Self-Driving Safety Report

2020

Content

03 Letter from CEO Logan Green

05 Introduction

07 Lyft's Safety Principles

10 Consumer Education

13 System Safety

17 Operational Safety

21 Operational Design Domain (ODD)

22 Object and Event Detection and Response
- The eyes of our cars
- The brain of our cars
- The knowledge of our cars

27 Fallback - Minimal Risk Condition

28 Validation Methods

31 Human Machine Interface

33 Cybersecurity

36 Crashworthiness

37 Post-Crash ADS Behavior

38 Data Recording

39 Federal, State, and Local Laws

40 Conclusion

41 Legal Disclaimer

42 Glossary of Terms

Letter from the CEO

Pioneering the future of transportation, together.

Lyft was founded in 2012 in part to use technology to radically shift the concept of personal transportation, becoming the first company to establish peer-to-peer, on-demand ridesharing. This was just the beginning of a movement to end car ownership and reclaim our cities that Lyft has been championing ever since.

Fast-forward to 2020, and we are speeding toward the next phase of transportation innovation – the era of autonomous vehicles. Lyft believes that self-driving cars will be critical to the improved transportation system of tomorrow, addressing the challenges we face on today's roadways, including congestion, environmental impacts, access inequality, and most importantly, safety. We stand firm that self-driving cars have significant potential to make our roads safer than ever before by dramatically reducing the tragic effects of human error.

Our vision for the future of transportation is centered around people, and not cars. We recognize that to center transportation around people will require self-driving cars to be available and accessible in the day-to-day lives of Americans. This will remain an aspiration if safety is not front and center. At Lyft, safety is fundamental to everything we do.

Which brings us to the Voluntary Safety Self-Assessment (VSSA) that you are reading today. This document provides a transparent overview of Lyft's overarching safety principles and details our approach and methodology to autonomous vehicle development and safety.

Ultimately, our goal for this VSSA is to deliver an objective framework for reference as we collaborate with the broader autonomous vehicle community, industry stakeholders and local, state, and federal policymakers and regulators to establish clear and transparent guidelines and regulations. Only together can we gain the public's trust and enable self-driving cars to deliver on their promise for safe, accessible, and environmentally sustainable transportation for the critical mass.

To gain that level of trust, we recognize that it must be earned. That's why we've developed a safety methodology and multi-staged testing protocol that allows us to first demonstrate our technology to be safe to ourselves, within controlled Lyft-owned testing environments, and then to regulators, as well as stakeholders, passengers and other road users. And since Lyft's focus on safety includes all types of transportation modes and road users, we think it is especially important to leverage this technology to address the safety of vulnerable road users, including pedestrians, bicyclists, and scooter riders. This is the path to public trust and adoption.

As we continue to champion the future of transportation, Lyft remains wholeheartedly committed to our original mission: to improve people's lives with the world's best transportation. It is important to note that self-driving technology will take time to evolve and it will take years or decades to be deployed at scale, across a wide range of geographies and environmental conditions. Even as self-driving cars become more prevalent, they won't be capable of doing all rides. Therefore, human drivers will continue to be a critical part of the Lyft platform and we are committed to our platform as a place to provide drivers with earnings opportunities now and for years to come.

With the acceleration of our autonomous vehicle fleet, Lyft has the opportunity to deliver one of the most significant societal shifts since the advent of the car. We do not take that responsibility lightly, and we intend to lead this next phase of transportation innovation with integrity, humanity, and strong execution, ensuring the safety of our riders and our communities every step of the way.

Together, we can make tangible progress toward realizing the future of transportation with self-driving cars steering the way toward safer streets and healthier cities, while also making traffic a thing of the past.

Sincerely,

Logan Green
Chief Executive Officer

Introduction

Today's transportation system has many challenges, including congestion, environmental impacts, access inequality, and most importantly, safety. In the 2018 calendar year, **36,560 people died on our nation's roads**, according to the National Highway Traffic Safety Administration (NHTSA), with basic human error contributing to 94% of the fatal crashes.

Yet society has largely internalized such a large number of motor vehicle fatalities as the unavoidable byproduct of our transportation system, and have come to accept these outcomes as an acceptably "safe" system. Consequently, only **modest, incremental progress** has been made in the last decade to increase vehicle safety and reduce the number of fatalities.

With the development of autonomous vehicle (AV) technology comes the long-awaited opportunity to significantly transform the entire transportation system for good. This change will be highlighted by advances in personal and public safety, comprised primarily of the potential for AVs to reduce the effects of human error. When combined with the benefits in mobility, accessibility, and emissions reduction, AVs can help shape cities of the future to serve people, and not cars.

Make no mistake — Lyft understands that for AVs to emerge as a mainstream transportation source, the public must first come to trust that the technology is safe and secure. That's why everyone involved with Lyft's self-driving division — from the operators and engineers to the data scientists and leadership — is dedicated to earning and maintaining the trust of regulators, stakeholders, passengers, other road users, and of course, the public at large.

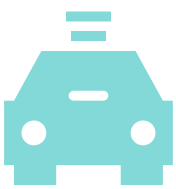
For the public to put its collective trust in autonomous technology, there is a need for transparent and understandable methods and metrics to demonstrate safety, which is a complex technical challenge in itself. We believe that simplicity in metrics is key to solve this challenge in a way that the public can see and understand. Currently, we are partnering with others to create the transparent and understandable safety framework needed to forge a way forward to quantify and demonstrate the safety of AVs.

Across transportation modes, Lyft is committed to improving safety for all, especially vulnerable road users (VRUs) such as pedestrians, bicyclists, and scooter riders. As we develop and deploy AVs, a priority focus is on VRU safety and how the vehicles can operate safely in an environment amongst a growing number of vulnerable road users that are increasingly reliant on walking, biking, and scooting in dense urban areas.

These ideas have shaped our AV program and brought us to our current state of testing and developing this technology. At this stage of development, Lyft's systematic safety approach includes the presence of human safety operators to reduce and mitigate risk. However, we fully expect to continuously advance the state of our technology to eventually operate without the immediate supervision of safety operators in the vehicle. This Voluntary Safety Self Assessment (VSSA) is intended to communicate our principled approach to AV safety, and to continue a forward-looking dialogue with regulators, legislators, partners, other stakeholders, and the public about the importance of this potentially safety-beneficial technology.

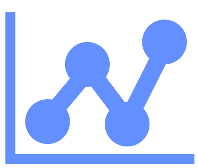
Lyft's Safety Principles

Safety is fundamental to everything we do. Because we want to focus on the outcome of increased safety, Lyft has established the following core safety principles that guide our autonomous vehicle program to help reduce all types of roadway risks:



Improve autonomous technology

Guard the safety of all road users



Quantify safety through metrics

Collaborate with others

Maintain trust

We will continuously seek to improve our AV technology to reduce the aggregate effect of human error on road safety by learning from experience and deliberately mitigating developmental risks.

Our current transportation system in the US today is far from perfect, and in fact no system is ever perfect. We have to strive for thoughtful and timely continuous improvement, and we believe that we can improve the transportation system by reducing the effects of human error that result in crashes. As we develop AV technology, Lyft believes it is critical to learn from experience as we systematically identify, understand, and resolve issues with this technology. We will strive to continuously mitigate risks and improve the technology through our systematic safety approach.

We will guard the safety of all road users, while attending to the uniqueness of vulnerable road users (pedestrians, bicyclists, scooter riders, etc.).

Walking, biking, and scooting are an increasingly important transportation mode in our cities and suburbs. Lyft envisions cities designed for people (not cars), including a continuous presence of pedestrian and micro-mobility road users. Lyft believes that vulnerable road users (VRUs) deserve special attention as we develop self-driving technology. We are convinced that the vigilance of sensors that don't have human characteristics, such as getting distracted or sleepy, is potentially powerful in preventing collisions with people. We will focus on these road users and hope to leverage our knowledge and experience on how people use micro-mobility devices in cities to aid our development of self-driving technology.

We will quantify safety through metrics, and when possible compare AV performance to aggregate human driver performance.

Lyft believes that establishing clear and understandable measures of safety for AVs is a critical step to earn the trust of our customers and stakeholders, including cities and states where we develop or intend to operate. To do that, we believe it is incumbent on industry developers to work with each other and with other stakeholders to develop simple, but meaningful, quantified metrics and methods to assure the safe operation of these vehicles. We also believe it is important to use these metrics, where possible, to compare to the performance of human drivers to understand societal outcomes for transportation safety.

We will collaborate with others to share safety best practices to improve safety for all road users.

Safety is a fundamental consideration in developing AV technology, and Lyft believes that we should work together with other developers and stakeholders to deliver on the safety potential of this technology. In truth, developing this technology is a significant technical and societal challenge, and AV developers and stakeholders must collaborate to establish and share best practices to further the safety of the transportation public. To that end, Lyft is committed to partnering with federal and state governments and other public and private stakeholders to implement the safe testing and deployment of autonomous vehicles.

We will maintain our customers’ and stakeholders’ trust in Lyft, and consider safety as critical to our decision-making process.

The safety of the millions of people using Lyft’s mobility platform has been fundamental to Lyft since its founding. We have worked hard to earn the trust of our customers and stakeholders by continuously improving the safety of the Lyft platform by developing innovative products, policies, and processes. Lyft’s approach to building an autonomous vehicle passenger service is no different, and customer safety and trust will always be the prime factors in our decision-making process.

Consumer Education

Since Lyft's founding, we have centered our platform around the safety of our users. Even before the first ride was given in 2013, we focused on building tools to help people get where they are going, and give them peace of mind about their safety. We're proud of our safety-first legacy and the standard for rideshare safety that it created, and we're applying this near decade of experience in rideshare safety to our autonomous future.

Rider safety and education is fundamental to our approach. Whether it's communicating with a rider on what to expect during a self-driving ride, providing in-car education, or offering riders multiple ways to provide feedback, we're focused on giving our riders peace-of-mind during every step of the self-driving journey.

Lyft's self-driving pilot program

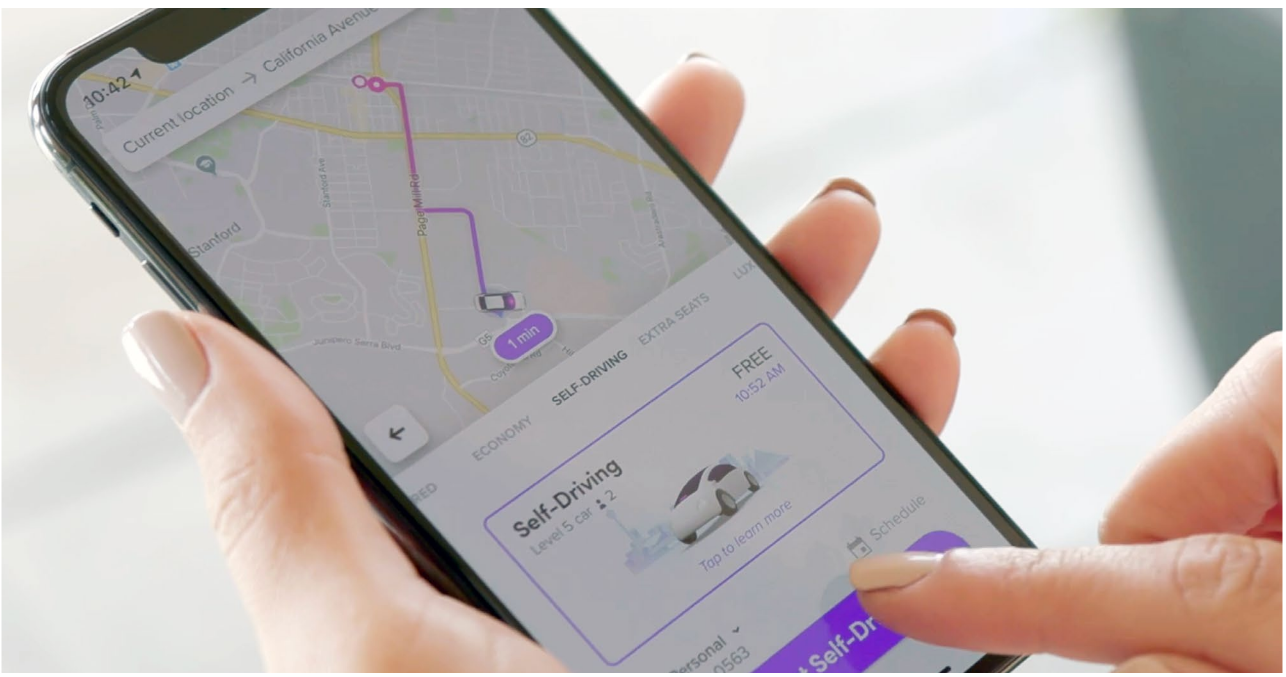
Our self-driving pilot program allows Lyft riders to engage directly with self-driving technology *today*, through the same Lyft app they already know and trust. Lyft riders in select markets are able to request a self-driving ride just as they would a standard Lyft ride, and offer feedback directly through their Lyft app. All pilot program rides include a safety operator in the driver's seat who is focused on safety at all times. Survey data shows this program allows consumers to gain a better understanding of self-driving technology. Ninety-five percent (95%) of riders in our Las Vegas, Nevada pilot are likely to take another self-driving ride in the future.

Our rider journey

Lyft's user experience is designed to help riders request self-driving rides seamlessly, understand the technology that powers the ride, and engage with the technology safely.

- **Before the ride:** Through the Lyft app and on the lyft.com/self-driving site, our riders can learn about the benefits of self-driving technology, as well as the basics of how and where they can experience it. They can also hear from real riders who have taken self-driving rides to help them better understand what to expect.
    - **Self-driving opt-in:** At Lyft, we believe the decision to try a self-driving ride should sit with the rider. All self-driving rides on our network are opt-in: A rider can always choose to use a standard Lyft ride instead of a self-driving ride.
    - **In-app education:** Before a self-driving ride is booked, the Lyft app educates the rider about key aspects of their self-driving ride, such as pick-up details and in-ride safety. This information is updated frequently as the technology evolves.

- **Taking a ride:**
    - **Verifying the vehicle:** Riders are provided with the same identifying information we provide for a standard Lyft ride, and prompted to verify that they are entering the correct vehicle.
    - **In-car education:** Once riders enter a self-driving car, Lyft's onboard display helps them understand the technology and how to engage with core safety features.
    - **Live support:** In addition to the in-car safety operator, a live support agent is always on call to assist with questions or issues that may come up, and can be reached either through the Lyft in-car app or through our critical response line. Should a safety-critical event occur, a critical response agent will provide riders immediate support and coordinate with third-party emergency personnel.
- **After the ride:** With teams spread across all time zones, we offer 24/7 support to our self-driving riders, even after their ride has ended.



Focus on accessibility

From day one, we have considered the accessibility of self-driving for all Lyft users. For example, we have partnered with the National Federation of the Blind to pilot self-driving rides with our blind and low vision users.

Partnering with the industry

Lyft partners with leading self-driving technology companies to deploy their AVs on our network.

As reflected in this approach, we believe that it's critical to collaborate with industry stakeholders to create a system that is safe, effective, and transparent. In fact, Lyft has been a leading force in establishing industry organizations that support safety and consumer education:

Lyft joined Partners for Automated Vehicle Education (PAVE) in February 2019 as a steering committee member.

Lyft joined the Automated Vehicle Safety Consortium (AVSC) in September 2019 to lead creation of industry standards.

Lyft is a founding and current Board member of the Self-Driving Coalition for Safer Streets, which works with lawmakers, regulators, and the public to realize the safety and societal benefits of self-driving cars.

Lyft works with first responders and local regulators in cities of operation to guide the safe movement of our fleet.

Lyft has partnered with the National Federation of the Blind to ensure blind and low vision consumers are included in the future of mobility.

System Safety

The development of autonomous systems requires a systematic approach to keep both passengers and road users as safe as possible. Unfortunately, no single definition or quantification of "safety" for AVs currently exists. With that in mind, Lyft aims to reasonably and deliberately mitigate both known and unknown risks.

We employ a robust systems engineering approach, including a focus on the safety of passengers and other road users. This starts with defining a safety case, a structured argument that our AV is safe to operate, that drives safety goals aligned appropriately to the development phase. This approach includes:

- Tightly defined and maintained operational design domain (ODD)
- Stable safety-based vehicle architecture
- Iterative and nimble multi-segment testing and validation process
- Continuous risk monitoring, assessment, analysis, and mitigation process

These safety goals drive system, subsystem, and component-level engineering requirements, which are tested and validated. We monitor the safety performance of our system through testing and simulation, and iteratively feed that experience back to inform our safety approach through our safety case. Lyft incorporates applicable principles and processes from existing industry standards and best practices, such as AVSC, SAE, ISO 26262, ISO 21448, as well as others. These standardized ideas from industry and stakeholders are important as they represent some of the best thinking of the industry as a whole.

Using novel processes alongside established tools and processes, such as hazard and risk analysis (HARA), fault tree analysis (FTA), and failure mode and effect analysis (FMEA), we:

- Theorize and identify possible hazards
- Analyze the likelihood that those hazards might occur
- Assess what level of severity these hazards present
- Mitigate severity and probability of occurrence of these hazards

In practice through iterative testing, our risk-based testing approach continually monitors for unknown, uncontrolled, or not-yet-identified risks – such as system faults in the self-driving system or the base vehicle, for example. Further, we maintain a safety envelope of vehicle performance so the system, including the self-driving control system and the safety operators, are always able to control the vehicle.

A safe, conservative approach to testing

We employ a systematic, multi-staged testing program that includes simulation, closed course, and on-road testing. We contend that a systems approach to autonomous development requires testing on public roads in challenging, real-world urban and suburban operational design domains (ODD). These dynamic ODDs are critical as they represent the hybrid mobility system of the future, where vehicles with dedicated automated driving systems will safely share the road with pedestrians, bicyclists, scooter riders, transit vehicles, emergency vehicles, and other road users.

At this stage of development, our systematic safety approach includes the presence of human safety operators to reduce and mitigate risk. When testing on public roads we always operate our AVs with a human safety operator and co-pilot to ensure complete coverage of all necessary tasks, as well as to maintain a constant state of vigilance.

These operators are carefully selected and highly trained. In addition, our AVs are equipped with numerous disengagement methods to maintain safe operations during self-driving test rides. Our safety operators are fully capable, ready, and technologically astute enough to control the vehicle. They are also trained to be conservative, and have full authority to disengage the driving automation system any time they judge that the safety of our operations, other human drivers, or VRUs are at risk.

These disengagement methods include the safety operator inputting signals into the vehicle's braking, steering, throttle, and other controls, as well as an emergency stop functionality. Additionally, the self-driving system self-monitors and can provide notification when it deduces that the safety operator should take control. This approach prioritizes the safe operation of the vehicle above all other considerations.

While we robustly test our system, we systematically record all disengagements — intended or otherwise — to understand their nature and root cause. To do so, we collect, bin, triage, and analyze this data extensively. This library of data drives our continuous iteration and rapid software improvement process where issues are quickly and systematically root-caused, resolved, re-coded, verified, regression-tested, and validated through a testing process involving simulation, closed course testing, and on-road testing segments.

We continually and critically analyze data logs from testing and feedback from safety operators to identify, qualify, quantify, and address any performance anomalies that are encountered throughout closed course and on-road testing on a daily basis. All issues are tabulated, analyzed, and resolved as part of this ongoing process. If at any time, any Level 5 team member identifies a concern regarding the way that the Automated Driving System (ADS) is performing, they are able and encouraged to raise a flag which triggers an analysis to review the need for and efficacy of potential mitigations, including a decision on whether the fleet should be grounded.

We employ an anonymous safety concern reporting system whereby any Level 5 team member can raise a flag on any potential safety concern. This triggers a separate review process resulting in data gathering, safety analysis, and a decision on how to address that concern with direct confidential feedback to the reporting employee.

Meaningful, consistent autonomous industry metrics

Lyft believes that organizations developing autonomous vehicles must collaborate to develop meaningful performance metrics. This will allow the safety of self-driving technology to be quantified and demonstrated to consumers, regulators, and the public at large. Defining key metrics and the test methodology to measure them is a critical next step.

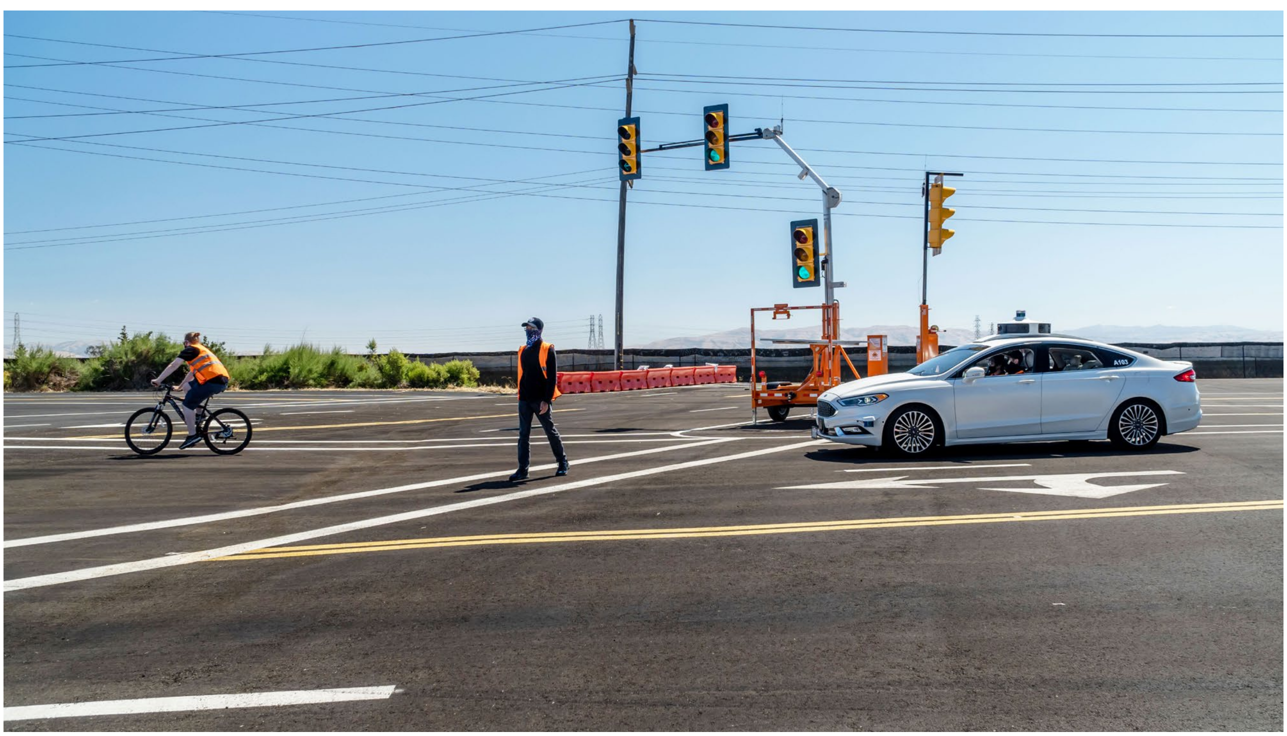
We believe that high-level performance metrics should meet the following criteria:

1. **Be meaningful and readily understandable to the public**
2. **Be measurable in a standardized and repeatable manner**
3. **Compare autonomous vehicle performance with human-driven performance in a given ODD**
4. **Apply to both physical testing and simulation**
5. **Be useful in development phases, as well as initial deployment and long-term evaluation phases**

Such high-level key performance metrics along with more detailed subsystem metrics will form the basis of quantifiable measures of safety and underpin an industry-wide systematic approach to safe AVs. To date, Lyft has joined other AV developers to collaboratively tackle these significant challenges, as well as to develop and share best practices that will advance AV safety and help prepare the technology for widespread deployment and adoption.

Operational Safety

Maintaining high operational standards is of utmost importance as we develop our new technology for AVs. Our approach is to learn from best practices that have proven to be effective across numerous industries, including aerospace, military, transit, and other modes of transportation to influence our strategy and implementation of operational safety. At this stage of development, Lyft's safety approach includes the presence of human safety operators. We pride ourselves on our thorough hiring, onboarding, and continuous training of our safety operators to perform those risk mitigation tasks.



Safety operator training at Lyft's East Palo Alto test facility

Selection of Lyft test operators

We employ a very thoughtful and diligent operator selection process. Our program fully meets all requirements set forth by the California Department of Motor Vehicles' Autonomous Vehicle Tester Program and goes beyond with our own rigorous operator vetting and selection process. All candidates must have a proven driving record with no recent or significant infractions and pass extensive, ongoing criminal background checks. In addition, all candidates are held to a strict grading rubric during the interview process and decisions are made based on their ability to prioritize and practice safety above all else.

Onboarding and initial training

As part of the rigorous onboarding process, all operators are extensively trained to perform both safety-critical roles: safety operator and co-pilot. To execute these roles, they are taught how to monitor and control the vehicle as the safety operator and as the co-pilot; launch software, troubleshoot software and hardware issues, read the information displayed in the autonomy visualization tool, recognize and take detailed notes on AV behavior, escalate issues, and give high-quality, post-mission feedback.

All operators are further required to undergo fault injection training where training staff inject a series of system failures that are meant to teach operators how to manipulate the AV outside of normal patterns. This training is executed on a closed course to train our operators on quick and appropriate disengagement methods. Safety operators are trained to be vigilant with a mentality that prepares them to disengage at any moment to manage safety-critical situations.

This extensive training is part of a five-week program that all Lyft safety operators are required to take. During the training, they are expected to pass a series of checkpoints consisting of written and practical examinations that cover a broad range of policies, procedures, best practices and systems knowledge. Examples include:

- **A** Advanced Driver Assistance Systems (ADAS) Function Awareness
- **B** Self-Driving Systems Knowledge
- **C** Manual Driver Training & Third-Party Vehicle Dynamics Training
- **D** Incident Protocol & Response Process
- **E** Best Practices for Interactions with the Public

Continuous training and learning

We instill an "always be training" attitude in every operator. Training does not stop after initial sessions are complete; rather it continues through each Lyft operator's tenure. All operators are required to keep abreast of and incorporate changes applied to the Operational Design Domain, the software's features, and any policy or procedure that may affect testing. All operators are expected to pass a series of quarterly audits consisting of written and in-vehicle practical examinations. In addition, they must undergo semi-annual incident response training drills to better prepare the team in the event of a collision.

Prevention of fatigue & distracted driving

Fatigue and distracted driving contribute significantly to collisions caused by human error. To combat this issue and maintain the safety of our operators, customers, and the public, in-cabin sensors monitor safety operators and co-pilots for signs of distraction and other improper driving behavior such as erratic speed or harsh braking. In addition, we manage both operators' time in the AVs and encourage them to self-assess and report their level of fatigue. When tired, they can self-nominate to be shifted to non-driving missions without repercussion.

Operational checklists

Prior to testing in the field, both the vehicle and its software must pass pre-operational checklists. The AV's interior and exterior are carefully inspected. Potential mission-critical issues, such as hardware or software malfunctions, are immediately mitigated and escalated with the assistance of our fleet technicians. Afterward, operators perform a software checklist for review before an AV can be operated again on public roads.

Alongside operators, Lyft's fleet technicians perform weekly preventative maintenance and periodic inspections of hardware, sensors, and equipment to maintain fleet integrity.

Operational Design Domain (ODD)

The operational design domain (ODD) as characterized by [AVSC Best Practice for Describing an Operational Design Domain: Framework and Lexicon] describes the specific conditions under which a given automated driving system or feature thereof is designed to function.

At this time, we deploy self-driving vehicles only *with* safety operators in well-defined ODDs where the system meets our performance thresholds, under appropriate environments and conditions, defined using our system safety engineering process.

We operate in a challenging real-world urban/suburban public road operational design domain (ODD). We chose this dynamic environment because we believe it is critical to test our driving automation system in environments that represent the mobility system of the future, where ADS dedicated vehicles will safely share the road with pedestrians, bicyclists, scooter riders, transit vehicles, emergency vehicles, and other road users.

We execute specific additions to this ODD as our technology development warrants, but only after completion of thorough review and assessment, including a safety and software sign-off. We train our safety operators on this new ODD before executing on public roads.

In addition, a distinguishing factor of our approach to self-driving is that our technology focuses only on the ODDs required to develop and operate a business-relevant, hybrid self-driving and human-based rideshare platform. We do this by leveraging our extensive experience in the rideshare business.

Object and Event Detection and Response

Object and event detection and response (OEDR) refers to the detection by the driver or ADS of any circumstance that is relevant to the immediate driving task, as well as the implementation of the appropriate level of response. AVs must be able to recognize and appropriately react to other road users, including all types of cars, trucks, buses, and vulnerable road users, as well as roadway and traffic control features and miscellaneous static and dynamic objects (e.g. roadside furniture, traffic cones, road debris, etc.) that are on the roadway for any reason. The ability, consistency, and effectiveness of the AV to perform this task are critical for operation, and this capability is expected to evolve significantly over the development period of the vehicle.

We enable highly-capable OEDR by incorporating multiple layers of data collection and analysis, starting with the design and layout of our sensor suite. Currently, we add our custom-built high-definition (HD) maps to augment the sensor suite.

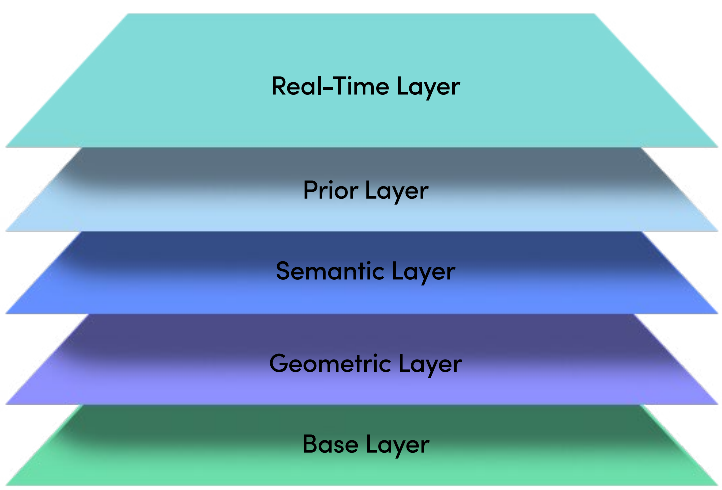
The Eyes of Our Cars

Our sensor suite

Our AVs are equipped with a full sensor suite that allows for the detection of objects and events at any given time. Light detection and ranging (LiDAR) sensors capture a 3D representation of the world around the vehicle and highlight potential objects and events. Cameras generate images that help accurately detect and classify objects. And radars provide reliable distance and speed information for detected objects. Together, these instruments are carefully calibrated along with other supporting sensors to provide a consistent view of the world, guiding our vehicle's perception pipeline.

A second pair of eyes: HD maps

We precompute several categories of historical road information in the form of HD maps to guide navigation. We use publicly available information for sources, as well as sensor data collected on previous drives, structured into a series of "layers":



A **base layer** which includes road names, road junctions, and high-level traffic control elements.

A **geometric layer** which includes a range of static objects that aid in determining the precise location of the vehicle (localization), composed as a compressed point cloud.

A **semantic layer** which includes lane geometry, traffic control elements, and connectivity between lanes.

A **prior layer** which includes aggregates of prior statistical information about dynamic obstacles observed while driving.

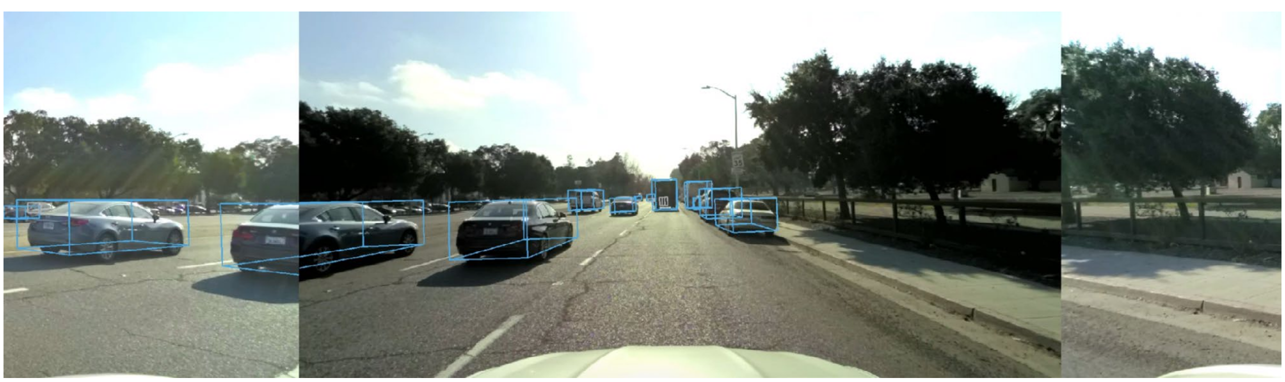
A **real-time layer** which includes information about current road or traffic conditions, or temporary features like work zones.

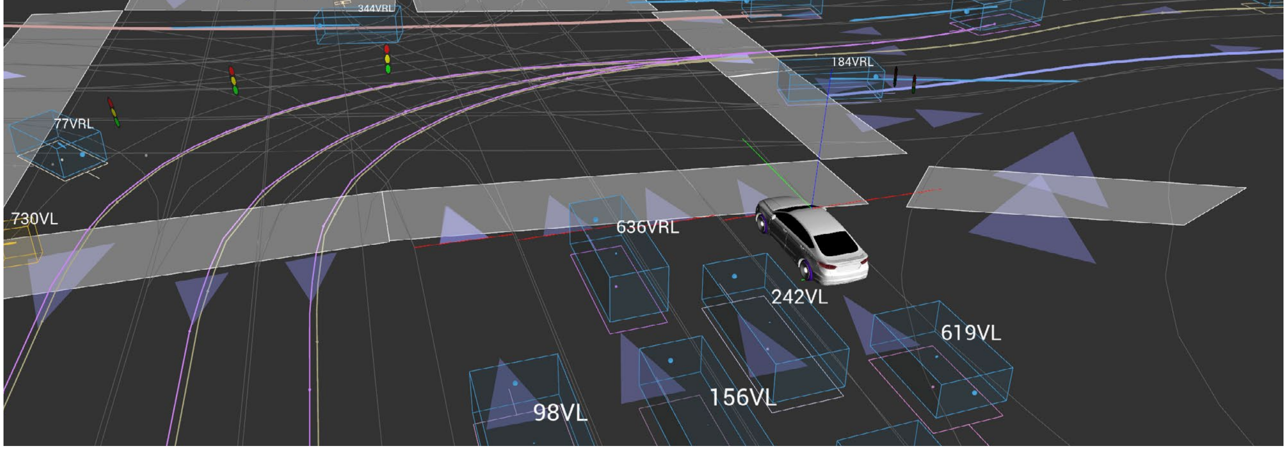
Each of these layers is regularly updated to reflect current ODDs. With our current technology, we operate our AVs only in areas that have fully validated HD maps.

Our perception pipeline

The complexity of the real world poses many challenges to perception, especially around detecting and reacting to VRUs, such as pedestrians, bicyclists, scooter riders and other micro-mobility users.

The goal of Lyft's perception pipeline is to achieve performance beyond the capability of human eyes using a robust multi-modal, fault-tolerant system. The data collected from multiple sensors is fused to produce a final interpretation of a given object. Other vehicles, VRUs, traffic lights, along with a variety of other static and dynamic objects, are constantly being detected, classified, and tracked. All such characterized data collections, or *models*, built on our perception pipeline are rigorously tested before every single release, and an extensive set of metrics is produced from each test run to enable a detailed comparison between models.





The Brain of Our Cars

The prediction and planning system

Our planning system ingests inputs from the perception system, localization system, and HD maps numerous times per second. The planner uses this information to:

1. Predict how the vehicle's surroundings will evolve over time
2. Determine the most appropriate behavior that should be applied
3. Choose an optimal trajectory for the vehicle to take

For each object in the vehicle's surroundings, the system calculates multiple hypotheses based on the type of road user, be it another vehicle or a VRU. It then uses information from the HD maps and perception system to determine the most likely paths that an object could take based on the current context. For example, based on a pedestrian's distance to a nearby crosswalk and their direction of travel, the system would anticipate where they will be precisely at some point in the future, or would create and track multiple hypotheses for this pedestrian's location.

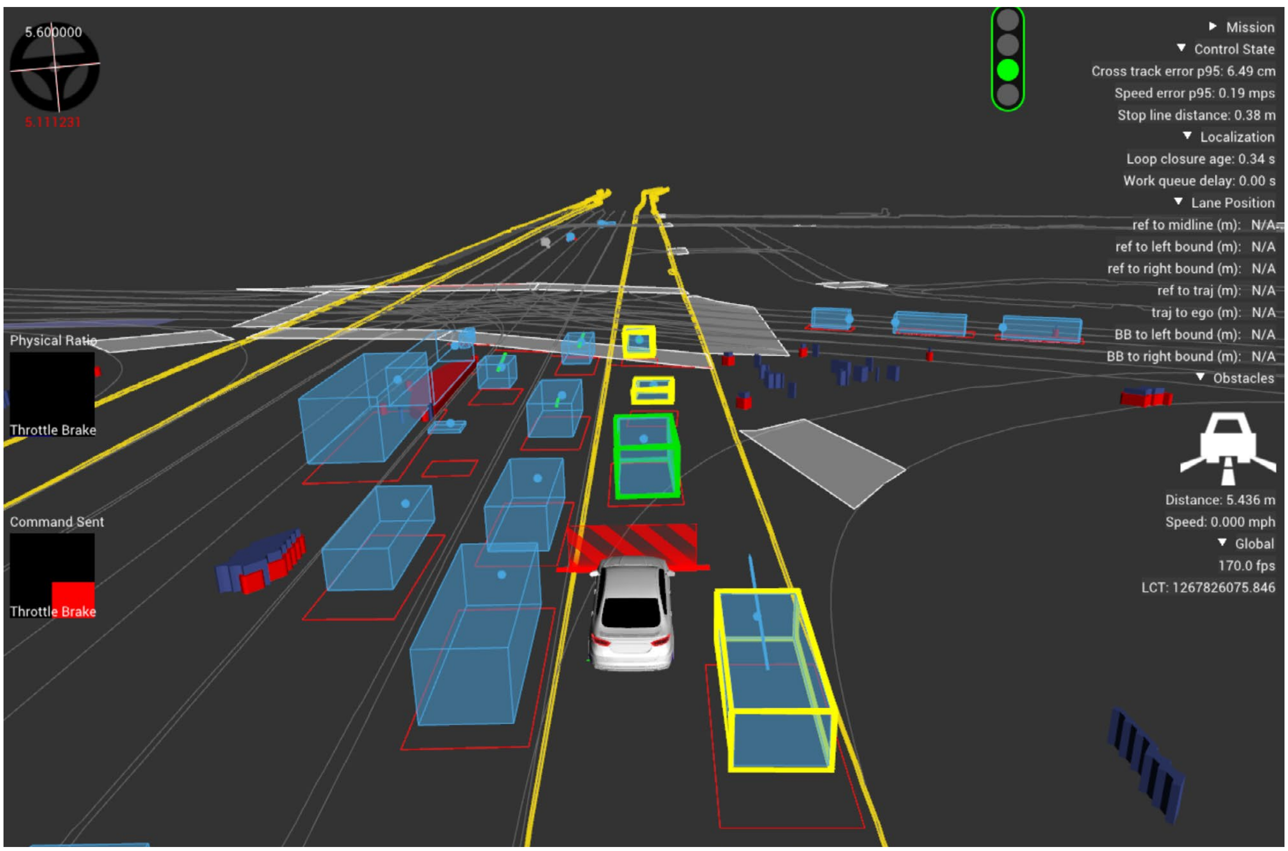
When determining the most appropriate behavior to implement, the following logic is used: first and foremost we ensure the AV's maneuvers are safe; second we ensure that they are legal; and third we consider comfort for both passengers and external parties. We do this by using a combination of machine-learned systems, expert systems and human driving data to ensure the planning system has both high precision — required for maintaining safety and adhering to the law — and high ability to generalize for ambiguous situations.

For example, when maneuvering around objects, spatial buffers are applied based on the object type to enable the vehicle to maintain a safe and legal distance at all times. We also adjust the speed and behavior of our AVs based on large scale observation of human driving data: When another vehicle abruptly enters the lane in front of the AV at a less-than-desirable distance (i.e. a "cut-in" scenario), the AV slows down in a way that mimics human drivers, resulting in a more comfortable and natural ride.

After creating a set of constraints to follow along a particular path, a large number of possible trajectories are generated, and then the most optimal path forward to satisfy these constraints is selected. These instructions are then transformed by the system controller into a set of instructions for steering, brake, and throttle commands.

The Knowledge of Our Cars

Human drivers rely on prior driving experiences to interpret the world, and so do AVs. At Lyft, we use the scenarios and miles that our autonomous vehicle fleet have accrued over the years to validate and verify new software and hardware features. For example, we are able to mine relevant scenarios and rerun the self-driving software with the same sensor inputs to ascertain that a new feature will have a safe, legal, and comfortable response in the target ODD. Additionally, we use past driving experiences to help guide us on the creation of new synthetic, yet realistic scenarios, that improve our test validation coverage.



Fallback - Minimal Risk Condition

As discussed above, we currently rely on our thoroughly trained operators as a fail-safe to ultimately maintain the safe operation of our AVs. Our self-driving system also monitors safety-critical aspects 100 times every second. In the event of a detected failure, the system can automatically disengage and simultaneously inform our operators to resume full manual control of the vehicle. In addition, the motion of our AVs is controlled within a safety envelope, or buffer, whereby our safety operators are able to maintain vehicle control, if needed.

Again, it is important to note that our operators are trained to be conservative and have authority to disengage the self-driving system to quickly regain full human control of the vehicle any time they judge it may be necessary. As mentioned previously, operators have full access to multiple disengagement methods, including the vehicle's braking, steering, throttle, and other controls, as well as emergency stop functionality. To further support our operators we ensure that the base vehicle's collision mitigation system remains operational throughout all our testing activities.

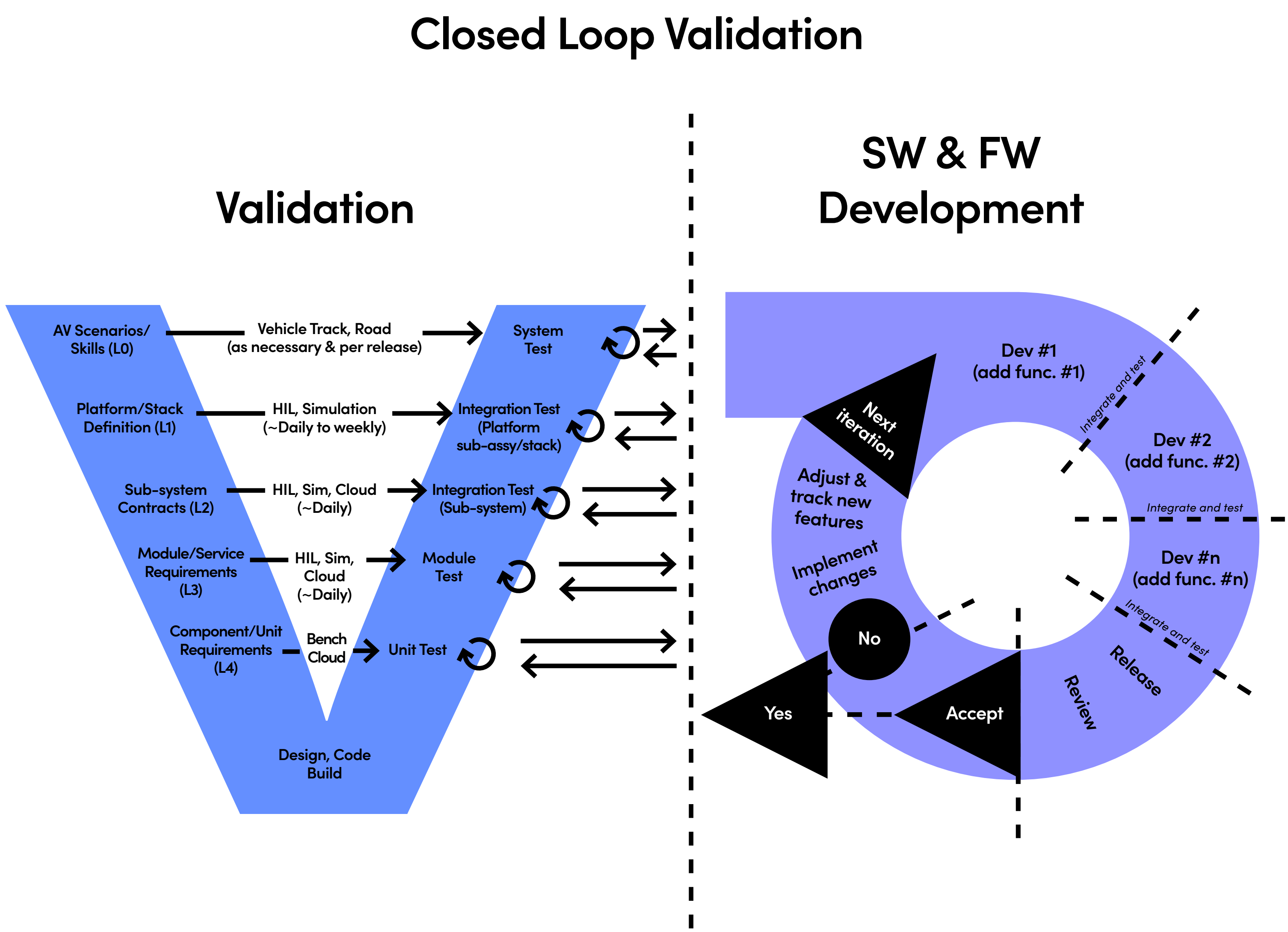
For our future-generation autonomous vehicle platform, we are actively working on the design of a fault-tolerant system architecture. This architecture could include redundant sensors, compute, power, and actuation that are capable of handling failures and bringing the vehicle to a safe state without the need for human intervention. This will also allow us to implement a more sophisticated fallback strategy where we can choose between different actions depending on the level of degradation in the system.

Validation Methods

As described in the System Safety section above, AV validation is critical to safely deploying autonomous technology. Lyft's approach to validation rests on four pillars:

1. **Safety First:** Safety is foundational for all development, testing, and operational activities
2. **Pragmatic Risk Assessment:** Quantitative risk-based prioritization allows safety assessment in realistic conditions
3. **Industry Collaboration:** Following and exceeding industry best practices (such as ISO26262) is an enabler for AV validation
4. **Feedback Loops:** Validation is an ongoing iterative process, not a one-time activity, requiring continuous feedback loops and re-validation

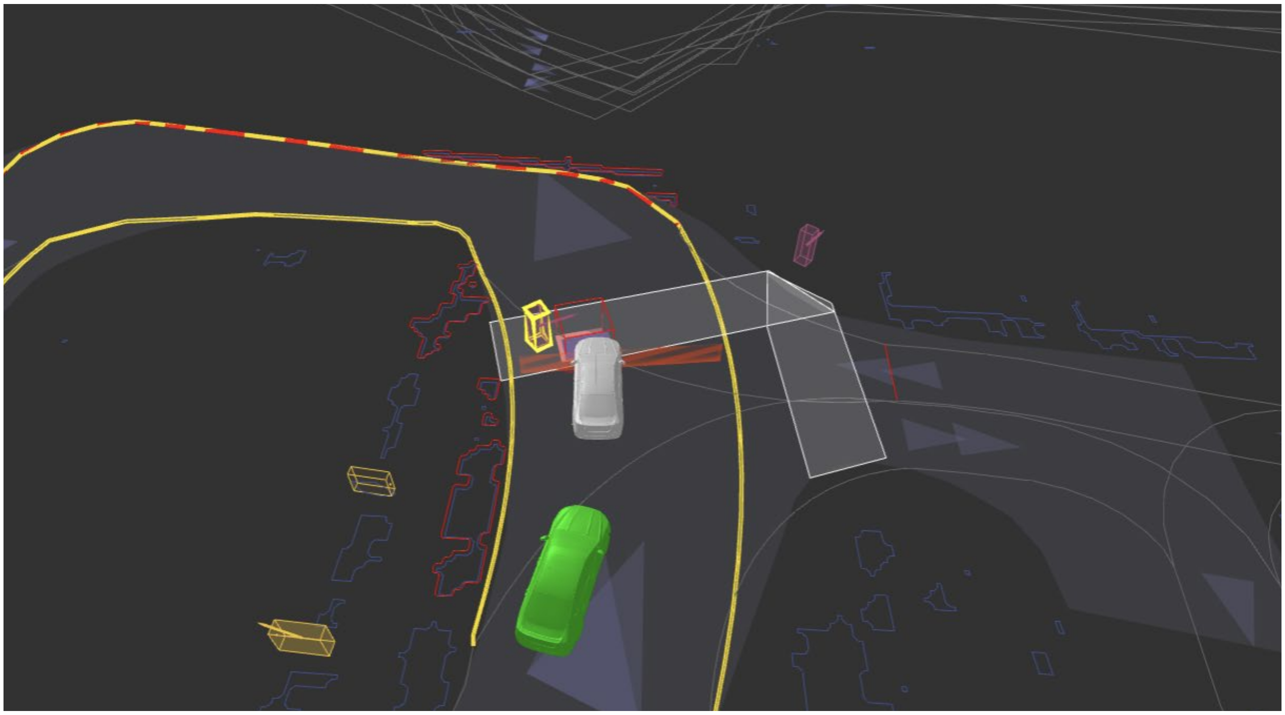
We leverage the "V-Model" approach to verification and validation defined in ISO26262 and execute our software development within this context through iterative development cycles.



Ultimately, before widespread deployment of AVs, every function must be designed and tested through a clearly defined test program that both *verifies* that the function works as intended and *validates* that it meets stakeholder needs. To accomplish that, it is critical to properly specify the intended function to accomplish robust verification. Our process specifies a set of basic competencies, starting with those defined by [NHTSA and CA-PATH] and augmented with scenario catalogs. Detailed scenarios are specified within those catalogs and are fully traceable to these basic competencies.

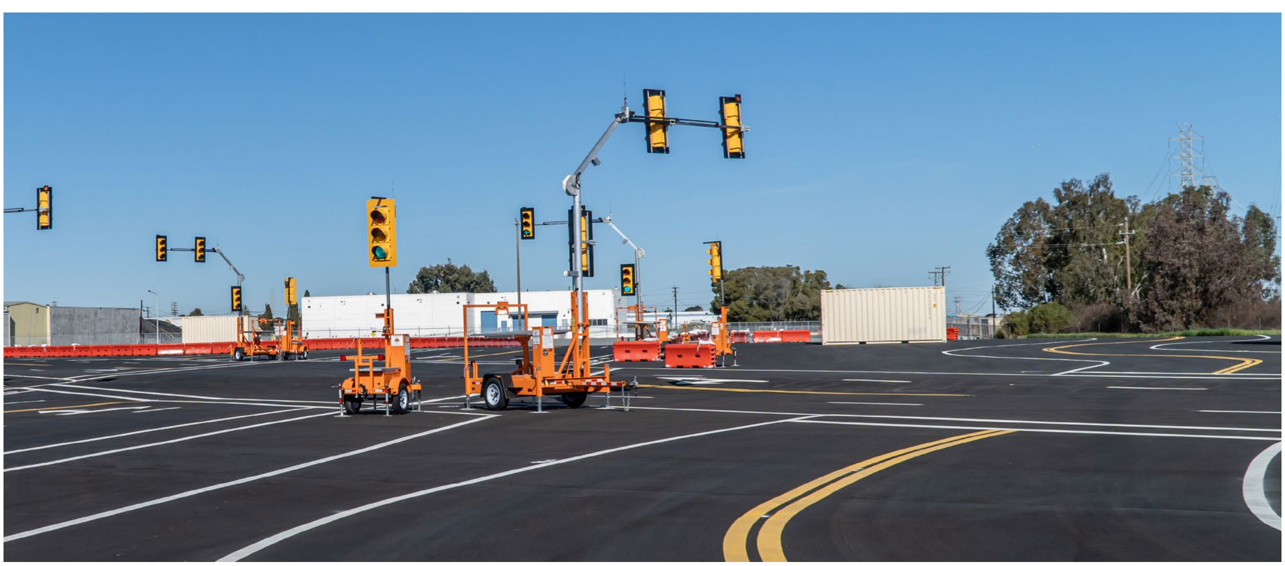
To that end, we take a layered approach to verification and validation of the ADS that includes:

- Verifying statistical autonomy performance through simulation
- Ensuring basic safety competencies are demonstrated for every software update
- Refining simulation performance with structured testing and public road testing



Finally, we maintain a rich set of environments for software, hardware, and integrated system testing, including:

- Software-in-the-loop environments for replay and system and component testing
- Hardware-in-the-loop environments for sub-system testing
- Parametric simulation with environment calibration and validation using real-world test data
- Structured testing of AV features and end-to-end behavioral competencies at test tracks, including our private test facility in East Palo Alto, CA and other closed course locations
- Public roads with trained safety operators



Human Machine Interface (HMI)

HMI from the safety operator perspective

Lyft's on-board human machine interface (HMI) is designed for simplicity, robustness, and high reliability. Using both visual and audio elements, the goal of our HMIs is to deliver the right information at the right time to keep safety operators abreast of critical AV system performance, allowing them to take over the vehicle as needed in the event of a system disengagement.

For instance, the driver-facing visual HMI element displays the state of the AV system in a simple, robust, and easily-interpreted manner to minimize distraction, as shown above. The co-pilot's HMI is a more comprehensive visual interface that provides greater detail about the vehicle status, surroundings, intent, and system health. The co-pilot's HMI also provides a method of note-taking and system control, when necessary.

In addition to the visual HMI elements, Lyft's AVs are outfitted with two layers of audio HMI. One element informs operators of any disengagement from autonomous control, allowing smooth transition to manual control of the vehicle. The secondary audio system provides a wide range of notifications to inform operators and riders about trip updates, AV system status, and customer support functions.

As noted above, safety operators have a wide range of surfaces by which disengagement from autonomy can be triggered. For example, operators can prompt a disengagement through the primary vehicle's braking, steering, throttle, and other controls as well as emergency stop functionality.

HMI from the passenger perspective

As a customer service and safety-oriented company, we leverage user experience research to design passenger HMIs that enable riders to feel safe and comfortable. The Lyft app is riders' first touch point with the self-driving vehicle, and it works hand-in-hand with on-board HMI components to share necessary safety information. When a rider requests a self-driving ride, the Lyft app immediately provides the rider with additional education related to the safety of their experience, such as the number of riders the vehicle supports.

Once inside the vehicle, all riders have access to ride-critical information, including their location along the route and status of critical safety systems. This display also provides riders with information intended to convey how the AV is able to safely interact with the world around it.

Additionally, all passengers in the vehicle have immediate access to remote assistance agents at any time during a ride. These representatives have a comprehensive display with information about the rider, their current ride, and the AV system status to provide timely resolution to any support requests that riders may have.

Cybersecurity

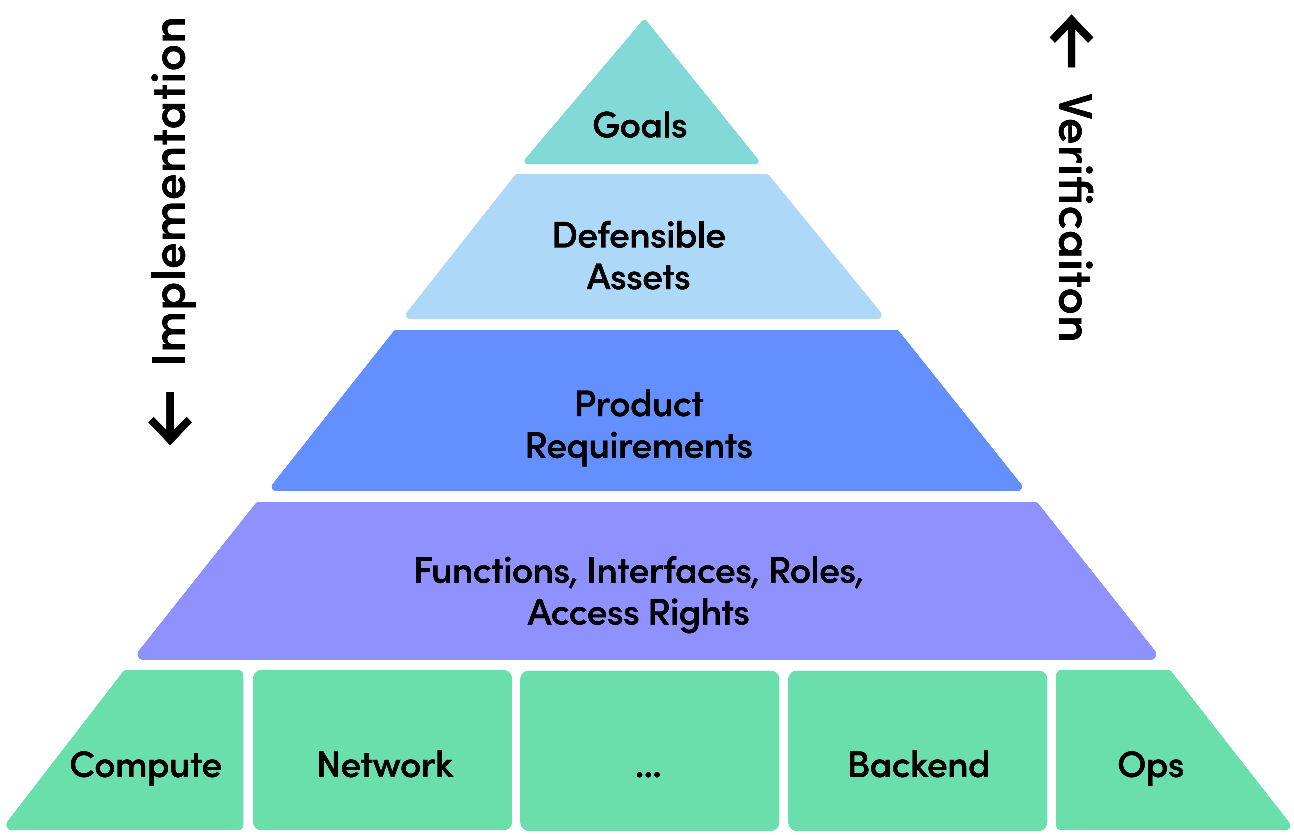
Lyft advocates that a strong approach to cybersecurity is essential to a safe autonomous program. The safety of a vehicle system cannot be fully maintained if its security, or the systems it relies on, have been compromised. Accordingly, our digital security goals cover not only the vehicle's safety but also the vehicle's larger connected system.

AVs utilize and record a variety of sensor data that has significant security and privacy implications. Keeping the vehicle safe from a variety of potential threats is of paramount importance. Defending the confidentiality of sensitive data, both in transit and at rest, is also essential. The integrity and provenance of recorded data used to generate machine-learning models and maps needs to be carefully controlled and monitored. Finally, an individual AV may be an entry point for an adversary to attack the cloud backend that manages the fleet. The cloud backend must therefore be protected against such an attack to protect other vehicles and assets in the connected system.

Our methodology

We take a methodical approach to security design, based on cybersecurity best practices followed by the IT industry, as well as guidance provided by NHTSA and Auto-ISAC.

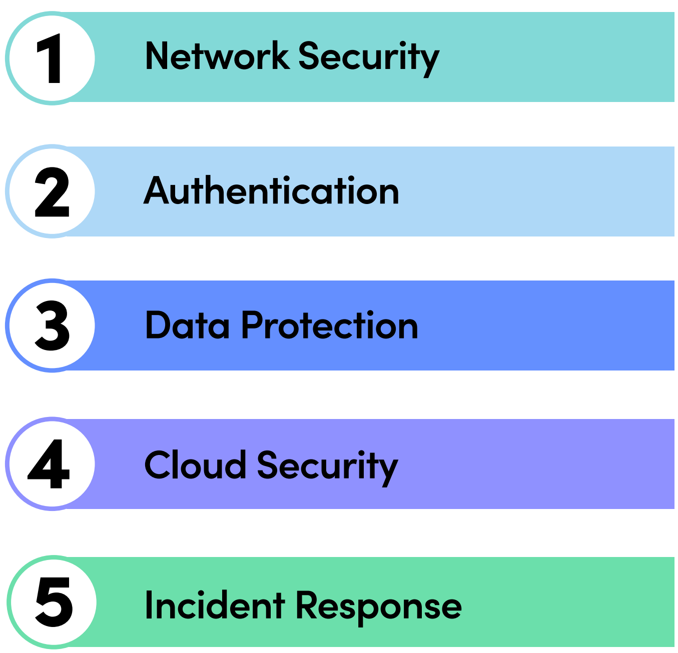
Following this approach, we identify adversarial risks and prioritize critical assets with appropriate defenses. Based on this prioritization, we develop the product requirements around these assets, and then develop detailed engineering designs that span the entire connected system to meet these product requirements. These designs are then implemented at the individual component level and tested through each layer and at various integration levels to ensure alignment with Lyft's cybersecurity standards.



Security pillars

We are pursuing a security design that stands on five pillars, including:

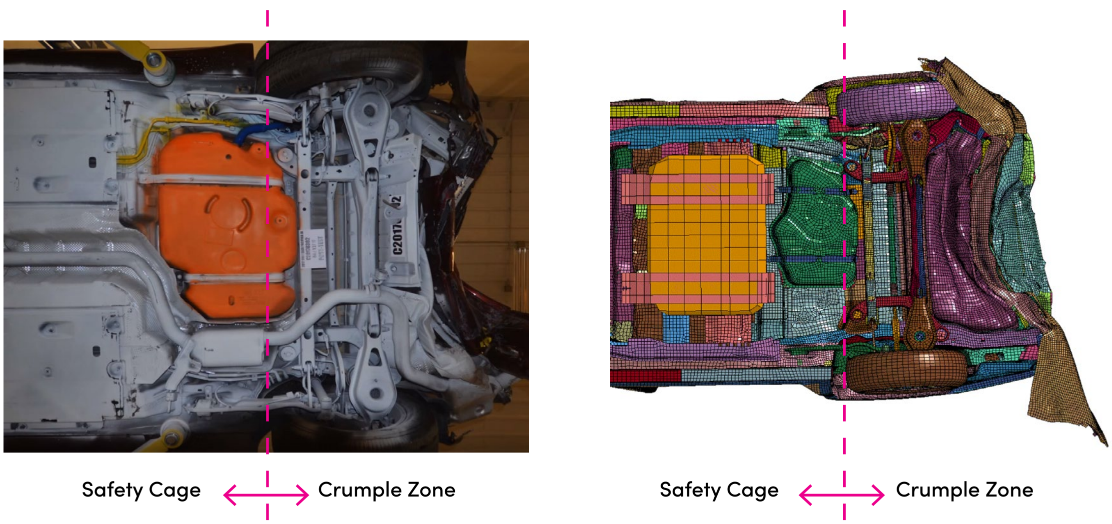
- **Network Security** – Securing the various networks, both inside and outside the AVs against a variety of intruders using a multi-layered approach.
- **Authentication** – Authenticating every piece of hardware and software, as well as static and dynamic data during updates, repairs, and operation. Authenticating various directives issued by the base vehicle backend to the AV system.
- **Data Protection** – Protecting data captured by the vehicle against tampering and eavesdropping.
- **Cloud Security** – Securing the cloud backend to protect the integrity of the various assets generated and consumed in cloud environments.
- **Incident Response** – Monitoring and responding in real-time to any anomalies detected in the connected system, as well as the continuously evolving security landscape.



Crashworthiness

Lyft believes that occupants of AVs, just like all other passenger vehicles, should have access to well-developed and proven injury protection technology in the event of a crash. While AV technology has the potential to significantly reduce the number of crashes, it will never avoid all collisions, and it will still be involved in incidents including being struck by other vehicles and other road users. Therefore, Lyft's focus is in mitigating the frequency and the impact severity of crashes while providing: (1) reliable and well-established safety approaches for AV occupants; and (2) innovative considerations for vulnerable road users.

During our current phase of AV development, our platform is based on modifications to a highly-capable traditional passenger vehicle that maintains well-understood seating arrangements and hardware. The crashworthiness, occupant protection, and compliance of this approach rely heavily on significant engineering and testing accomplishments of the base vehicle by the original equipment manufacturer (OEM). We purposely minimize any modifications to OEM safety systems, including maintaining the base vehicle's structure. We do not modify the restraints and airbags, and are diligent to not affect their operation. In cases where additional hardware and systems equipment is added that could affect vehicle structure and crashworthiness, we carefully engineer modifications to ensure the base vehicle's structure and restraint systems are maintained while performing simulation and testing where appropriate to verify the design. We also ensure that the crash avoidance technology of the base vehicle remains fully operational.



Typical deformation to rear structure in FMVSS crash test (left) and the simulation (right)

In addition to the safety of our passengers, Lyft is committed to designing an AV system that considers and protects the safety of other road users. While no sensor is perfect, AVs have a potential advantage over human drivers when it comes to detecting vulnerable road users: they are always alert and do not get distracted, sleepy, or otherwise inattentive. Our AV sensor suite is designed to provide a direct and constant view of visible and relevant road users, including VRUs, as part of the overall road scene. This provides a high potential to detect and react to VRUs when possible to prevent or mitigate a collision. Additionally, since VRUs can and eventually will impact the AV at no fault of the AV, we strive to design the AV sensor suite to provide rounded, minimally-protruding, and contact-friendly surfaces in an attempt to reduce the potential for VRU injury in case of contact.

Post Crash ADS Behavior

Lyft's current Automated Driving System (ADS) is automatically isolated from controlling the underlying base vehicle in the event of a crash. For first responders, the ADS isolation leaves the base vehicle (e.g. power systems) in an unmodified state. Additionally, all modifications to the base vehicle, such as high-voltage runs, are clearly marked for first responders. In future generations, our ADS will bring the vehicle to a safe-stopped state, engage emergency flashers, and disengage its control of the base OEM vehicle platform.

Incident protocol

We train our operators to approach collisions with a safety-first mindset and attitude. Accordingly, every operator must be familiar with Lyft's incident response and escalation process, including notifying law enforcement in the event of injury.

While we take every reasonable step to prevent vehicle collisions, they are inevitable. Lyft has a world-class Customer Experience and Trust team across the globe that manage and triage incidents on a minute-by-minute basis, operating against the company's proprietary response protocol to manage such incidents.

Operators and third-party occupants (if applicable)

Upon receipt of notification that an incident has occurred, we immediately dispatch one of our AV rapid response teams to the scene to assist the operators and any impacted third-party (if applicable) in completion of post-crash protocols.

Data Recording

Lyft's self-driving system includes a data logging system that is operational at all times when the vehicle is in autonomous mode. It is capable of logging complete ADS input and output parameters, including what the AV's sensors see, objects detected and tracked, maneuvers planned and executed, and vehicle actuator responses. In the event of an incident, these logs will be analyzed to make a determination of the decisions that the AV made given the surroundings it encountered.

The goal of these logs is to help determine:

- What raw sensor data was available to the system
- What the AV perceived from this sensor data
- How the AV planned to interact with the perceived world
- What the AV commanded the base vehicle to do
- How the base vehicle responded to these commands

The logs help us analyze an incident if and when it occurs, and make any updates needed to the ADS to minimize the recurrence of such an event.

Federal, State, and Local Laws

As the regulatory requirements for AVs become more defined, we applaud efforts made by federal, state, and local policymakers to evaluate current safety standards and to work with industry leaders like Lyft in creating the appropriate environment for the safe adoption of AV technology. To promote innovation and enable AV technology to reach its full potential, Lyft will continue to engage in active discussions with governmental stakeholders to advocate for the adoption of technology-neutral policy solutions, ensuring a level playing field for all participants, not just traditional auto manufacturers.

Lyft looks forward to the opportunity to work with other stakeholders as we further expand our program.

Conclusion

Safety is at the heart of Lyft's approach to autonomous vehicle technology development and deployment. Beginning with our core safety principles and focus on our customers, down to our rigorous engineering and testing, driver training and consumer education processes, the safety of our riders and our communities guides our decision making every step of the way. This will never stop as we strive to realize a future of transportation that is built around people, and not cars.

Lyft's AV safety program is guided by our mission to improve people's lives with the world's best transportation, and is based on the core principles of improving autonomous technology, guarding the safety of all road users, quantifying safety through metrics, collaborating with others, and most importantly, maintaining the trust of our users and all stakeholders. We employ a strategic customer-focused systems safety approach, including a conservative and diligent validation and testing regime focused on operational safety and quantified objectively by meaningful metrics. We employ rigorous validation and verification methodologies for hardware, software, and integrated systems, and well-executed HMI, cybersecurity, and data systems. We also mitigate risks by ensuring proper functionality of crashworthiness, crash avoidance, and data recording technologies. We collaborate with other developers, regulators, and stakeholders to improve the technology and develop appropriate rules, regulations, and laws.

With each iteration of Lyft's AVs, our ultimate goal is to produce technology that can improve transportation and reduce collisions caused by human error and limit their severity. Though the task is challenging, by collaborating with industry partners and regulators, it is surmountable. Together, we can realize a transportation future that increases safety, mobility, and accessibility for all.

Legal Disclaimer

This submission, including but not limited to the letter from CEO Logan Green, contains Lyft, Inc.'s forward-looking statements, which involve substantial risks and uncertainties. Forward-looking statements generally relate to future events or our future financial or operating performance. In some cases, you can identify forward-looking statements because they contain words such as "may," "will," "should," "expect," "plan," "anticipate," "could," "intend," "target," "project," "contemplate," "believe," "estimate," "predict," "potential" or "continue" or the negative of these words or other similar terms or expressions that concern our expectations, strategy, plans or intentions. You should not rely upon forward-looking statements as predictions of future events. We have based the forward-looking statements contained in this submission and letter from the CEO primarily on our current expectations and projections about future events and trends that we believe may affect our business, financial condition, results of operations and prospects. The outcome of the events described in these forward-looking statements is subject to risks, uncertainties and other factors, including those described in the section titled "Risk Factors" and elsewhere in the Company's Quarterly Report on Form 10-Q filed on May 8, 2020. Moreover, we operate in a very competitive and rapidly changing environment. New risks and uncertainties emerge from time to time and it is not possible for us to predict all risks and uncertainties that could have an impact on the forward-looking statements contained in this submission and CEO letter. We cannot assure you that the results, events and circumstances reflected in the forward-looking statements will be achieved or occur, and actual results, events or circumstances could differ materially from those described in the forward-looking statements.

Glossary of Terms

ADAS: Advanced Driver Assistance Systems

ADS: Automated Driving System

Auto-ISAC: Automotive Information Sharing & Analysis Center

AV: Autonomous Vehicle

AVSC: Automated Vehicle Safety Consortium

FMEA: Failure Mode and Effect Analysis

FTA: Fault Tree Analysis

HARA: Hazard and Risk Analysis

HD: High-Definition

HMI: Human Machine Interface

ISO: International Organization for Standardization

LiDAR: Light Detection and Ranging

NHTSA: National Highway Traffic Safety Administration

ODD: Operational Design Domain

OEDR: Object and Event Detection and Response

OEM: Original Equipment Manufacturer

PAVE: Partners for Automated Vehicle Education

SAE: Society of Automotive Engineers

VRU: Vulnerable Road User (e.g. pedestrians, bicyclists, and scooter riders)

VSSA: Voluntary Safety Self-Assessment lyft.com/self-driving