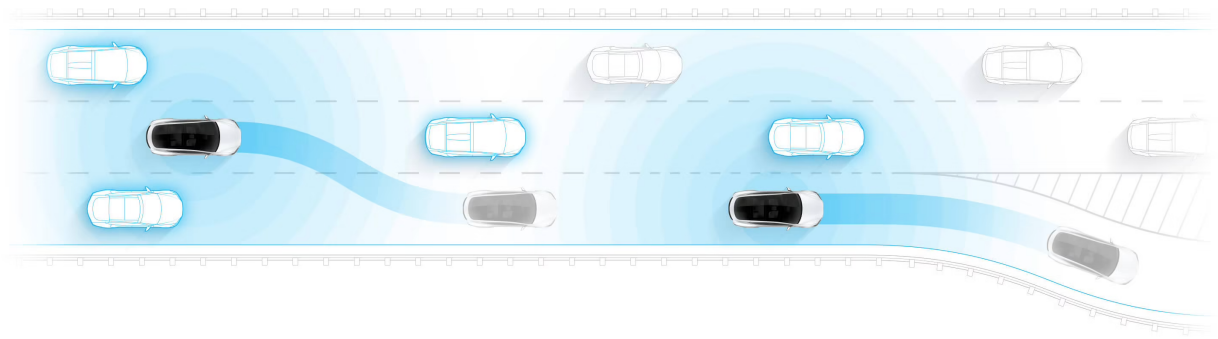
ENSURING THE

SAFETY OF ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) IN AUTOMOBILES

AS WE HEAD TOWARDS AN AUTONOMOUS FUTURE



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Final Report

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and the

INNOVATRIUM®

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EXECUTIVE SUMMARY

My team and I were approached by a client looking to assess the feasibility of providing value-added services to help the automotive aftermarket continue to thrive in the rapidly changing automotive industry. Currently, there is a large problem in the automotive aftermarket repair industry to safely return vehicles equipped with Advanced Driver Assistance Systems (ADAS – cruise control, lane keep assist, backup cameras, etc.) to the road. Industry growth is expected to explode as cars become more advanced and more reliant on ADAS, presenting a tremendous opportunity for the automotive aftermarket to thrive in the future if they can adapt now.

We started the current state analysis by determining the total addressable market. By 2030, it is estimated that there will be $1.09B of annual revenue earned from ADAS parts in the U.S. While this is great news, after surveying 450 collision and repair shops, we found that only about 20% of total shops will service ADAS. Specifically, only about 7% of small mechanical shops service ADAS. The three primary reasons for this are 1. many independent shops can't afford the necessary equipment to profitably perform services on these vehicles right now, 2. shops don't have the demand to justify the cost, and 3. ADAS service to too difficult for technicians to learn. As a result, aftermarket shops not only miss out on revenue since they are forced to turn away customers and send them to name-brand dealerships, but they are also hurting their future potential for success. Additionally, we looked at consumer behavior and discovered that a large majority of consumers turn off ADAS on their cars. Those who use ADAS were concerningly found to drive less safe when they do so.

Three problem areas were identified from the current state: the cost of ADAS repairs, the shop competency in ADAS service, and the consumer usage of ADAS-enabled vehicles. My team and I then used the Competing Value Framework to analyze these target areas and develop recommendations for our client.

Our first recommendation for the client is to pursue an initiative that mandates regular ADAS system inspection. Doing so will keep consumers safe and drive more demand to the aftermarket. Our second recommendation for the client is to develop a certification program that is accessible, noticeably beneficial to the technicians, and integrates better into their work-life environment. Doing so should help more technicians and shops to gain the skills necessary to service the increased ADAS service demand. Our third recommendation is for the client to lobby for regulations so consumers cannot turn off ADAS systems. We believe that this regulation is necessary, or the safety capabilities of ADAS may never fully be realized. These recommendations will help the client position the automotive aftermarket to thrive for years to come.

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INTRODUCTION

My team and I were approached by a client looking to assess the feasibility of providing value-added services to help the automotive aftermarket continue to thrive in the rapidly changing automotive industry. Throughout this semester-long project, we worked with the client to understand the automotive aftermarket industry, discover their problems, and develop recommendations on how to fix them. The following report summarizes the work my team and I completed, although some details may be omitted for NDA reasons. Much of this project was completed as a team, but to demonstrate my contribution to the Engineering Honors faculty, I will highlight the research, analysis, and work I individually completed when applicable.

Problem Definition

There is a large problem in the automotive aftermarket repair industry to safely return vehicles equipped with Advanced Driver Assistance Systems (ADAS) to the road. Many independent shops can't afford the necessary equipment to profitably perform services on these vehicles, so they are forced to turn away any customers that need ADAS service and send them to name-brand dealerships (i.e. BMW of Ann Arbor, Suburban Chevrolet, etc.). Growth is expected to explode as cars continue to become more advanced and more reliant on ADAS, presenting a tremendous opportunity for the automotive aftermarket to thrive in the future if they can adapt now.

Background

The following subsections define what ADAS is and introduce the team, the Innovatrium, and the acclaimed Competing Values Framework that was used to develop our value creation options.

What is ADAS?

ADAS (Advanced Driver Assistance Systems) is a family of electronic technologies that enable automation of portions of vehicle operation (i.e. cruise control and blind-spot detection). There are several functions that ADAS accomplishes, with safety being one of the primary focuses. These systems are paving the way for fully autonomous vehicles and are commonly divided into three subgroups: RADAR/LiDAR, camera, and ultrasonic-based systems. Figure 1 shows many of the ADAS systems currently, or soon to be, installed on new vehicles.

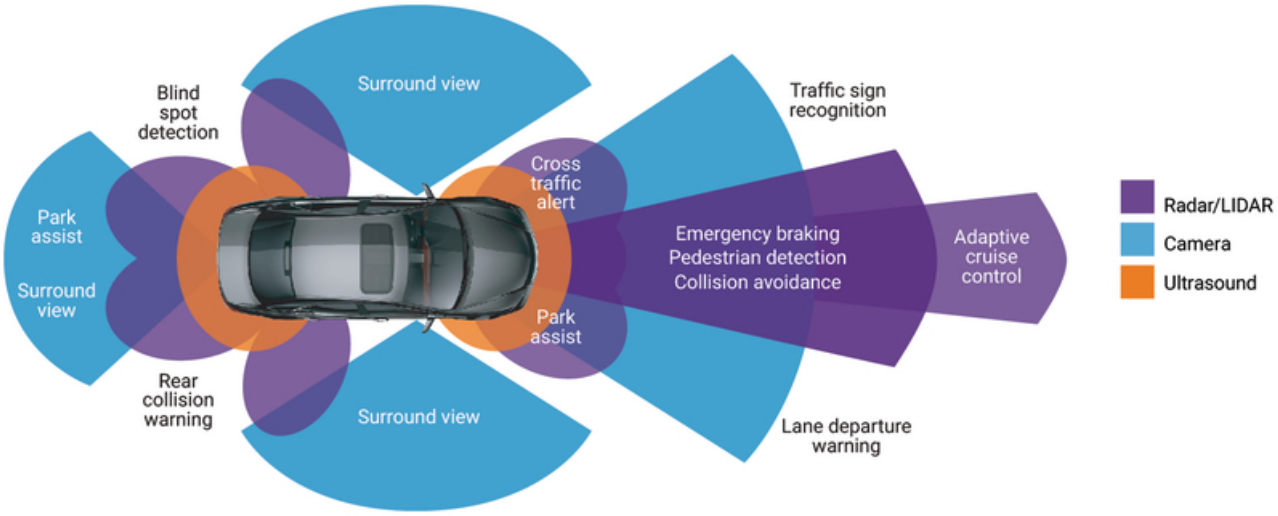


Figure 1: An overview of common ADAS systems[1]

For each of the following systems, we researched how they work, their capabilities and specifications, who supplies them to the OEMs (Original Equipment Manufacturers – e.g., GM, Ford, Toyota, etc.), and how they are validated:

- Long Range RADAR (I researched this one – see Appendix B)
- Short/Medium Range RADAR
- LiDAR
- Visual Camera-Based Systems (I researched this one – see Appendix C)
- Ultrasonic Sensors
- V2X Communications

The details of each of these systems are not necessary for this report, but for those interested I have attached my research on Long Range RADAR and Visual Camera-Based Systems in Appendices B and C, respectfully.

Team

I worked on a team employed by the Innovatrium. The project was overseen by Prof. Jeff DeGraff, but I also worked with three consultants and two students from the University of Michigan. I was the only student with a background in engineering, so my technical skills were leveraged during the data collection and analysis portions.

Innovatrium

This project was sponsored by the Innovatrium, an innovation and creativity consulting firm based in Ann Arbor, MI, and led by Prof. Jeff DeGraff. The

[1] What is ADAS?, https://www.synopsys.com/automotive/what-is-adas.html

Innovatrium specializes in fostering organic growth in clients' innovation ecosystems. They have worked with many large and complex organizations, including Fortune 500 companies, community leaders, foundations, industry associations, and educational institutions. Their role as an idea market, think tank, and research lab for innovation projects, allows them to develop the organizational culture and competency needed to manage and lead innovation.

Competing Values Framework

The Competing Values Framework (also known as the Innovation Genome) was developed initially from research conducted by University of Michigan faculty members on the major indicators of effective organizational performance.[2] It is an extremely useful model for organizing and understanding a wide variety of organizational, market, and individual phenomena, including theories of organizational effectiveness, market dynamics and opportunity identification, stages of life cycle development, financial strategy, and brain functioning. The robustness of the framework is one of its greatest strengths. In fact, the framework has been identified as one of the 40 most important frameworks in the history of business.

Figure 2: The Competing Values Framework (a.k.a. The Innovation Genome)

[2] Robert E. Quinn, Herbert W. Hildebrandt, Priscilla Rogers, and Michael P. Thompson, "Effective Management Communication: A Competing Values Framework" (1990).

It is composed of four distinct forces that influence individuals, organizations, and markets:

- **Collaborate:** Discover what customers want and what your people want
- **Create:** Identify trends and emerging technologies
- **Control:** Understand standards and regulations
- **Compete:** Consider competitors and opportunities to make money

New value creation is borne from the creative conflict between opposite corners of the Innovation Genome framework.

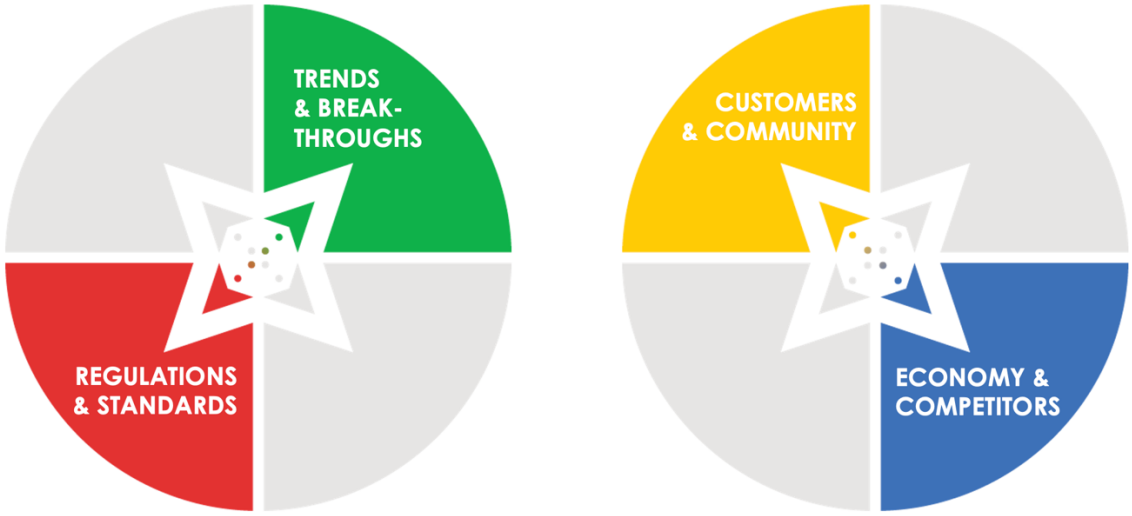


Figure 3: Competing Corners of the Innovation Genome

When the **Collaborate** and **Compete** quadrants are put into conflict with each other, the trend towards **Collaborate** creates slow-moving growth with a sustainable, long-term payoff, while the trend towards **Compete** creates fast-paced growth, though not sustainable in the long-term horizon. The conflict between these two forces influences your speed of innovation or how fast innovation happens.

When the **Control** and **Create** quadrants are at odds, the trend toward **Create** produces big, breakthrough innovation, while **Control** produces incremental improvements. The conflict between these two forces determines the magnitude of innovation or how much innovation each of these approaches produces.

Organizations must adapt to these evolving forces in the external environment or risk stalling out. Research shows that once an entity stalls, fewer than 10% of them recover. The only solution is continuous innovation and value creation for their customers and stakeholders.

Prof. Jeff DeGraff has conducted extensive research on this framework and has developed his own adaptions based on its structure. The Innovation Genome is at the heart of how the Innovatrium creates value and, thus, is the framework that we will use to develop value creation options for the client.

Goals & Objectives

There are two goals I had for this project: personal goals and client objectives.

Personal Goals

My personal goals for this project were to learn what it was like to successfully work on a consulting team, experience a real-world application of the Competing Values Framework, and learn about and get to know people in the automotive industry.

Client Objective

My other objective was to provide value to the client. Up to this point, I have been on several project teams, many of which have had real-world applications, but other than my past summer internship in supply chain with Walmart, I have yet to complete a project that actually provides substantial value to an organization. As someone who truly cares about making the world a better place, providing real value to others excites me.

Purpose

There are also two purposes for my involvement in this project: to get credit for my Engineering Honors Capstone and to help my team provide value to the client.

Honors Capstone

As a member of the University of Michigan Engineering Honors Program, I have to complete a capstone project senior year before I graduate. Of the five focus areas I could choose from, my project falls within Entrepreneurship. Consulting, by nature, is entrepreneurial because it aims to help companies develop, organize, and run successful businesses in a world full of uncertainty. In this case, we are helping our client develop solutions to help the automotive aftermarket continue to thrive.

Help Client

As much as my involvement in this project is an academic requirement, the purpose of my work was to help my team assess the feasibility of providing high value-added services for our client. If we can develop recommendations that they can then implement, the project will be successful.

CURRENT STATE (METHODS & RESULTS)

The following sections detail the research and analysis conducted. We looked at the history and types of part certifications, performed a total addressable market analysis for ADAS parts, gathered aftermarket electronic part pricing data, surveyed aftermarket repair and collision shops, and researched consumer driving behavior with ADAS-equipped vehicles.

Certifications

Certifications are critical for any part used in an automobile to ensure consistency and safety across the industry. As ADAS parts continue to be produced by a growing number of manufacturers, it is important to ensure that the parts that are used in the aftermarket are as safe and functional as those used by the OEMs.

Certification Histories

For each of the following components, we researched when the component was introduced on vehicles, when they were mandated, and how they are specified:

- Anti-Lock Braking Systems (ABS) [I researched this one – see Appendix D]
- Airbags (I researched this one – see Appendix E)
- Bumpers
- Headlamps
- Seatbelts

The details of each of these components are not necessary for this report, but for those interested I have attached my research on ABS and airbags in Appendices D and E, respectfully.

Methods for Vehicle Component Specification

There are three primary methods of vehicle component specification: regulations, standards, and specifications. Each is detailed below:

- **Regulations:** These are government-mandated requirements that the operation of a vehicle component must exhibit. In the U.S., the National Highway Traffic Safety Administration (NHTSA) administers the regulations outlined in Federal Motor Vehicle Safety Standards (FMVSS)
- **Standards:** These are suggested and set by standards bodies such as the Society of Automotive Engineers (SAE) for vehicle function and operation.
- **Specifications:** OEMs specify the requirements for the vehicle solutions and they determine how to meet these requirements for their vehicles. Specifications are then validated either by the OEM or via their supply base.

Total Addressable Market for ADAS Parts

The Total Addressable Market (TAM) for ADAS aftermarket parts, which measures the total annual revenue in the U.S, is made up of two sources: collision and component failure. Collision demand is driven by the replacement of parts from vehicle crashes and component failure replacement demand is driven by post-warranty normal wear failure of the component.

Collision

Collision demand is derived from the total possible replacement parts sold due to vehicle accidents or a comprehensive claim. Collisions are calculated by using total appraisal from shops for all vehicles and then applying that data to each model year equipped with ADAS. We used currently equipped data from the Highway Loss Data Institute to determine collision loss by ADAS. We then used collision type data from CCC to determine the classified loss associated with the collision and the historical usage of used parts. We also used the University of Michigan Transportation Research Institute (UMTRI) data to estimate the reduction in crashes due to better ADAS systems. This yields a final TAM for Collision.

Part Failures

Part failure is derived from representative data based on like part failures. Electronic components, unlike mechanical assemblies, rarely have wear-out mechanisms that are significant before many decades of operation. As shown in Figure 4, of the failures that occur in the first 20 years, most happen in the first year.

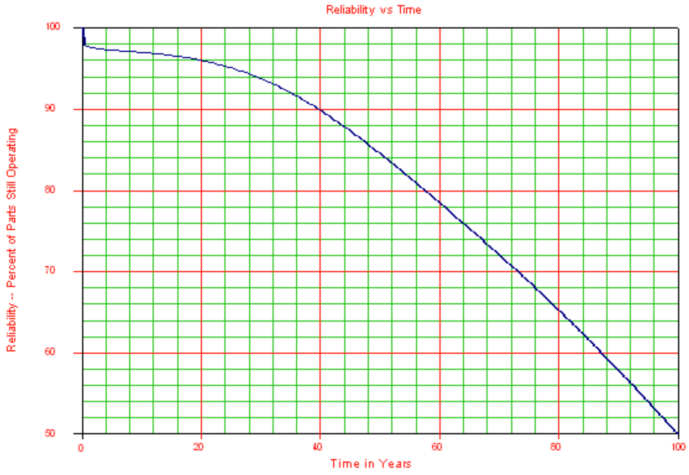


Figure 4: Failure Rate Curve for Leading Edge Technologies[3]

Initially, the standard failure rate of .18% per year was taken based on the data above, however, this does not account for the higher heat and vibration in the

[3] The Bathtub Curve and Product Failure Behavior, https://www.weibull.com/hotwire/issue21/hottopics21.htm

vehicle environment. We, therefore, decided to use the failure rate of ignition switches, .53% per year, since they have already thoroughly experienced the automotive environment.

TAM was calculated by taking the number of vehicles in operation and determining the number of ADAS-equipped vehicles by year of age. We then took the average cost of the ADAS system components repair for each of the ADAS type systems (short-range RADAR, medium-range RADAR, long-range RADAR, cameras, etc.) and then multiplied that by the anticipated failure rate of .53% per year, based on the comparable component.

The results for 2020, 2025, and 2030 are summarized in Table 1 below. The $1.09B 2030 TAM does consider the reduction in accidents that will occur by using ADAS.

Table 1: Total Addressable Market Results Summarized

Year	2030	2025	2020
Insured Vehicles	305,151,000	291,783,000	279,000,000
Claims per 100	6.07%	6.07%	6.07%
Crash Type			
Front	48%	48%	48%
Rear	30%	30%	30%
Side	21%	21%	21%
After Market Percentage	81%	81%	81%
Average Price			
Rear Camera	$69	$72	$76
Rear Parking Sensors	$80	$85	$89
Blind Spot Detection	$292	$308	$324
Lane Departure Warning	$297	$313	$329
Adaptive Cruise Control	$363	$382	$402
AEB	$363	$382	$402
Part Life Failure Replacement			
Part Failure per year	.53% per year	.53% per year	.53% per year
Parts Failure TAM	**$ 501,468,739**	**$ 307,679,280**	**$ 51,995,960**
Collision Replacement			
Collision TAM w/o CR	$ 908,788,455	$ 577,056,943	$ 297,580,099
Collision w Crash Reduction	**$ 592,855,991**	**$ 378,123,896**	**$ 191,533,525**
Total Addressable Market			
Total TAM w/o CR	$ 1,410,257,194	$ 884,736,224	$ 349,576,058
TAM w Crash Reduction	**$ 1,094,324,730**	**$ 685,803,176**	**$ 243,529,485**

Aftermarket Electronic Part Pricing

A key to the consumer cost advantage in the aftermarket is the choice of parts that are available to repair a vehicle, versus the OEM parts available at a dealership. To estimate the cost savings of aftermarket parts for ADAS systems, we surveyed 8 OEM's price differential for electronic parts (I specifically surveyed GM, FCA, and Mercedes). The prices for components such as ignition coils, mass airflow sensors, and ABS wheel speed sensors were gathered from each OEM's website and then compared against the prices listed on Advanced Auto Parts and AutoZone.

We expected a material cost advantage in the aftermarket which is why businesses like Advanced Auto Parts and AutoZone exist, but we also discovered that there is a high variance between aftermarket pricing from OEM to OEM as shown in Figure 5. For example, there is a 71% price advantage for buying aftermarket parts for Nissan vehicles, but only a &% price advantage for GM vehicles.

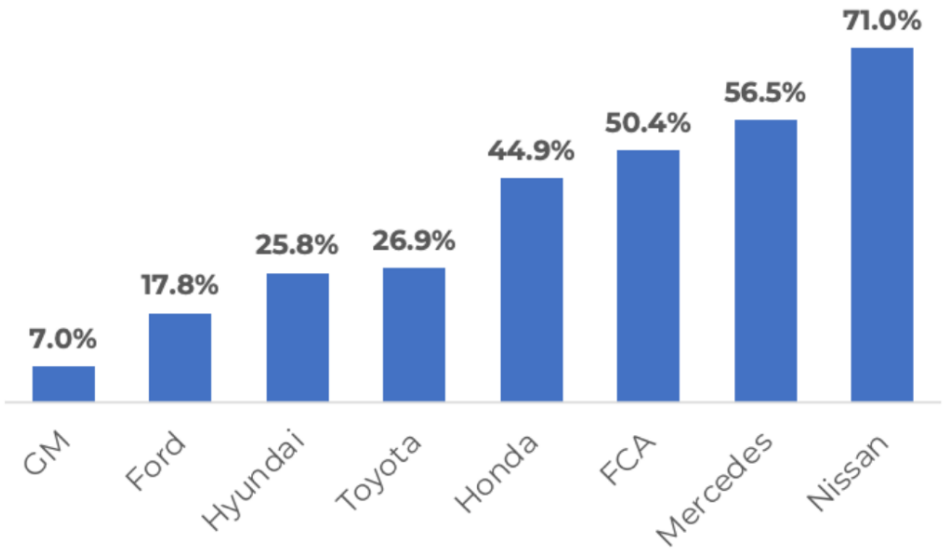


Figure 5: Cost Advantage of Aftermarket Part vs. OEM Part

We studied these cost differences to understand the consumer opportunity with choice in ADAS parts in the future. When we volume-weighted the cost advantage with the percentage of vehicles of each OEM, we can confidently estimate a 26.3% cost advantage on average when electronic components are procured in the aftermarket versus obtaining them from an OEM Dealership.

Aftermarket Shop Surveying

We surveyed over 250 mechanical repair and over 200 collision repair shops to get a look at how ADAS is serviced in the aftermarket today. Excluded from this

survey were OEM dealerships as well as collision shops affiliated with OEM dealerships. The survey was designed to be geographically and shop size neutral.

To make sure our sample wasn't biased, we compared a few statistics such as the average number of bays and the average number of technicians against the published values in the Auto Care Factbook.[4] We also used the Auto Care factbook to learn that there are roughly 35,000 independent collision repair facilities and 6,400 facilities that are operated in affiliation with an OEM dealership, and 81,000 general repair and 6,400 specialty repair shops. Since we are focusing solely on the automotive aftermarket, these figures exclude OEM-based service shops.

We gathered several interesting results from our surveying. We first asked shops whether they perform any ADAS component replacement and/or calibration. The results are shown in the graphs in Figure 6 and divided by type of shop and number of bays.

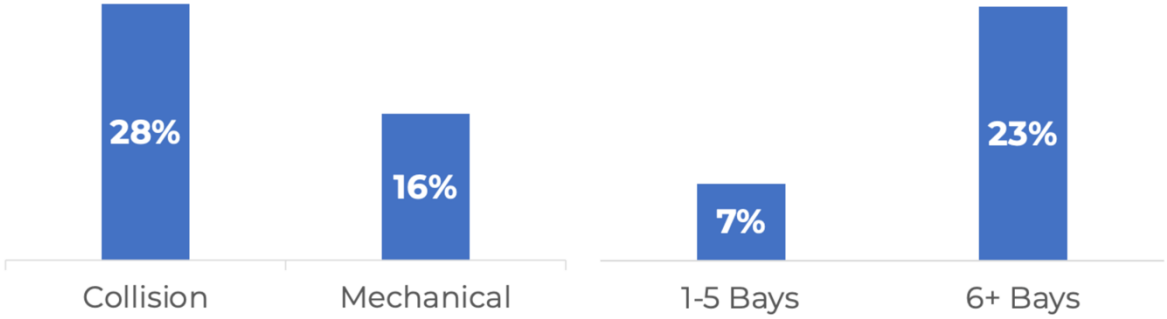


Figure 6: Survey Results to Question of "Do You Perform ADAS Component Replacement and/or Calibration?"

These results show that a larger percentage of collision shops service ADAS, but the overall service rate is still relatively low for both. These results also show that an incredibly low number of small shops (with 1 to 5 service bays) service ADAS and less than 1 in 4 large shops (with 6 or more service bays) service ADAS. When asked why they don't service ADAS, there were three primary answers: "it's too expensive", "we don't see the demand yet", and "it's too difficult to learn".

Performing ADAS component replacement and/or calibration not only requires shops to acquire the necessary and expensive tools and equipment, but it also requires that shops have a large space to perform the calibrations as shown in Figure 7. This creates a problem for small shops that only have a couple of service

[4] Auto Care Factbook, https://www.autocare.org/data-and-information/market-research/Auto-Care-Factbook

bays to begin with. We asked the shops that serviced ADAS systems if they have dedicated bays for ADAS calibrations. The results are presented in Figure 8.

Figure 7: ADAS Component Alignment and Calibration System[5]

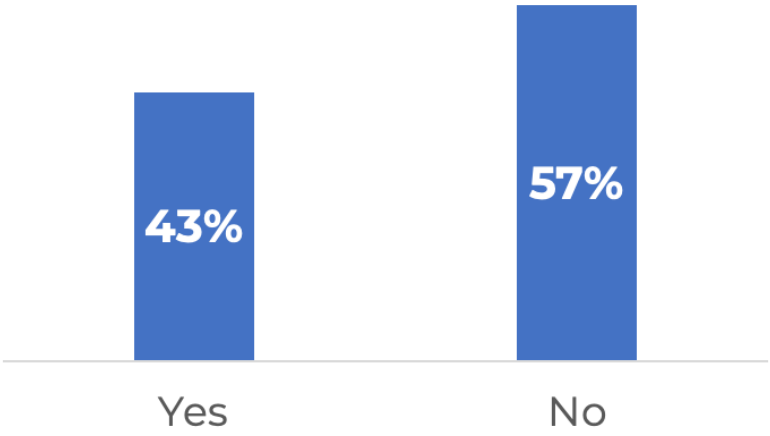


Figure 8: Survey Results to Question of "Do You Have A Dedicated Bay for ADAS Component Replacement and/or Calibration?"

These results show that less than half of the shops currently servicing ADAS systems have dedicated service bays for ADAS.

Since a large number of these shops are unable to service ADAS, the final question we asked them is about what they do if they receive a car that needs an ADAS component serviced. The results are shown in Figure 9.

[5] Brand new ADAS calibration set introduced by Bosch, https://garagewire.co.uk/news/company/bosch/brand-new-adas-calibration-set-introduced-bosch/

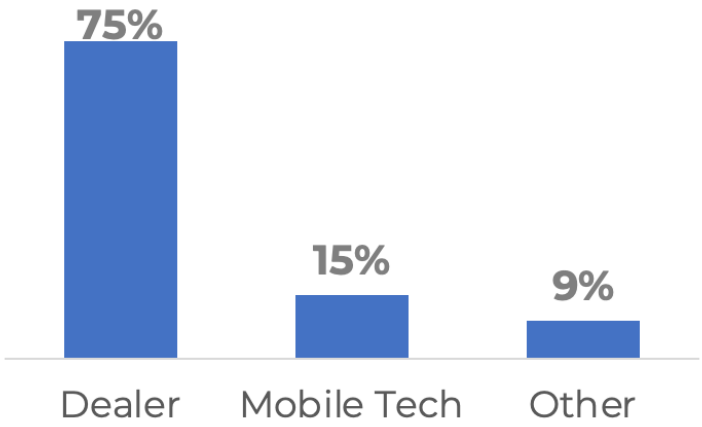


Figure 9: Survey Results to Question of "Where Do You Send Vehicles that Require ADAS Service?"

Given the current low volume of ADAS repairs, especially in the mechanical channel, it was not a surprise to see most of the work that is needed is sent to the dealer.

Consumer Behavior

There are two dimensions to the problems being faced in the ADAS space. Most of this report, and this project as a whole, has focused on the repair ecosystem. However, it is also important to observe the behaviors of vehicle operators. Although OEMs are moving rapidly toward broadening the ADAS content on new vehicles, most vehicles on the road today do not have these systems beyond the mandated rear camera and park assist.

In a recent study, 65% of drivers indicated awareness that they can disable ADAS features, and 70% of them have, citing three concerning reasons:[6]

- 41% believe they weren't working
- 41% stating they were distracting
- 30% stating they are not needed

Additionally, Insurance Institute for Highway Safety (IIHS) researchers found that drivers in vehicles featuring adaptive cruise control and lane-centering sped at a 24 percent greater rate than drivers without these features.[7] The behavior of consumers regarding ADAS and their safe operation is quite concerning and leads us to believe that unperformed maintenance will become endemic as ADAS systems age. Without intervention, the true safety benefit potential of ADAS may never be realized.

[6] CCC Crash Course, https://cccis.com/crash-course-2021/

[7] Speeding behavior while using adaptive cruise control and lane centering, https://www.iihs.org/topics/bibliography/ref/2222

VALUE CREATION OPTIONS

Based on the results from the current state analysis, we identified three target problems areas:

- **Target 1:** Cost of ADAS Repairs
- **Target 2:** Shop Competency in ADAS Service
- **Target 3:** Consumer Usage of ADAS

Solutions for each of these targets were brainstormed by using one or more of the lenses from the Competing Values Framework.

Blue (Compete) Value Option

Target 1, the Cost of ADAS repairs, will be assessed using two of the lenses, blue and yellow. The Blue Quadrant is all about speed and short-term focus. The fastest way to deliver value creation is to simply buy or partner with a competency you need. It is the competitive quadrant; results need to be shown rapidly or the endeavor gets scrapped. To deliver value in this quadrant means putting together highly focused teams with the resources required to deliver their goals.

We believe that the aftermarket could experience immediate relief in the cost of repairs, specifically the cost of parts, by enabling more parts from more sources to come to market. In the area of safety-critical components, like ADAS, these parts would only be widely adopted if the repair ecosystem was convinced they were safe. A trusted source of critical parts could be delivered via a certification program, similar to those previously discussed in section two of this report. Through the Blue "Speed-Focused" lens, forming partnerships with entities already immersed in certification activities would deliver the optimized approach to reducing parts cost.

One major concern we have with this Blue Quadrant approach is the lack of precedent in the aftermarket. While certification of components is well known and utilized in the collision space, in the mechanical space the examples are few. However, there are several different entities capable of providing partnership for such an initiative if we were to move forward with this initiative. (I personally researched these, but they are out of the scope of this report – see Appendix F if interested).

Overall, we feel that partnering with an experienced certification firm offers speed and risk mitigation, but there are no clear precedents to offer confidence in a path forward. Experimentation would be critical prior to incorporating partnerships as a core strategic initiative as is the presence of a supportive regulatory framework.

Yellow (Collaborate) Value Option

We also used the Yellow lens to brainstorm solutions to Target 1. The Yellow Quadrant of organizational value creation is oppositional to Blue and focuses on sustainable actions with a long-term focus. As it is collaborative, speed is sacrificed for a better community endeavor. Collaboration takes time to achieve buy-in, and profitability often suffers as it isn't prioritized over the achievement of the betterment of the community. Applying established practices from other ecosystems is a particularly powerful Yellow exercise.

A different approach to certification via partnership would be an open collaborative model. The Yellow Quadrant is where open collaborative models are dominant because a long-lasting and sustainable community benefit is the primary goal, not profit.

We believe that certification via partnerships would be an open collaborative model. One successful implementation of this would be to set standards that are published, and then allow the community of the supply base to self-certify their compliance with those standards. These standards would become adopted legislation and, thus, it becomes illegal to sell a product that does not meet the specifications of the certification mark.

This model appears to work in Europe, but there is also a recently discovered problem with this approach in the U.S. Self-certification, in the form of having a "registered" class of automotive parts, was attempted by National Sanitary Foundation (NSF) in the last five years, with that program being discontinued in 2019. They had so much trouble enforcing the presence of the NSF certification mark, that they offered distributor certification to solve the problem of distributors not delivering the certified parts that had been ordered by the repair shop.

Overall, we feel that open collaborative models for certification have potential merit as a low-risk option, but they face the challenge of demand in mechanical shops which is uncertain.

Green (Create) Value Option

For Target 2, the Shop Competency in ADAS Servicing, we used the green lens to brainstorm solutions. The Green Quadrant creation is what is typically thought of as innovation. This is the WOW!, would that work?, Elon Musk-type Quadrant. This is high-risk, high-reward so bets must always be hedged when activating in the Green space. Google's "Moonshots" division is a great example of running multiple high-risk experiments for future advantage and Amazon often talks of "wandering" in a space on problems worth solving as key to their ability to continuously deliver new value propositions.

We believe a technology-enabled platform for technical training on ADAS systems is an opportunity worth considering. Training on ADAS systems is fragmented and the major of the long-recognized training entities do not yet have training specific to ADAS. There are dozens of "training" programs available, but none developed specifically for the technician. In fact, the primary path of a technician receiving knowledge about ADAS is not through traditional educational sources, but through YouTube videos, webinars and on-site hands-on training by mobile technicians or the rare entrepreneurial shop that holds sessions in the ADAS equipped bay in the evenings. We think there is a market need for targeted certification training on ADAS technologies, and an opportunity to rethink how training is delivered to the working technician.

One problem with this is that a lot of technicians either don't have the time or the desire to learn about new systems that they aren't having to work on yet. This challenge, however, provides a unique opportunity to experiment with new methods of delivering training (interactive modules/videos, integrate within work already being performed, financial incentive, etc.) and to rethink how the benefits of training are marketed to technicians.

Overall, we feel that this is an out-of-the-box thought that utilizes new technology in a new space, and forges new dimensions of a relationship with the aftermarket. It might be a bit of a strategic stretch, but perhaps it is worth a few inquiries with shops willing to try it.

Red (Control) Value Option

Lastly, we brainstormed ideas for Target 3, Consumer Usage of ADAS, using the Red Lens. The Red Quadrant is based on standards and processes. The approach tends to take patience to execute, as value creation here is made of many incremental steps, rather than leaps forward. An integrated organization that slowly builds competencies needed for the future is dominant in Control value creation.

We believe that parts could be best assured safe and compliant if there were regulatory bodies (NHSTA, SAE, etc.) creating standards for the parts to achieve. These standards would ensure that the aftermarket part must comply with the standard and that the standard is required for parts to be introduced into the aftermarket. These regulations would ensure that any certification program would have to meet the standards.

The significant downside to this approach is that these regulatory bodies move quite slowly and will require years of lobbying efforts to become enacted.

Overall, we feel that this is the least risk, most complete way to accomplish certification adoption and resulting safety is through regulation. This path will take a significant amount of time and require years of effort to accomplish, but it is necessary since the aftermarket repairer and customer will likely only adopt certified repair parts and calibration if the repair meets regulated levels of quality.

RECOMMENDATIONS

After analyzing the various value creation options, we developed three distinct recommendations for the client that align with each of the three targets.

Protect Vehicles via Inspection

Our first recommendation is for the client to pursue an initiative that mandates regular ADAS system inspection. In Germany, for example, passenger vehicles are subject to mandatory safety and emission inspections every two years. There is no inspection mandate in the U.S., which for the most part has been sustainable. Most drivers can tell if their headlamps or door locks are not working and then send their car to get fixed. With many of the ADAS systems, however, drivers will not be able to tell when and if they are not working, making it critical for safety reasons that they are inspected regularly. The benefits of an inspection mandate are two-fold; not only does it ensure that consumers are safer, but it will also drive significantly more ADAS service volume to the aftermarket since the OEM dealer networks will not be able to handle every inspection. This increased demand will help shops justify the cost of purchasing the necessary ADAS service equipment and incentivize aftermarket part producers to spend more resources on producing specification-worthy parts.

Certify Technicians to Service ADAS

Our second recommendation is for the client to develop a certification program that is accessible, noticeably beneficial to the technicians, and integrates better into their work-life environment. Certification will be necessary eventually given the complexity and variety of ADAS repairs and calibrations, but if the training can achieve these objectives, then it will help technicians get trained proactively out of interest instead of reactively out of necessity. The more technicians that learn how to service ADAS, the more reliant and successful the aftermarket will be in 2025 and 2030.

Pursuit of Regulatory Framework

Our third recommendation is for the client to lobby for regulations so consumers cannot turn off ADAS systems on their own. As more of these systems are installed on vehicles, they will continue to become more interconnected and more reliant

on each other. Thus, turning off one system may inadvertently impact the performance of another. ADAS pass rigorous performance tests and have an outstanding track record of avoiding accidents, so given the consumer trends we observed towards unsafe driving behavior, we believe that this regulation is necessary or the safety capabilities of ADAS may never fully be realized.

Going Forward

These recommendations, while backed by research, data, and theory from leaders with extensive experience in the automotive industry, are not set in stone. They will continuously need to be re-evaluated and may need adjusting based on updated consumer trends, technology, regulations, and client goals. The automotive industry will continue to create new, exciting, and safe transportation for consumers, but without a successful structure in the automotive aftermarket, these innovations will eventually collapse. Our recommendations will help the client position the automotive aftermarket to thrive for years to come.

CONCLUSION

The Recommendations section above is the formal conclusion of the project, but I wanted to add an additional ending for my Honors Capstone.

What I Learned

I honestly learned so much from working on this project this semester, but there are two lessons that I wanted to share.

The first is the automotive industry. I've always had a passion for cars but never much experience with them other than growing up with parents that work at GM. This project was not only a great introduction to the industry but also showed me a whole different side that I never even thought much about. The automotive aftermarket is huge, and it was fascinating to see how small changes made by OEMs can significantly impact the aftermarket. I think this is a great lesson in thoroughly trying to investigate the full impacts of any engineering decision and one that I will continue to remember in automotive, and non-automotive, projects in the future.

The second was working in a diverse team. To be fair, many of the teams I have had the pleasure of working with over my college career had been diverse but held together by a common factor. In college, most of that has been a similar degree (IOE) or similar background (engineering). This project allowed me to work on a team with a different measure of diversity: one of different backgrounds, levels of experience, and unique expertise held together by an interest in cars. I

believe that I will continue to experience this as I pursue a career in consulting, but it was nice to get a taste of what it will be like while I am still in college.

Thank You

I wanted to thank everyone who was involved with this project. I'm very fortunate for the opportunity to pursue this project with Prof. Jeff DeGraff. I've come to learn that he is a big deal in the world of Innovation, so I am grateful for him for finding the time and providing the resources for me to be able to do this with the Innovatrium. I also wanted to thank the rest of my team members and project leads for putting in tremendous effort and making this project a success. And, finally, I want to thank my Honors advisors, faculty, and friends for this incredible program. I have really enjoyed my time in Honors, and I will always look back happily knowing that I decided to join the Engineering Honors Program.

Go Blue!

APPENDIX A: BIOGRAPHIES

I, **Robbie Elliott,** am a senior from Waterford, Michigan studying Industrial & Operations Engineering at the University of Michigan with a minor in business. I will be graduating with a Bachelor of Science in Engineering in December 2021 but will stay at Michigan for three additional semesters to earn my master's in Industrial & Operations Engineering as well. Next summer, I will be interning at McKinsey & Company as a Summer Business Analyst in Miami, Florida. Given my plan to pursue a career in consulting and love for cars, there couldn't have been a more perfect project for his Engineering Honors Capstone.

Jeff DeGraff is both an advisor to Fortune 500 companies and a professor at the Ross School of Business at the University of Michigan. His simultaneously creative and pragmatic approach to making innovation happen has led clients and colleagues to dub him the "Dean of Innovation." He has written many books, including Leading Innovation, Innovation You, The Innovation Code, and The Creative Mindset. Jeff's thoughts on innovation are covered by Inc., Fortune, and Psychology Today amongst others and he has a regular segment on public radio called The Next Idea.[8]

[8] Innovatrium, https://www.innovatrium.org/our-team/

APPENDIX B: LONG RANGE RADAR

How It Works

RADAR, which stands for Radio Detection and Ranging, works by emitting electromagnetic waves that reflect off obstacles they encounter and bring back information about the object's location and speed when they return to the receiver as shown in Figure 10.

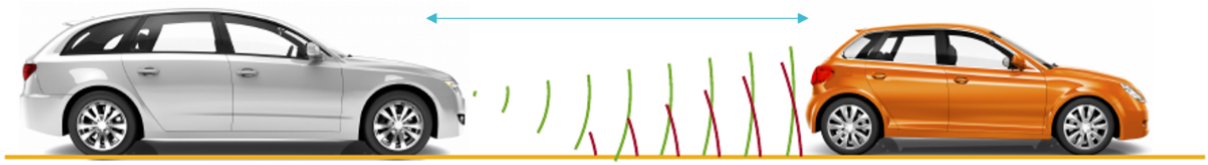


Figure 10. RADAR Wave Reflection[9]

This system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, a transmitting antenna, a receiving antenna (which is often the same antenna used for transmitting and receiving), and a receiver and processor to determine the properties of the object(s).[10]

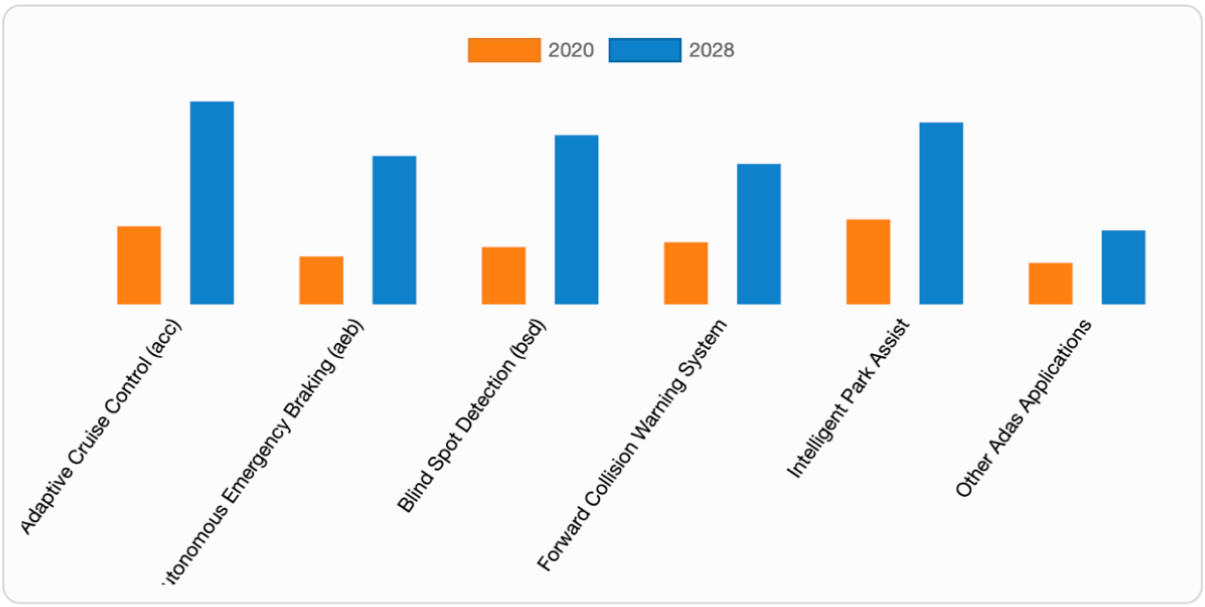
Long-range RADAR functions by detecting objects at far distances (200-300 meters) and achieves this by amplifying higher frequency waves (around 77 GHz). Currently, they are used in technologies such as adaptive cruise control, collision avoidance, and emergency brake assist systems, but as autonomous vehicles continue to develop, new technologies will rely more on long-range RADAR.[11] The diagram in Figure 11 shows the use of RADAR systems by application in 2020 car models compared to the projected use in 2028, and the diagram in Figure 12 shows the use of RADAR systems by frequency in 2020 car models compared to the projected use in 2028.

Capabilities/Specifications

Much of the reason why RADAR has become widely used (beyond its relatively low cost) is due to its range of capabilities. Like its autonomous technology counterpart LiDAR, RADAR provides a lot of information about objects in an environment including location and speed. However, RADAR can perform these

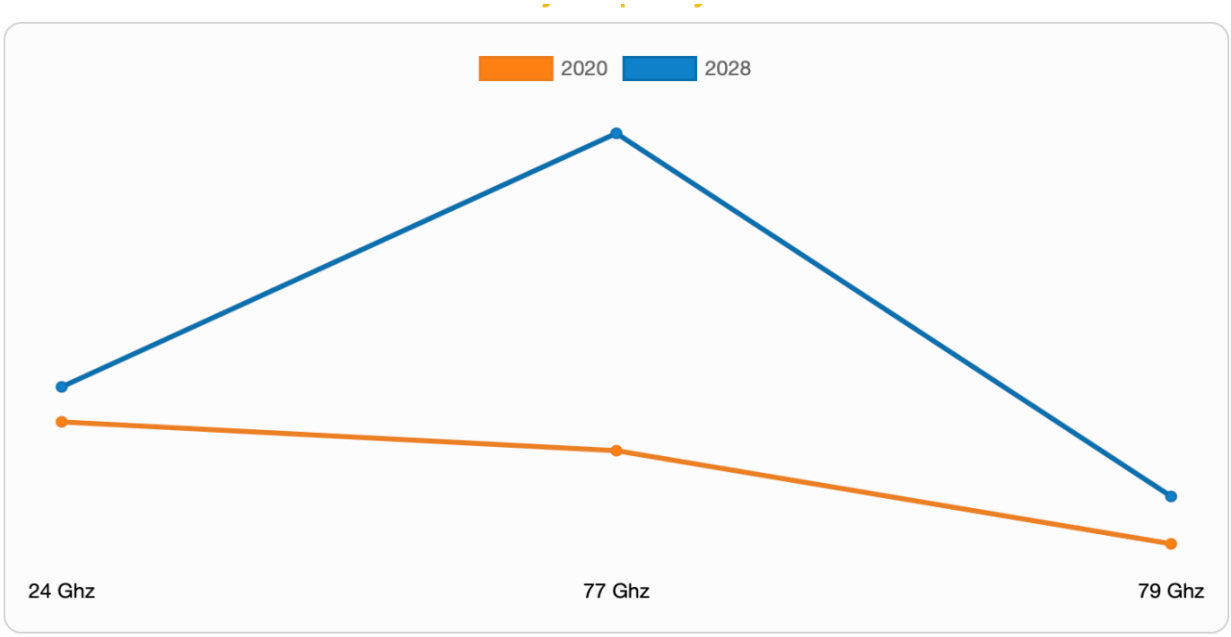
[9] How RADARs Work,: https://medium.com/think-autonomous/how-radars-work-1eb523893d62
[10] LiDAR vs RADAR for Applied Autonomy, https://semcon.com/offerings/applied-autonomy/lidar-vs-radar-for-applied-autonomy/
[11] High-tech solution for anticipatory driving: 20 years of Continental long-range radar in series production, https://www.automotiveworld.com/news-releases/high-tech-solution-for-anticipatory-driving-20-years-of-continental-long-range-radar-in-series-production/

functions properly in varied conditions and environments like rain and fog which LiDAR cannot. Figure 13 shows a comparison of RADAR vs. LiDAR.



Adaptive Cruise Control (ACC) segment is projected as the most lucrative segment

Figure 11. Automotive RADAR Market by Application[12]



77 GHz segment projected as the most lucrative segment

Figure 12. Automotive RADAR Market by Frequency

[12] Allied Market Research: Automotive RADAR Market, https://www.alliedmarketresearch.com/automotive-RADAR-market

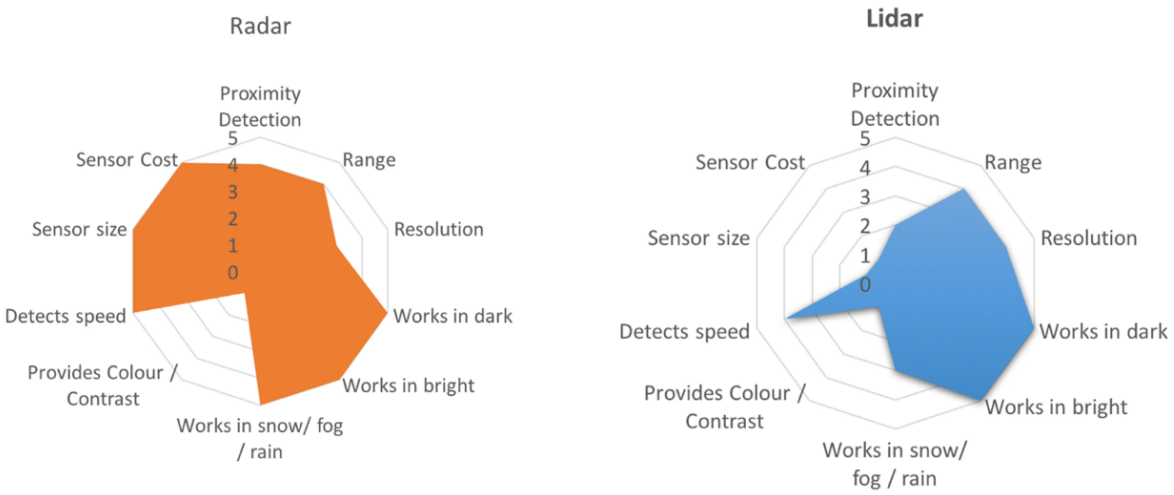


Figure 13. RADAR vs. LiDAR

Additionally, RADAR systems have the ability to be highly precise at a variety of distances, of which long-distance is necessary for autonomous environment mapping.[13] Continental recently developed a long-range RADAR that can gather accurate information on objects over 300 meters away. Other companies are developing RADAR systems that are smaller and cheaper for the ever-expanding automotive applications.

Who Supplies Them to OEMs Today?

The automotive RADAR market is projected to reach a market size of USD 6.61 billion by 2021. The automotive RADAR market consists of various major system and chip manufacturers. Companies such as Robert Bosch GmbH (Germany), HELLA KGaA (Germany), Continental AG (Germany), Denso Corporation (Japan), Delphi Automotive PLC (U.K.), Autoliv Inc. (Sweden), and Valeo S.A. (France) are the system manufacturers and companies such as Infineon Technologies AG (Germany), NXP Semiconductors N.V. (The Netherlands) are the chip manufacturers in this market.[14]

How Are They Validated?

RADAR is primarily validated through simulation systems in controlled laboratories. One group that conducts these tests is dSPACE Automotive RADAR Test Systems (DARTS). With DARTS, radar sensors can be tested in the laboratory in clearly

[13] MMW Radar-Based Technologies in Autonomous Driving: A Review, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7766872/
[14] Markets and Markets: Automotive RADAR Market, https://www.marketsandmarkets.com/Market-Reports/automotive-radar-market-75536718.html

definable, reproducible scenarios. DARTS simulate object reflections that occur in road traffic at different distances, speeds, and sizes in real-time.[15] These systems receive the signal from a radar sensor, generate an internal echo, and return it to the sensor which allows the RADAR sensor to be operated and tested exactly as in a real environment.

Another method of RADAR validation is with a camera. In this approach, RADAR data and images are taken simultaneously and then compared against one another.[16] This is particularly useful because the power of cameras and RADAR in autonomous vehicles is improved when used together.

[15] dSPACE Automotive RADAR Test Systems, https://www.dspace.com/en/ltd/home/products/systems/darts.cfm

[16] Ainstein: Successful demonstration of AI-based camera and radar cross-validation with 77 GHz Automotive Safety Radar, https://ainstein.ai/ainstein-demonstrates-cross-validation-between-camera-and-automotive-safety-radars/

APPENDIX C: VISUAL CAMERA-BASED SYSTEMS

How It Works

Camera use in cars is not a novel idea – the first rearview camera was introduced on the 1956 Buick Centurion XP-301 Concept[17]. Over the last 65 years though, the technology of cameras and cars has changed significantly, and, subsequently, the use of cameras in cars has developed as well. Today, cameras are used in numerous applications, the majority of which are highlighted in Figure 14: night view, driver recording, driver monitoring, ADAS, eMirror/blind spot detection, cabin monitor, and rearview.

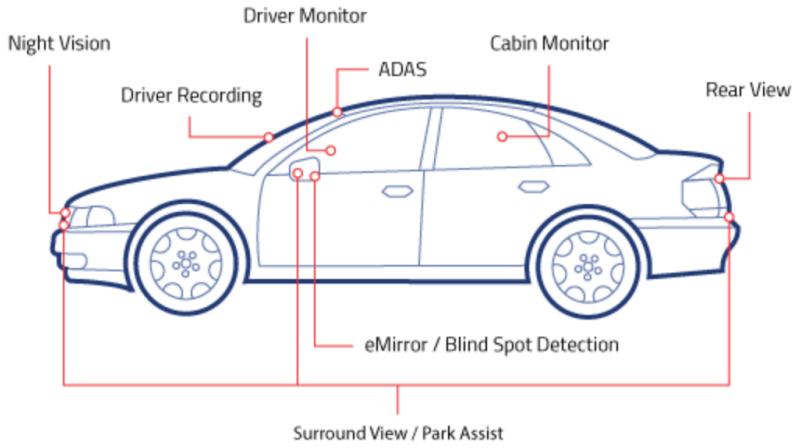


Figure 14. Machine Vision and Display Based Applications[18]

The modern use of cameras in cars can be broken down into three primary purposes: safety, surveillance, and autonomy.

- *Safety:* Safety was the first purpose for widely introducing camera use on cars. This system was developed primarily through the rearview "backup" camera which works by placing a rear-facing camera on the back of a car and a screen in the center counsel for viewing. The goal of implementing this technology was to help reduce the accidents, injuries, and fatalities caused by drivers reversing into objects and people. Before backup cameras were legally mandated to be installed on every new car in the U.S. in 2018, nearly 300 people were dying annually in the U.S. from backup collisions (31% of fatalities were children 5 years or younger and 26% of fatalities were adults 70 years and older).[19] Cameras have also been more

[17] Why the 1956 Buick Centurion Was the Car of the Future, https://www.motorbiscuit.com/why-the-1956-buick-centurion-was-the-car-of-the-future/
[18] OmniVision: Automotive Imaging, https://www.ovt.com/automotive-imaging/overview
[19] Are backup cameras required on new vehicles? (Updated), https://www.autoinsurance.org/are-backup-cameras-required-on-new-vehicles-updated/

recently introduced in mirror systems (even mirror replacements on the McLaren Speedtail and Koenigsegg Gemera) to help with blind-spot detection to reduce the number of accidents.

- *Surveillance:* The 2018 Automotive Trends Report found one major similarity among consumers across the U.S., Germany, and Japan automobile markets – the desire for more cameras.[20] In this digital age, consumers want to record what goes on while they are driving (for personal interest, court evidence, insurance claims/benefits, etc.) and they want camera technology to assist them as a "second pair of eyes". OEM designers have listened to this customer input, and now have numerous new applications to provide drivers more visibility over their vehicles. Through night vision, driver recording, driver monitoring, cabin monitoring, and 360° view[21] systems, drivers can more easily park, maneuver trailers, go off-roading, and record laps on a racetrack. OEMs are also using camera surveillance systems as a competitive advantage and are marketing their vehicles accordingly.[22]
- *Autonomy:* The use of cameras in future ADAS systems is almost as certain as the autonomous future of automobiles itself. Most of the early and current adoption of ADAS systems relies heavily on RADAR and LiDAR technologies. However, those systems are very costly and, thus, make the scale and affordability of ADAS-enabled automobiles more difficult. A 2020 study conducted by researchers at Cornell University discovered that a stereo camera (a camera with two or more lenses that simulates human binocular vision giving it the ability to capture three-dimensional images[23]) can be a viable and low-cost alternative to LiDAR.[24] Tesla fully believes this idea which is reflected by their new Tesla Vision autonomous system comprised entirely of cameras. Other OEMs may be hesitant to go all-in on camera-based autonomous systems, but as ADAS continue to develop, cameras will likewise continue to be used in different forms.

Capabilities/Specifications

The capabilities of modern cameras are remarkable. They continuously improve their ability to capture high-quality pictures and videos which, in turn, expands the capabilities of their uses. Based on the design, cameras can specialize in

[20] Auto trends 2018: In-car cameras heat up as drivers embrace video, https://www.thinkwithgoogle.com/consumer-insights/consumer-trends/2018-auto-video-trends/
[21] 360-Degree Surround View Cameras: How Do They Work? | Ride Tech, https://www.youtube.com/watch?v=xqWkJJOcU4g
[22] Chevrolet: Silverado Camera Technologies, https://www.chevrolet.com/trucks/silverado/camera-technology
[23] What is a Stereo Camera?, https://www.vmresource.com/camera/cameras-general.htm
[24] Pseudo-LiDAR from Visual Depth Estimation: Bridging the Gap in 3D Object Detection for Autonomous Driving, https://arxiv.org/pdf/1812.07179.pdf

capturing content at different distances and widths. This is imperative for the variety of implementations in ADAS. The diagram in Figure 15 summarizes the types of exterior cameras used on current Tesla automobiles, but many of the other OEMs follow a similar arrangement.

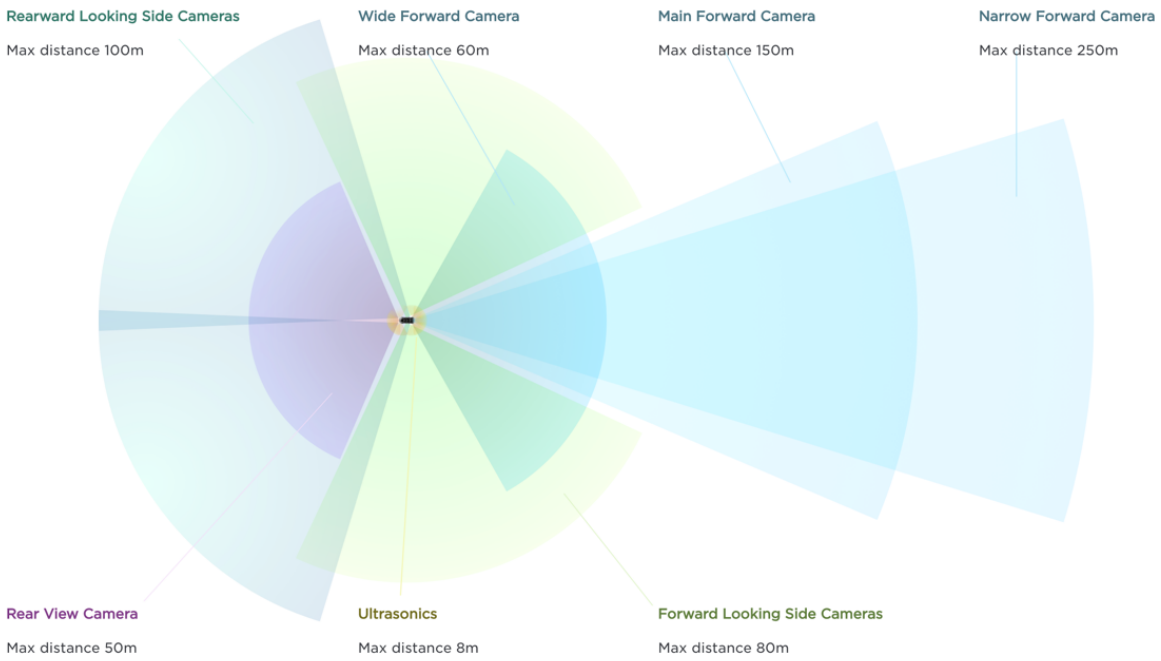


Figure 15. Tesla autopilot camera sensors[25]

Rearview cameras are the shortest viewing distance with up to 50m of range; forward-looking side cameras have the widest viewing angle and when combined with rearward-looking side cameras capture a full 360° view of the car up to 80m; the narrow forward camera has the smallest viewing angle but the longest viewing distance at 250m; the wide forward cameras and main forward camera provide more visual data closer to the front of the car.

As previously mentioned, the Cornell University study determined that stereo cameras can be used in place of LiDAR in autonomous systems. Cameras will continue to improve their capture quality, become smaller, and reduce in price, all of which suggest a strong adoption and dependence in future autonomous and ADAS-enabled vehicles.

Who Supplies Them to OEMs Today?

It is projected that the automotive camera market will reach a total of $19 billion by 2025. The primary companies in this market include Continental AG, Veoneer,

[25] *Tesla: Autopilot and Tesla Vision,* https://www.tesla.com/autopilot

Magna International Inc., Robert Bosch GmbH, Valeo, Denso Corporation, Aptiv PLC, and Mobileye. These camera providers are collaborating with the leading tech companies to develop systems that will be deployed in future vehicles.[26] [27]

How Are These Systems Validated?

Most of the systems are validated via test drives. The purpose of these drives is to expose the cameras and camera systems to as many of the scenarios that consumers would encounter to assess whether they function properly. In some cases, specific testing environments need to be artificially created. Another method of validation is "hardware-in-the-loop" where camera systems are connected to driving simulation software which allows for the detection of deficiencies in the early development phase.[28]

[26] Automotive Camera Market to Reach $19 Billion by 2025, https://epsnews.com/2019/06/13/automotive-camera-market-to-reach-19-billion-by-2025/
[27] Global Market Insights: Automotive Camera Market, https://www.gminsights.com/industry-analysis/automotive-camera-market
[28] Test Methodology for Vision-Based ADAS Algorithms with an Automotive Camera-in-the-Loop, https://www.researchgate.net/publication/328761692_Test_Methodology_for_Vision-Based_ADAS_Algorithms_with_an_Automotive_Camera-in-the-Loop

APPENDIX D: ANTI-LOCK BRAKING SYSTEMS (ABS)

When was the technology introduced?

The idea of ABS was developed nearly 100 years ago when French and German engineers were experimenting with anti-slip systems for airplanes and trains. Through the 1950s and 1960s, these systems were continuously refined and tested on motorbikes, Formula One cars, and jets. However, the collaboration between Mercedes-Benz and Bosch was the first mass-market introduction of ABS when it was officially introduced to mass-market automobiles via the 1978 W116 S-Class shown in Figure 16.

Figure 16. 1978 Mercedes-Benz W116 S-Class ABS Test Car

In a statement by Mercedes at the time of the launch, they said:

> *"The anti-lock braking system uses a computer to monitor the change in rotational speed of each wheel during braking. If the speed slows too quickly (such as when braking on a slippery surface) and the wheel risks locking, the computer automatically reduces the brake pressure. The wheel accelerates again and the brake pressure is increased again, thereby braking the wheel. This process is repeated several times in a matter of seconds".*[29]

The components of Bosch's 1978 ABS technology are pictured in Figure 17 below.

[29] Anti-Lock Brakes, the First Technology to Help You Avoid a Crash, Turn 40, https://www.roadandtrack.com/car-culture/car-accessories/a22811340/anti-lock-brakes-the-first-technology-to-help-you-avoid-a-crash-turn-40/

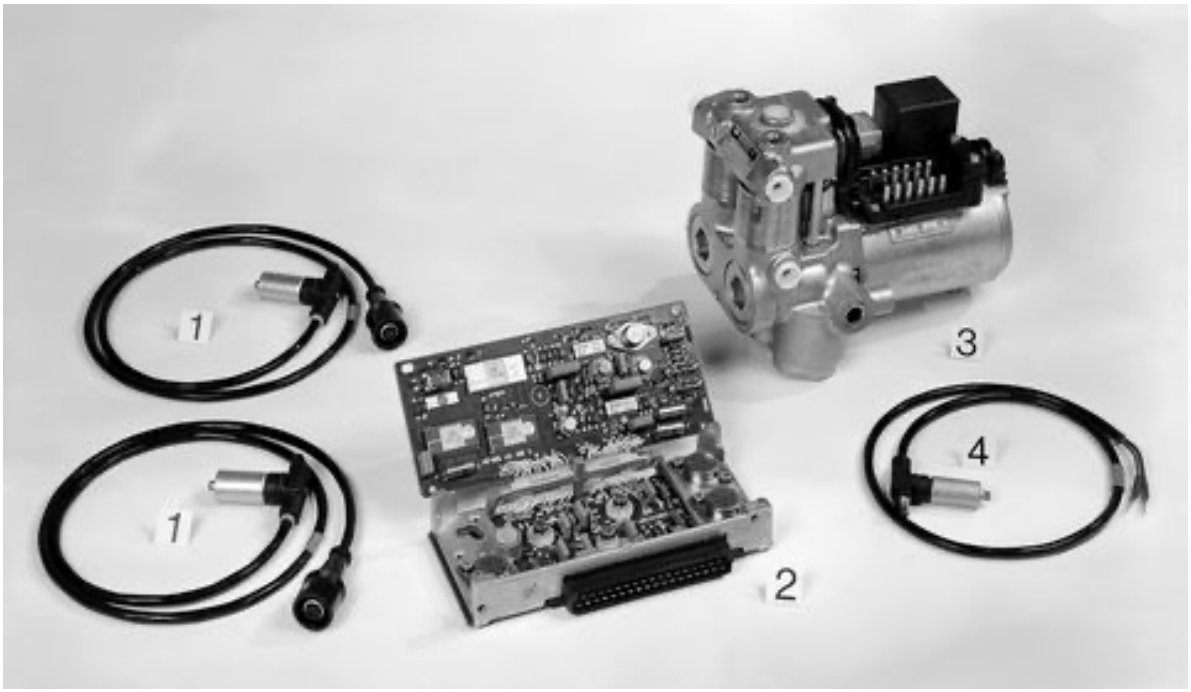


Figure 17. Bosch's ABS System from 1978.

ABS forces the brake pads to temporarily release the brake disc during periods of intense braking to prevent the brakes from locking. Doing this allows drivers to steer while braking and brake in a shorter distance. Over 40 years later, this technology has been adopted by every automobile manufacturer on the planet and is a standard feature in almost every new car. It has allowed drivers to avoid countless accidents and has saved many lives.

When were they mandated?

ABS has been mandated in the European Union since 2004, but it wasn't mandated in the U.S. until September 1, 2012. The National Highway Traffic Safety Administration (NHTSA) mandated ABS in conjunction with Electronic Stability Control (ESC) under the provisions of Federal Motor Vehicle Safety Standards (FMVSS) No. 126.[30] [31]

How are they specified?

ABS are specified federally by the NHTSA in the FMVSS No. 122.[32] There are specific standards for both automobiles and motorbikes including their capabilities and

[30] Are Anti-Lock Brakes a Mandatory Safety Feature?, https://drivetribe.com/p/are-anti-lock-brakes-a-mandatory-A_I2LRctSd2qJNWA6_RAOg?iid=CIms3ok1TDWL9uqOXseyDA
[31] NHTSA: Electronic Stability Control Laws & Regulations, https://web.archive.org/web/20160918065210/http://www.nhtsa.gov/Laws+%26+Regulations/Electronic+Stability+Control+%28ESC%29
[32] FVMSS No. 122, https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/tp-122-03_tag.pdf

how they are tested. The FMVSS also mandates that all vehicles follow the internationally recognized ABS symbol.[33] OEMs do specify, however, which of the three types of ABS (four-channel/four-sensor, three-channel/ three-sensor, and one-channel/one-sensor[34]) to place on which types of models such as SUVs vs. sedans.

[33] Federal Motor Vehicle Safety Standards; Motorcycle Brake Systems; Motorcycle Controls and Displays, https://www.federalregister.gov/documents/2021/01/08/2020-27375/federal-motor-vehicle-safety-standards-motorcycle-brake-systems-motorcycle-controls-and-displays

[34] Anti-Lock Braking System (ABS) Problems?, https://www.mobil.com/en/lubricants/for-personal-vehicles/auto-care/vehicle-maintenance/anti-lock-braking-system-abs-problems

APPENDIX E: AIRBAGS

When was the technology introduced?

The idea for a safety cushion assembly device was first developed and patented in the U.S. in 1953 by John Hetrick after a crash he was in with his family. Around the same time, Walter Linderer received a German patent for a similar device.[35] Both designs, however, lacked sensors that could tell the airbags when to deploy, so it wasn't until Allan Breed developed the airbag sensor in 1968 that airbags became a feasible safety feature.[36] Pressured by consumers and the government to make automobiles safer, airbags first appeared as an option in 1972 on the Mercury Monterey. This technology wasn't well adopted by the automotive manufacturers though, and by 1977, General Motors had stopped offering airbags as an option and lobbied with Ford against their requirement. Safety concerns did not cease, and by the late 1980s manufacturers started to design cars with airbags again.

When were they mandated?

In 1998, a Congressional law passed that mandated front dual airbags be installed in every new automobile. In the wake of the Takata AirBag Scandal[37], there have been some recent concerns about airbag fatalities, but according to the NHSTA, frontal airbags saved 50,457 lives between 1987 and 2017[38]. Today, there is no longer a question of if airbags should be standard equipment.

How are they specified?

Airbags are specified both federally by the NWSTA and by industry via the Society of Automotive Engineers (SAE). FMVSS No. 208 requires the placement of airbags within the vehicle and that airbags be engineered and calibrated to be able to save the life of an unbelted 50th percentile size and weight male.[39] SAE specifies the technical performance and validation requirements for the inflator assembly used in airbag modules in USCAR 24-2.[40]

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[35] Who Invented Airbags and When Were They First Introduced?, https://www.motorbiscuit.com/who-invented-airbags-and-when-were-they-first-introduced/
[36] Allen K. Breed, 72, A Developer of Air Bag Technology for Cars, https://www.nytimes.com/2000/01/14/business/allen-k-breed-72-a-developer-of-air-bag-technology-for-cars.html
[37] Takata Air Bag Scandal Timeline, https://www.usatoday.com/story/money/2017/06/25/takata-air-bag-scandal-timeline/103184598/
[38] NHTSA: Air Bags, https://www.nhtsa.gov/equipment/air-bags
[39] FVMSS No. 208, https://www.nhtsa.gov/sites/nhtsa.gov/files/nprm_208.pdf
[40] SAE: USCAR 24-2, https://www.sae.org/standards/content/uscar24-2/

APPENDIX F: CERTIFICATION PARTNERSHIP PROFILES

Intertek

Intertek Group plc is a multinational assurance, inspection, product testing, and certification company. They were founded in 1888 and are headquartered in London, England. They currently have 44,000 employees in 1000 locations in over 100 countries and had a 2020 revenue of £2,741.7 million (net income of £262 million). Intertek provides a systemic approach to supporting customers' Quality Assurance efforts in each of the areas of their operations including R&D, raw materials sourcing, components suppliers, manufacturing, transportation, distribution and retail channels, and consumer management.
https://www.intertek.com/

TÜV SÜD America

TÜV SÜD America is a trusted partner of choice for safety, security, and sustainability solutions. They provide value to their partners and customers through a comprehensive portfolio of testing, certification, auditing, and advisory services. They were founded in 1866 and are headquartered in Munich, Germany. They currently have 25,000 employees in 1000 locations and had a 2017 revenue of EUR 2.427 billion (EUR 216.7 million in earnings adjusted EBIT). The company America works in the following industries: chemical & process, consumer products and retail, energy, healthcare and medical devices, infrastructure and rail, manufacturing, mobility and automotive, and real estate.
https://www.tuvsud.com/en-us

SGS

SGS is a multinational company that provides inspection, verification, testing, and certification services. They were founded in 1878 and are headquartered in Geneva, Switzerland. SGS has more than 93,000 employees and operates over 2,600 offices and laboratories worldwide. Their 2020 revenue was CHF 5.6 billion with a net income of CHF 505 million. They ranked on Forbes Global 2000 (largest global companies) in 2015, 2016, 2017, 2020, and 2021. The company works in the following industries: agriculture and food, chemical, construction, consumer goods and retail, energy, finance, industrial manufacturing, life sciences, logistics, mining, oil and gas, public sector, and transportation.
https://www.sgs.com/

F2 Labs

F2 Labs is a full-service accredited regulatory testing laboratory with more than 25 years of experience performing EMC and Safety evaluations on an extensive

range of products. They have a fully accredited state-of-the-art safety testing facilities designed and set up for the testing and evaluation of electrical and mechanical products for certification approvals in the North American, European, and international markets. F2 Labs works in industries including electrical and mechanical safety, environmental testing, enclosure water and dust evaluation, and others across a wide variety of industries including automotive. They have facilities located in Maryland (headquarters), Ohio, and Indiana. There are no reputable sources of revenue, net income, or number of employees for F2 Labs, but they are a small company.
https://f2labs.com/

ICS Laboratories

ICS Laboratories, Inc. is an accredited third-party testing laboratory that specializes in the conformity assessment of personal protective equipment (PPE) for manufacturers and developers. They frequently work with clients throughout the entire product design, development, and release cycle offering insights into the best certification schemes, managing timelines, and ensuring timely finalization of certification projects. They were founded in 1995 and are headquartered in Brunswick, Ohio. They work in the following industries: sporting goods, construction, manufacturing, and general industry, emergency response, recreation and leisure, and defense and tackle. There are no reputable sources of revenue, net income, or number of employees for ISC Laboratories, but they are a small company.
http://www.icslabs.com/