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# Exploring Strategies for Adapting Traditional Vehicle Design Frameworks to Autonomous Vehicle Design

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This is to certify that the doctoral study by

Alex Munoz

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

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Walden University
2019

Abstract

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by

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MS, American Public University, 2015

BA, American Public University, 2012

Doctoral Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Information Technology

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Abstract

Fully autonomous vehicles are expected to revolutionize transportation, reduce the cost of ownership, contribute to a cleaner environment, and prevent the majority of traffic accidents and related fatalities. Even though promising approaches for achieving full autonomy exist, developers and manufacturers have to overcome a multitude of challenged before these systems could find widespread adoption. This multiple case study explored the strategies some IT hardware and software developers of self-driving cars use to adapt traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs. The population consisted of autonomous driving technology software and hardware developers who are currently working on fully autonomous driving technologies from or within the United States, regardless of their specialization. The theory of dynamic capabilities was the conceptual framework used for the study. Interviews from 7 autonomous vehicle hard and software engineers, together with 15 archival documents, provided the data points for the study. A thematic analysis was used to code and group results by themes. When looking at the results through the lens of dynamic capability theory, notable themes included regulatory uncertainty, functional safety, rapid iteration, and achieving a competitive advantage. Based on the findings of the study, implications for social change include the need for better regulatory frameworks to provide certainty, consumer education to manage expectations, and universal development standards that could integrate regulatory and design needs into a single approach.

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# Dedication

I want to dedicate this study to my loving wife, Elena, and my curious daughter, Sarah, for supporting me throughout the study process and often sacrificing time together when I had to focus on my research. Thank you both, and I am hoping that my meticulous, dedicated, and steadfast enthusiasm for learning will equally inspire them today and in the future to embark on similar journeys. Furthermore, I want to dedicate this doctoral study to all my friends who lent an ear and their eyes when I needed it most, and who continued to support my efforts, even when I was unable to share much time with them.

Acknowledgments

There are not enough words I can find that adequately express my gratitude for the chair of my committee, Dr. Nicholas Harkiolakis. Dr. Harkiolakis provided me with encouragement, direction, and inspiration throughout my journey as a doctoral student, while also sparking my curiosity to rethink approaches and often providing unfiltered feedback to push me when needed. Dr. Harkiolakis is a knowledgeable and relatable mentor whom I came to respect and admire, and hope to continue to be able to work with in the future. Furthermore, I would like to thank the other members of my study committee, Dr. Burchell and Dr. McKeeby, for providing their valuable feedback throughout the study approval process and steering my work in the appropriate direction.

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# Section 1: Foundation of the Study

Automobile manufacturers have envisioned and promised fully autonomous vehicles for many years, but only recent advancements in image processing and significantly increased computational power puts engineers finally within reach of delivering on this promise. The recent use of graphics processors has enabled researchers to perform complex image analysis using neural networks for adding context (Johnson, Karpathy, & Fei-Fei, 2016). Complex image analysis was previously hard to achieve due to the required computational cost, including the power, space, and cooling requirements of suitable technologies. As a result, regulatory requirements, consumer expectations, and the design frameworks manufacturers use for traditional vehicle development may no longer apply. Therefore, developers may waste valuable resources on design practices that may be unable to comply with consumer expectations or regulatory requirements. Without understanding the importance of and how regulatory requirements, consumer expectations, and current vehicle design frameworks interact with each other, manufacturers may need more time to develop their solutions or have to start over in case of failure.

## Background of the Problem

One way to significantly reduce traffic accidents, deaths, and related injuries is to develop and introduce autonomous cars (AC) that can operate and navigate more safely than human drivers most of the time (Althoff, Stursberg, & Buss, 2009). Although Mitchell, Payton, and Keirsey (1987) argued that autonomous vehicles must rely on multi-level independent control systems with a high level of situational awareness and independent decision-making systems, researchers do not agree on how they should specifically design these systems.

Yim, Kim, Shin, and Park (2014) suggested that an AC can achieve full autonomy by only using a path library and visual object analysis to navigate complex environments. However, Jo, Kim, Kim, Jang, and Sunwoo (2014) suggested that the multi-sensor approach favored by Volkswagen, Toyota, and Google, for example, where engineers combine visual object analysis with non-human sensings, such as Light Detection and Ranging (LIDAR), Radio Direction and Ranging (RADAR), or Sound Navigation and Ranging (SONAR), will likely emerge as the most successful solution. In contrast, Azimirad, Haddadnia, and Izadipour (2015) stated that acquiring more sensor information leads to richer data but also emphasized that researchers must develop a specialized data-level fusion architecture first; otherwise, computing requirements become too demanding in the context of a moving vehicle. In this context, my study focused on the perceived relationships between autonomous vehicle design frameworks, consumer expectations, and regulatory requirements. Organizations can use this knowledge as a benchmark for exploring technologies that their peers and competitors prefer for the development of their fully autonomous vehicles and to bring their products more quickly to market while also reducing the likelihood of costly mistakes and engineering dead-ends.

## Problem Statement

While the design teams working on autonomous vehicles use and develop various technologies to achieve different levels of autonomy, consumer and regulatory requirements insufficiently influence their current design frameworks (Borenstein, Herkert, & Miller, 2017).

Without standardized design frameworks enabling the general and unrestricted use of fully autonomous vehicles on public roads today (Vellinga, 2017), recent performance reports from California’s limited self-driving test program indicate that current design frameworks can lead to as many as 625 noncompliance incidences with respect to consumer and regulatory requirements in 935 driven miles (Lv et al., 2018). The general IT problem is that IT teams often lack appropriate design frameworks in the development of autonomous vehicles that address consumer and regulatory requirements. The specific IT problem is that some IT hardware and software developers of self-driving cars lack strategies for adapting traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs.

## Purpose Statement

The purpose of this qualitative multiple case study was to explore the strategies some IT hardware and software developers of self-driving cars use to adapt traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs. The targeted population consisted of autonomous driving technology software and hardware developers from two or more organizations and who are currently working on fully autonomous driving technologies, regardless of geographic location. Due to the variety of design frameworks and the multidisciplinary nature of the technologies currently in use or development for creating autonomous vehicles, the study targets IT hardware and software engineers regardless of their respective specialization within the field. The implication for positive social change includes the potential to reduce car-accident related deaths and injuries as well as decreasing the cost of transportation, as soon, as autonomous vehicles become available.

## Nature of the Study

I selected a qualitative research methodology to approach my doctoral study. Qualitative methods focus on exploring lived experiences or collecting rich data on phenomena, causes, and consequences through the eyes of individuals (McCusker & Gunaydin, 2014). Since the goal of this study was to provide an understanding of the strategies some IT hardware and software developers of self-driving cars use to adapt traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs, the qualitative methodology allowed me to understand the approaches of those working in the field. Quantitative approaches focus on testing hypotheses and the statistical analysis of numerical data (Yilmaz, 2013). I decided against using a quantitative methodology because the goal of my study was to understand the strategies of developers involved in autonomous vehicle designs and not to measure relationships between numerical data. The remaining option would have been to use a mixed-method design by combining the analysis of individual experiences and numerical data to evaluate relationships between variables (McCusker & Gunaydin, 2014). However, I decided against using a mixed-method because the purpose of this study was to understand the perceptions and resulting strategies of those involved in autonomous vehicle designs and not to measure relationships between numerical data. Based on the arguments above, the multiple case study design was most appropriate for this research.

I used a multiple case study research design for my study. By selecting a multiple case study design, researchers can compare and contrast different perspectives, search for patterns, and gain an in-depth understanding of a problem through rich and detailed contextual data

(Touw, 2017). Because I wanted to study the strategies of those involved in autonomous vehicle designs through many perspectives, a multiple case study was most appropriate. A multiple case study design allowed me to explore the perceptions and strategies of individuals at two or more organizations. Other qualitative research designs include historical research, ethnography, and phenomenology (Rutberg & Bouikidis, 2018). Phenomenology examines the lived experiences (Duckham & Schreiber, 2016). However, as my study focused on understanding the strategies, IT hardware and software developers use to adapt autonomous vehicle design frameworks to meet consumer and regulatory requirements and not lived experiences, using phenomenology would have been inappropriate. Ethnography aims at understanding cultural behavior (Rutberg & Bouikidis, 2018). Because I explored individual perceptions, ethnography was not a suitable qualitative research design. Lastly, researchers use historical research designs to examine past events by using documents and personal recollections (Rutberg & Bouikidis, 2018). As I was not examining past events or historical documents, using historical research would have been inappropriate. Based on the arguments above, the multiple case study design was most appropriate for this research.

## Research Question

The research question for this proposed study was as follows:

What strategies do some IT hardware and software developers of self-driving cars use to adapt existing autonomous vehicle design frameworks to regulatory requirements and consumer expectations?

## Demographic Questions

1. Without including your name or your organization's name, what is your current role, and how long have you been in similar roles?
2. What experience do you have working on autonomous driving systems or related technologies?

## Interview Questions

1. What strategies and/or design practices do you use or have used while working on autonomous driving systems?

   Probe: Why did you select this strategy or used this particular design practice?

   Probe: Did you find your strategy or design practice to be a good fit for achieving autonomy with your design, or did you have to make changes?

2. How do you measure the success of your strategies and frameworks for achieving fully autonomous driving capabilities?
3. What strategies have you used to align your autonomous vehicle design approaches with consumer expectations?

   Probe: How can you be sure that your interpretation of consumer expectations align with what consumers actually expect, considering that autonomous vehicles are not yet publicly available?

4. What, if any, barriers do you see for widespread autonomous vehicle design introduction and acceptance?

5. What strategies do you use to align your autonomous vehicle designs with current regulatory requirements?

   Probe: How do you intend to adapt your designs to changing regulations?

   Probe: What strategies do you use to shape and influence future regulations?

6. Is there anything else you would like to add about your autonomous vehicle design strategies that we have not addressed already?

## Conceptual Framework

I used the theory of dynamic capabilities as a basis for this study. Dynamic capabilities theory focuses on achieving competitive advantage in dynamic environments through congruence, reconfiguration, and renewal of internal and external functional competencies, organizational skills, and effective use of resources. First developed in 1997 by Teece, Pisano, and Shuen as an alternative to other models of strategy, such as the theory of competitive forces, the theory of strategic conflict, and the resource-based perspective, the dynamic approach offers a framework for organizations on how to approach and rapidly expand their capabilities. The dynamic capabilities framework focuses on processes, positions, and paths, as well as reliability and imitability of organizational positions and processes to assess competitive advantage (Teece, Pisano, & Shuen, 1997). I have developed Figure 1 to illustrate the interrelationships and elements of the forces that contribute and lead to the creation of dynamic capabilities within an organization.

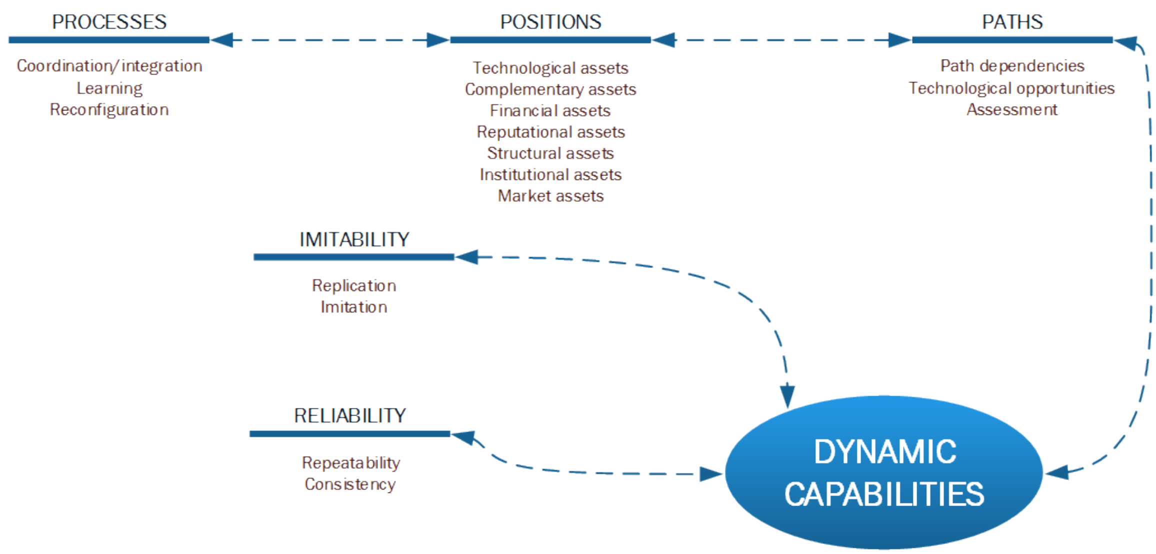


*Figure 1*. Illustration of some Elements of the Dynamic Capabilities Model.

Dynamic capabilities theory applied to this study. Autonomous driving frameworks must incorporate and are subject to reconfiguration and transformation, technological opportunities, path assessment, and selection, in addition to the management and expansion of technological, financial, reputational, and structural assets in response to rapidly evolving consumer and regulatory demands and requirements. With rapidly changing regulatory requirements, the evolution of perceived consumer expectations, and consistently updated vehicle design frameworks, the theory of dynamic capabilities provides a theoretical framework from which to examine the strategies IT hardware and software developers use to develop autonomous vehicles in the context of processes, paths, and positions, but also reliability and imitability. A firm's ability to innovate depends on its dynamic capabilities (Teece et al., 1997), which in this case relates to an organization's ability to leapfrog its competition while also meeting perceived consumer expectations and current regulatory requirements. Current vehicle design frameworks may be unable to accommodate the technological needs associated with rapidly changing requirements and limitations in the area of autonomous driving technologies, and, therefore, a firm must develop dynamic capabilities they can use to gain a competitive advantage.

## Definition of Terms

*Self-Driving car*: an autonomous vehicle capable of Level-3, Level-4, or Level-5 autonomy and defined as a car that can operate autonomously in some or all environments without human interaction or requiring a human driver to be able to take control in an emergency (Society of Automotive Engineers, 2016).

*Autonomous vehicle design frameworks*: methodologies, standards, tools, or technical frameworks autonomous vehicle manufacturers use to design their products and align them with consumer expectations and regulatory requirements (Falcini & Lami, 2017).

## Assumptions, Limitations, and Delimitations

Assumptions, limitations, and delimitations are essential factors in the interpretation of the results of a research study. I include the following subsections to discuss how they influenced, shaped, and limited my data collection process, the selection of my population, and my research design.

### Assumptions

A researcher's assumptions are the basis for their views and beliefs that guide their interpretation of reality (Haegele & Hodge, 2015). I based my assumptions on the requirements for this study. Qualitative research (QR) focuses on the contextual interpretation of findings and patterns by the researcher (Yilmaz, 2013). Therefore, qualitative research is subjective and not without bias, because the researcher acts as the data collection instrument and all analysis is the result of an insider's view and their understanding of the data (J. Park & Park, 2016). To address this assumption, I used open-ended questions instead of yes-or-no alternatives throughout the study, and I reduced bias when designing the interview questions minimizing my influence on the interviewee.

My first assumption for this study was that all participants were familiar with the design and development process of fully autonomous vehicles or driving systems and were qualified to answer the interview questions of the study. Secondly, I assumed that the sample of this study was representative of the population and that each participant will answer the survey questions truthfully and to the best of their knowledge. Lastly, I assumed that my qualitative research approach enabled me to collect raw data that will be adequate to evaluate further and answer my research question.

**Limitations**

Limitations, or potential weaknesses of a study (Schafer Astroth, 2018), may include issues concerned with behavioral, social, relational, causal, research design, external validity, and the interview protocol. For example, by relying on a multiple case study research design, I was limiting myself to examining the perceptions and strategies of a limited number of cases (Touw, 2017). However, there may be additional behavioral, social, relational, or causal factors that influence the design decisions of hard- and software engineers working on autonomous vehicles, which this study did not examine. I did not design my interview protocol to collect data beyond the information I expect to be useful for answering my research question. Knowing these limitations, I was able to reduce bias and interpret the data and my findings honestly and objectively.

Another limitation of this study is my choice of research method. While qualitative designs are well equipped to include contextual and supplemental information, they cannot generally collect and analyze empirical data (Zyphur & Pierides, 2017). Therefore, my findings will be limited by my interview protocol and research method, although the collected data should provide valuable insights for future studies. Lastly, by choosing a qualitative research design, I am limiting the scope of my study to rich contextual and descriptive data, which will lack testable measures associated with quantitative research, making it also impossible to use statistical analyses, for example.

Researchers use case studies to collect rich contextual data and examine perceptions of constructs in the context of a given environment (Kumar, 2011). Using a qualitative research method may limit the findings of the study and its applicability to a general population because the results may be localized and only relevant to the participants (Rutberg & Bouikidis, 2018). Therefore, validity in a qualitative study largely depends on the qualifications of the researchers and the established interview protocol (Yilmaz, 2013). I will discuss the validity of my study in more detail in the validity section of my study.

## Delimitations

Delimitations refer to the scope and boundaries as they apply to the study (Thomas, Silverman, & Nelson, 2015). While I intended to sample my population from any geographic location, I limited the scope of the study overall to only include autonomous driving technology

IT research or development teams. Furthermore, the boundaries of my study included conducting interviews among IT software and hardware engineers who are currently developing fully autonomous driving technologies to understand their perception of the relationship between existing autonomous vehicle design frameworks, consumer expectations, and regulatory requirements.

## Significance of the Study

The results of this multiple case-study may offer insights to IT practitioners and organizations about the strategies some IT hardware and software developers of self-driving cars use to adapt autonomous vehicle design frameworks for addressing consumer and regulatory requirements. While various technological approaches already exist today, the widespread and low-cost adoption by consumers requires that self-driving cars comply with regulations and meet consumer expectations (Bunghez, 2015). Contributing to the development of industry standards and technical frameworks as the outcomes of the research will enable manufacturers and engineers to focus their attention on the practical application instead of researching and building an autonomous system from scratch (Molina et al., 2017). The findings of this study contribute to the existing literature on autonomous driving systems and offer new insight into how existing autonomous vehicle design frameworks could be improved to meet consumer expectations and regulatory requirements better.

The results from this study have implications for social change because they contribute to the understanding of how existing autonomous vehicle design frameworks could be improved to meet regulatory and consumer expectations better. Furthermore, individual users and society will directly benefit from the faster availability of smarter, safer, more convenient, and more attractive autonomous vehicles, which can significantly contribute to a changing lifestyle and actively reduce traffic-related accidents (Ingrid Pettersson, 2017).

However, the projected benefits for society do not end with reducing traffic-related accidents or transforming lifestyles, but instead, go much further and indirectly affect everyone on a global scale. It is not often that novel technology can quickly transform society, but autonomous vehicles are expected to significantly mediate the effects of global climate change through a reduction of fuel consumption by as much as 80% (Pettigrew, 2017). Other implications for social change include improved mobility for the elderly or disabled, lower cost of ownership, and improved time management (Pettigrew, 2017).

## A Review of the Professional and Academic Literature

I included a collection of resources in the literature review to illustrate the current understanding of the relationship between autonomous vehicle design frameworks and consumer and regulatory requirements. For example, Mushtaq, Riaz, Mohd, and Saleh (2018) conducted a study among more than 100 travelers and drivers in Dubai and found that uncertainties associated with safety and privacy in autonomous vehicles result in a much more cautious approach to accepting self-driving technology than otherwise expected with the adoption of new product trends. In another example, Vellinga (2017) asserted that the cautious approach to acceptance by consumers and regulators is the result of incoherent legal development across all jurisdictions for the use, testing, and commercial deployment of autonomous vehicles on public roads.

In addition to selecting seminal works, I considered peer-reviewed articles and journals, reports, regulations, and theses published since 2015 in my review of the literature. Out of the 163 resources I used in this study, 146 (89.57%) were published between 2015 and 2019, and 74 (98.66%) of the 75 resources I referred to in the literature review were peer-reviewed. I used databases such as EBSCOhost, ScienceDirect, Google Scholar, SAGE Journals Online, ProQuest, and Thoreau as an aggregator to access additional databases. Although my resources include select seminal works, I also verified the peer-review status of academic journals through Ulrich's Global Serials Directory. When accessing databases, my strategy for searching the literature included the use of keywords related to my theoretical framework, existing design frameworks used to develop autonomous vehicles, and consumer and regulatory requirements. The keywords I used included combinations of *autonomous vehicle, autonomous car, dynamic capabilities theory, self-driving, design framework, automotive framework, consumer expectations, social change, society, vehicle safety, vehicle regulations, autonomous regulations,* and *legal challenges*. I then screened the search results for relevance, first read available abstracts, and continued to evaluate the literature in detail where appropriate. Furthermore, I also took the keywords used by authors of the examined literature to find additional articles and applied reverse-search approaches to find other studies that may have referenced the works I found initially.

I focused my review of the academic literature on four areas: (a) dynamic capabilities theory, (b) autonomous vehicle design frameworks, (c) consumer expectations, and (d) regulatory requirements. By organizing and limiting the academic and professional literature to these themes, I was able to limit the scope of my research to focus on examining the extent to which existing autonomous vehicle design frameworks meet consumer and regulatory requirements. In a rapidly evolving environment, both from the technological and the regulatory and consumer requirement perspective as they relate to design frameworks, I was able to examine the interaction between my dependent and the independent variables by using the theory of dynamic capabilities as a theoretical framework.

## Dynamic Capabilities Theory

Teece et al. (1997) defined the theory of dynamic capabilities as an extension of the resource-based view (Wernerfelt, 1984) by focusing on how firms can achieve competitive advantage in dynamic environments through the renewal of internal and external functional competencies, effective use of resources, congruence, reconfiguration, and development of organizational skills. Instead of merely seeing an organization's competitiveness as a function of competitive forces, strategic conflict, or resource-based perspectives, the dynamic capabilities framework focuses on positions, paths, and the reliability and availability of organizational processes (Teece et al., 1997). The interpretation of dynamic capabilities in the context of various highly competitive and rapidly evolving disciplines continues to evolve and attracts a large amount of research, especially when applied to emerging and changing technologies (Klara-Marie & Veit, 2017).

Key tenets of this theory are (a) factors of production, the available and disaggregated undifferentiated inputs; (b) firm-specific resources, such as trade secrets or specialized engineering experience, for example; (c) organizational competencies, such as systems integration or processes, for example; (d) core competencies of an organization as derived from looking at its services and products and when compared with competitors; (e) dynamic capabilities, or the ability of an organization to build, integrate, and reconfigure its external and internal competencies to adapt to a rapidly evolving environment; and (f) products, particularly the price, quality, and demand of produced goods and services in relation to offers from competitors (Teece et al., 1997). When applied to the theory of dynamic capabilities, consumer and regulatory requirements pertain to factors of production and products, whereas autonomous vehicle design frameworks relate to resources but also organizational and core competencies. However, regulatory requirements and design frameworks are equally subjected to the dynamic capabilities of a firm, as rapidly changing regulatory and consumer demands may force an organization to change its strategy or frameworks to achieve a competitive advantage or stay compliant with the law (Hanna & Kimmel, 2017). As explained by Ki-Jung, Byeonghwa, and Taikyoo (2016), achieving competitive advantage through dynamic capabilities requires the interaction between multidimensional constructs and continuous technological innovation to improve operational performance.

The theory of dynamic capabilities applies to this study, and I used it as a theoretical framework to examine the relationship between autonomous vehicle design frameworks and consumer and regulatory requirements. Researchers often use the dynamic capabilities theory as a basis for examining highly competitive and emerging environments. For example, the current literature often focuses on the relationship between variables in areas such as product development, supply chain management, corporate strategies, and approaches to risk mitigation.

The measurable constructs of the dynamic capabilities theory provide me with a reference from which I will able to measure the interrelationships between my study variables.

**Evolution of Dynamic Capabilities Theory**

First developed by Teece et al. (1997), the theory of dynamic capabilities started as an extension of the resource-based view (RBV). The RBV focuses on the resources and capabilities of an organization as they relate to achieving competitive advantage (Barney, 1991), but it mostly fails to account for dynamic environments where these competencies must evolve to ensure continuing competitive advantage (Teece et al., 1997). To succeed in highly competitive and quickly evolving environments, organizations must be able to respond timely with flexible and rapid product innovation but also improve and redeploy external and internal competencies and management capabilities to align with evolving strategies and new products (Teece et al., 1997).

In an expansion of the original work, Teece (2000) argued that intangible assets, such as difficult-to-imitate knowledge, are essential elements of a firm's ability to innovate and achieve competitive advantage. While these and other intangibles are also dependent on tangible assets, such as actual products, for example, without highly valuable knowledge that an organization can use to create products or services that set them apart from their competitors, achieving and sustaining a competitive advantage is unlikely (Teece, 2000). Furthermore, Schoemaker, Heaton, and Teece (2018) argued that organizations with dynamic capabilities know how to do "the right things at the right time"(p. 17). Even though these firms must master ordinary capabilities, their ability to maintain competitive advantages is the result of their proprietary assets, including, for example, technologies and know-how.

By including know-how as an essential element of the value-chain in rapidly evolving environments, managerial strategies and organizational execution become somewhat less important for achieving competitive advantage. Teece (2007) further refined dynamic capabilities to include social and behavioral managerial differences, which are equally important for achieving success in competitive markets. As an extension of knowing what to do and when (Schoemaker et al., 2018), sensing and understanding opportunities combined with a desire to get things done, entrepreneurial management may be the most critical factor for maintaining competitive capabilities (Teece, 2007). This newly added emphasis on personality traits may illustrate the importance of leadership, vision, and charisma, and it may explain why only a few organizations can maintain competitive advantages over a long period, whereas most others struggle with continuous innovation. This expanded view of dynamic capabilities then must include managerial competencies as defined by personality traits often associated with entrepreneurs, access to resources and general capabilities, and the maintenance and continuing expansion of proprietary know-how (Schoemaker et al., 2018).

## Application of Dynamic Capabilities Theory

Researchers use the theory of dynamic capabilities in quantitative and qualitative research designs to examine and analyze a firm’s ability to reconfigure and transform itself in competitive environments (Barreto, 2009). Unlike other theories, dynamic capabilities seek to evaluate competitive forces in the context of an organization’s ability to seek, develop, and exploit technological opportunities (Teece et al., 1997). For example, in one application of dynamic capabilities, researchers evaluated the extent to which dynamic capabilities influence a firm's abilities to market and innovate (Ferreira, Cardim, & Branco, 2018). The study found that dynamic capabilities provide a foundation for and support marketing and innovation capabilities, while in return, the feedback can further improve an organization's performance and result in sustained competitive advantage benefits (Ferreira et al., 2018).

Krzakiewicz and Cyfert (2017) used dynamic capabilities theory to evaluate strategic choice processes within organizations. The authors used dynamic capabilities as an element of a chain of competencies that they believe result in a competitive advantage. Krzakiewicz and Cyfert (2017) argued that delivering high-quality products in a competitive market is not enough to succeed, but instead, competitiveness is the result of incorporating and building-out core competencies. In this case, the dynamic capabilities theory provides context for a firm's strategic decisions and how they help to facilitate the development of competitive advantages.

In an empirical survey study of 206 small- and medium-sized firms in Korea, researchers used the theory of dynamic capabilities to examine how innovative supply chain management influences operational performance and technological innovation at an organization (Ki-Jung et al., 2016). The researchers found that optimizing the efficiency of supply chain management processes alone has a limited impact on a firm's dynamic abilities and suggested that a static supply chain may reduce a firm's competitive advantage and its dynamic capabilities (Ki-Jung et al., 2016). Furthermore, Ki-Jung et al. (2016) found that dynamic capabilities in supply chain management positively influence an organization's operational performance and its ability for technological innovation.

In an in-depth "longitudinal case study," Kodama (2017) employed dynamic capabilities theory to examine NTT-Docomo's ability to innovate its communication products and networks continuously. In the highly competitive environment of mobile communications technology achieving strategic innovation capabilities is the result of an innovation loop that spans across several domains and includes core competencies, as well as specialized capabilities (Kodama, 2017). The theory of dynamic capabilities provided a framework that the author of the study used to examine the complex relationships between various factors for driving innovation at an organization and to advance an understanding of the strategic development loop.

Jurksiene and Pundziene (2016) evaluated whether a firm's productivity and competitiveness are the results of dynamic capabilities, or whether other relationships and factors are equally important. By using dynamic capabilities theory as a framework for examining an organization's ability to compete, renew itself, and expand specific capabilities, the authors suggested that dynamic capabilities may only indirectly affect competitiveness, and instead are the result of mediating factors (Jurksiene & Pundziene, 2016). Furthermore, the theory of dynamic capabilities provided a lens for the researchers through which they examined organizational ambidexterity, that is the firm's ability to develop and implement incremental and radical activities simultaneously, and found that dynamic capabilities alone are insufficient to explain and achieve competitive advantage (Jurksiene & Pundziene, 2016). Using dynamic capabilities theory as a framework for the analysis, the authors were able to study competitiveness and make recommendations for future research.

In another example, Queiroz, Tallon, Sharma, and Coltman (2018) suggested that a firm's ability to buy, retire, and build new IT applications is the result of its orchestration capabilities. By using the theory of dynamic capabilities as a framework, the authors found that building out internal software development capabilities and orchestrating the interaction between various resources a firm can achieve a competitive advantage. In this context, the ability to align processes and products for gaining an advantage in a rapidly evolving marketplace is a specialized dynamic capability, which is the result of orchestrating several capabilities instead of just managing and exploiting resources (Queiroz et al., 2018). In the context of this study, the authors used the theory of dynamic capabilities to examine the complex interactions between resources, strategic direction, competitive forces, and various capabilities in organizations that can derive significant value from IT applications.

The above literature illustrates how researchers are using dynamic capabilities theory to analyze and explain an organization's ability to continuously renew itself and achieve advantages in highly competitive environments. While many factors can influence a firm's ability to innovate and successfully compete, dynamic capabilities offer a unique perspective focused on the renewal of internal and external functional competencies. Furthermore, dynamic capabilities also include the effective use of resources, congruence, reconfiguration, and the development of organizational skills in rapidly changing and evolving markets and environments (Teece et al., 1997). The current uncertainty regarding regulatory and consumer requirements for autonomous vehicles requires manufacturers working on autonomous vehicle designs to quickly adapt their approach to these challenges and use or develop design frameworks that are capable of meeting today's requirements (Hanna & Kimmel, 2017). Adding to the complexity of this issue is that developers must also incorporate ongoing changes as technologies and expectations continue to evolve (Vellinga, 2017).

## Supporting Theories

Researchers use various theories to examine the sociological, economic, ethical, and technological aspects of self-driving technologies, consumer expectations, and regulatory requirements (I. Pettersson & Karlsson, 2015). Generally, most literature concerned with these concepts and technologies focuses on the evaluation of single aspects, rather than multiple complex and interconnected relationships of the involved factors and variables under investigation. Previously, some studies relied on variations of systems theory (Mahajan, Bradley, & Pasricha, 2017), actor-network theory (Sovacool, 2017), and the technology acceptance model as theoretical frameworks (Moták et al., 2017). To examine the relationship between vehicle design frameworks, consumer expectations, and regulatory requirements, I have chosen the theory of dynamic capabilities as a theoretical framework for this study. I include the following supporting theories to illustrate their use in past research associated with autonomous vehicles technologies or regulatory requirements or consumer expectations, even though I decided against using them as the theoretical framework for this study.

**Unified theory of acceptance and use of technology.** The unified theory of acceptance and use of technology (UTAUT) theory incorporates eight different theories to explain how a user might adopt new technology at the workplace by focusing on four elements, including (1) performance expectancy, (2) social influence, (3) facilitating conditions, and (4) effort expectancy (Venkatesh, Morris, Davis, & Davis, 2003). Sovacool (2017) researched how UTAUT could be used to explain how consumers would approach and accept the transition to electromobility. The researcher found that the UTAUT can be used to examine performance expectancy, effort expectancy, hedonic motivation, and social influence to the extent of technology acceptance in general, but other theoretical frameworks can supplement the insights to get a complete understanding of the problem (Sovacool, 2017).

In a different study, Leicht, Chtourou, and Ben Youssef (2018) used the UTAUT as a base model for examining user acceptance of autonomous cars. The researchers evaluated consumer perceptions, technology expectations, and willingness to adapt to new transportation technologies but noted that there are several shortcomings they were unable to address. These concerns include managerial impact, a changing social environment as it relates to expectations and acceptance, and specific product features that may not yet be available or have yet to be regulated (Leicht et al., 2018). The UTAUT seems to be better suited to examine relationships around autonomous driving technologies and consumer acceptance and expectations, but less so when considering the recursive connection between autonomous vehicle design frameworks, consumer expectations, and regulatory requirements.

**Socio-technical systems theory.** The socio-technical systems theory is primarily used to study the impact of technical systems on social behavior (Tyfield & Zuev, 2018). For example, Mendez et al. (2018) used socio-technical systems theory to examine how a semi-automated software assistance system influences user behavior and perceived workload. Tyfield and Zuev (2018), on the other hand, used socio-technical systems theory to examine the recursive relationship between electromobility, autonomous cars, governmental regulations, and consumer acceptance and expectations. The researchers argue that quickly regulating new vehicle driving technologies alone is not enough to facilitate consumer acceptance or the development of better technologies. As it relates to autonomous vehicles, the socio-technical systems theory is well suited to examine societal changes, but limited for studying the relationship between capabilities, consumer expectations, and regulatory requirements.

**Technology acceptance model.** The technology acceptance model (TAM) assumes that perceived ease of use and perceived usefulness influences an individual's acceptance of technology (Venkatesh et al., 2003). TAM is one of many theoretical frameworks researchers often use to analyze how individuals adopt technology (Hong, Lin, & Hsieh, 2016). For example, Panagiotopoulos and Dimitrakopoulos (2018) used TAM to study consumer acceptance of autonomous vehicles but noted that their study is incomplete because participants had to imagine the use and usefulness of autonomous driving technologies because this technology is emerging and very few have any real-world experience with these systems. In another study, E. Park, Kim, and Ohm (2015) relied on TAM to examine use acceptance of car navigational systems and found that locational accuracy, perceived system reliability, satisfaction, and service & display quality are all important factors influencing consumers' willingness to accept and use these systems. As these examples illustrate, in the context of this study, the TAM could be useful to show the acceptance of autonomous driving systems as they relate to regulatory requirements, but it would be inadequate to examine the interconnection between autonomous design frameworks, consumer expectations, and regulatory requirements.

**General systems theory.** Researchers have used general systems theory (GST) to explain technological, organizational, and even biological interactions between elements in a given system, where changes of individual components are the response to the result of sensed information (Tuan & Shaw, 2016). For example, Mahajan et al. (2017) used systems theory to examine a lane-keeping assist system from a technical perspective. Mämmelä, Riekki, Kotelba, and Anttonen (2018), on the other hand, applied GST and other theories to their study of self-organizing and autonomous technologies used in multiple disciplines to understand decision-making processes in highly intelligent systems. GST could be used to examine the interaction between consumer expectations or regulatory requirements and autonomous design frameworks. However, by focusing on the interactions of elements within a system, GST would be better suited to explain and predict the impact of sensed actions rather than examining the relationships between autonomous driving frameworks, consumer expectations, and regulatory requirements. GST assumes a cause and effect relationship between various elements of a given system, whereas this study aims to establish whether such a relationship even exists.

### Contrasting theories

Even though I have identified various supporting theories from which to explore all or some relationships between autonomous vehicle design frameworks, consumer expectations, and regulatory requirements, others exist that partially or indirectly relate to the theoretical framework I have chosen for this study. I have chosen the theory of dynamic capabilities to apply to this study as the theoretical framework. I examine some contrasting theories by highlighting their constructs and why they would be inappropriate as a theoretic framework for this study.

**Complexity theory.** Researchers often use complexity theory to examine organizational or technical complexity in high-risk systems (Mihić, Dodevska, Todorović, Obradović, & Petrović, 2018). One can define complexity as the degree of operational interdependence between different elements of technology, or it can refer to interactions between agents in a network or the structures and components it is comprised of (Mihić et al., 2018). While complexity theory can be used to study the technical or organizational complexity of systems and technologies for risk assessment or to evaluate uncertainty, this study focuses on whether there is a relationship between autonomous vehicle design frameworks, consumer expectations, and regulatory requirements. Even though complexity theory would allow for the study of the complexity of individual systems to understanding their components and how they interact with each other, it would do so from a risk assessment and management perspective. This study aims to evaluate the relationship between the research variables without making assumptions about individual risks or evaluating uncertainty.

## Design Frameworks for developing Fully Autonomous Vehicles

### Autonomous Vehicle Designs

The Society of Automotive Engineers (SAE) categorizes the technical abilities of self-driving vehicles into five levels of autonomy, including (1) driver assistance, (2) partial automation, (3) conditional automation, (4) high automation, and (5) full automation (Society of

Automotive Engineers, 2016). Issued in 2014, governments and manufacturers of self-driving technologies widely recognize the SAE J3016 standard as a de-facto definition of autonomous vehicle capabilities and a guideline for drafting their regulations and designing products (Lv et al., 2018). While SAE J3016 levels one and two are automated driver assist systems (ADAS), which require human monitors to be able to take over at any time, level three provides conditional automation for some environments but still requires a human as a fallback. Only levels four and five can navigate some or all environments without a human driver present and, therefore, are much more complicated to develop, test, or certify autonomous vehicles (Mohan et al., 2016).

As it pertains to this study, I exclusively focus my research on autonomous vehicle design frameworks, consumer expectations, and regulatory requirements related to SAE J3016 Level 4 and Level 5 automation. Achieving full autonomy continues to be challenging because self-driving vehicles must be able to solve unexpected problems in complex environments and behave and react similarly to human drivers (Pozna & Antonya, 2016). Furthermore, ADAS and conditional automation rely to a high degree on mathematical and control feedback solutions to enable self-driving in very limited and familiar environments. With these systems, there is no need for complex autonomous decision-making because a human driver is present and can take over when necessary (Wörner et al., 2016). While there are many different approaches to solving the challenges associated with designing fully autonomous vehicles, all current developments use primarily passive or active technologies, with most of them incorporating both to a varying extent (Van Brummelen, O’Brien, Gruyer, & Najjaran, 2018).

**Passive Technologies**. In autonomous vehicle systems, passive systems include global navigation satellite systems (GNSS) receivers for adding location-awareness, single-sensor cameras for path prediction, and object and obstacle identification, stereo vision cameras for added depth perception, and accelerometers (Bresson, Alsayed, Yu, & Glaser, 2017). Passive systems depend on available data and are unable to initiate measurements to correlate sensor data actively; they exclusively rely on the perception of information at the time of data collection (Van Brummelen et al., 2018). For example, for Simultaneous Localization and Mapping (SLAM) an autonomous vehicle may use GNSS to verify its location and, then, is subject to a varying degree of uncertainty because of the requirement for an unobstructed view to the sky and the inherent inaccuracy associated with the system in general (Bresson et al., 2017). To prevent system failure from inaccurate and unreliable sensor data, passive approaches must verify and correlate readings with those from other sensors.

For these reasons and because of demanding computational requirements, many researchers believe that passive visual sensing alone is unable to provide the reliability and depth of information required to achieve full autonomy (Dang, Sriramoju, Tewolde, Kwon, & Zhang, 2017). However, significant progress in image processing through the use of Convolutional Neural Networks (CNN) suggests that cameras can provide reliable contextual information by adding meaning to the captured images, something no other sensor technology is currently able to accomplish (Karpathy & Fei-Fei, 2017). Furthermore, even single cameras can be used to accurately estimate the path and track objects in complex environments (Zhang et al., 2018). This approach is not without its challenges because of the training requirements of CNNs, the considerable computational cost for analyzing hundreds of images from multiple cameras each second, object detection errors, and failure to detect mistakes on time (Ramanagopal, Anderson, Vasudevan, & Johnson-Roberson, 2018).

**Active Technologies**. Active sensor technologies include RADAR, LIDAR, and SONAR. By using sound, radio waves, or laser light, active technologies emit signals to sense their environment, estimate their position about other objects, or track movement (Van Brummelen et al., 2018). Generally, active sensors are unable to provide contextual information about the objects they identify, but they may offer advantages in object detection. For example, a combination of SONAR, RADAR, and LIDAR sensors can enable an autonomous vehicle to detect objects close by and far away at comparatively low computational cost, making it a preferred approach by many manufacturers of semi-autonomous vehicles today (Van Brummelen et al., 2018).

While using active sensing technologies can improve the reliability of a system, commercially available LIDAR sensors continue to be relatively large, obtrusive, and expensive, all of which are limiting their practical application for developing fully autonomous driving technologies (S. Shi et al., 2018). However, reliable, fast, and low-cost LIDAR solutions currently in development may significantly accelerate the commercial availability of vehicles relying on these types of sensors (S. Shi et al., 2018). Even though active sensor technologies may currently offer advantages when it comes to detecting an object's speed and path, they are not without issues. For example, LIDAR has difficulties in rain and snow or with highly reflective surfaces, SONAR offers low resolution and only works in close distance, whereas

RADAR often fails to detect humans or animals reliably (Van Brummelen et al., 2018). By fusing RADAR, SONAR, AND LIDAR sensor data, engineers can increase the reliability of the combined system, but they cannot overcome the inherent limitations, such as lack of descriptive context, for example.

**Design Frameworks Overview**

Today's cars often rely on hundreds of electronic control systems, so vehicle manufacturers use design frameworks to reduce the cost of development, improve time to market, and ensure interoperability between systems sourced from various suppliers. With the introduction of ADAS and the expanding interest in developing fully autonomous vehicles, existing frameworks are expanding to accommodate regulatory requirements and consumer expectations (Fürst & Bechter, 2016). This evolutionary approach ensures compatibility with already developed systems, giving engineers access to a known working environment, and promises shorter development cycles while retaining interoperability with supplier solutions as they emerge. However, relying on iterations of technologies that were never designed to enable full autonomy results in some difficult to address challenges (Falcini & Lami, 2017).

There are generally two approaches to designing autonomous vehicles, including (1) the expansion and use of existing technologies and platforms, and (2) starting from scratch (Mohan et al., 2016). While it is conceivable that an autonomous vehicle startup may want to incorporate some existing third-party technologies due to a lack of vertical integration, vehicle manufacturers use design frameworks and standards generally for three reasons: (1) to align with regulatory requirements for certification purposes, (2) to ensure quality and functionality, or (3) to seamlessly integrate technologies from various suppliers into a working product. The following section provides an overview of five major design frameworks currently used by various manufacturers working on the development of autonomous vehicles.

**AUTOSAR**. AUTOSAR is a mature software design reference framework automotive engineers use to improve interoperability across all vehicle design domains through an electronic control unit (ECU) embedded component-based layers (Falcini & Lami, 2017). Furthermore, AUTOSAR provides a reference architecture consisting of an application layer, a runtime environment, and basic software (BSW), where the latter establishes a standardized software layer from which other AUTOSAR components run and provide functionality (Sreekanth, Srikanth, Aditya, Satish, & Ramchandran, 2017). Even though the software layers in the AUTOSAR Classic Platform are not limited to particular functionalities, the included application programming interfaces (API) effectively define and limit some services and communication between them to reduce complexity and ensure interoperability between vendors. One approach to address the growing need for more adaptive environments, such as they may be necessary to build autonomous vehicles, is to expand AUTOSAR with specialized versions, such as the AUTOSAR Adaptive Platform (Fürst & Bechter, 2016).

*Limitations.* AUTOSAR is a software framework and reference model, that is, it provides abstraction from hardware so that engineers can focus on the portable functionality of the software, rather than hardcoded solutions that are tightly integrated and require a specific technological environment to function. Primarily designed to enable manufacturers to source their ECUs from multiple providers and reuse existing technologies, separating the functionalities from the operating system results in a multi-tiered collaboration between developers, giving application designers the freedom to abstract their software from the hardware but at the cost of having very little control over the hardware directly (Martínez-Fernandez, Ayala, Franch, & Nakagawa, 2015). Also, AUTOSAR is complex, requires significant ongoing investment into development tools and extensive training, is specific in its functionality, makes inefficient use of resources, and permanently locks developers into the AUTOSAR ecosystem (Martínez-Fernandez et al., 2015).

*Application to autonomy.* Some of the core tenets of AUTOSAR include reusability, maintainability, redundancy, portability, complexity, and testability, all of which could be considered essential elements for the development of fully autonomous vehicles. The AUTOSAR Adaptive Platform aims to address some of the shortcomings of the AUTOSAR Classic Platform by switching to a POSIX-based operating system for improved signal processing, thread-handling, and support for higher computational performance (Fürst & Bechter, 2016). Even though many vehicle manufacturers use the AUTOSAR Classic Platform today, they are unable to rely on this architecture to design fully autonomous vehicles due to its shortcomings. However, the AUTOSAR Adaptive Platform promises to meet the requirements of autonomous vehicle designs better, but it is still developing and not yet mature.

**ISO 26262**. ISO 26262 is a risk-based safety standard vehicle manufacturers use as a framework for managing the automotive safety lifecycle, covering safety aspects throughout the development process, confirmation, and validation for ensuring acceptable levels of safety and providing and determining automotive-specific risk classes (Falcini & Lami, 2017). One of the requirements of ISO 26262 is the vertical and horizontal traceability of software and system requirements, their architecture and software units, change requests, and the tests that verify and control the performance of these individual elements (Maro, Steghöfer, & Staron, 2018). ISO 26262 also includes the assessment and control of calibration and configuration data among individual components of a vehicle's electronic systems, although it is not yet explicitly equipped to address the challenges and requirements of neural networks and deep learning environments (Falcini, Lami, & Costanza, 2017).

*Limitations.* While ISO 26262 establishes a framework for controlling safety and risk in electric and electronic systems as they relate to automotive applications, autonomous vehicles are beyond its scope (Molina et al., 2017). Furthermore, many autonomous vehicle designs use deep learning to understand and navigate the environment. Deep leaning is a training-based, non-transparent, and probabilistic error rate approach to enable autonomy in vehicles (Rao & Frtunikj, 2018); however, even if a system functions as designed, there is no guarantee that it will perform without error due to its neural network structure (Rao & Frtunikj, 2018). Because ISO 26262 assesses safety through validation and confirmation of functional components, its framework is challenging, if not impossible, to apply to deep learning solutions currently in development for most self-driving cars.

*Application to autonomy.* Vehicle manufacturers rely on ISO 26262 to meet, document, and verify the safety compliance with performance expectations of various in-vehicle electronics (Maro et al., 2018). Autonomous vehicles utilize much higher computational power, use more sensors, and require complex electronic systems, all of which must work as intended to ensure safety with and without passengers present. Using the mature ISO 26262 as a framework for designing autonomous vehicle systems puts an emphasis on safety and testability, which regulators may require once they finalize their rules for allowing self-driving vehicles on public roads in large numbers (Falcini & Lami, 2017). However, because governments have yet to finalize regulations for autonomous vehicles and because of the inherent concerns associated with deep learning systems, it is unknown whether ISO 26262 will be able to address concerns and meet future safety requirements.

**Safety of the intended functionality (SOTIF)**. Unlike ISO 26262 which assesses safety through mitigation of fault failures, the ISO/AWI PAS 21448 Road Vehicles – SOTIF aims at assessing the safety of an intended functionality, that is, whether the intended functionality is safe and operating as designed, even if it, by itself, is not free from fault under certain circumstances (Falcini & Lami, 2017). For example, a video-based path analysis may fail to detect lane markings due to surface reflections, even though its image processing engine works as designed, and there is no fault in the hardware. While ISO 26262 would mark this incident as a safety violation, SOTIF allows for some faults to occur when a system operates within its expected design parameters.

*Limitations.* SOTIF is currently under development, and its framework has yet to be standardized (Falcini et al., 2017). While SOTIF is better-suited to address the inherent systematic challenges associated with self-driving technologies and potential regulatory requirements in the future than ISO 26262, the standard itself is in the process of flux and refinement. SOTIF is currently insufficiently equipped to address provisional regulatory requirements or consumer expectations. Although SOTIF aims to allow for some faults to occur in systems that work as designed and intended otherwise, the lack of regulatory approval, industry preference, or finalization makes it challenging to anticipate whether this framework can meet autonomous vehicle design challenges.

*Application to autonomy.* SOTIF is better suited than ISO 21448 to assess, monitor, and verify the safety of an autonomous system in the context of its performance as designed. In system components with individual uncertainty, such as LIDAR, RADAR, SONAR, or image analysis, SOTIF supports sensor fusion and risk mitigation through other means than raw data validation. For example, road markings may disappear, but understanding where they should be in relation to the vehicle will allow the rest of the system to perform as if road markings are still present. The ability to extrapolate and estimate an environmental configuration is an essential requirement for autonomous vehicles to function correctly in real-world environments, where sensor data may be flawed occasional and for many reasons (Jiménez, Clavijo, Naranjo, & Gómez, 2016). One of the premises of SOTIF is to address this challenge, which is not specific to this application only, but a must-have requirement for self-driving cars.

**Automotive SPICE**. Vehicle manufacturers use Automotive SPICE (ASPICE) to facilitate software process improvements among suppliers and particularly in software-intensive systems (Falcini & Lami, 2017). Unlike other frameworks and standards which are more concerned with safety and the performance of a system as designed for a given purpose and scenario, ASPICE includes a Process Reference Model, a Process Assessment model, and a measurement framework to rate and manage processes (Falcini & Lami, 2017). Furthermore, ASPICE focuses on the ability of processes and how they support business goals, rather than the particular hardware or software elements of a given system. As an assessment model, ASPICE is better suited to evaluate the reliability of software than statistical modeling (Touw, 2017).

*Limitations.* ASPICE is primarily a standard designed to regulate the relationship between manufacturers and suppliers while providing effective process evaluation and management to improve product quality and reduce conflict between these stakeholders (Maro et al., 2018). As an assessment model, Automotive SPICE is mostly concerned with evaluating and improving the performance of processes concerned with software development activities; it may be less suitable as a tool for meeting consumer expectations or primarily hardware-based design activities.

*Application to autonomy*. Autonomous vehicle designs rely mainly on software, and most approaches use one or many convoluted neural networks (CNN) and deep-learning approaches for training (Gallardo, Gamez, Rad, & Jamshidi, 2017). ASPICE offers mature process-related analytics that are particularly applicable and important to deep learning automotive software development approaches. Deep learning of neural networks is an inherently uncertain process where the logic for identifying and categorizing objects is subject to change, and, therefore, a process-oriented framework for improving the quality of a solution is better suited to address the needs of autonomous vehicle designs, than other, more static solutions (Falcini et al., 2017). ASPICE is also suited for addressing concerns related to performance degradation that can frequently occur in neural networks with localized faults.

**ISO TS 16949**. ISO TS 16949 is based on the ISO 9001 standard, and many car manufacturers use it as part of their quality management system (QMS) to improve the confidence among their automotive suppliers (Falcini & Lami, 2017). ISO TS 16949 favors a process-oriented approach to develop further, enact, and improve a QMS. While ISO TS 16949 is not explicitly concerned with hardware or software approaches to autonomy, quality management is an essential aspect of modern car manufacturing practices and provides the necessary framework which vehicle designers can use to iterate their technologies and verify functionalities and compliance.

*Limitations.* ISO TS 16949 can be used to enact and improve processes associated with quality management, and also processes related to autonomous vehicle technologies. However, the primary focus of this standard is to provide a framework for integrating with a QMS in automotive applications. ISO TS 16949 does not have specific hard- or software requirements but instead solely focuses on processes by utilizing five core tools, including (1) Advanced Product Quality Planning, (2) Production Parts Approval Process, (3) Failure Mode and Effects Analysis, (4) Statistical Process Control, and (5) Measurement System Analysis (Misztal, Grecu, & Belu, 2016). By focusing on processes, ISO TS 16949 is best suited to address and manage quality concerns within the entire supply chain (Joanna, 2016), even though one could use it for more specialized applications but would then require additional metrics and strictly defined specification. While applying ISO TS 16949 to processes related to autonomous vehicles is possible, the framework lends itself to better address consumer expectations and qualitative measures over other aspects associated with the development and design process.

*Application to autonomy*. Vehicle manufacturers use ISO TS 16949 already to improve the quality of their products and better address customer expectations, but they also rely on the severity, probability, and the likelihood of detection of non-compliance as contained within the framework to meet government safety regulations (Misztal et al., 2016). Therefore, ISO TS 16949 can be used as a framework to ensure the performance and quality of individual autonomous vehicle components, especially as far as the supply chain is concerned. Using ISO TS 16949 enables manufacturers to improve the quality of the individual components they use in their autonomous vehicle designs but also implement and track improvement processes to better address consumer expectations and changes in regulatory requirements (Misztal et al., 2016).

**Challenges Common to Current Design Frameworks**

All current design frameworks that manufacturers of autonomous vehicles can incorporate today are subject to very similar limitations, namely that they originate from an environment of non-autonomous, combustion-engine-based vehicles and focus firmly on quality and process improvements between manufacturers and their suppliers. These origins bring with it some severe design limitations that make it difficult for manufacturers of autonomous vehicles to meet consumer expectations or regulatory requirements quickly. Today, the underlying technology is far from being mature and subject to rapid iterations and frequent design changes, especially with the necessary safety considerations in mind (Bhat, Aoki, & Rajkumar, 2018). Furthermore, current design frameworks are unable to answer questions of liability for manufacturers or the owners of autonomous vehicles and fail to incorporate the dynamics of certification and recertification in vehicles that are expected to frequently change the software they rely on for performing autonomous tasks throughout their lifecycle (De Bruyne & Werbrouck, 2018).

Further complicating the task of creating or matching with a design framework that can address the above challenges is that press and manufacturers already suggest near-term availability of self-driving cars while also exaggerating their current capabilities, for example fully autonomous parking or driving without requiring a driver to be able to take over, that consumers could expect soon (Hinderer, Stegmüller, Schmidt, Sommer, & Lucke, 2018). The stark disconnect between consumer expectations and actual functionality or market availability is a product of manufacturer marketing and promised capabilities of these autonomous vehicles, which continue to confuse potential buyers and regulators alike (Ingrid Pettersson, 2017). Without clear regulations in place, manufacturers may continue to advertise future capabilities, and consumers may continue to expect levels of autonomy that are currently unachievable and not supported by the necessary design or legal frameworks (Stilgoe, 2018).

Even though researchers continue to explore novel approaches to design methodologies and frameworks as they relate to autonomous vehicles, existing solutions are better suited for developing static and hard-coded systems. A common approach to autonomous vehicle designs is to rely on some form of artificial intelligence (AI) or neural networks to make sense of the environment and base decisions on a set of fixed parameters, but always in the context of a given situation (Schellekens, 2015). Existing design frameworks are incapable of establishing and verifying trust within these ever-changing systems because they often assume predictable outcomes for a given scenario, when in a real-world application multiple courses of action may be appropriate, or the behavior of the system may evolve and refine autonomously over time (Sadighi et al., 2018). With the uncertainty of evaluation, prediction, and solution in AI-based autonomous vehicle systems, the performance of a given system is often hard to quantify because verifiable benchmarks do not yet exist.

Although existing design frameworks continued to support manufacturers in the development of ADAS components and paved the way for electromechanical controls in modern vehicles, self-driving cars have much higher computational requirements and need high-speed communication networks that are significantly faster than those used in traditional, non-autonomous vehicles today. Furthermore, some researchers argue that the design frameworks manufacturers use to develop vehicle electronics today are insufficient for autonomous systems. Fully autonomous vehicles must master multi-disciplinary challenges, including those related to technology, consumer expectations, cost constraints, following ethical rules, and meeting the rapidly evolving regulatory requirements in various jurisdictions (Schäfer, Kriesten, Chrenko, & Gechter, 2017). Considering that many of the ongoing challenges associated with fully autonomous vehicles are new to automotive manufacturers and their design processes, it is understandable that the current design frameworks are inadequately equipped to meet consumer expectations and regulatory requirements fully. Especially when one considers the many orders of magnitude higher computational cost of running a neural network in a vehicle it becomes evident that autonomous driving is foremost an IT problem and to a much lesser extent a mechanical or engineering challenge (W. Shi, Alawieh, Li, & Yu, 2017).

**Consumer Expectations.** Three main factors influence consumer expectations about autonomous vehicles and their perceived capabilities, including (1) science fiction, (2) marketing, and (3) personal experience (Mushtaq et al., 2018). One way to look at expectations is by evaluating whether human drivers would trust an autonomous vehicle and, if so, under which circumstances. In a recent study with 200 participants, researchers found that 65.5% of participants would be comfortable with a car that can operate autonomously on the highway, but only 14.5% would feel the same if the car had no manual controls for the passenger to intervene in case of an emergency (Lazányi & Maráczi, 2017). The issue of trust in a system and whether the passenger believes they should or must intervene is a problem that one can associate with human-machine interfacing and human factors. Human factors are concerned with the interactions between humans and machines, human expectations of performance, and the resulting human behavior. Over time, humans may experience sensory fatigue or get used to the apparent functionality and reliability of a given autonomous system, which can lead to longer reaction times and attribution of imaginary performance (Kyriakidis et al., 2017). While imaginary performance expectations are more likely in ADAS designs, this research illustrates how consumer expectations can dramatically differ from the actual performance of an automated system. Even though building trust in the capabilities of self-driving cars is essential, it seems that consumers might abandon any concerns quickly, once they get the impression that an autonomous vehicle performs reliably (Mushtaq et al., 2018).

Performance expectations of self-driving cars and associated trust in their technology also depend much on the location, frequency of use, and age of the driver. In a study with 489 participants, researchers found that drivers above the age of 60 are less likely to use autonomous vehicles, and while younger drivers tend to value the potential benefits of being able to perform other tasks while being driven, those who commute more often are also less likely to embrace self-driving cars (König & Neumayr, 2017). Coincidentally, the same study identified the ability to solve transport issues for older and disabled people as the primary benefit, but only as far as younger drivers are concerned (König & Neumayr, 2017). One might expect that older participants would embrace and expect self-driving cars to materialize quickly, as they are the primary beneficiaries, at least according to the expectations discovered by the survey. These results further illustrate the disconnect between consumer expectations and their desire to own or ride in an autonomous vehicle, once they become available.

As explained earlier, the current design frameworks used to develop autonomous vehicles have limited abilities for establishing consumer trust into an autonomous system that primarily relies on changing interpretations of its environment. The very nature of a neural network is that its interpretation of and reaction to sensed information is changing while the network continues to grow and refine itself during training (Rao & Frtunikj, 2018). In a study about the effects of perceived performance expectations on trust in an automated luggage screening system, researchers found that participants who had high expectations about the capabilities of the system were also more sensitive to a change in its reliability (Pop, Shrewsbury, & Durso, 2015). Therefore, presumably, the higher the expected level of automation is in a given system, the more sensitive operators might be to changes that they did not expect.

Mostly, consumers are basing their expectations about the performance of self-driving cars on limited or no experience with semi-autonomous vehicles, perceived benefits they may associate with a fully autonomous vehicle, and general attitude toward the acceptance of new technologies and the expected performance they may associate with these products (Mushtaq et al., 2018). Building trust with existing design frameworks and technologies is complicated because consumers will quickly note changes in the expected behavior of an autonomous system. These changes are, however, by design, and whenever a system based on neural networks improves its capability, it is likely also going to change its behavior in a given situation (Rao & Frtunikj, 2018). Furthermore, some human drivers seem to expect self-driving cars to behave like them and may require months of perfect use to trust the system, whereas others may be reluctant to give up the pleasure of driving themselves (I. Pettersson & Karlsson, 2015).

**Regulatory Requirements.** Although the SAE specifies five levels of autonomous vehicle capabilities for self-driving cars (Society of Automotive Engineers, 2016), the standard is merely a recommendation which local jurisdictions and governments can use to define and refine their rules and regulations as they apply to the technology on public roads. There are currently numerous efforts by governments and individual states to grant temporary permissions for testing self-driving cars on public roads, even though federal or international rules have yet to be established (Stilgoe, 2018). Further complicating the issue of finalizing regulations concerning autonomous vehicles is whether changes in traffic laws are required, and what ethical rules lawmakers and the public decide must apply to these robots (Thornton, Pan, Erlien, & Gerdes, 2017).

Current design frameworks and methodologies assume that autonomous vehicles must meet or exceed the capabilities of average human drivers; however, agreed to capabilities or methodologies for accurately measuring compliance have yet to emerge (Koopman & Wagner, 2017). Further complicating the issue of meeting regulatory requirements is that (a) those requirements have yet to be defined, and (b) the inherent security and safety risk associated with connected autonomous vehicles. Even though existing design frameworks offer fault protection based on expected performance parameters, some of those parameters are continually changing because of how neural networks operate. It will be increasingly difficult for manufacturers to adequately meet safety standards or prove functionality as designed, once lawmakers incorporate these requirements into law (Koopman & Wagner, 2017).

Another issue that current design frameworks and methodologies are unable to address directly is the threat of malicious actors and comprehensive intrusion prevention in autonomous vehicles (Alheeti & McDonald-Maier, 2016). While non-autonomous cars have been using in-vehicle networks for several years, the electronic control units (ECU) generally lack internet connectivity and require a physical connection to proprietary diagnostic equipment for firmware updates or manipulation of settings (Falcini & Lami, 2017). Autonomous vehicles, on the other hand, will at least require some form of internet connectivity to update maps and other data, and some solutions may even support vehicle to vehicle communication (Alheeti & McDonald-Maier, 2016). Furthermore, some of the sensory information a self-driving car may rely upon to navigate an environment may be subject to tampering. For example, a malicious actor could modify GPS information to misguide a vehicle, use false visual representations to force an accident, reprogram a planned route and destination, or merely cause traffic congestion (Plosz & Varga, 2018). Regulators may require manufacturers to eliminate and account for these risks, even though current design frameworks are unable to address all of these concerns.

## Gap in the Literature

To date, most studies concerned with consumer expectations about autonomous vehicles rely on the interpretation of the technology by participants who are more influenced by marketing and projected capabilities than experience with a self-driving car (Ingrid Pettersson, 2017). Therefore, the extant literature on the subject of consumer expectations is not comprehensive because most researchers evaluate individual assumptions through hypothetical scenarios and not experience (Borenstein et al., 2017). Therefore, studies on consumer expectations, as illustrated in Table 1, focus on consumer perception of the technology, which is primarily driven by marketing, science fiction, and the limited exposure some consumers may have had to ADAS systems (Mushtaq et al., 2018). Once self-driving cars with capabilities that go well beyond what current ADAS solutions can deliver are available to a broad audience, the currently identified themes around issues of trust, expectations of capabilities, and general acceptance of these autonomous vehicles may change significantly (Kyriakidis, Happee, & de Winter, 2015). Although current design frameworks are inadequate for directly addressing concerns related to trust in self-driving technologies, once actual products are available to consumers, this may have wide-ranging implications.

Table 1

*Selected Studies on Consumer Expectations and Regulatory Requirements*

| Author/date | Research Focus | Findings |
| --- | --- | --- |
| Mushtaq et al. (2018) | Autonomous vehicle perception concerns and adoption trends | Safety, privacy, and personal travel preference strongly influence consumer expectations and behavior. |
| Hinderer et al. (2018) | Requirements and consumer expectations for autonomous on-demand mobility in rural areas | Participants expect autonomous on-demand transportation to be free or nearly free, and only some users may accept deviations to pick up new passengers |
| Lv et al. (2018) | Autonomous vehicle disengagement reports as required by California law | Disengagement reports for self-driving cars in California illustrate regulatory and technological challenges |
| Kyriakidis et al. (2017) | The role of the human driver in autonomous vehicles | current challenges include greatly varying opinions about self-driving cars and the role of humans, but also a lack of certification and regulation of autonomous systems with both leading to trust issues and false performance expectations of this technology among all stakeholders |
| Vellinga (2017) | Binding and non-binding regulations about autonomous vehicles in various jurisdictions | The authors see addressing liability and insurance concerns when no human driver is present as ongoing regulatory challenges |
| Ingrid Pettersson (2017) | Consumer expectation about the use and functionalities of autonomous vehicles | Consumers expect smarter and more efficient lifestyles through the introduction of autonomous vehicles, but most participants remain skeptical about trusting the autonomous systems and fail to understand or rationalize current capabilities |
| Hanna and Kimmel (2017) | Current US government policy framework for self-driving vehicles | The areas of privacy, security, safety, and the environment are all insufficiently addressed by current regulations |
| Kyriakidis et al. (2015) | Consumer acceptance of and willingness to buy partially or fully autonomous vehicles | Consumer concerns about self-driving vehicles include privacy, misuse, legality, safety, and joy and most participants assume that fully autonomous vehicles are commercially available after 2030; conversely, the single largest group of respondents indicated that they believe self-driving cars will be available as early as 2020, suggesting that consumer expectations and perceived capabilities may vary significantly among potential users. |

Although I reviewed existing literature on regulatory requirements, lawmakers have yet to write or establish the applicable laws (see Table 1). Therefore, most literature focuses on regulations as they apply to autonomous test vehicles on public roads and discussions among stakeholders about what these regulations should cover. While most current regulations have similar requirements, they all lack a comprehensive framework that manufacturers can use to design their self-driving cars with future compliance in mind. In addition to the design challenges, governments and insurance companies have yet to address issues associated with liability, ethical behavior, safety, security, traffic laws, and coexistence of autonomous and human-based vehicles on public roads. Although some existing design frameworks used by autonomous vehicle designers throughout their development processes are aiming to support governmental requirements, it is unlikely that those efforts are going to be sufficient because applicable laws have yet to be drafted and are subject to change, just like the technologies they ultimately aim to regulate (De Bruyne & Werbrouck, 2018).

## Transition and Summary

In section 1, I introduced some challenges that researchers continue to associate with the development and introduction of autonomous vehicles. I discussed the background of the problem and gave an overview of the literature on autonomous vehicle design frameworks, consumer expectations, and regulatory requirements. Furthermore, I reviewed the theory of dynamic capabilities as the underlying theoretical framework from which I plan to examine the independent and the dependent variables in my study and discover the relationships that may exist between them. To complete my review, I discussed the evolution of dynamic capabilities theory, but also provided several supporting and contrasting theories.

Section 2 expands on the previous discussion by describing the methodology, participants, and the role of the researcher for collecting and analyzing the data for this study. I will also discuss population and sampling, instrumentation, study validity, and ethical research as it relates to the study. Lastly, I detail the interview protocol I used for this study and explain my preference for the chosen methodology.

## Section 2: The Project

In this section, I further expand on my research study by restating the purpose statement, discussing my role as the researcher, and providing an overview of the participant population and the sampling techniques I have applied.  I also describe the research method and design, my approach to data collection, and then expand on the instruments and techniques I used as part of this process.  Furthermore, I detail my analysis process and address ethical research concerns. Lastly, I am concluding this section by discussing the reliability and validity of my study and transition to Section 3.

### Purpose Statement

The purpose of this qualitative multiple case study was to explore the strategies some IT hardware and software developers of self-driving cars use to adapt traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs. The targeted population consisted of autonomous driving technology software and hardware developers who are currently working on fully autonomous driving technologies, regardless of geographic location.  Due to the variety of design frameworks and the multidisciplinary nature of the technologies currently in use or development for creating autonomous vehicles, the study targeted IT hardware and software engineers regardless of their respective specialization within the field.  The implications for positive social change include the potential to reduce car-accident related deaths and injuries as well as decreasing the cost of transportation, as soon, as autonomous vehicles become available.

## Role of the Researcher

Qualitative research methods put the researcher at the center of the data collection process by effectively making them the primary instrument, whereas in quantitative methods, the researcher assumes the position of an impartial data collector who relies on an instrument other than themselves (Rutberg & Bouikidis, 2018). By becoming the research instrument, researchers using qualitative methods are often subject to bias, although they can effectively reduce this risk through transparency and by using an interview protocol (House, 2018). Furthermore, while it is essential to consider the internal and external validity of an interview protocol, a researcher should emphasize conducting their study ethically with a focus on its purpose instead of merely inferring abstract relationships that may not align with the original intent (Zyphur & Pierides, 2017).

With more than 25 years of experience in information technology (IT), I have developed extensive knowledge of in-vehicle networking. I designed and patented a Controller Area Network (CAN)-bus interface for monitoring and modifying CAN messages autonomously or through user input. This early interest in vehicle communication networks continued for many years and evolved into photographic and video image processing, both of which are technologies that are now essential components of autonomous driving systems. As an evolution of these interests, I have also developed and applied for a patent on a novel imaging and lighting device, which creatives can use for various applications and which incorporates AI to offer a computational solution for professional photographers and motion industries. It is this passion for AI, image processing, and in-vehicle networks that formed the basis for my continuing interest in autonomous vehicles as a logical continuation of my research efforts. To remain unbiased, I had no relationship with participants of this research and used an interview protocol that I administered through Skype audio calls. I also took extensive field notes during all interviews to document the process. Using an interview protocol and field notes can be an essential tool for aiding in assessing data saturation, the point at which a researcher has discovered all knowledge about their study subject and where additional collection efforts may no longer lead to new information (Fusch & Ness, 2015).

While there are many ethical concerns a researcher must address when considering their research approach (Zyphur & Pierides, 2017), the Belmont Report provides specific guidelines for conducting research involving human subjects (U.S. Department of Health & Human Services, 2018). As a prerequisite to this study, I read the Belmont report and completed the National Institutes of Health Protecting Human Research Participants training course online (Certification Number: 2597072, Appendix A). Using the Belmont Report as a valuable resource, I gained an understanding of how to protect human subjects in research and insight into the required ethical principles and guidelines I must pursue for completing my study.

## Participants

The participants of this study consisted of autonomous driving technology software and hardware developers from two or more unrelated organizations who are currently working on fully autonomous driving technologies, regardless of geographic location. Qualified participants actively worked on technologies related to autonomous vehicle systems and systems design. Other team members, and those who only focused their work on limited aspects and components of self-driving vehicles, or those who pursued ADAS systems exclusively were not part of the study.

Researchers often rely on convenience sampling when selecting their participants (Costanza, Blacksmith, & Coats, 2015). Convenience sampling means that a researcher selects participants based on how easily they have access to them (Jager, Putnick, & Bornstein, 2017). Because qualitative research aims to understand perspectives and not find generalizable statements, convenience sampling is less of a concern than it might be in quantitative methods (Jager et al., 2017). Instead, qualitative studies rely on the rapport and trust the researcher establishes with participants to facilitate efficient and effective data collection, which can enable them to understand perspectives from the participant's point of view (Yilmaz, 2013).

I used purposeful sampling among the contacts shared by the gatekeepers to solicit at least six participants for reach case or until I achieved data saturation. Qualified participants actively work or have worked on the development of autonomous vehicle technologies. I established a working relationship with participants by disclosing the purpose and nature of my study beforehand and assuring them that their participation remains confidential and that I will collect all responses anonymously. I also reiterated that I will securely store all data I collected in a safe for five years, after which I will delete it permanently and that I require everyone working with the data throughout the study to sign a confidentiality agreement (Appendix B). Lastly, I have disclosed the details and parameters of the study to each participant and asked for their informed consent before the interview. Asking for informed consent enabled me to ensure that participants have a clear understanding of all relevant aspects of the study.

# Research Method and Design

I used a qualitative research method with a multiple case design to examine the strategies some hardware and software developers working on self-driving cars employ to align existing autonomous vehicle design frameworks with regulatory requirements and consumer expectations. Researchers can use several methodologies for conducting their study, including qualitative, quantitative, and mixed methods (Abutabenjeh & Jaradat, 2018). By using a multiple case study design, researchers can compare and contrast several approaches for identifying themes and similar solutions to a given problem through the collection and evaluation of rich and nuanced data (McCusker & Gunaydin, 2014).

## Method

I chose a qualitative research method. Qualitative research methods enable individual interpretation by the researcher that they do not derive by quantitative or statistical means (Yilmaz, 2013). Qualitative research focuses on the exploration of phenomena, individual, groups, methods or processes, or behavior, and it is best suited for understanding individual perspectives and lived experiences (Rutberg & Bouikidis, 2018). Qualitative research is inductive and enables inference without imposing pre-existing expectations on the researcher or the setting (Wark & Webber, 2015). The qualitative research method was appropriate for my study because I was exploring the strategies some hardware and software developers working on self-driving cars use to align existing autonomous vehicle design frameworks with regulatory requirements and consumer expectations for achieving a competitive advantage.

In contrast, a quantitative research method could be useful for examining the relationship between regulatory requirements, consumer expectations, and existing autonomous vehicle design frameworks using quantitative and statistical means. Researchers use quantitative methods for the systematic analysis of numerical data (J. Park & Park, 2016). Quantitative methods are best suited for testing hypotheses and examining relationships between variables (House, 2018). Furthermore, quantitative research methods enable the study of individual data related to large populations and the generalization of findings, as well as asserting cause and effect relationships (Savela, 2018). Because the goal of this study was to examine some perceptions of some hardware and software developers working on self-driving cars, instead of examining relationships between variables or testing hypotheses, a quantitative method was inappropriate for this study.

Mixed research methods combine elements of quantitative and qualitative approaches, enabling researchers to combine lived experiences and rich, descriptive, and empirical data within a single study (Schrauf, 2017). Researchers use mixed methods research to combine two or more different methodologies when one in isolation is insufficient for explaining or examining the phenomena they aim to study (Schoonenboom, 2018). Furthermore, a researcher can use mixed methods to improve the validity of their findings, primarily when one method alone would only result in a limited data set. By combining the data from two different methods, triangulation often merges qualitative and quantitative data for a better understanding of the phenomenon and the findings from various perspectives (Flick, 2016). Because my study did not rely on the combination of qualitative and quantitative research methods, choosing a mixed-methods approach was inappropriate.

**Research Design**

I selected a multiple case research design for this study. Studies that use multiple case designs aim to identify themes and gain an in-depth understanding of a problem through the collection of rich, detailed data (Yilmaz, 2013). While other approaches, such as correlational research designs, for example, aim at quantifying the extent of relationships between study variables (Pinder, Prime, & Wilson, 2014), a multiple case study helps the researcher understand a problem from the perspective of those who experience the issue firsthand (McCusker & Gunaydin, 2014). Other qualitative research designs I considered for this study include phenomenology and ethnography.

Phenomenology focuses on the examination of lived experiences (Duckham & Schreiber, 2016). Phenomenology enables researchers to gain an in-depth understanding of an individual's approaches and motivations through the perspective of the person who had the experiences forming their opinions (Kruth, 2015). However, as my study focused on understanding the strategies, IT hardware and software developers use to adapt autonomous vehicle design frameworks to meet consumer and regulatory requirements and not lived experiences, using phenomenology would have been inappropriate.

Ethnography aims at understanding cultural behavior and social relationships (Rutberg & Bouikidis, 2018). Researchers using ethnography are generally interested in studying cultural diversity and its influence on societies from within groups and communities (Merriam & Tisdell, 2015). Because I was exploring individual perceptions and strategies IT hardware and software developers use to adapt autonomous vehicle design frameworks to meet consumer and regulatory requirements and not cultural behavior or social relationships, ethnography was not a suitable qualitative research design.

I used a multiple case research design to explore how some hardware and software developers working on self-driving cars perceive the influence of regulatory requirements and consumer expectations on existing autonomous vehicle design frameworks. I developed and administered an interview protocol to collect the data for my study. While many IT professionals may be more likely to respond to an online questionnaire than a paper-based survey or other data collection approaches (Ebert, Huibers, Christensen, & Christensen, 2018), in-depth interviews can be particularly useful as long as they adequately address the participant's concerns, especially as they relate to ensuring confidentiality (Petrova, Dewing, & Camilleri, 2014). Even though an online survey may offer advantages over other approaches to data collection (Loomis & Paterson, 2018), using in-person and in-depth interviews in multiple case studies is most appropriate if the researcher wants to collect rich data, ask follow-up questions, and include field notes to supplement the process and other data they collect (Moser & Korstjens, 2018a).

## Population and Sampling

The targeted population of this study consisted of autonomous driving technology software and hardware research teams who are currently developing fully autonomous driving technologies, regardless of geographic location. Due to the variety of design frameworks and the multidisciplinary nature of the technologies currently in use or development for creating autonomous vehicles, the study targeted all IT hardware and software engineers regardless of their respective specialization within the field. I viewed all participants as representative of the unit of analysis/organizations that are doing research and developing self-driving cars. Although several manufacturers have announced that they are working on self-driving vehicles because these efforts are isolated and spread out across the world, by including all geographic locations, I was able to collect data on diverse perspectives and gain access to gatekeepers at potentially more organizations.

There are two challenges for determining the appropriate sample size in studies using qualitative research designs: (1) the number of in-depth interviews the researcher should conduct, and (2) how to select the participants from the identified population. Determining the number of needed interviews depends on the problem and access to the population. Generally, a researcher can stop conducting additional interviews or collecting data when they reach the point of saturation, that is, when additional data or interviews are unlikely or unable to provide new information or insights the researcher did not already cover previously (Fusch & Ness, 2015). In some cases, fewer than six, but most likely, not more than twelve in-depth interviews are sufficient for achieving data saturation (Guest, Bunce, & Johnson, 2006). For this study, I planned for a sample size of at least six individuals or until I achieved data saturation for each case. Researchers can further reduce the number of in-depth interviews by selecting representative and knowledgeable participants from their population on purpose, rather than merely based on convenience (Malterud, Siersma, & Guassora, 2015). By selecting program managers and development team leaders, I was able to achieve data saturation earlier.

Convenience sampling assumes that the researcher selects their participants based on how easily or conveniently they can conduct their data collection process with them, even though better candidates may otherwise exist (Jager et al., 2017). Convenience sampling occurs when a researcher selects participants that may be local or those with whom they have already built a personal connection, or merely because they are available when it fits the researcher's schedule (Costanza et al., 2015). Convenience samples, therefore, often are less representative of the population than other sampling methods, and may increase the number of in-depth interviews before the researcher can reach data saturation (Malterud et al., 2015).

To address these shortcomings, I plan to use purposeful sampling instead. Purposeful sampling requires the researcher to find and select their participants from their population based on their qualifications and expected abilities to meaningful answering the researcher's questions (Palinkas et al., 2015). By selecting participants purposely to collect in-depth information that aligns with the objectives for the study, researchers can reduce the number of required participants and often achieve data saturation faster than with other sampling methods (Gentles, Charles, Ploeg, & McKibbon, 2015). Therefore, I selected highly qualified participants for each of my cases from my identified population and continued recruiting participants until I have included a minimum of six individuals or achieved data saturation. By including and preferring those IT professionals with more experience in designing autonomous driving systems and those who have achieved higher-level self-driving designs already, I expected to be able to get more meaningful and in-depth responses through my interviews. Relying on qualification criteria helped me in answering my research question and meeting my study objectives while also achieving data saturation quickly.

## Ethical Research

An essential element of informed consent is that individuals freely agree to participate in research (Wolf, Clayton, & Lawrenz, 2018). Receiving consent requires that the participating individual has the mental capacity to comprehend the implications of their participation and then decide whether they want to proceed (Spike, 2017). By obtaining informed consent, the researcher can meet and ensure ethical standards in research while also respecting and protecting the rights of participants (Lühnen, Mühlhauser, & Steckelberg, 2018). Before their participation in this study, I provided all participants with a consent form (Appendix C), which I asked them to sign electronically. Furthermore, I also disclosed the purpose and nature of this study to the participants and ensured them that their participation remains confidential. Including these elements in the consent form is a common practice in research (Sugiura, Wiles, & Pope, 2016).

An important aspect of ethical research is that a participant can revoke their participation at any time (Sugiura et al., 2016). Participants in this study could choose to not start or abandon the interview at any time if they felt that the terms or conditions of the study were unacceptable. While the information contained in a consent form can vary greatly, it is crucial for the researcher to address confidentiality, including the option to rescind participation, and emphasize that participation is voluntary, so that individuals can make an informed decision (Karbwang et al., 2018). I considered discontinued interviews as incomplete and, therefore, did not include them in this study. I did not offer any incentives to participants in this study and made a copy of the results available to anyone upon request.

The privacy and confidentiality of participant information are paramount. Researchers should disclose their identity and research methods openly, detail what voluntary participation entails, how they will ensure confidentiality, and how they will protect the participant's identity and data (Gupta, 2017). I have password-protected all data originating from the study and stored it on an encrypted, password-protected disk drive, which I keep in a secured safely at my home office for five years. At the end of this period, I will destroy all data through established data protection procedures. Furthermore, I collected all data in this study anonymously and without reference to organizations or individuals, including names, email addresses, or any location information. I am assuming that all participants expect their participation to be confidential, and by not collecting personally identifiable information, I can ensure confidentiality. I started data collection for this study after receiving approval and an assigned approval number from Walden University's Institutional Review Board.

## Data Collection

I used semi-structured interviews to collect the data for this study, which I supplemented with participant-provided organizational reports and publicly available documents. Using multiple sources of evidence is an effective tool for data triangulation and enables me to more accurately understand the participant's perspective (Yin, 2018). Although quantitative methods usually rely on a structured and well-defined approach, the process of data collection in qualitative studies is inherently different, as data collection and initial data screening often coincide (I. Pettersson & Karlsson, 2015). It is, therefore, imperative for the researcher to take field notes during data acquisition so that they can reconstruct the collection and analysis processes that took place during their interactions with participants (Phillippi & Lauderdale, 2017). The subsequent sections illustrate my approach to instrumentation, data collection techniques, and data organization.

**Instruments**

Unlike quantitative research, which relies on already validated or newly developed data collection instruments, in qualitative studies, including the multiple-case design I use here, the researcher acts as the primary data collection instrument (Yilmaz, 2013). I primarily collected the data for my study through semi-structured interviews, which adhered to my interview protocol (Appendix D). I also took field notes during my interactions with participants for enriching the responses I got with additional information, such as body language, facial expressions, and tone of voice, for example, and adding contextual references where necessary. Using field notes can enable a researcher to identify themes better and shape their interactions with participants during data collection so that they can collect as much useful information as possible (Phillippi & Lauderdale, 2017). Furthermore, I asked participants to provide any documentation or other artifacts they can share, or offer physical demonstrations of some of the technologies they work on to support their answers. For example, these documents may include but are not limited to, quarterly published vehicle safety reports, U.S. Securities and Exchange Commission (SEC) reports and filings, surveys, and any other articles, whitepapers or documents an organization or individual has published on the subject. Asking participants in qualitative study designs to provide supplemental information is a common approach for researchers to increase the validity of their findings and reach data saturation more quickly (Heath, Williamson, Williams, & Harcourt, 2018).

Researchers generally ask questions for two reasons: (a) to answer their research question or (b) to qualify the participants of the study (Hughes, Camden, & Yangchen, 2016). Asking demographic questions serves three main objectives: (1) enabling the researcher to verify whether participants are representative of the population they planned to study, (2) describe participants so that other researchers are better-equipped to replicate the study, and (3) inform readers about the sample so that they know whether findings are limited or are more generalizable (Hughes et al., 2016). Therefore, I added several questions to my interview protocol with a focus on demographics, such as work qualifications and the role of the participant within a self-driving program, for example.

One primary challenge of qualitative research is establishing the reliability and validity of the instrument. Because the researcher acts as part of the primary instrument, there are several techniques that they can use to improve validity and reliability, including member checking, transcript reviews, and data triangulation (Varpio, Ajjawi, Monrouxe, O'Brien, & Rees, 2017). I used data and methodological triangulation to compare multiple interviews and data sources for their alignment with each other, effectively allowing me to improve the validity of my findings by identifying unique cases and outliers. Researchers use data triangulation to reach data saturation more quickly, whereas other forms of triangulation, for example, help with identifying and comparing overarching themes and patterns or reducing bias (Flick, 2016). Furthermore, transcript reviews and member checking are often-used tools for verifying whether the researcher has captured the participant's answers accurately and whether their interpretation thereof accurately reflects the meaning from the perspective of the participant (Birt, Scott, Cavers, Campbell, & Walter, 2016). I used member checking to ensure the accuracy of my collected data and interpretations thereof. In member checking, the researcher shares a synthesis of their interpretation of interview responses with the corresponding participants to ensure that what they understand aligns with what the participant meant to convey (Birt et al., 2016). As part of my approach to member checking, I conducted at least one follow-up interview with all participants individually.

**Data Collection Technique**

Before proceeding with any data collection, I reached out to prospective participating organizations and obtained a letter of cooperation from them and subsequently seek IRB approval for inclusion as part of my multiple case study. Once I had permission to collect data, I worked with a gatekeeper at each organization to identify suitable participants and obtain their email addresses so that I can contact and include them in my research. In the context of organizational hierarchy, gatekeepers are individuals who control access to employees and often other resources, and they can be essential for gaining access to a specific population (Gursakal & Bozkurt, 2017). In this context, the senior autonomous driving program managers at each organization are most likely the gatekeepers who will control access to my targeted population, which is why I intend to contact them first.

Through this formal process of gaining access (Singh & Wassenaar, 2016), I will ask the gatekeepers to provide me with email addresses of potential and qualified participants, which I will use to solicit their participation. Following their interest in participating in my research, I will provide important details about the study and ask for their permission to interview before proceeding with my data collection (see Appendix C). Once confirmed and depending on the geographic location of the participant, I scheduled a Skype audio interview with them. I utilized the same interview protocol during all remotely administered interviews. One advantage of semi-structured interviews is that they follow an interview protocol, that is, the researcher will ask participants the same questions in the same order, which can significantly reduce the complexities of later data analysis and comparison (McIntosh & Morse, 2015).

Furthermore, to aid me in the data collection process and capture responses accurately, I recorded all the interviews. I asked participants to consent to these recordings before starting the interview. Recording interviews is a common practice in qualitative research, enabling researchers to create accurate transcripts of the conversation, which improves the accuracy of the data they collect for analysis (Nordstrom, 2015). I also used field notes to further enrich the data with context and impressions I may have during the interview process. Following this process, I used member checking to determine the accuracy of my findings. Researchers use member checking to confirm significant findings, themes, or descriptions, for example (Birt et al., 2016). This process can include follow-up interviews to ensure that my understanding of the previously collected data is correct and complete. I conducted these follow-up interviews through Skype.

**Data Organization Techniques**

Data organization can be particularly challenging in qualitative studies because of the unstructured nature of the data, the various data sources, and the variances across each collected data set (Reis, Costa, & Souza, 2016). I used NVivo 12 software to store and organize the data I collected throughout this study. While NVivo allows for the storage and export of several data formats, including text files, database files, audio recording, images, and video, it will not perform any analysis automatically. NVivo requires the researcher to code, categorize, and select concepts manually before the software can generate meaningful reports and illustrate findings (Vaismoradi, Jones, Turunen, & Snelgrove, 2016).

Furthermore, and because NVivo serves as a central database for all artifacts and recordings from this study, I export a project file with all its contents and the raw data. I then encrypted this project file and stored it in a secured safe for five years. I also shredded any hardcopy notes or documents I obtained but already added to NVivo previously. At the end of this five-year period, I will destroy any stored data by overwriting it with random information and then physically destroy and dispose of the storage media.

## Data Analysis Technique

The techniques and data analysis processes researchers use in qualitative and quantitative research vary greatly. Qualitative research is inductive and tries to identify themes and gain an in-depth understanding of a problem from the perspective of the person having the experience, whereas quantitative methods focus on deduction, prediction, causal explanations, and generalisability instead (Yilmaz, 2013). While researchers using qualitative and quantitative methods may rely on triangulation to compare the results of their findings across data sources, the lack of instrument validation in qualitative studies makes triangulation a vital technique I also plan to use. There are four primary types of triangulation, including (1) methodological triangulation. (2) theory triangulation, (3) data triangulation, and (4) investigator triangulation (Fusch & Ness, 2015).

Investigator triangulation relies on more than one researcher, and theory triangulation assumes that the research will use two or more theoretical frameworks to evaluate their data (Varpio et al., 2017). As I was the only researcher conducting the interviews, researcher triangulation does not apply to this study. Furthermore, because I only examined my results through the lens of a single theoretical framework, the theory of dynamic capabilities, performing theory triangulation, is equally impossible, as I only used one theory instead of many that would be otherwise required. Methodological triangulation refers to the analysis of the collected data through multiple methods by incorporating numerous data sources, whereas data triangulation assumes that the researcher compares and contrasts data from multiple participants (Fusch & Ness, 2015). Because I used multiple data sources and several participants, data and methodological triangulation applied to this study.

Therefore, triangulation involved comparing and contrasting the publically available documents I was able to collect from participating organizations or individual participants, which may include the organization’s design and software strategies, quarterly published vehicle safety reports, SEC reports and filings, surveys, whitepapers, or disengagement records, for example. Since some of this data may be proprietary, I aimed to further supplement my understanding and the context of these artifacts by also including documents that are in the public domain, especially if I needed a better understanding of a given solution or approach. Using various sources and collecting different types of documents can lead to a better understanding of a phenomenon or issue by the researcher (Moser & Korstjens, 2018a).

Furthermore, I also triangulated the insights I gained through the in-depth personal interviews with the data I gathered through document collection; that is, I looked for recurring evidence of the strategies and themes I have identified on each data source and the presence of incongruencies. By comparing and contrasting the contents of all data sources, the researcher may gain a deeper understanding of the study subject in the context of the participants' actions (Varpio et al., 2017). I conducted this analysis prior to scheduling my follow-up interviews so that I could seek clarification where I noticed a mismatch, or ask participants to elaborate further where I feel that I may not have fully understood or captured the meaning of or approach to a given strategy or issue.

Researchers using qualitative methods generally analyze their data for themes and content through coding, grouping, theme identification, and categorizing (McCusker & Gunaydin, 2014). For example, a content analysis offers the researcher the ability to quantify data to identify frequencies, whereas thematic analysis is better suited to identify recurring themes in coding, without some of the restrictions imposed by categories (Yilmaz, 2013). By relying on thematic analysis in this study, I effectively coded and analyzed all data I have collected and then searched for and defined major themes to aid me in the presentation of my findings (Vaismoradi et al., 2016). To reduce bias, I exclusively relied on the member-checked versions of my findings and focused on the representations of the information without injecting my personal opinions during the analysis process.

I used a commercial third-party interview transcription service (temi.com) to transcribe my recordings and to enable participants to review and validate the resulting transcripts. Temi.com follows a strict privacy policy, which ensures that all recordings I share for transcription remain private and upon my acceptance of the transcript are deleted entirely with no recoverable backup. Temi stores all recordings and transcripts encrypted on their servers, and the necessary keys to decrypt all contents are tied to my user account with them, making third-party access impossible without first breaking the encryption. I was the only person with access to the raw audio files and transcription documents throughout the transcription and refinement process.

I added all raw data and the member-checked transcriptions of the interviews into NVivo for coding, theme identification, and other analyses. Before coding, I made sure that I had familiarized myself with the responses and all data I have collected throughout the study so that I could better assess and identify phrases and words that accurately described the content and intent of the statements I evaluated. I followed a three-level coding and thematic analysis process, starting with (1) open coding, followed by (2) axial coding, and concluding with (3) selective coding.

In open coding, the researcher looks for common phrases and words in the participant's responses, enabling them to create a crude organization of related themes (Williams & Moser, 2019). Open coding is usually the first step in qualitative thematic analysis. What follows is axial coding, where the researcher attempts to identify core codes by sifting through open codes and looking for relationships or related themes (Alhassan, Sammon, & Daly, 2019). The grouping and condensing of open codes to core codes, serves as the foundation for last level of coding, selective coding, where the researcher then aims to achieve an even higher level of abstraction (see figure 2) which aids in the overall analysis process and serves as an essential element for developing a theory (Williams & Moser, 2019). Throughout this process, I continued to use member-checking to aid me with theme identification, incorporate new knowledge I gained during my ongoing research, or conducting follow-up interviews if I needed further clarification on new information or understanding I found or have developed throughout the study process.

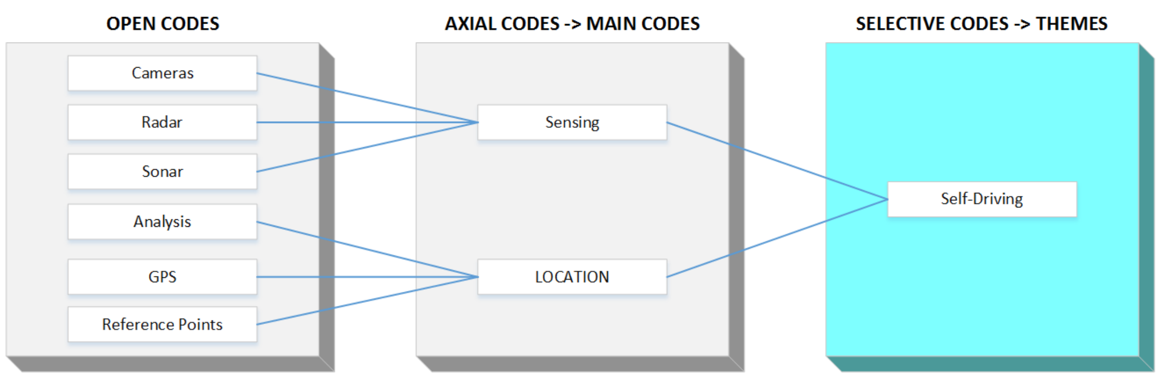


*Figure 2*. Illustration of the Three-Level Approach to Finding Selective Themes.

## Reliability and Validity

Reliability and validity are essential aspects of any research. Reliability is concerned with the repeatability of a study but also whether the measurements obtained with its instruments are consistent (Bolarinwa, 2015). As a researcher, I was the primary instrument in this study.

Therefore, I will discuss how I addressed the validity and reliability concerns of my data collection instrument in the following sections.

**Reliability**

Reliability is concerned with the accuracy of data extraction and its ability to produce the same results consistently (Flower, McKenna, & Upreti, 2015). One way to ensure the reliability of an instrument is by relying on one that other researchers have used to obtain similar results, or by assessing its equivalence, stability, or homogeneity (Heale & Twycross, 2015). Although there are additional methods for assessing the reliability of instruments in quantitative studies (Shirali, Shekari, & Angali, 2018), most of the commonly used approaches do not apply to qualitative studies (Heale & Twycross, 2015). In qualitative studies, the researcher acts as the primary data collection instrument, which makes member checking, documentation, researcher awareness, and following strict protocols the preferred tools for improving reliability and validity (Yilmaz, 2013).

One of the core challenges with reliability in qualitative studies is that reliability is concerned with the extent to which another researcher would be able to repeat the results reliably if they use the same approach (López, Ponce-Espinosa, Rios-Zaruma, & Espinoza-Torres, 2018); however, this definition only fits in the context of quantitative studies. Qualitative studies are, by design, less reliable, because of the individual perspectives and experiences of participants and the researchers conducting the study (Wark & Webber, 2015). Therefore, researchers instead often equate dependability and consistency with reliability in qualitative studies where the focus is on a representative assessment and understanding, rather than on the ability for others to replicate a study and come to the same conclusions (Leung, 2015).

**Dependability and consistency**. Dependability describes the extent to which the findings of a study are stable over time (Moser & Korstjens, 2018b), whereas consistency refers to the structural components of the data collection process (Moser & Korstjens, 2018a). There are several approaches to ensuring consistency and dependability. Member checking can help to ensure that the collected data is accurate and dependable, and researchers can use field notes to supplement and validate the data they directly collected from their participants (Birt et al., 2016). Furthermore, utilizing interview and observation protocols throughout the data collection process can contribute to obtaining consistent results because all participants will answer the same questions in the same order and all field notes will align with the same observation guidelines and protocol (May Luu, Ismail, Ismail, & Hamzah, 2018). Lastly, by collecting additional notes throughout the study, I was able to document the process and my observations, thoughts, and impressions without being solely confined to the data collection processes.

**Confirmability.** Confirmability is concerned with the degree to which others with access to the same data could reasonably confirm the researcher's findings (Moser & Korstjens, 2018b; Yilmaz, 2013). Therefore, confirmability describes the trustworthiness of the researcher and the processes they used to conduct their study (Amankwaa, 2016). Trustworthiness in qualitative research is the result of documentation, verification, and well-defined processes. Researchers most commonly use member-checking, interview and observation protocols, recordings and other artifacts, transcript verification, and note-taking to achieve verifiable results and establish trustworthiness (Birt et al., 2016; Petrova et al., 2014). Confirmability may begin with a thorough data collection process, the ongoing verification, as well as triangulation across multiple data sources and other studies or theories, aids the researcher in reaching data saturation and presenting their findings while also increasing the trustworthiness of the study and it process at the same time (Fusch & Ness, 2015; Moser & Korstjens, 2018a).

## Validity

Assessing the validity of a research instrument is vital in any scientific research. Validity is concerned with the extent to which an instrument can measure a variable or construct as intended (Bolarinwa, 2015). There are many varieties of validity, including internal and external validity, face validity, construct validity, content validity, and criterion validity (Heale & Twycross, 2015), for example. However, assessing validity in qualitative studies significantly differs from quantitative methods. In qualitative studies, the researcher is the primary instrument; therefore, using existing instruments from other studies to increase validity is impossible. I am discussing some of the methods researchers use in quantitative studies below to compare and contrast the differences in approaches as they relate to qualitative research designs.

**Transferability.** Transferability describes the extent to which the findings of the study and its collected data will also apply to a generalized population (Torre & Picho, 2016). An influential core factor in transferability is sample size (Bernstein, 2018). By using more participants, a researcher can increase transferability because the sample becomes more representative of its population and, therefore, raises the probability of true parameter estimation (Zyphur & Pierides, 2017). Researchers can also improve transferability by following proper sample techniques, reducing sampling bias and error, and selecting an appropriate population (Hales, 2016). Qualitative methods focus on understanding the participant's perspectives, interpreting the findings, and contextualizing the data for an in-depth understanding of a problem (J. Park & Park, 2016). Transferability is essential if the researcher aims to understand the implications or applicability of a phenomenon on a large population (Merriam & Tisdell, 2015). Although this qualitative multiple case study also aimed to understand individual perspectives, the strategies I explored could lead to some generalizable explanations. Case study design often focuses on exploring strategies or phenomena on a limited scope and through the lens of a theoretical framework and the perspectives of those who take part in the case study (Yin, 2018). While more extensive case studies may aim to generalize their findings and apply them to an overall population, the limited number of cases I consider in this study may not allow for a full understanding of all strategies due to the limited scope of the research.

**Credibility.** Credibility is concerned with the authenticity of data from a participant's perspective (Leung, 2015). A researcher can improve the credibility of their data through member checking, participant transcript review, data triangulation, and by reaching data saturation, for example (Birt et al., 2016; Fusch & Ness, 2015; Varpio et al., 2017; Yilmaz, 2013). I used member checking through follow up interviews, triangulation by examing artifacts and related studies, and reaching data saturation throughout my study to improve the credibility of my instrument. Data saturation occurs when the researcher can reasonably assume that further data collection will no longer result in additional knowledge about the phenomenon they study (Fusch & Ness, 2015).

Furthermore, I improved and documented the authenticity of my data by following an interview protocol, taking descriptive notes during my interactions with the participants, using member checking to verify data accuracy, and relying on triangulation to support statements (Flick, 2016; Varpio et al., 2017). In contrast, the trustworthiness of findings related to emerging themes improves with the amount of data a researcher collects, and trustworthiness reaches its peak once data saturation occurs (Guest et al., 2006; Vaismoradi et al., 2016; Williams & Moser, 2019). Using the above techniques to improve the authenticity and trustworthiness of the collected data, I was effectively able to improve the validity of my instrument.

## Transition and Summary

In Section 2, I reviewed and justified my research methods and compared and discussed quantitative, qualitative, and mixed-method approaches. I also discussed my role as the researcher and the strategies I will use to collect data and recruit the participants for this study. Furthermore, I detailed my data collection process by discussing my instruments and the organization and analysis techniques I used to analyze the information. I justified and discussed my use of a multiple-case research design and supported my decisions with peer-reviewed literature.

Furthermore, I described my sample population while also specifying my approach to calculating my sample size for reaching data saturation. Finally, I also discussed how assessed and ensured reliability and validity in the context of my study, and as it relates to my measurement instrument. In continuation of this document, I will provide an analysis of the collected data and the results of my study in the following Section 3.

# Section 3: Application to Professional Practice and Implications for Change

## Introduction

The purpose of this qualitative multiple case study was to explore the strategies some IT hardware and software developers of self-driving cars use to adapt traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs. I collected data from organizations that work with autonomous vehicles and on specific solutions for problems inherent to developing these systems and its various hardware and software components. All participants were managers and team leaders located in the United States and took part in interviewing and member-checking sessions. In addition to the data I collected from seven highly qualified participants, I also obtained 15 documents to enhance my understanding of technologies and systematic approaches I discovered. The participants in this study had first-hand know-how of various elements of autonomous driving systems and are considered experts in their fields, with some of them having more than 30 years of industry leadership experience.

I categorized participants into two groups with (1) consisting of experts focused on solving a single problem with autonomous vehicles and (2) those engineers and leaders working on comprehensive solutions for achieving full autonomy. All participants were male, which is not entirely unrepresentative of the predominantly male autonomous vehicle industry (Beede, Powers, & Ingram, 2017). All themes in this study were organized by major and sub-themes. The resulting reference counts are based on the occurrence of keywords I related to each theme or sub-theme within the data collection. These associations are not exclusive, and while one reference may be specific to a theme, some references were applied to multiple themes equally.

## Presentation of the Findings

I used the following research question to inform my understanding and guide my interviews: What strategies do some IT hardware and software developers of self-driving cars use to adapt existing autonomous vehicle design frameworks to regulatory requirements and consumer expectations?

Despite the varying backgrounds and development focuses of participants within the autonomous vehicle design process, there was agreement about the lack of regulations and the difficulties of some challenges and competing priorities present to developers. While all participants indicated that they are using some form of agile or scrum-based framework throughout various development processes, a definition of consumer expectations or how to meet these expectations varied greatly. Furthermore, the lack of regulatory requirements and guidance resulted in a multitude of design approaches, business models, and technologies, all of which participants used to augment existing frameworks to meet the immediate design needs of developers working on autonomous vehicle systems. Opinions also differed among participants on how to achieve a sustainable competitive advantage, how one would describe such an advantage, and how it could be integrated reliably into processes.

### Theme 1: Focus on Developing Autonomous Driving Technologies

The prominent themes discovered in this study included a focus on developing autonomous driving technologies. The focus on developing autonomous driving technologies theme related to the design choices hardware and software engineers made to develop parts of or entire autonomous driving solutions. Because of the multitude of technical solutions currently in development, the focus on technology also included design choices, hardware, and software as identified sub-themes. Design choices in the context of this study included known automotive design frameworks, such as ISO 26262 and AOTOSAR, for example, but also unique or uncommon approaches to developing the technology the participants thought are necessary to achieve full autonomy.

Table 2

*Themes of Focus on Developing Autonomous Driving Technologies with Supporting Metrics*

| | Participant | | Documents | |
|---|---|---|---|---|
| **Major Theme** | **Count** | **References** | **Count** | **References** |
| Focus on Developing Autonomous Driving Technologies | 7 | 73 | 11 | 102 |
| **Sub-themes** | | | | |
| Design Choices | 7 | 31 | 9 | 41 |
| Hardware | 7 | 18 | 7 | 28 |
| Software | 7 | 24 | 7 | 33 |

All participants in this study expressed a strong focus on technology throughout the interviews, which was supported by 11 of the 15 documents (see Table 2 for the theme and sub-theme metrics). This emphasis on developing technology was expected, considering that there are many approaches to sensing and processing with no superior technology emerging yet (Vincentelli & Vigna, 2017). All participants indicated that they believe that the necessary technology for enabling fully autonomous vehicles is not yet ready, and it may take decades for it to reach the necessary level of maturity. Participant P6 noted that “it may never get there,” acknowledging that some difficult to overcome limitations of the technology may challenge engineers for a long time. All other participants were less pessimistic but still agreed that the maturity required of these systems to take over large portions of transportation systems is decades away.  For example, P7 noted that “limited application autonomous vehicles are possible today.”  However, participant P4 explained, “it may take at least ten years for the law to allow autonomous vehicles on public roads.”  Litman (2019) went even further and suggested that it may take more than 40 years for this transition to take place.

The theme of focus on developing autonomous driving technologies aligns well with the theory of dynamic capabilities because of its similarity to the processes, positions, and paths elements (Teece et al., 1997).  Paths refer to path dependencies, technological opportunities, and assessment as part of the theory of dynamic capabilities (Jurksiene & Pundziene, 2016), which aligns with the participants’ focus on assessing and pursuing technological opportunities through changing hardware or software approaches.  A core premise in the theory of dynamic capabilities is that organizations must develop processes that enable them to achieve a competitive advantage (Lina & Bo, 2018).  Processes may include elements of efficient resource management, an innovative and entrepreneurial culture within the organization, and proprietary technologies and unique strategies (Kodama, 2017).  The theme of focus on developing autonomous driving technologies represents the aim of AV developers to create technologies and processes that enable them to go to market faster or offer other advantages that competitors cannot easily match.  As such, a focus on developing autonomous driving technologies represents as much a necessary step for evolving AVs as it provides processes and competitive advantages that align well with the theory of dynamic capabilities.

Similarly, some existing literature on autonomous vehicle technologies seems to struggle with finding a consensus for the best approach (Pozna & Antonya, 2016), which might suggest that AVs are subject to intense competitive forces until superior solutions emerge. Therefore, the findings from this theme align well with the existing literature because, as Vincentelli and Vigna (2017) noted, autonomous vehicles are a playground for sensors, even though the answers of the participants in this study seem to indicate that both hardware and software approaches are equally in flux and extremely unstructured at this point. Considering that hardware, software, and design choices may similarly impact the ability of a firm to achieve a competitive advantage, information technology senior managers should consider integrating the different design teams to derive sustainable strategies instead of only going with what works best at the time.

**Subtheme: design choices**. Most notably, all participants agreed that the design choices they make are essential for developing their product. Participant 4 noted that a new version of a middleware they use added: "critical functionalities we wanted to have two years ago." While three participants suggested that a long-term strategy informs their short term decisions, the remaining participants suggested that this approach may be less useful for developing a product with little regulatory guidance, proven consumer expectations, or established business models. Participant P6 suggested that "impressing investors is more important than long-term strategy." Furthermore, while all participants have heard of automotive frameworks for designing vehicle electronics, such as ISO 26262, for example, they also acknowledged that they only follow established automotive frameworks as far as it is required by their industry partners. Unanimously, participants suggested that ISO 26262, just like other industry standard frameworks today, is insufficiently equipped to address the needs of autonomous vehicle developments adequately. Participant P3 thought that ISO 26262 is an automotive standard that is “unable to meet the requirements of autonomous vehicle development.” This finding was somehow expected, considering that previous analyses came to similar conclusions (Falcini & Lami, 2017; Stilgoe, 2018).

Considering the lack of appropriate autonomous vehicle design frameworks, the participants in this study unanimously chose an agile or scrum-based framework instead. Agile development approaches focus on team-building, collaboration, working solutions, simplicity, and regular updates to facilitate progress (Santos, Cunha, Moura, & Margaria, 2017). P1 noted that “agile frameworks have helped us to make a better product and has been proven to be more suitable than frameworks preferred by traditional vehicle manufacturers.” This notion further illustrated a strong focus on software and the frameworks commonly used by software engineers over traditional approaches prevalent in the automotive industry. Even though there is now a proposed framework for testing the performance of autonomous vehicles in the United States (U.S. Department of Transportation, 2018), the framework is not binding or makes recommendations as to what design choices may be acceptable or preferred for the development of autonomous vehicles. Without appropriate design solutions or governmental requirements, the regulatory vacuum forces autonomous vehicle developers to make design choices that work for them for the technologies that currently exist (Borenstein et al., 2017).

The participants also indicated that their design choices vary greatly and may change based on short-term objectives related to product development progress, investor relations, test cases, or the exploration of new business models. For example, P4, P5, and P7 noted that some of the projects they worked on exclusively focused on the development needs and requirements of autonomous vehicles destined for a single-use case, such as an autonomous shuttle bus operating in a closed community, for example. As P5 noted, “we assess the needs on a project basis and then make changes to our systems to get as close as possible.” Some of these cases required unique approaches both conceptually and organizationally, leading to unique design choices made for these systems. In the discussions, all participants noted that while they aim to develop universal solutions, their short term design choices are often driven by immediate feedback from customers or consumers on the product or the specific design needs of a business case.

As mentioned by the participants, one reason for their design choices is to develop technological, structural, and market assets, which aligns with the positions tenet of the theory of dynamic capabilities (Pisano, 2017). Furthermore, processes in the theory of dynamic capabilities refer to learning, integration, coordination, and reconfiguration, all of which are elements that can be found in the strategies the participants use to develop autonomous vehicles and the necessary technologies. As participant P7 noted, “We must adapt our approaches constantly,” which is a clear indication of an ongoing assessment for finding better solutions and improving design choices, which also aligns well with the theory of dynamic capabilities.

Furthermore, design choices are processes as much as they are strategies for developing technology and meeting design requirements. These design choices and strategies significantly reduce the risk and impact the abilities of a firm to develop its products, bring them to market, and gain a competitive advantage (Slagmulder & Devoldere, 2018). Therefore, the participants’ emphasis on making the right design choices to gain a competitive advantage aligns well with the theory of dynamic capabilities. Furthermore, the existing literature also emphasizes the importance of design choices for developing AVs (Van Brummelen et al., 2018), even though a certifiable and legally binding approach has yet to emerge (Stilgoe, 2018).

Considering the differing design approaches even among members of the same team, information technology team leaders and executives may benefit from communicating a clear strategy and creating teams that have a similar understanding of the challenges ahead and which then can work coordinated and in unison toward a solution.

**Sub-theme: hardware**. All participants also indicated that their systems or approaches are hardware agnostic. Even though the participants have shown differing preferences for the hardware they use or develop as part of autonomous driving system development, a consensus was that the hardware itself must be able to adapt to different needs, or the overall system should be able to adapt to different hardware. Participants P1, P2, and P7 noted that software-definable hardware offers the most flexibility for integrators because it can adapt quickly to changing requirements. A software-definable system enables the operator to change some of its parameters, assign resources where needed, or configure inputs and outputs to meet specific technical requirements, for example (Nkenyereye & Jang, 2018). Software-definable hardware may also offer additional advantages in case of regulatory changes. Participant P1 noted that using a software-definable system enables them to tailor their approach to different market requirements but also make adjustments, within limits, “to address regulatory concerns without the need for a redesign.” All Participants agreed that software-defined hardware should lead to lower-cost long-term and shorter development cycles overall.

Autonomous vehicles are complex systems, and the engineers working on these systems come from various disciplines with greatly differing backgrounds, even among those trying to solve a single challenge. The theory of dynamic capabilities aims to derive processes that can incorporate these varying skills and combine them for achieving a competitive advantage (Lina & Bo, 2018). Considering that some participants specifically mentioned how they use software definable hardware to reduce cost and differentiate themselves from others, using specific strategies for developing and incorporating hardware differently can result in competitive advantage, which aligns well with the tenets of dynamic capabilities theory.

Furthermore, the theory of dynamic capabilities emphasizes the importance of developing processes and technologies that enable a firm to gain a competitive advantage directly through technology, or as a mediator for other products. For example, a firm may work on sensor technologies that enable their AVs to navigate the world more reliable, but they may also design the machines and hardware that produces these sensors. Therefore, the theory of dynamic capabilities does not limit the importance of technologies to final products but also emphasizes how intermediary processes and designs can aid in achieving a competitive advantage that goes beyond the product they helped to produce (Jurksiene & Pundziene, 2016). As such, the emphasis by all participants on hardware development is justified and also aligns well with the theory of dynamic capabilities. Furthermore, researchers continue to discover new ways for optimizing processes or deriving novel technologies (Van Brummelen et al., 2018), which suggests that focusing on hardware as part of the technological approach remains an essential aspect of AV development. IT senior managers and strategists may benefit from using some of these approaches to hardware development and integration to streamline their operations and leapfrog their competition.

**Sub-theme: software**. All participants also strongly emphasized the importance of software as part of their design decisions. Participants P4, P5, and P6 preferred the use of middleware, such as the Robot Operating System (ROS), for example, where others suggested that developing the necessary software stacks from scratch offers more flexibility in terms of controlling the outcome and making more granular adjustments. All participants relied on some form of software simulation and simulated environments to test the performance of their hardware and software. As participant P4 noted, this approach “is more cost-effective as no human will be in danger of getting involved in an accident with an autonomous vehicle,” and design issues can be identified before they cause physical harm. The cost of operating actual vehicles on public roads may be prohibitive for most developers, even though software simulated environments are not accurate representations of the real world (Dang et al., 2017).

The majority of participants noted that some of the challenges they face with their software development are the results of disagreements about design approaches, which may be partially attributed to the multidisciplinary backgrounds of the hardware and software engineers working on autonomous vehicle designs and their managers. The majority of participants noted that there is no agreement within their organization as to what hardware or software approach is most efficient. Participants P5 and P6 went further and expressed concerns that their current software approach may be “unable to meet all requirements” of their autonomous driving solutions, at least not in the short term. P5 noted that their system “might work well for one application," but is unlikely to be able to evolve beyond that, as would be needed for a more generalized solution. One solution to these challenges are self-learning systems, which rely on software that organizes itself and finds solutions to problems without requiring the engineers to write specific code or design algorithms (Sadighi et al., 2018).

While the majority of participants specifically mentioned the use of AI or CNNs as part of their software strategy, all participants agreed that these approaches come with their own challenges, especially as they may relate to regulatory approval. P7 noted that a CNN often lacks the ability to make the same decisions at all times, and "small changes can have adverse effects on vehicle behavior even when it worked as intended before." For example, CNN's use filters and layers to identify objects (Musoles, 2016). These filters lead to classifications of images and objects based on annotations engineers make to objects, resulting in code that is created automatically and which changes throughout this training process and as image classifications are added (Rao & Frtunikj, 2018). While these CNNs can solve many robotics and coding issues, they also require an enormous amount of data to enable semantic analyses and incorporation of edge cases (Hatcher & Yu, 2018). The resulting codebase, therefore, may frequently change, and without a clear understanding of the software itself, regulators may find it challenging to evaluate code for its performance when its performance can change over time (Falcini & Lami, 2017). The participants agreed that software engineers might have to use a mix of CNN's and AI combined with traditional approaches to robotics and hope that regulators will incorporate evaluation criteria for these dynamic systems once clear rules for self-driving cars are established.

Some software engineers have a strong preference for CNNs; others may prefer more traditional robotics with coding and algorithms instead, for example. Participant P7 noted that "engineers need to be able to be creative and must be allowed to do things," rather than being forced to deliver solutions on a fixed timetable. These notions illustrate the difficulties these hardware and software teams face in the absence of proven design approaches or established regulatory requirements. In the context of the theory of dynamic capabilities, these struggles with finding a superior solution align well with paths, competencies, and reconfiguration (Queiroz et al., 2018).

The theory of dynamic capabilities suggests that the struggle between finding a solution and continuing reconfiguration of processes and products to align with market demands is, in itself, a method for achieving and sustaining a competitive advantage (Ferreira et al., 2018). With most of the decision-making systems AVs use relying heavily on computer software for training, simulation, and self-driving, it was no surprise to see how software development as a theme frequently emerged throughout this study. In particular, all participants relied on an agile-type framework to develop their software, which is often found in traditional software development processes and approaches (Santos et al., 2017). Agile frameworks enable teams to develop software quickly, iterate through revisions, and make changes when needed to more efficiently develop a final product. All of these elements align well with the development processes described by the participants but also with the theory of dynamic capabilities, which includes ongoing assessment and reconfiguration as one of its core tenets. Furthermore, the existing literature also suggests that these reconfiguration cycles are necessary to develop autonomous vehicles, even though a constantly changing codebase presents its own challenges (Falcini & Lami, 2017). IT decision-makers can benefit from these findings if they continue to incorporate and encourage reconfiguration and experimentation, as long as they use strategies that help them to systematically document progress and manage knowledge effectively throughout an organization (Schäfer et al., 2017).

### Theme 2: Focus on Meeting Regulatory Requirements

Another prominent theme that emerged in this study was the focus on meeting regulatory requirements. Regulatory requirements may apply to components or individual systems of autonomous vehicles and autonomous vehicles as a whole. Within the major theme of focus on regulatory requirements, two sub-themes frequently came into focus among the participants: (1) functional safety, and (2) regulations. Although functional safety, in particular, might be a requirement regulators will include in future regulations, it also reduces the likelihood of liability throughout the development process.

All participants in this study were aware of regulatory requirements and the lack thereof, which was also referenced in seven of the 15 documents collected for this study (see Table 3 for the theme and sub-theme metrics). While there are some proposed standards for classification of capabilities, proposed frameworks for performance testing, and limited licenses for operating autonomous vehicles on public roads, federally mandated and binding regulations do not yet exist (Falcini & Lami, 2017; Society of Automotive Engineers, 2016; Stilgoe, 2018; U.S. Department of Transportation, 2018). Participants P3, P4, and P6 noted that while they are aware of regulations, regulations do not apply to them yet. These three participants exclusively worked with simulations, operated their product only on non-public communities, or used closed proving grounds for their testing. The remaining participants either operated their own fleet of vehicles or worked with partners who had the necessary licenses to drive on public roads or on private property.

Table 3

*Themes of Focus on Meeting Regulatory Requirements with Supporting Metrics*

| | Participant | | Documents | |
|---|---|---|---|---|
| **Major Theme** | **Count** | **References** | **Count** | **References** |
| Focus on Meeting Regulatory Requirements | 7 | 45 | 7 | 53 |
| **Sub-themes** | | | | |
| Functional Safety | 7 | 23 | 6 | 33 |
| Regulations | 6 | 22 | 3 | 20 |

A common understanding among all participants about the perils of having to meet regulations eventually was that their systems currently undergo rapid iterations and are subject to frequent changes. P6 noted that their approach to finding solutions had "changed at least five times in the past two years." The majority of participants argued that focusing on regulations primarily when the system that will be subject to these regulations is not yet working as expected would be a waste of their limited resources and would not aid them in finding viable solutions quicker. P3 suggested that even if they had a working system today, there are "no laws that would allow using it on public roads without drivers." All participants agreed, however, that ignoring safety in the absence of regulation or a requirement to meet any such regulations immediately is dangerous and may lead to public backlash, overregulation, liability issues, and could set back the industry for many years. P1 emphasized that "the actions of one bad actor could set back the industry for many years." Even though some licenses to operate autonomous vehicles on public roads as part of the development process define parameters clearly, liability issues in particular for these test platforms and future operation of commercially available vehicles persist (De Bruyne & Werbrouck, 2018).

The focus on meeting regulatory requirements both ties in with existing approaches to IT hardware and software development automotive applications and also presents unresolved challenges. For one, meeting regulations for developers of traditional vehicles without autonomy is well established. Even as it relates to ECUs and in-vehicle software, these established standards are used extensively by all manufacturers to meet regulations and obtain certifications for their vehicles (Falcini & Lami, 2017). However, as illustrated by the lack of suitable frameworks that can address the needs of autonomous vehicle hardware and software developers and the reliance of all participants on some form of agile or scrum-based frameworks instead, showcases the need for IT professionals to develop better-suited approaches. Whether the extension of existing frameworks is sufficient remains to be seen, but likely entirely new approaches for testing the performance and meeting future regulatory requirements are needed (Stilgoe, 2018; U.S. Department of Transportation, 2018).

One could argue that meeting regulations, once they become a requirement, are an essential element of being competitive in a given market. Therefore, the theme of focus on meeting regulatory requirements aligns well with the theory of dynamic capabilities because it requires a firm to meet market demands, and through reconfiguration and transformation, develop new products or adjust processes to adapt to a changing environment (Slagmulder & Devoldere, 2018). A vital tenet of the theory of dynamic capabilities is risk management from the perspective of sustainability and gaining a competitive advantage (Slagmulder & Devoldere, 2018). Regulatory requirements currently present a very high risk for AV developers, because the laws that will govern autonomous vehicles have yet to be written, just as those vehicles have yet to be designed and mature enough for widespread adoption (Stilgoe, 2018). While participants have consistently referred to regulatory requirements, a lack of binding regulation created a vacuum in which developers design systems that ignore future regulations or bypass current and projected rules through loopholes or by operating vehicles, knowing well that these operations can only be temporary. Therefore, regulatory requirements as a theme align well with the tenets of the theory of dynamic capabilities, but unlike technologies, which participants acknowledged are essential, regulatory requirements were less seen as issues and potential threats to their operations.

The literature similarly aligns well with these findings from the theme as it became evident here that IT professionals may currently underestimate the dangers of not being able to meet future regulations, which could invalidate an entire product or product line if they are unable to achieve certification with their preferred solution. Underestimating regulatory challenges is a theme that resonates across the current literature that tries to examine the non-technical challenges autonomous vehicles face before they can operate on public roads (Crane, Logue, & Pilz, 2017; Falcini & Lami, 2017; Stilgoe, 2018). While some IT managers are evidently focused on short-term success to please investors, deriving strategies that would allow an organization to make satisfactory intermediate progress while also focusing on long-term solutions for meeting future regulations may allow them to achieve a competitive advantage.

**Sub-theme: functional safety**. While the number of participants and total references by them on functional safety and regulations was almost identical, only three documents mentioned regulations, whereas six referenced aspects of functional safety. Functional safety is the ability of a system to protect itself against fault, operate as designed, and perform in a predictable manner (Koopman & Wagner, 2017). All participants mentioned functional safety as an essential aspect of limiting liability in the absence of regulatory requirements. Participants P4 and P7 argued that functional safety might apply to a component level, but once various systems are integrated, the resulting performance may be different and unexpected. P1 noted that they only “deliver solutions with functional safety in mind to avoid any legal issues.” P7 suggested that “functional safety may be challenging in systems that reconfigure themselves,” such as those based on CNNs or AI. Therefore, it may be much more difficult to certify complex autonomous vehicles systems consisting of a multitude of sensors, computers, and proprietary or machine-generated software because even if the component works as designed, the combined system may still fail to meet performance expectations (Falcini & Lami, 2017).

Especially functional safety is a concept that directly relates to repeatability and consistency in the theory of dynamic capabilities, as a core aspect here is predictability, which becomes an essential element of reliability (Teece et al., 1997). While dynamic capabilities theory focused on repeatability as a means for ensuring uniform processes, if these processes are part of the product a firm sells, then it is equally important to ensure that the product performs as designed. Furthermore, functional safety incorporates risk management, predictability of performance, reliability of operation, and the processes for meeting these requirements, all of which also serve to create and sustain a competitive advantage. Deriving strategies or products to manage risk efficiently is a core premise of the theory of dynamic capabilities (Krzakiewicz & Cyfert, 2017). Therefore, the focus on functional safety aligns well with dynamic capabilities theory because the participants aim to limit risk and achieve a competitive advantage, similar to what the theory suggests a firm should do.

Similarly, the current literature also emphasizes the challenges associated with designing safe and reliable solutions in the absence of binding regulations, development frameworks, or certification requirements(De Bruyne & Werbrouck, 2018). Considering the challenges developers face for ensuring the functional safety of CNN and AI-based autonomous driving systems, IT managers may want to incorporate and design processes early in the development process that could help them to integrate the various components of the AV better and derive methods to verify their behavior and reliable performance.

**Sub-theme: regulations**. Participants P1, P4, and P7 noted that their approach to meeting regulations is “proactive” through their emphasis on functional safety but also by making design decisions that serve long and short term objectives. Participant P1 noted that “nobody is really doing what we do because it takes longer,” continuing that this approach has served them well and, while harder to bring to market, offers competitive advantages once regulations may require their or similar approaches. A majority of participants suggested that it will be easier for them to meet future regulations by focusing on small steps and iterations of their systems, thus being able to make adjustments as they see fit or as lawmakers may require. However, P7 noted that this approach may result in many iterative steps that lead to a system that "becomes less flexible," and may be unable to transform into a solution that could meet regulations "if those regulations are different from today's expectations." A positive side effect of this approach is that developers of self-driving technologies can limit their liability and prove functional safety and safe operation of vehicles overall on a small scale, in restricted areas, or at much slower speeds than otherwise necessary to integrate with regular traffic (Litman, 2019).

Meeting regulatory requirements may equally depend on competencies in positions and reliability aspects as they relate to the theory of dynamic capabilities. As mentioned previously, positions in the theory of dynamic capabilities are mostly concerned with obtaining and building out various assets throughout the organization (Teece, 2000). One may argue that reputational, technological, and market assets are all critical elements informing the focus on meeting regulatory requirements. Even though meeting regulations could be seen as a competitive advantage that would align well with the imitability tenet of the theory of dynamic capabilities (Teece et al., 1997), the lack of clarity on future regulatory requirements makes it difficult to assume a connection at this point.

In particular, competencies and reliability may align the focus on regulations best with the theory of dynamic capabilities. The participants agreed that to meet regulatory requirements, regulations must be well-defined, legally binding, and based on certifiable processes. While there is currently a lack of binding regulations or certifiable processes for AVs, once defined, the focus on regulations will directly align with the theory of dynamic capabilities, as meeting those rules will require new competencies and verifiable reliability of processes and technologies (Hanna & Kimmel, 2017). By extension, then, the theory of dynamic capabilities is well-suited to support the theme of focus on regulations once regulations become legally binding. The developers of autonomous vehicles may then shift their attention toward achieving other goals than merely creating assets and ensuring the reliability of their products.

**Theme 3: Focus on Consumer Expectations**

Focus on consumer expectations was another theme that emerged throughout the interviews. While the definition of consumers was different among participants, with some of them focused on working on systems destined for fleet and commercial applications, whereas others had more direct experience with drivers and passengers, receiving feedback and meeting expectations was universally relevant among all participants. Unlike several previous studies which either focused on hypothetical scenarios or assumed experiences based on hearsay or fiction (Panagiotopoulos & Dimitrakopoulos, 2018; Ingrid Pettersson, 2017; Zmud & Sener, 2017), participants in this study got their knowledge of consumer expectations from people who are using or have used their product. Throughout the interviews, two sub-themes emerged: (1) commercial users and (2) personal users. Even though there were seven documents that referred to commercial user expectations, only four documents mentioned expectations of personal users (see Table 4 for the theme and sub-theme metrics).

Table 4

*Themes of Focus on Consumer Expectations with Supporting Metrics*

| | Participant | | Documents | |
|---|---|---|---|---|
| **Major Theme** | **Count** | **References** | **Count** | **References** |
| Focus on Consumer Expectations | 7 | 56 | 7 | 65 |
| **Sub-themes** | | | | |
| Commercial Users | 7 | 34 | 7 | 47 |
| Personal Users | 7 | 22 | 4 | 18 |

Regardless of whether participants worked with commercial or personal users of their technologies, their first-hand experiences led them to make changes to their products in direct response to the feedback they received. All participants agreed that meeting the requirements of their respective consumers is a high priority for them. Participant P6 noted that "if they don't like it, they won't use it." For some participants, the challenges were mostly technical, for example, how the autonomous vehicle interacts with safety drivers, but others were more concerned with the user experience of the passengers. For example, participant P6 noted that whenever a vehicle behaved differently than a human driver in a given situation, "passengers and safety drivers would feel uneasy." Participant P7 explained that some safety drivers unnecessarily disengage the autonomous vehicle because "they were under the impression that the following action would lead to an accident," even though an analysis of logs later showed that the vehicle would have performed as intended and not caused an accident. These observations align well with previously researched motivations for acceptance of self-driving technology and reflect major concerns consumers expressed even without having driven or being a passenger in an autonomous vehicle (Mushtaq et al., 2018).

The theme of focus on consumer expectations through product design and marketability improvements aligns with making strategic choices, which can be found as an important element in the theory of dynamic capabilities (Kodama, 2017). The participants in this study all aimed to make products they can sell eventually, and therefore, they tended to make decisions that would support this goal. However, it was not always clear whether these intentions reliably lead to actionable and repeatable process refinements, something that would suggest at least a partial misalignment with dynamic capabilities theory.

Furthermore, the theory of dynamic capabilities assumes that achieving a competitive advantage is, at least partially, also dependent on a firm's ability to assess demands and create products that are highly desirable and different from those that competitors may offer (Jurksiene & Pundziene, 2016). As such, the focus on consumer expectations can also be found in the theory of dynamic capabilities where process refinement and assessment seem equally important. While all participants emphasized the importance of meeting customer expectations through the refining of their products, a disconnect between the existing literature on consumer expectations and what participants deemed to be relevant data emerged. Participants discounted most of the existing research on the matter as being irrelevant because it is not based on first-hand experience.

This aligns with some of the limitations stated in the existing literature, which also includes studies on perceived and assumed consumer expectations (Mushtaq et al., 2018; Ingrid Pettersson, 2017). The findings from this theme suggest that the participants are more interested in firsthand experiences with users of the technology than projected consumer expectations, which they often deemed to be inaccurate or of lower value for designing sellable products in the short term. Therefore, IT managers may want to focus on systematic implementation of these assessment and refinement processes throughout an organization to document changes and plot a sustainable path forward that can take the feedback from many teams into account consistently. The studies on consumer expectations currently available focus primarily on projected and imagined benefits (Leicht et al., 2018), and thus may not be suitable for reliably guiding autonomous vehicle product development at this stage.

**Sub-theme: commercial users**. While these challenges seem trivial in the process of refining and achieving fully autonomous driving systems, all participants agreed that the infrastructure, user interface, and education of users and drivers are currently inadequate for addressing these shortcomings. P5 noted that commercial users might also be “more susceptive to liability issues,” which may keep them from embracing the technology and advocating for a faster transition. Acknowledging the disconnection between current technologies and expectations, some commercial and personal users have today, the majority of participants also noted that these assumptions would likely evolve as autonomous vehicles become more commonplace. Participant P4 explained that their research indicated that currently, “a vast majority of drivers would welcome autonomous vehicles and eventually want to own one,” even though “they do not intend to operate the vehicle autonomously at this point.” Wanting to own an autonomous vehicle but not using it as such stands in stark contrast to some of the benefits promoted about autonomous vehicles, where a potentially much safer form of transportation should outweigh the desire for and joy of driving a car, countering all other concerns users may have (Kyriakidis et al., 2015).

Risk management is a crucial aspect of dynamic capabilities theory, where selecting a path forward also includes analyzing risks of projects and products that are subject to deep uncertainty (Slagmulder & Devoldere, 2018). As indicated by the participants, acceptance, and infrastructure currently lack sufficient development, and there is an uncertainty of how users of the technology will react, given that there is almost no firsthand experience yet. In cases of uncertainty, the theory of dynamic capabilities offers a structured approach that could enable a firm to react better to changing market environments, changes in technologies, making adjustments to processes, and designing proprietary systems that could result in competitive advantages (Ferreira et al., 2018; Slagmulder & Devoldere, 2018). Considering the quality of data the participants expect from firsthand user experience, these experiences may well be unique to the firm and their technological approach, and thus serve to create paths and differentiators that are difficult to replicate for others without access to the same information. As such, the expectations relevant to potential commercial customers and users of AV technologies align well with the theory of dynamic capabilities.

While the current literature almost exclusively focuses on suggested or simulated benefits of AV technologies, the separation of the focus on consumer expectations into commercial and personal users aligns with current research as well. While the perceived expectations of commercial users and personal users alike may benefit from extensive education and firsthand experience, there is also evidence that these two user groups and applications will have very different expectations and needs (Mohan et al., 2016). As suggested by some participants, the education of users may play an essential role in reducing uncertainty and creating a sustainable market. Therefore, IT managers may want to invest some resources into educating the public and potential commercial users so that they can become more familiar with the technology so they could let go of preconceptions and some of their concerns.

**Sub-theme: personal users**. All participants in this study valued and encouraged the direct and first-hand experience of their consumers with their products. Unlike with other products that heavily rely on IT, users have yet to learn about and understand the unique capabilities of autonomous vehicles (Bunghez, 2015). Furthermore, introducing consumers to fully autonomous driving technologies within the realm of traditionally manually controlled vehicles presents its own challenges. While one might expect that someone who uses a smartphone for the first time can place a phone call or write an email, operating or being driven by an autonomous vehicles offers an entirely different experience and requires new skills (Cerf, 2018). As participant P4 noted, hard and software "developers cannot expect consumers to be familiar with or know how to use autonomous vehicles and," therefore, must equally seek discovery of expectations but also "engage in extensive education to build the foundation for broader acceptance."

In addition to paths, processes, and positions, imitability may also apply to the focus on consumer expectations as it relates to the theory of dynamic capabilities. Imitability is concerned with establishing and maintaining systems and structures that foster innovation and reduce the likelihood of replication (Schoemaker et al., 2018). The participants in this study emphasized that their approach to achieving full autonomy is based on the feedback received from their consumers, which encouraged them to modify their solutions to meet market demands. This process of refinement makes it harder for competitors to imitate or replicate these solutions because they may lack the same direct experience with consumers. If the user experience is as essential as the technological approaches to hardware and software that enable them, then meeting consumer expectations better can become a valuable asset for an organization to differentiate from its competitors.

Similarly to the focus on commercial user expectation, the competitive advantage a firm could gain by better analyzing consumer expectations and basing the findings on firsthand experience versus simulated or projected outcomes and benefits instead aligns well with the core tenets of the theory of dynamic capabilities. Furthermore, without a technological differentiation and in the absence of certification and other legal requirements, designing products that work better may be essential elements for introducing commercially available solutions sooner. For example, P7 noted that only their extensive research among users of their technology revealed that safety drivers did not appreciate when “a vehicle performed technically correct in situations where human drivers would have reacted differently.”

Concerns about how a vehicle reacts align well with the existing literature, which also suggests that the user experience in an AV is essential and must include more than just enabling a vehicle to travel between places (Panagiotopoulos & Dimitrakopoulos, 2018). IT managers may benefit from continuing on a path of refinements and data collection from their users as long as the majority of personal users have yet to experience autonomous vehicles. These firsthand experiences can provide an essential cornerstone for achieving competitive advantage through lessons learned that are not yet discussed in the general literature.

**Theme 4: Focus on Competitive Advantages**

The last major theme emerging in this study was the focus on competitive advantages. For autonomous vehicle development, achieving a competitive advantage could be the result of designing difficult to imitate hardware, engineering unique software, having access to more data than competitors, having more vehicles on the road than others, meeting consumer expectations better, or being reading for market introduction sooner. Three important sub-themes informed the development of the major theme of focus on competitive advantages: (1) business development, (2) proprietary solutions, and (3) time to market. While these three sub-themes may also be commonly found in other highly competitive industries and especially among startups, the perceived importance of and emphasis on each significantly varied among the participants.

Table 5

*Themes of Focus on Competitive Advantages with Supporting Metrics*

| | Participant | | Documents | |
|---|---|---|---|---|
| **Major Theme** | **Count** | **References** | **Count** | **References** |
| Focus on Competitive Advantages | 7 | 99 | 14 | 109 |
| **Sub-themes** | | | | |
| Business Development | 7 | 46 | 5 | 26 |
| Proprietary Solutions | 7 | 28 | 8 | 27 |
| Time-to-market | 7 | 25 | 14 | 56 |

All participants in this study had experiences working in startup environments and more often prioritized business development over proprietary solutions and time to market in their references about achieving a competitive advantage. In contrast, only five documents mentioned business development as an important aspect for dominating the competition, but 14 out of the 15 total documents examined as part of this study discussed time-to-market extensively as a potential differentiator (see Table 5 for the theme and sub-theme metrics). The rather strong disconnect in preference between prioritizing time to market or business development for achieving a competitive advantage may have to do with the corporate structure of most organizations working on autonomous vehicle designs and technologies. Participants P5 and P6 noted that their investors and executives often have a very “different understanding of” how to quantify “progress” than the engineers working on the hardware and software solutions for autonomous vehicles or their colleagues in charge of making and developing business cases for their products. In particular, P6 explained that their “funding is highly dependent on short-term progress.”

The theme of focus on competitive advantage aligns well with the theory of dynamic capabilities because many of its described tenets serve the purpose of documenting processes and capabilities, so they can be fostered and replicated for continued innovation and to achieve long-term strategic and actual competitive advantages (Teece et al., 1997). While the theory of dynamic capabilities offers many elements which a firm could apply individually for improving their operational performance, all of the premises are designed to achieve a sustainable competitive advantage (Pisano, 2017; Schoemaker et al., 2018). Throughout the discussion with participants, the focus on achieving a competitive advantage took on different forms and priorities. P3, P4, and P6 suggested that achieving a competitive advantage enables the organization to survive and continue to raise money, whereas P1, P2, and P7 were less concerned about funding but instead wanted to position the firm so that it would develop products that are unique and difficult to replicate. Both reasons align well with the theory of dynamic capabilities, even though one aims for a short term benefit, whereas the other is more strategic.

Similarly, the literature aligns with the findings from this theme and its sub-themes because participants also illustrated an organizational culture and approach to running a business that differs from practices common at traditional automotive vehicle manufacturers and their supply-chain (Falcini & Lami, 2017; Joanna, 2016; Misztal et al., 2016), and seems to align much better with approaches commonly found at tech-startups (Woodside, Bernal, & Coduras, 2016). Relying on a startup culture may be a necessary shift in approaching autonomous vehicle development because the required technologies under development are primarily IT hardware and software problems and do not align well with traditional vehicle manufacturing challenges at this time. However, hardware and software engineers working on autonomous vehicles may benefit from aligning part of their corporate culture more closely with suppliers and manufacturers early on, to facilitate a smooth transition from developing technologies to deploying them on a large scale.

**Sub-theme: business development**. A critical sub-theme that was frequently referred to by participants was time to market. Interestingly, the majority of participants repeatedly mentioned they are being pushed to deliver products that show progress toward delivering a viable solution to the market, even when it frequently requires the use of less than ideal or somewhat limited intermediate solutions. P3 noted that their limited resources often require them to "come up with solutions that may fix one issue but create another." Most participants would prefer to be able to develop better products rather than working toward introducing solutions quicker. Participants P1 and P4 did not share these concerns and emphasized that their organizations generally prefer a more "robust solution" over one that gets introduced too quickly and may set back the industry significantly if it leads to accidents and even fatalities. P1 explained that, in his opinion, “one or two more years really makes no difference.” Similarly, recent literature suggests that neither the hardware or software are ready for full autonomy regardless of regulations (Sadighi et al., 2018), and leading developers of autonomous vehicle technologies continue to struggle with reducing forced disengagements of the system due to driver intervention (Lv et al., 2018). Therefore, taking a more cautious approach may be warranted, although, as participants P3, P5, and P7 noted, not all startups may be able to afford these delays.

The theme of business development aligns well with positions and paths, where market assets and technological opportunities form the basis for competing with other organizations by seeking new opportunities and developing markets (Kodama, 2017). Arguably, business development may be subject to long-term strategies, but often the immediate needs of the firm may become the focus of daily operations (Schoemaker et al., 2018). Business development is, therefore, well-aligned with the tenets of achieving long-term strategic advantages in the theory of dynamic capabilities, but in reality, it may fall short due to the immediate need to show progress at many organizations working on autonomous driving technologies.

In particular, aligning an organization to meet short term needs in highly competitive environments may be beneficial to the survival of the organization, and, on occasion, might be a requirement for successfully competing in specific markets (Slagmulder & Devoldere, 2018). Because participants in this study mostly relied on agile-based frameworks, integrating short-term IT decision-making processes with development goals for designing AVs may be beneficial

(Sudrajat, Budiastuti, Setiadi, & Supeli, 2016). As such, the focus on business development aligned well with the theory of dynamic capabilities, because participants, similarly to some of the tenets found in dynamic capabilities theory, aimed to design solutions they can sell sooner to leapfrog the competition and secure the survival of their organization. While there may be many reasons for why a firm may want to achieve and sustain a competitive advantage, the existing literature suggests that AVs will transform entire industries (Litman, 2019), which aligns well with the desire of the participants to carve out and further develop business opportunities. IT decision-makers may benefit from realizing this disconnect and could make adjustments that serve the strategic business development needs, as well as the meeting immediate goals for showing progress to investors and working with limited resources.

**Sub-theme: proprietary solutions**. While the majority of participants mentioned that they develop custom software to enable full autonomy in their systems, the core infrastructure, including the middleware and hardware they use, is based on technologies that are available to any of their competitors. In contrast, participants P1, P2, and P7 emphasized that their proprietary hardware and software approach to autonomy, or some of its integrated systems, is the result of a long term strategy and the desire to create products that are more difficult to replicate. For example, participant P1 noted that “purely mechanical scanning systems,” such as some LIDAR sensors, “are easy to copy,” but when the sensor uses novel technology and requires unique software to function, competitors will have difficulties imitating the technology without extensive research. Furthermore, participants P4 and P7 noted that training CNNs requires large datasets, which in itself could be seen as a proprietary solution if nobody else has access to the same data. P7 suggested that “gaining access to unique data for training CNNs may result in a unique solution that others cannot merely copy.” The notion of proprietary datasets aligns with some of the existing literature that illustrated the advantages of using CNNs for achieving fully autonomous driving systems, but also acknowledges the logistical challenges required to train these systems and the competitive advantage a developed CNN could offer to any manufacturer (Gallardo et al., 2017; Hatcher & Yu, 2018; Rao & Frtunikj, 2018; Zhang et al., 2018).

Overall, proprietary solutions relate well to the processes, reliability, and imitability concepts found in the theory of dynamic capabilities (Ferreira et al., 2018). Therefore, pursuing proprietary solutions also aligns well with the core premise of dynamic capabilities, which is focused on achieving competitive advantages through the development of unique products and processes that are difficult to copy (Kodama, 2017). IT managers may find that seeking strategies that foster the development of proprietary solutions will have an overall positive effect on a firm’s ability to gain a competitive advantage. In particular, in the field of autonomous vehicles, where universally accepted standards and development frameworks do not yet exists, IT professionals can shape the future of an entire industry by leading the field through advancements that go beyond merely integrating a supplier’s product.

**Sub-theme: time to market**. In the absence of other competitive advantages, such as the ones associated with creating unique hardware and software, three participants suggested that finding a niche and creating sustainable business models can also result in more advantageous positioning within the market. Participant P6 explained that while “it may take decades to develop fully autonomous vehicles" that they could sell, they are very confident with operating a small fleet of autonomous shuttles in a well-defined area or on non-public roads, as long as the speed of the vehicle is minimal. The participant noted that this serves three objectives: (1) "it brings in revenue;" (2) "it provides data" that they can use to develop their more advanced systems further; and (3) "it serves as a showcase" to new investors and the public about their abilities to deliver a working product. While participants P3, P5, and P6 acknowledged that they aim to develop unique technologies and solutions to gain a long-term strategic advantage, they also admitted that having an intermediary product they can sell enables them to "continue their work" toward following their strategies. P3 noted that "deploying limited solutions on a small scale" gives them exposure to potential customers while allowing them to refine their technologies safely. However, following long-term strategies may be particularly difficult for startups because of the multidisciplinary challenges they have to overcome. The lack of fully developed systems and frameworks requires developers to customize their solutions, and the need to extensively test these approaches for safety and performance is a tedious and costly process (Dang et al., 2017; Koopman & Wagner, 2017).

Therefore, time to market loosely aligns with paths, positions, and processes to explain how the process of learning, building assets, and taking advantage of technological opportunities could result in products that can reach customers faster (Queiroz et al., 2018). Focusing on time to market may come at the expense of imitability and reliability, and, therefore, only partially aligns with the theory of dynamic capabilities. While reliability and imitability are core concepts and essential parts of the theory of dynamic capabilities, so are achieving competitive advantage through processes, paths, and resource management (Krzakiewicz & Cyfert, 2017; Schoemaker et al., 2018). By extension, then, the desire of the participants to derive strategies that enable them to design products they can bring to market faster, even at the expense of not pursuing and aligning these solutions with long-term goals, is still supported by the theory of dynamic capabilities. Especially in highly competitive environments, the pace of innovation and managing risks adequately throughout to ensure the survival of a firm may result in a competitive advantage, even if managers may have to abandon long-term strategies temporarily (Schoemaker et al., 2018; Slagmulder & Devoldere, 2018; Teece et al., 1997).

Furthermore, the existing literature suggests that time to market may offer a competitive advantage by suggesting that early developers of new technology often achieve a technological lead or can define public perception of new technologies that competitors struggle to overcome (Mushtaq et al., 2018). Considering that these advantages may not survive the changing consumer demand or new regulations, IT managers may benefit from assessing the need for a sellable product in the context of finding partners that are willing to sacrifice short-term success for long-term competitive advantages. In particular, the many stakeholders in autonomous vehicle development and deployment, such as consumers, manufacturers, and regulators, for example, may not benefit from a faster time to market at all, suggesting that IT managers may be better off by focusing instead on proprietary solutions and overall business development.

## Applications to Professional Practice

The specific IT problem which served as the basis of this study was that some IT hardware and software developers of self-driving cars lack strategies for adapting traditional vehicle design frameworks to address consumer and regulatory requirements in autonomous vehicle designs. The participants in this study provided insights into what strategies they use to develop their products and aligning these products with consumer expectations, while also meeting regulatory requirements. What became apparent throughout this study is that most participants did not care about meeting regulatory requirements or shaping future regulations. The lack of wanting to meet or shape regulations may have to do with not seeing it as an immediate priority, shying away from the perceived cost of engaging with regulators and other stakeholders, or it may be the result of the managers not having enough information about the requirements, challenges, and necessary strategies to incorporate these considerations into their design processes. Furthermore, while one could argue that the participants in this study were using strategies to align their products with regulatory requirements and consumer expectations, participants agreed that these strategies are based on patchwork that may lead them to achieve short-term desired outcomes but without any guarantee as to their long-term viability.

While this study did not aim to establish the causality of the identified relationships and strategies the participants use to develop fully autonomous vehicle technologies, the major themes and sub-themes illustrate a design approach that is unlike one may expect when looking at traditional vehicle manufacturing. Traditional vehicle manufacturing heavily relies on established frameworks and regulatory requirements (Falcini & Lami, 2017), whereas participants in this study admitted that these frameworks are not a good fit for their products and that other frameworks or regulations do not yet exist to fill the void. Therefore, there may be many reasons for this difference in approaches, including corporate culture, lack of regulations and oversight, and the supply chain. However, this also suggests that if these highly innovative startups want to outgrow developing and testing eventually to deploy their solutions on a large scale, either the transportation industry may have to adapt to their design approaches and strategies, or these innovators may have to adjust theirs. Furthermore, autonomous vehicles and traditional vehicle design objectives may be vastly different, at least initially.

Traditional manufacturers may often focus on refining their existing products through design and user interfaces, whereas teams working on autonomous vehicles must innovate in an area that currently only exists on paper and in optimistic predictions. All participants agreed that fully autonomous vehicles do not yet exist and that they are likely decades away from large scale deployments. In contrast, manufacturers of traditional vehicles sell millions of cars each year across all markets, and the rules and regulations they have to meet are well established, as are the expectations consumers have about the quality and performance of these vehicles. In stark contrast, autonomous vehicle consumer expectations are not yet developed or based on firsthand experience, and while some regulations are proposed, ratifying and refining these proposals and enacting sweeping reforms will also likely take decades (De Bruyne & Werbrouck, 2018).

Therefore, all stakeholders concerned with autonomous vehicle technology development may find the results of this study useful. Manufacturers may use the findings to develop proactive approaches that could facilitate the feedback loop between hardware and software engineers working on autonomous vehicles, while suppliers could use this opportunity to develop certification systems for these technologies and engage regulators more actively to shape processes early on. Some executives at organizations developing autonomous vehicle technologies may use the findings of this study to reevaluate their approach to market introduction and producing shareholder and investor value in the short term so that the business models align better with the culture and work practice commonly found among hardware and software engineers. These same executives may also use this opportunity to align their overall strategies more consistently with the theory of dynamic capabilities to reap all its benefits, both short and long-term.

## Implications for Social Change

At the beginning of this study, my assumption about the impact of autonomous vehicles on society, in general, was that the sooner the technology becomes available, the greater the benefits. Benefits include less air pollution by transitioning to electric vehicles and reducing the amount of vehicles on the road today, reducing traffic accidents and fatalities to rare events from constant threats today, saving resources and reducing cost of ownership, and improving mobility for disadvantaged communities and individuals with disabilities, for example (Bunghez, 2015). My understanding of the benefits has not changed after conducting the study, and participants seem to agree that the impact of autonomous vehicles on society, in general, will be transformative. However, a common theme emerged throughout my discussions with the participants about the difficulties associated with the technologies at the heart of autonomous driving and the continuing regulatory vacuum that limits development progress and also prevents widespread market introduction.

Instead of trying to achieve full autonomy quickly and somewhat leapfrog regulations by setting a technical precedent in hopes appropriate legislation will follow, the majority of participants suggested that society may benefit at large by incrementally introducing technologies sooner. Introducing incremental advancements supports two objectives: (1) getting society used to semi-automated systems and appreciate their benefits, and (2) show functional safety to regulators so they can make informed decisions about creating the necessary legal frameworks that also support fully autonomous vehicles. Society, then, may reap the benefits by reducing fatalities, avoiding the potential setbacks and unintended consequences of introducing a technology that is not yet ready for mass adaption, and transforming not just the transportation industry but affording the time to all of its connected services and related industries to adapt to the changing environment.

While an incremental and arguably much slower approach to making transportation autonomous may still offer many benefits to society, such as making transportation more accessible through cost reduction and reducing accidents and associated fatalities, for example, following this approach may also have negative consequences. For one, all participants in this study agreed that the future of autonomous transportation would require the electrification of drivetrains. Electrification of transportation results in a significant reduction of greenhouse gases overall and, especially in highly populated areas, can improve the air quality significantly (Tyfield & Zuev, 2018). If one assumes that electrification of transportation is a requirement for autonomous vehicles, taking a slower approach to finalize the development of AVs may also slow down the transition from combustion engines to electrified propulsion systems, making it less likely for autonomous vehicles, or precursors thereof, to have a significant impact on air quality for the foreseeable future. Furthermore, the many societal benefits of AVs emerge from the premise that more autonomy will exponentially reduce the need for vehicles. Fewer vehicles on the road will have a lower environmental impact, reduce the cost of ownership, reduce traffic, and, as a result, may further reduce accidents (Vellinga, 2017). With a slower rate of adaption and implementation of these transformational technologies, society may have to wait much longer to reap its benefits.

Therefore, the findings of this study suggest a more structured approach that would benefit society by introducing the technology that is ready today while continuing to refine the systems that are not yet meeting the requirements of consumers, engineers, or regulators. However, for this approach to be successful and beneficial to society, regulators must increase their effort to engage with manufacturers of automotive vehicles and system components to proactively develop and ratify binding globally applicable regulations. Without these regulations, manufacturers may have fewer incentives to pursue the development of more advanced autonomous systems and thus may resort to minor incremental changes of their solutions that may end up providing fewer benefits to society than more aggressively developed systems could offer.

## Recommendations for Action

Even though participants in this study came from very different backgrounds and continue to work on various aspects of individual systems or autonomous vehicles as a whole, they all understood the concept of design strategies and the use of frameworks throughout the development processes. Furthermore, all participants had heard of the various development frameworks discussed in the literature review section of this study, but admittedly they are not directly aligning or basing their development strategies on these industry standards. Some participants argued that these frameworks are either inappropriate or insufficiently equipped for supporting the rapid iterative processes these organizations go through when developing their products. Most commonly, participants mentioned the use of agile and scrum as their choice of framework when it comes to developing solutions. At the same time, interviewees agreed that the lack of binding legal frameworks makes it more difficult to develop solutions and that automotive development frameworks are currently insufficiently equipped to address most of the challenges these developers must overcome.

Recommendations for actions are particularly challenging as it relates to autonomous vehicles because of the multidisciplinary nature of the research and development for these products. In particular, lawmakers may rely on the findings of this study to accelerate their legislative and rulemaking processes concerned with autonomous vehicles to offer better guidance for developers of these technologies and providing a path to meeting safety requirements. Furthermore, decision-makers at all levels of autonomous system components and vehicle designs may want to rethink their development strategies to emphasize regulatory alignment and functional safety as part of their approaches. While startups and researchers may be able to afford to skip adherence to established automobile development frameworks, as they lack supplier relationships and bureaucracies designed to integrate and take advantage of these established systems, they may eventually have to meet regulatory requirements. Currently, regulatory safety requirements vehicle manufacturers must meet are supported by various frameworks so that systems and components thereof can be validated and certified. Assuming that regulatory frameworks will eventually exist to allow the deployment of autonomous vehicles and components, stakeholders should have a vested interest in establishing standards and design frameworks as soon as possible.

To facilitate the discussion about the findings in this study, related articles could be published in journals, books could expand upon the themes and further examine the industry-wide impact, and training programs could create awareness among stakeholders and also prepare the public to better understand the technologies and their impact on society, for example. Lastly, presenting the findings at conferences could lead to a more in-depth discussion among participants and across entire industries, sparking future research and serving the foundation for advocating a change in current design approaches and legislative processes.

## Recommendations for Further Research

I base my recommendations for future research on the experiences I have had throughout conducting this study, the knowledge I gained from the existing literature, and the limitations inherent to qualitative approaches like the one I chose for this study. Considering that the individual perceptions of hardware and software engineers working on autonomous vehicles are underresearched, one of the goals of this study was to explore and identify strategies so that future research could more precisely measure variables to examine the existence of correlations further. Furthermore, another limitation of this study was its sample size. While choosing experts can result in representative data for a larger population, transferability is likely limited and requires a study that would examine a much larger audience to get more universal results.

One aspect of conducting research among a population that is highly competitive and often bound by non-disclosure agreements (NDAs) is that finding suitable participants who are willing to interview is extremely difficult. Even though privacy and confidentiality are ensured throughout the process, it was almost impossible to find suitable participants who also happen to be highly qualified. This is not uncommon in any competitive environment and, therefore, not unique to autonomous vehicle development, but using a different research approach would likely result in better participation overall. My recommendation, therefore, is to focus further research on quantitative approaches that do not require in-depth interviews or revealing personal interactions between the researcher and the participants.

In particular, I was able to identify several themes and design approaches through my interviews, but due to the chosen research design, I was unable to measure the relationship between these variables or the efficacies of the discovered approaches. Future research could focus on analyzing these connections and rely on a larger sample to create transferable and meaningful results that could further inform stakeholders about the overarching understanding of development approaches and perceptions among industry professionals. While the findings of this study suggest a lack of alignment with regulatory requirements and few efforts of shaping legislation, I recommend investigating whether these assumptions hold true among a broad audience and what, if any, solutions stakeholders may suggest for mitigating these concerns.

## Reflections

As an IT hardware and software professional with a passion for in-vehicle computer networks my desire to conduct this study was driven by my curiosity about AI and AVs in general, but also because I saw a gap in the literature that aligned with what I thought to be an exciting contribution to the literature from a behavioral and organizational psychological point of view. Even though I had meticulously planned how I would find and reach out to participants for inclusion in my study, the very secretive nature of autonomous vehicle technologies and developments and the already fierce competition among some influential organizations presented almost insurmountable challenges. Further complicating my desire to investigate experts in autonomy about their perceptions was that most employees are bound by very strict NDAs, making it impossible to recruit some participants that this study could have benefitted from having.

Overall, the process was much more difficult than I could have initially imagined, but also more rewarding because I was able to find extraordinary participants who were openly providing me with essential information I used to answer my research question. For this support by the very few who decided to take a chance with me and my study, in particular, I am incredibly grateful. While the process of conducting these interviews felt natural to me, getting to have these conversations with participants was what gave me pause and often seemed like an insurmountable obstacle. Having conducted this study with rather difficult to recruit participants also provided perspective and an appreciation for those fellow researchers who similarly struggle with their research in hard to define or difficult to reach populations. Finally, my study succeeded in finding fascinating perceptions about the state of autonomous vehicles and helped me to refine my area of interest for future research further.

## Summary and Study Conclusions

Autonomous vehicle development seems to progress at a rapid pace, even though fully autonomous vehicles are not yet available to the public. The findings of this study confirmed that the technologies used to develop autonomous vehicles are as much in their infancy, as the regulations that will govern their use. Litman (2019) suggested that these and other factors are likely going to delay a quick and widespread adaption of autonomous vehicle technologies and result in a transformative process that could well take more than 40 years to complete. Autonomous vehicle technology is still emerging, but a lack of legal frameworks and specifically development frameworks applicable to autonomous vehicles manufacturers and developers could use to speed up their design processes, are absent, or falling short of the necessary clarity. Without precise legal, design, and testing requirements and processes, some manufacturers may continue to rely on frameworks adapted from other industries, such as agile scum, for example. Using these borrowed frameworks may merely manage current development processes, but they are unable to offer a mandate or assurances that the resulting products and design approaches will be certifiable eventually. Therefore, the success and timeliness of the introduction of autonomous vehicles will as much depend on the rapid development of mature technologies, requiring universal and transparent regulations, but also consumer acceptance and an exponentially growing demand for AVs through market forces or regulatory requirements.

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Appendix A: National Institutes of Health Certificate of Completion

## Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Alex Munoz** successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 01/14/2018.

Certification Number: 2597072.

## Appendix B: Confidentiality Agreement

**Name of Signer:**

During my/our activity in collecting or processing data for this research: “Exploring Perceptions of the Relationship between Existing Autonomous Vehicle Design Frameworks, Consumer Expectations, and Regulatory Requirements,” I /we will have access to information that is confidential, and I should not disclose. I acknowledge that the information must remain confidential and that improper disclosure of confidential information can be damaging to the participant.

**By signing this Confidentiality Agreement, I acknowledge and agree that:**

1. I will not disclose or discuss any confidential information with others, including friends or family.
2. I will not, in any way, share, copy, release, sell, loan, alter, or destroy any confidential information except when duly authorized.
3. I will not discuss confidential information where others can overhear the conversation. I understand that it is not acceptable to discuss confidential information, even if the participant’s name is not used.
4. I will not make any unauthorized transmissions, inquiries, modification, or purging of confidential information.
5. I agree that my obligations under this agreement will continue after the termination of the job that I will perform.
6. I understand that violation of this agreement will have legal implications.
7. I will only access or use systems or devices I am officially authorized to access, and I will not demonstrate the operation or function of systems or devices to unauthorized individuals.

Signing this document, I acknowledge that I have read the agreement, and I agree to comply with all the terms and conditions stated above.

**Signature:** **Date:**

# Appendix C: E-mail Invitation to Participate in the Study

Date: [Insert Date]

Re: Invitation to Participate in a Research Study

Dear [Insert Recipient]:

My name is Alex Munoz, and I am a doctoral student at Walden University, pursuing a Doctor of Information Technology degree (DIT). I am conducting a research study titled “Exploring Perceptions of the Relationship between Existing Autonomous Vehicle Design Frameworks, Consumer Expectations, and Regulatory Requirements.“ I am writing to you to request your participation in my study. Participation involves completing an interview via Skype audio.

The goal of my study is to explore the perceptions of the relationship between regulatory requirements, consumer expectations, and existing autonomous vehicle design frameworks as perceived by hardware and software developers working on self-driving cars. I want to help autonomous vehicle program managers to develop strategies or a framework from which to design autonomous driving systems that can successfully and quickly align with consumer expectations and regulatory requirements. If you are part of a software and hardware research team and are currently developing fully autonomous driving hardware or software technologies, I would greatly appreciate your participation in my study.

If you do not wish to participate in this research, please disregard this message. Otherwise, I am attaching a copy of Walden University’s Institutional Review Board approval and a consent form. Please sign and return a copy of the consent form to me via <email address redacted>. I plan to conduct interviews through Skype audio starting <date to come> and possibly extending into <date to come>. I will adjust my schedule to meet yours so that my interview will interfere with your other tasks and overall schedule as little as possible.

I appreciate you considering participation in this study and look forward to working with you.

Sincerely,
Alex Munoz
DIT Student, Walden University
<email address redacted>

# Appendix D: Interview Protocol

## Interview Protocol

1. Introduce myself to the participant and thank them for their participation.
2. Remind the participant about the interview process and the recording of the conversation.
3. Turn on the recording device, make sure the recording works, and note the time and date of the interview.
4. Start the interview and follow through with the list of questions but allow the participant to respond to each question. Take notes throughout and ask additional probing questions if necessary.

## **Interview Questions**

1. Without including your name or your organization’s name, what is your current role, and how long have you been in similar roles?
2. What experience do you have working on autonomous driving systems or related technologies?
3. What strategies and/or design practices do you use or have used while working on autonomous driving systems?
    a. Probe: Why did you select this strategy or used this particular design practice?
    b. Probe: Did you find your strategy or design practice to be a good fit for achieving autonomy with your design, or did you have to make changes?
4. How do you measure the success of your strategies and frameworks for achieving fully autonomous driving capabilities?

5. What strategies have you used to align your autonomous vehicle design approaches with consumer expectations?
    a. Probe: How can you be sure that your interpretation of consumer expectations aligns with what consumers actually expect, considering that autonomous vehicles are not yet publicly available?
6. What, if any, barriers do you see for widespread autonomous vehicle design introduction and acceptance?
7. What strategies do you use to align your autonomous vehicle designs with current regulatory requirements?
    a. Probe: How do you intend to adapt your designs to changing regulations?
    b. Probe: What strategies do you use to shape and influence future regulations?
8. Is there anything else you would like to add about your autonomous vehicle design strategies that we have not addressed already?
9. Ask the participant if they want to add anything or clarify previous statements.
10. Ask the participant if they have any documents they can share with me to supplement the responses they have given me throughout the interview. For example, these documents may include, but are not limited to, design and software strategy documentation, disengagement records, quarterly published vehicle safety reports, (SEC) reports and filings, surveys, and any other articles, whitepaper or documents an organization or individual has published on the subject.

11. Explain the concept of member checking and that I will share my interpretation of the interview to make sure that I have accurately captured what the participant meant to say.
12. Stop the audio recording.
13. Thank the participant for partaking and their time, and confirm that we both have each other’s correct contact details for any follow-up questions or concerns.