies?</td></tr>
</table>

Table 16 (cont'd)

Safeguarding Questions.	Broadly, how did the coronavirus (COVID-19) affect the planning processes of NAIAS?	Prior to the FEMA decision, what safeguards had been put in place to help ensure the event could still take place?
What impacts will pandemics have on the deployment of new technology at the Auto Show?	What impacts will this decision to postpone have on the perception of AVs for Michigan communities?	Were there additional concerns (threats) since the technology is intended for public use?
	What impacts will this decision to postpone have on the deployment of AVs for Michigan communities?	What are the benefits of waiting until next year?
Future event questions.	Why was June 2021 chosen for the future of the show?	Between now and next year's show will there be any online programming available? Why (or why not)?
How can various stakeholders work together to mitigate the effect of large-scale disruptions?	How can policy-makers and involved stakeholders work together to create safeguards for mitigating the effects of disruptions?	Can you explain this further for how event officials should respond? What about state and local officials?
4. Conclusion		
At this time I would like to thank you for participating in my interview process, and providing me with information related to this event and its planning processes. At this time I would like to offer you the opportunity to ask any follow-up questions or to elaborate on any of the topics we discussed.		
Thank you for your participation, it was great to hear from you. I will follow-up with your signed copy of the consent form, and please do not hesitate to reach out with any further questions.		

APPENDIX B: List of Interviewees

Table 17: List of Interviewees

Interview Number	Affiliation	E-mail Invite Sent	Follow-up E-mail Sent	Interview Conducted
1	State Municipal Agency	2/21/2020	3/3/2020	3/9/2020
2	State Municipal Agency	2/21/2020	3/3/2020	3/10/2020
3	State Municipal Agency	2/21/2020	-	3/24/2020
4	State Municipal Agency	2/27/2020	3/3/2020	3/24/2020
5	Private Stakeholder	3/27/2020	-	3/30/2020
6	Non-Profit Agency	3/26/2020	-	3/30/2020
7	Private Stakeholder	3/31/2020	-	4/2/2020
8	Private Stakeholder	3/31/2020	-	4/2/2020
9	Private Stakeholder	3/30/2020	-	4/3/2020
10	Non-Profit Agency	3/26/2020	-	4/6/2020
11	Private Stakeholder	3/30/2020	4/7/2020	4/8/2020
12	NAIAS Affiliate	3/28/2020	4/7/2020	4/9/2020
13	Private Stakeholder	3/31/2020	-	4/9/2020
14	Private Stakeholder	4/5/2020	-	4/10/2020
15	State Municipal Agency	3/10/2020	4/7/2020	4/20/2020
16	State Municipal Agency	4/28/2020	-	4/29/2020
17	Private Stakeholder	4/12/2020	5/6/2020	5/8/2020
18	NAIAS Affiliate	3/27/2020	4/7/2020	5/8/2020
19	State Municipal Agency	4/28/2020	5/6/2020	5/11/2020
20	Private Stakeholder	5/8/2020	-	5/15/2020
21	State Municipal Agency	5/11/2020	-	5/21/2020
22	NAIAS Affiliate	5/24/2020	-	6/2/2020
23	Local Municipal Agency	5/24/2020	-	6/3/2020
24	Local Municipal Agency	6/1/2020	-	6/5/2020
25	NAIAS Affiliate	6/5/2020	-	6/15/2020

APPENDIX C: Interview Data Focused Codes

Table 18: Interview Data Focused Codes

Interview Questions	Focused Codes
Framing Questions (Demographics and NAIAS Experience)	• Experience with AVs • Event in the auto show
What have you learned about AV adoption/deployment through NAIAS?	• Agencies at NAIAS can help pilots navigate state/federal policy • The first portion of the event has savvy attendees • NAIAS behind in educating public • Value of event changes across demographics (for disabled people too) • NAIAS is a platform for showing off new technology • Consumer shows provide customer research on trends and new items • Demonstrations can change perception (and increase knowledge) • Opportunity to mix with real traffic • Michigan relies on open policies to open testing options for everyone • Different vehicles require different regulations • Planning necessary for pilot programs • Safety • First time for this environment • NAIAS brings people together • Shared success helps the industry • Technology is crucial for furthering pilots • AVs tie the State into NAIAS • Transfer of information • Parameters of how AVs operate had to be refined • Other technology is needed to access AVs (full autonomy) (enhance them) • Opportunity to find repeat users • AVs are open for all users • Must plan for riders as well • Tech adoption can be accelerated if people's expectations meet tech's current ability (awareness) • NAIAS is for marketing, legal, accounting aspects of tech • Goal is to transform transportation with AVs • Show how AVs work with the existing market • Contained demos in the real-world help programmers install set infrastructure for cars to recognize • Getting data from pilots validates using expensive pilots

Table 18 (cont'd)

	• (needs to be synthesized not all policymakers are engineers) • Increase comfort • NAIAS emphasizes the overall vehicle more than specialized tech • Demos can help but the main goal is real deployment • AVs need to interact with human drivers • 2020 layout allowed outdoor interaction space • Change can happen rapidly • Critical look at vehicles • People are already deeply familiar with cars • First-hand experience • Different NAIAS events represent a multi-disciplinary approach to mobility • Airport shuttles provide potential riders and limited AVs have airport access (long-range) • Includes a survey for the design and experience of using AVs

Table 18 (cont'd)

How did COVID affect planning?	• Uncertainty creates problems because there is no standard response • Adjustments will be necessary as new data comes out • Time is needed, duration of show and amount of people spreads resources thin • It is important to have the facilities to equip when necessary (proactive) • Must plan for the event to go on as planned • Pandemic adds complexity • All scenarios must be planned for • Public is unpredictable • Cannot stop the planning process (will get behind) • Salvage already completed work • Planning for the event includes financial and volunteer coordination • Global event • Health is a new risk • Screens in vehicles could use voice commands to eliminate touching • Planning now includes planning for when to cancel • Postponing may impact the event center most • Urban areas will be most affected by COVID • NAIAS will be impacted by limiting gatherings • Moving NAIAS impacts secondary events • Length of disruption will determine impacts • Need to collaborate in changing environment • Increased need to rely on tech • Focus shouldn't be on setbacks • Best practices can be repeated for disaster relief • Disaster planning needs diverse task forces • Follow-up after the disaster is important • Travel restrictions • Systemic process for learning about disruptions and hard to do during one • Hard to determine sensitivity to disruptions until they occur • Over time more understanding exists for the pandemic • Pandemics mean less person-to-person interactions • Social distancing is impossible in a tight space (factory or event center) • Layout of the event will change • A second wave could impact planning • Regulatory changes can be done quickly to mobilize AVs during a crisis

Table 18 (cont'd)

	• Regulations will come out to respond to COVID, not focus on AVs (near term) • Long-term event means most planning was already done • Pandemic effects all systems, not just NAIAS • Goal is still deployment • Pandemic will create a "new norm" • Planning officially stopped when TCF became a field hospital • Permits are needed (navigating city planning process)
What impacts will decision have on perception of AVs?	• Perception can change how people accept technologies (especially since no one has them) • Without a driver there should be a way to give riders information or answer questions • Mobility as a tool • Perception matters as well as tech readiness • Concern over sharing vehicles • People are already skeptical • People don't understand what tech is capable of • People won't focus on AVs during the pandemic • AVs get awareness from the news • People have more time to be educated on AVs • Educating people helps bridge the gap between public and professionals • Delay in exposure • Skepticism of large gatherings • Smaller NAIAS events may limit inventiveness • People will be skeptical of public transit • Public cannot control public vehicles (how they're cleaned, when)

Table 18 (cont'd)

What impacts will decisions have on deployment of AVs?	• Benefits for urbanized communities • People cannot rely on a pilot because it's temporary • AVs must work with other forms of transportation • Priority will come for AVs because they are new • AVs will be public so they may still operate in some capacity • Technological advances can make adoption easier • Policy can be formed for from testing • Technology can help make places cleaner • Public health must be included for public vehicles (sanitation) • Safety • People will be needed to clean AVs • May not be different than cleaning public transit • Sanitation must be scheduled (too expensive between every ride) • Tech struggles with some functions • AVs need infrastructure to accommodate them (left hand turn lines) • Deployment is tied to economic assets • Different ways to clean • AVs cannot operate in all conditions • Public transit will see a decline from lack of travel • Testing can be rare even in the field • Innovation has steps • Not having NAIAS is not the most severe for implementation • Delays from the pandemic can be a chance to improve technology • Feedback is necessary for final products • Delay will impact funding from developers (budgets and layoffs) • Initial testing should not come from events • Economic argument for smaller AVs • Deployment is multi-faceted • The pandemic stopped vehicles at different stages of completeness • This is a way to test accessibility • Development process will continue for companies (event cancellation won't stop their work) • Increased focus on EVs since pandemic has slowed emissions • Deployment needs diverse stakeholders

Table 18 (cont'd)

Why was June 2021 chosen?	• Has to be summer so demos can happen • Set areas of open space so it needs to be re-planned to fit • One year means safety plans can be installed • One year allows event planners to install touchless features • Budgets must be re-adjusted due to uncertainty • The FEMA contract with TCF Center is 6 months and pushed back NAIAS 6 months at a minimum
What about online programming?	• If face-to-face is eliminated there needs to be work done to simulate that experience • There are more ways now to get people online information • Auto manufacturers need to upgrade their tech support • Online could work better for professionals • Videos already exist but are different than real cars • Videos don't simulate autonomy • Online programming doesn't allow user feedback • Online is not possible if no one enables it • Online is cheaper • Digital technology has grown to where it can be done online • Investment doesn't come across the same on video • Online programming means the show must be re-imagined • Could be educational webinars/showcases • Potential for online portion to assume some functions (fundraising)

Table 18 (cont'd)

How can policymakers work together to create safeguards?	• Policymakers must keep up good communication with companies regarding policy and legal frameworks • Policy needs to be streamlined for each level of government • Policy is focused on AV deployment not specific functions • Levels of governance (federal and state) • Testing needs to involve diverse stakeholders • A sanitation plan can be based in best practices • Diverse stakeholders helps generalize findings • All stakeholders and public officials must work together • Equitable solutions • Legislation can help testing and grow technology • Michigan relies on open policies to open testing options for everyone • Collaboration between stakeholders is necessary • Quality of life • This is an opportunity to start accumulating policy based on best practices • Contingency plans • Communication is important (and faster) • Public/private partnerships (can be grown and improved in the year off) • Automakers cannot represent each other • TCF Center is event planning entity • Drivers are a key independent stakeholder (unpredictable) • Policy can shape infrastructure needs • Must be common ground with policy makers and tech developers • Rideshare providers will play a role in enhancing mobility • Policy solutions can mitigate future disruptions • Policy must build off of existing policy individually per state • Policy also can be rooted in technological capabilities

APPENDIX D: Delphi Study Questionnaire

Delphi Study Questionnaire

Introduction

The aim of this study is to determine if a large-scale disruption has the potential to hinder or benefit the deployment of new technology. The disruption in this instance is the COVID-19 pandemic and the new technology in question is autonomous vehicles. The development process includes the inception of the ideas, design of the products, testing, and finally deployment of the new technology.

The case study being examined for this study is the 2020 North American International Auto Show (NAIAS). In this phase of the study please review the attached table, and indicate to what extent you believe the pandemic response policies affect the development of AVs based off of the data gathered surrounding the NAIAS event. The pandemic response policies in this research are listed below, in order of least severe though most severe:

- *Self-Quarantine*: Self-quarantine is a voluntary measure where individuals may place themselves in quarantine if they believe they are infected or have come into contact with an infected person until proper testing may be completed.
- *Travel Constraints*: Travel constraints refer to the limitation of flights, trains, or other public transit methods to eliminate inter- and intra-population contact.
- *Location Closures*: Local closure is the systematic closure of potentially high-risk transmission locations, such as restaurants, schools, and retail shopping centers.
- *Cap on Gatherings*: Limiting gatherings refers to the cancellation of large gatherings, even if they are located outside. For instance, religious pilgrimages, concerts, and other venues where people may be in close contact.
- *Shelter in Place*: Shelter in place, or community quarantine, policies are a stricter version of self-quarantine. This policy refers to when entire communities may be encouraged to stay at home, rather than just those who are infected.
- *Complete House Arrest*: Complete house arrest refers to a mandatory stay at home order where people are not allowed to leave their homes except for emergencies. At this phase there may be fines or surveillance mechanisms in place for enforcement.

There is a total of 24 Likert Scale questions to follow, plus demographic questions at the end. At the end of each question there is the option for an open-ended response where you have the opportunity to suggest additions or subtractions to each cell of the data table.

Inception

The following questions ask you how you believe Covid-19 policies affect the inception stage of autonomous vehicle technology. Inception refers to the original idea generation, research, and identification of partnerships that set the stage for developing new technologies.

1. Based on the table provided, to what extent do you believe self-quarantine will benefit, or hinder, the inception phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

2. Based on the table provided, to what extent do you believe travel constraints will benefit, or hinder, the inception phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

3. Based on the table provided, to what extent do you believe location closures will benefit, or hinder, the inception phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

4. Based on the table provided, to what extent do you believe placing a cap on gatherings will benefit, or hinder, the inception phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

5. Based on the table provided, to what extent do you believe shelter in place policies will benefit, or hinder, the inception phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

6. Based on the table provided, to what extent do you believe complete house arrest will benefit, or hinder, the inception phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

Design

The following questions ask you how you believe Covid-19 policies affect the design stage of autonomous vehicle technology. Design refers to the planning process for identifying how the new technology will look, act, and function, including opportunities for feedback and refinement.

7. Based on the table provided, to what extent do you believe self-quarantine will benefit, or hinder, the design phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

8. Based on the table provided, to what extent do you believe travel constraints will benefit, or hinder, the design phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

9. Based on the table provided, to what extent do you believe location closures will benefit, or hinder, the design phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

10. Based on the table provided, to what extent do you believe placing a cap on gatherings will benefit, or hinder, the design phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

11. Based on the table provided, to what extent do you believe shelter in place policies will benefit, or hinder, the design phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

12. Based on the table provided, to what extent do you believe complete house arrest will benefit, or hinder, the design phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

Testing

The following questions ask you how you believe Covid-19 policies affect the testing stage of autonomous vehicle technology. Testing refers to the process where new technologies are operated on test tracks to provide data and feedback to refine how the product can function in the real-world.

13. Based on the table provided, to what extent do you believe self-quarantine will benefit, or hinder, the testing phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

14. Based on the table provided, to what extent do you believe travel constraints will benefit, or hinder, the testing phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

15. Based on the table provided, to what extent do you believe location closures will benefit, or hinder, the testing phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

16. Based on the table provided, to what extent do you believe placing a cap on gatherings will benefit, or hinder, the testing phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

17. Based on the table provided, to what extent do you believe shelter in place policies will benefit, or hinder, the testing phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

18. Based on the table provided, to what extent do you believe complete house arrest will benefit, or hinder, the testing phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

Deployment

The following questions ask you how you believe Covid-19 policies affect the deployment stage of autonomous vehicle technology. Deployment refers to the final stage of developing new technologies where the final products are sent out for purchase or to serve the public.

19. Based on the table provided, to what extent do you believe self-quarantine will benefit, or hinder, the deployment phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

20. Based on the table provided, to what extent do you believe travel constraints will benefit, or hinder, the deployment phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

21. Based on the table provided, to what extent do you believe location closures will benefit, or hinder, the deployment phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

22. Based on the table provided, to what extent do you believe placing a cap on gatherings will benefit, or hinder, the deployment phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

23. Based on the table provided, to what extent do you believe shelter in place policies will benefit, or hinder, the deployment phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

24. Based on the table provided, to what extent do you believe complete house arrest will benefit, or hinder, the deployment phase of autonomous vehicle development?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder
5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

Concluding Questions

25. Based on the table provided, do you believe that the COVID-19 pandemic will benefit, or hinder, autonomous vehicle development in general?

1. Greatly benefit
2. Benefit
3. Neither benefit nor hinder
4. Hinder

5. Greatly hinder

Please use this section to provide recommendations on items to add or subtract from the data table, or to provide additional comments regarding your answer:

26. How has the COVID-19 pandemic impacted you personally?

1. Greatly positively
2. Positively
3. Neither positively nor negatively
4. Negatively
5. Greatly negatively

Demographics

The following set of questions is a series of multiple-choice and open-ended demographic questions.

27. What is your age?

1. 18-29
2. 30-39
3. 40-49
4. 50-59
5. 60-69
6. 70 and up

28. What type of organization are you employed by?

1. Government entity
2. Non-profit (social advocacy group)
3. Higher education/University
4. Private industry
5. Other (please specify): _____________

29. Please explain how you work with autonomous vehicles or intelligent transportation systems?

30. How long have you been working in your current position?

APPENDIX E: Delphi Study Respondents

Table 19: Delphi Study Respondents

Respondent Code	Date of Contact	Round 1 Completed	Round 2 Completed	Round 3 Completed
1	8/3/2020	9/10/20	9/30/20	Did not complete
2	8/3/2020	8/30/20	10/7/20	Did not complete
3	8/3/2020	8/4/20	9/22/20	10/9/20
4	8/3/2020	8/6/20	9/27/20	10/10/20
5	8/3/2020	8/27/20	9/21/20	10/13/20
6	8/3/2020	8/4/20	Did not complete	10/8/20
7	8/4/20	8/4/20	9/21/20	10/8/20
8	8/4/20	8/4/20	9/22/20	10/8/20
9	8/26/20	8/28/20	9/22/20	10/8/20
10	8/26/20	8/26/20	9/28/20	10/14/20
11	9/2/20	9/10/20	10/4/20	Did not complete
12	9/2/20	9/3/20	9/22/20	10/14/20
13	9/2/20	9/5/20	9/22/20	10/9/20
14	9/2/20	9/4/20	9/22/20	10/13/20
15	9/2/20	9/2/20	9/28/20	Did not complete
16	9/2/20	9/3/20	9/24/20	10/13/20
17	9/2/20	9/2/20	9/22/20	10/8/20
18	9/2/20	9/2/20	9/21/20	Did not complete
19	9/9/20	9/9/20	9/25/20	10/14/20
20	9/9/20	9/14/20	9/28/20	10/7/20
21	9/9/20	9/14/20	9/21/20	10/13/20
22	9/9/20	9/14/20	Did not complete	Did not complete
23	9/9/20	9/15/20	9/22/20	10/8/20
24	9/9/20	9/15/20	Did not complete	10/8/20
25	9/9/20	9/15/20	9/28/20	10/9/20
26	9/9/20	9/17/20	10/5/20	10/7/20

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