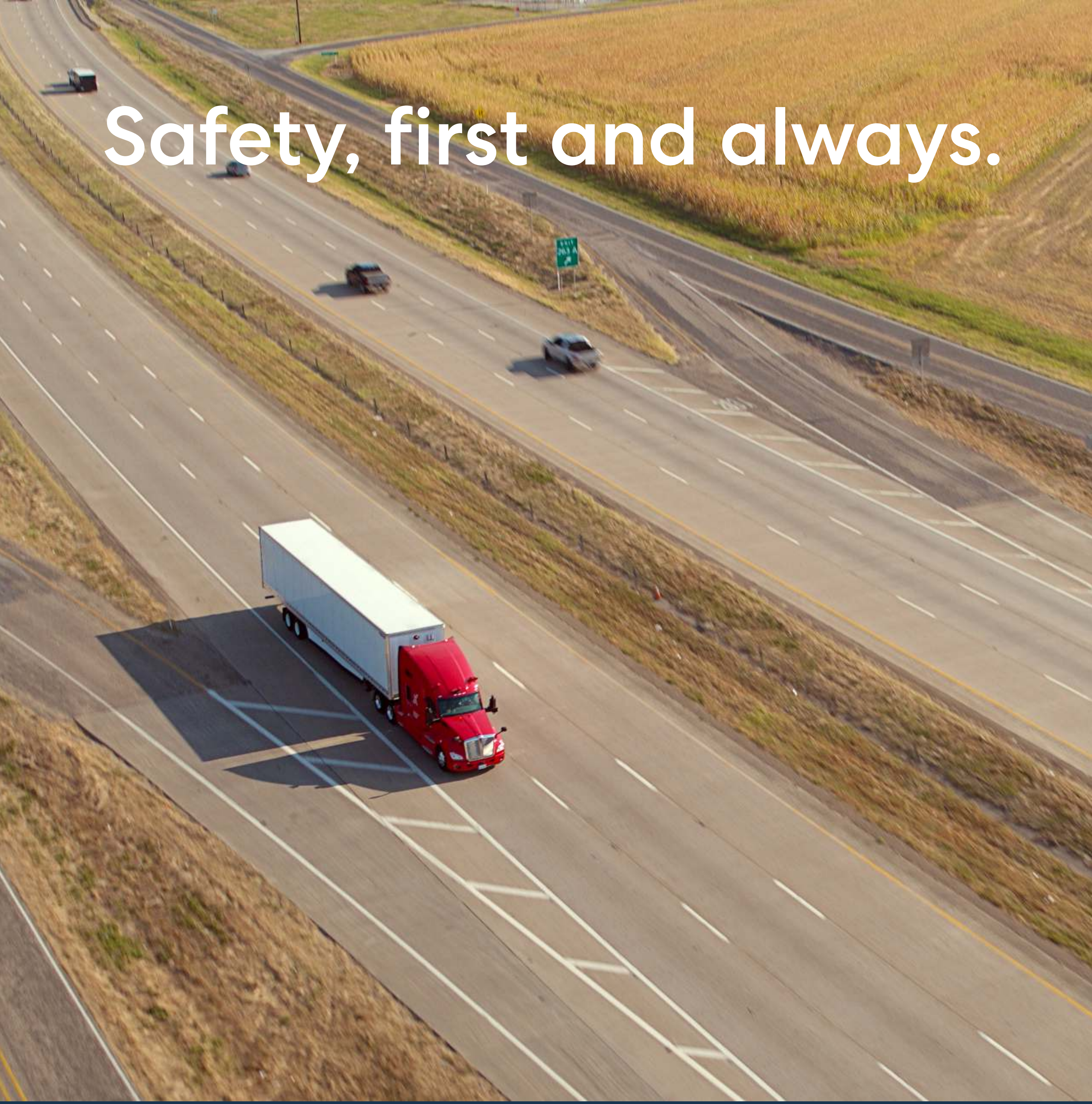
Safety, first and always.



Kodiak Safety Report 2020

We founded Kodiak in April 2018 with a clear mission: to build a safer, smarter freight carrier—so people, partners, and the planet thrive.

Core to that mission is a big belief about technology: that self-driving trucks, driven on highway routes, will be the first autonomous vehicles deployed on American roads at scale. This belief was not built on hype, but instead rests on our deep experience building self-driving vehicles. We believe it is that experience—not rudderless ambition—that will allow us to see self-driving technology through to true, commercial deployment, and truly change the world.

Our experience in the self-driving industry has taught us a few important lessons. Most important is that autonomous systems need to be optimized for safety from the beginning. With that in mind, we are proud to submit this Kodiak Safety Report because we see it as the next important step in our journey. We recognize that self-driving technology remains shrouded in mystery for many people. As we move towards deploying our technology over the next several years, it's critical to begin the process of explaining how we are safely testing our vehicles, and describe how we're going to prove, mathematically and in plain English, that our vehicles are comprehensively safe even without a safety driver behind the wheel. It's one thing to believe that self-driving trucks will one day be safer than human-driven trucks, and another to feel confident in that safety when the first self-driving trucks are deployed.

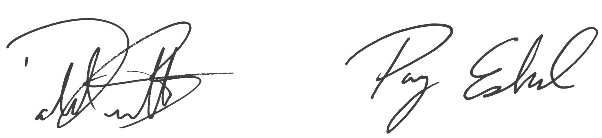
In this Safety Report, we hope to demonstrate to those we share the roads with and our regulatory partners just how deeply we are committed to safety. We also believe we have a duty to share safety-relevant advances with the industry, so that we can do our part to make self-driving technology as safe as possible for everyone.

As such, we think it's critical to be transparent about what our system, which we call the Kodiak Driver, can and can't do, without sugar-coating or resorting to marketing speak. We hope that by articulating our vision and values, we will overcome people's understandable skepticism and build trust with our fellow motorists.

Figuratively and literally, we've covered a lot of ground since our first on-road test—from making our first commercial delivery in July 2019 to opening our Texas logistics hub to receiving our tenth truck. Today, we're making regular commercial deliveries in Texas, hauling paid loads on behalf of our customers and beginning to prove out our business model. We would like to take this opportunity to thank our team who have worked so hard to advance our values and vision while always prioritizing safety. We would also like to thank our many partners who made this incredible progress possible: from truck manufacturers and suppliers to our friends in Texas to the USDOT, among many others who have helped us get here.

We hope that this Safety Report will give you a picture of what makes Kodiak so special, and look forward to sharing more about our company in the coming months and years.

Safe and sound journeys,



Don Burnette and Paz Eshel, Co-founders

Though Kodiak is still a young company, we've worked hard to live by the values that drive us every day. In this Safety Report, you will find examples of how these values manifest themselves at Kodiak, and how they help us build on our commitment to safety.

Kodiak values

Safety, start to finish.

Intellectual honesty, principled debate.

Disciplined innovation.

Better together. For a better future.

Exceed expectations. Earn respect. Repeat.

The Kodiak Safety Report represents the culmination not only of Kodiak's work over the last two years, but of our team's careers in the AV industry and beyond. We hope that this document not only helps to explain our commitment to making roads safer, but also provides a window into our safety practices, beliefs, and culture. Further, we hope this Safety Report can serve as a resource for people who want to learn more about our company, and can help those who we share the road with understand that they should not only trust our trucks, but should have extra peace-of-mind when they see the Kodiak logo. We also hope we can contribute meaningfully to the important conversation happening globally around how to define safety for self-driving vehicles.

Sprinkled throughout this Safety Report, you'll also find introductions to parts of what makes Kodiak so special—from our people to our values to our technology. We hope that the Kodiak Safety Report will help you understand just how seriously we take safety, from every angle and at every point of our process, and anticipate that it will develop and grow with time, as industry standards and best practices evolve.

The Kodiak Safety Report satisfies the twelve safety design elements identified by the U.S. Department of Transportation (USDOT) in its AV 2.0 guidance for Voluntary Safety Self-Assessments. Please see the table at the end of this report to see how the sections of the Kodiak Safety Report align with USDOT guidance.

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Meet Kodiak

Introducing Kodiak and why self-driving trucks will matter to you.

What self-driving trucks mean to you

Over the last few years, self-driving "robotaxis" have captured the public's imagination and gotten the bulk of the attention and excitement around autonomous vehicles. The impact of self-driving commercial vehicles will probably be less obvious, but it will still be profound. ***Just about everything we touch is delivered on a truck, so moving goods across the country in a brand new way will have wide-ranging impacts on our economy and our society.*** Given Kodiak's focused approach, we believe we'll be able to deploy our trucks in just a handful of years, safely bringing the benefits of self-driving technology as quickly as possible.

Self-driving truck benefits

Safety — Self-driving trucks will soon be safer than human-driven trucks, saving and transforming lives. Over 4,000 Americans died in accidents involving commercial trucks in 2018. Estimates suggest over 90 percent of those accidents were due to human error. The Kodiak Driver will never text and drive, or drive drunk, distracted, or drowsy. Plus, unlike human drivers, our trucks learn in parallel: when one truck learns something, they all do.

More predictable driving — Once you get used to them, self-driving trucks will actually be pretty boring. They'll largely stay in the right lane, they'll never weave in and out of traffic, and they'll never speed.

Reduce traffic — Self-driving trucks won't be in a rush, so they'll be able to avoid busy highways at busy times of the day. The Kodiak Driver doesn't care whether it's 5 pm or 5 am, so it will be able to stay off the roads when other motorists need them the most. This will make our transportation system safer and more efficient.

Efficiency — Self-driving trucks will be more efficient than human-driven ones. They'll be able to drive nearly 24/7, just stopping to refuel, receive self-diagnosed maintenance, and pick up new loads.

Sustainability — Self-driving trucks will be more fuel-efficient than human-driven ones, both through more efficient driving and through keeping to the speed limit (speeding burns a lot more fuel than you would think).

Resilience — self-driving trucks don't get injured or sick, and will make our critical transportation infrastructure more resilient to natural disasters and other crises.

The Kodiak Driver: Designed for Highways

Our team's experience building self-driving vehicles over the last decade has led us to an inarguable conclusion: that today's self-driving technology is best suited for highway driving. ***As great as cities are, they are tough for computers to navigate. Pedestrians, bikes, and pets can be hard for a computer to understand and predict.*** Despite the higher speeds, highway environments are relatively structured: they contain far fewer of those complex variables that are hard for computers to predict. Given the technological constraints, we believe that highway-only autonomous systems will be the first on-road systems to be deployed at scale.

We've built Kodiak around our belief in this highway-first model. Like others in the self-driving industry, Kodiak is building a complete hardware and software solution that can drive a vehicle safely and efficiently. ***Rather than build a general-purpose system, we're building the Kodiak Driver to operate in the relatively-narrow set of environmental conditions required for long-haul trucking.*** We're designing our trucks to drive safely and efficiently from highway entrance to highway exit, what we call the middle mile, plus the limited frontage roads it needs to drive to reach a *truckport*. At a truckport, the load can be switched to a manually-driven truck, or a driver can hop in the cab of our self-driving truck. By leaving the difficult work of first-mile pickup and last-mile dropoff to highly-skilled human drivers, this middle mile model will allow us to deploy our self-driving technology in the relative near term.

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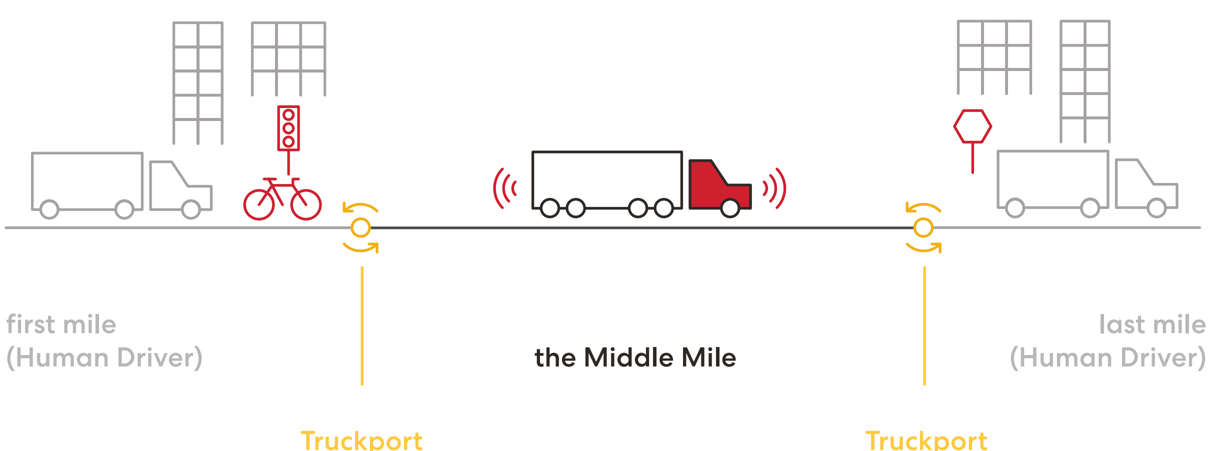

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The self-driving industry refers to the environmental, geographic and roadtype conditions a self-driving system is designed for as an Operational Design Domain (ODD). At the time of this writing, Kodiak's ODD is fairly simple: we operate only on highways in Texas, day or night, with or without a trailer, in dry weather or light to moderate rain, above freezing. We also conduct public-road test runs in California, operating as a "driver-assist" system. Before the Kodiak Driver engages, it checks that the truck is in its ODD—if it's not, the Kodiak Driver won't engage. The system also automatically comes to a safe stop if it approaches the limits of its ODD, due to, for example, extreme weather. Soon, we will expand this ODD by expanding to new geographies, new weather conditions, and other factors. As we add to our ODD, we will conduct extensive testing and validation to ensure system capability and safety.

Exceed expectations. Earn respect. Repeat.

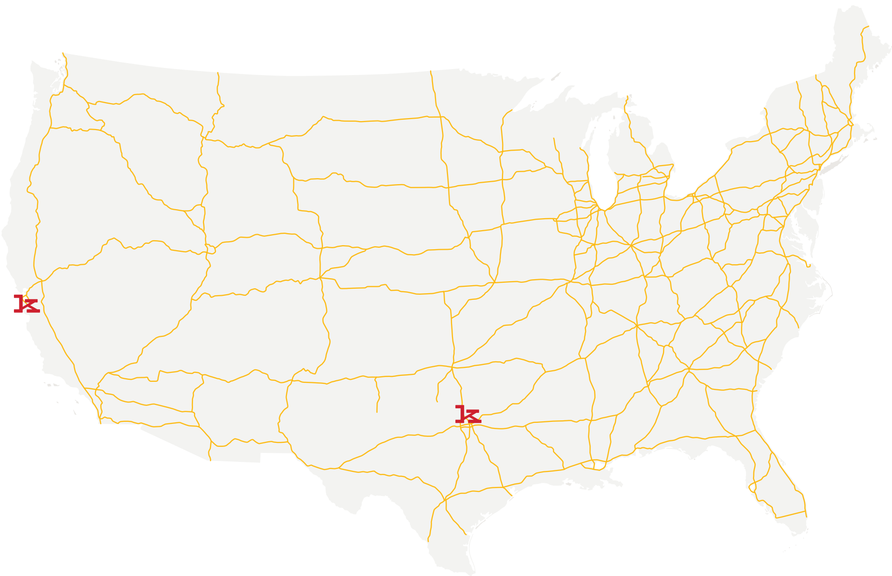
Kodiak believes that earning trust is an ongoing process. Our mission isn't just to build technology: we want to build the world's most efficient, reliable, and respected trucking carrier. To build that carrier, we need to build the trust of our customers and our fellow motorists through our actions, not just our words.

To build a great freight carrier, we need to build a great operations team that will be ready to deploy our technology as soon as we prove its safety. Building operations experience is part of why we began hauling freight just months after we began on-road testing: we want to show our partners that we can exceed expectations over and over again. By prioritizing what matters most to our partners, we can deliver results.

We're not looking to disrupt the logistics industry – instead, we're planning to use our self-driving technology to become a new, safe, highly-efficient link in the logistics chain, designing solutions that delight our customers while making their jobs easier. Our market is competitive, which means we have to work hard to win our customers' business, as well as respect from those with whom we share the road.

Exceeding expectations means testing the Kodiak Driver at different times of day, with different weather conditions, and carrying different loads, to build out the expertise we need to run a great freight company. By exceeding expectations in everything we do, we can demonstrate how safe and trustworthy our technology is.

Federal, State, and Local Compliance



Kodiak believes it's not enough to comply with federal, state, and local laws and regulations. Since our founding, we've worked closely with legislators and regulators to shape national, state, and local policy around self-driving vehicles. We're working with officials from across the country to help them prepare our laws and infrastructure for tomorrow.

As we've built the Kodiak Driver, we have actually hard-coded the rules-of-the-road into the Kodiak Driver, taking into account local variations in vehicle regulations. We are actively participating in Federal legislative and rulemaking processes, to ensure policymakers are educated on how self-driving trucks can be safely integrated into the nation's vehicle fleet. We have also worked to ensure our trucks remain compliant with the Federal Motor Vehicle Safety Standards, by, for example, ensuring our sensor mounts do not widen the vehicle beyond legal limits.

At a state level, we've engaged closely with regulators in our two home states: California, home to our corporate headquarters, and Texas, home to our testing and deployment hub. In California, we've worked closely with policymakers to advocate for sensible heavy-duty autonomous vehicle regulation. ***In Texas, we've engaged closely with state agencies including the Governor's Office, the legislature, the TxDOT, the Texas Department of Public Safety, and the Texas Workforce Commission.*** We were honored to be chosen to join the Governor's Connected and Autonomous Vehicle Task Force, and have worked to advise TxDOT on next-generation freight infrastructure issues.

Better together. For a better future.

Building an autonomous freight carrier is a tremendous undertaking: we know we can't get there alone. Instead, we're building deep partnerships with truck manufacturers, component suppliers, and other industry partners, working hand-in-hand every step of the way. In other words, we're not hacking our partners' systems; we're working with our partners to leverage their platforms, expertise, and experience to build the Kodiak Driver.

We recognize that as excited as we are about our technology, many drivers remain skeptical. Since few Americans will ever get to ride in a Kodiak truck, we need to put in extra work to demonstrate to the public that our vehicles are safe.

As such, we strive to take every possible opportunity to demonstrate our trucks to the public, through demo days, educational events, or other programs. We see our consumer education process as critical, and believe it's critical to have a strong presence in the communities in which we operate. From joining Chambers of Commerce and Trucking Associations to having a robust online presence, we want to make sure the public has the chance to get to know and trust Kodiak. It's not good enough to just build the Kodiak Driver – we want to make sure we're making a positive impact in people's lives.

Trucking regulations

As a freight carrier, Kodiak must comply with the complex regulatory structure that governs the trucking industry, from Hours of Service regulations that govern how long our Safety Drivers can work and drive in a day, to vehicle inspections that enable law enforcement agents to ensure we're keeping our trucks properly maintained. Kodiak takes its responsibilities as a freight carrier extremely seriously, and is committed to being an industry leader on compliance and safety. We work cross-functionally within our company as well as with industry partners to ensure compliance with critical trucking industry regulations.

In addition, we're working closely with law enforcement to ensure that they're ready for the arrival of self-driving trucks. We cooperate closely with both California and Texas Highway Patrol, so that law enforcement is well-aware of our trucks and how they operate. Our team is partnering with the American Trucking Association's Technology and Maintenance Council and the Commercial Vehicle Safety Alliance to lead a task force on self-driving truck inspection policy, so that we can create the policies we need to make sure that self-driving trucks on the road are safe.

Introducing the Kodiak Driver

The Kodiak Driver, and how Kodiak's technology is optimized for self-driving trucks operating on the "middle mile".

Purpose-built for trucks

Kodiak's team has learned from experience that building a self-driving passenger car is just different from building a self-driving truck. Trucks have very different sizes and shapes from cars, and they're also driven differently: trucks are designed to run for a million miles, while hauling tens of thousands of pounds of freight. So while much of the underlying technology appears similar, building a self-driving truck requires a very different approach. That's why we've built every part of the Kodiak Driver—from our software architecture to our hardware to our test program—specifically for heavy-duty trucks.

Kodiak's truck have:

- Sensors placed specifically to meet the needs of a Class 8 truck
- A computer "brain" designed to reliably make complex decisions safely at highway speeds
- A software stack purpose-built for the unique challenges of delivering freight safely and efficiently on highways, not city streets
- A motion-planning system designed specifically for highway driving
- Controls designed and tuned specifically for heavy-duty trucks, which drive with and without a trailer, and with various load types and sizes

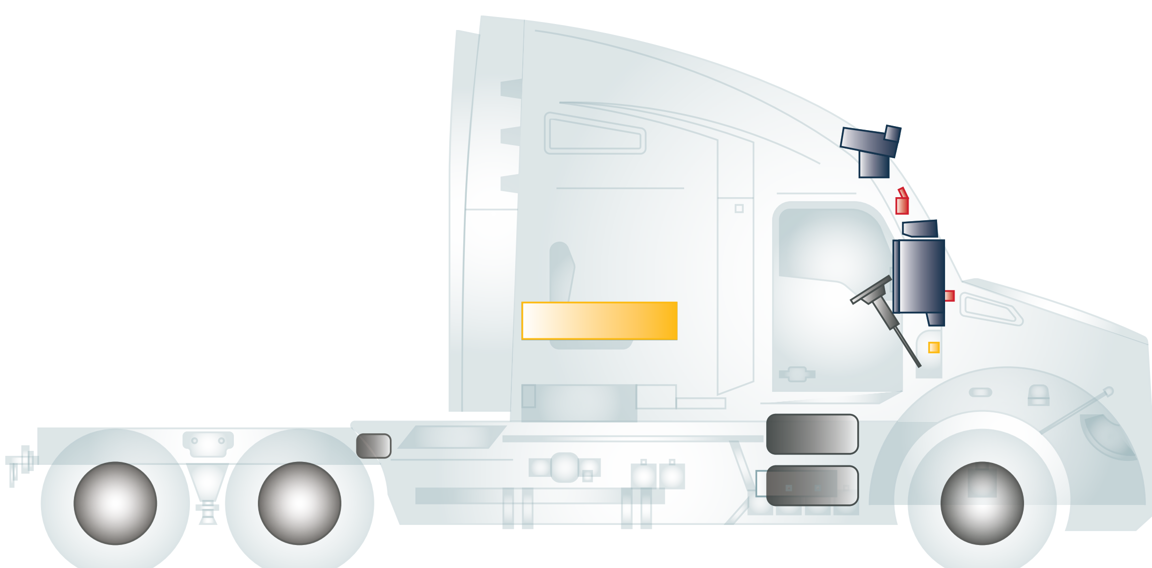
What we’re building

We at Kodiak recognize that we’re experts in self-driving technology, not in building trucks. That’s why ***we’ve chosen to partner with some of the industry’s leading truck and component manufacturers to build the Kodiak Driver***. We work closely with our partners to ensure that our trucks are as close to production vehicles as possible, and we therefore strongly believe that our trucks have the same level of reliability and crash-worthiness as their base vehicles.

The only external modifications we make to our trucks are those required to mount our sensors and antennas. This includes our custom-designed mirror pods, which hold both sensors and mirrors while maintaining compliance with the Federal Motor Vehicle Safety Standards—the government regulations that dictate the design, performance, and safety of motor vehicle components. Under the hood, we add off-the-shelf, computer-controllable brakes, throttle, and steering actuation components that allow our trucks to “drive by wire."

Sensing
- Forward-facing sensors
- Custom, patent-pending mirror pods with side-facing sensors

Human-machine interface
- Driver Monitoring System
- System Operator Display
- Electronic Logging Device
- System Status light and Emergency Stop button



Thinking
- Custom-designed computer
- Control computer

Acting
- Power
- Brakes
- Steering column
- Throttle

Kodiak's Software Stack

Driving a vehicle is complicated: we often forget how challenging driving truly is. ***That humans can mostly drive effortlessly while singing along with the radio is a minor miracle.***

Driving requires conducting numerous complex, overlapping actions. To drive, you need to simultaneously determine your vehicle's location, identify other vehicles on the road, predict how those vehicles will behave, decide where you should drive in response, and then turn the wheel and actuate the pedals just the right amount to get where you want to go.

Even with today's most powerful sensors and computers, completing these tasks can be incredibly complex for robots. Autonomous vehicle developers therefore build complex software and hardware system layers, each of which is responsible for a different component of the self-driving task.

These critical tasks are performed on Kodiak's onboard computers. ***Kodiak believes that our trucks' safety envelope must be entirely contained within the vehicle, i.e. that all safety-critical processing must happen on the truck.*** In other words, we can't depend on external resources and connectivity to maintain safety, though we can use external data as an additional safety input.

Kodiak's onboard computers are specifically designed for self-driving: they are enormously powerful, and have processors designed to do the types of machine learning computations that self-driving requires. They are also designed to be more robust and redundant than traditional PCs, to meet the demands of operating safely on the road.

Kodiak's software stack:

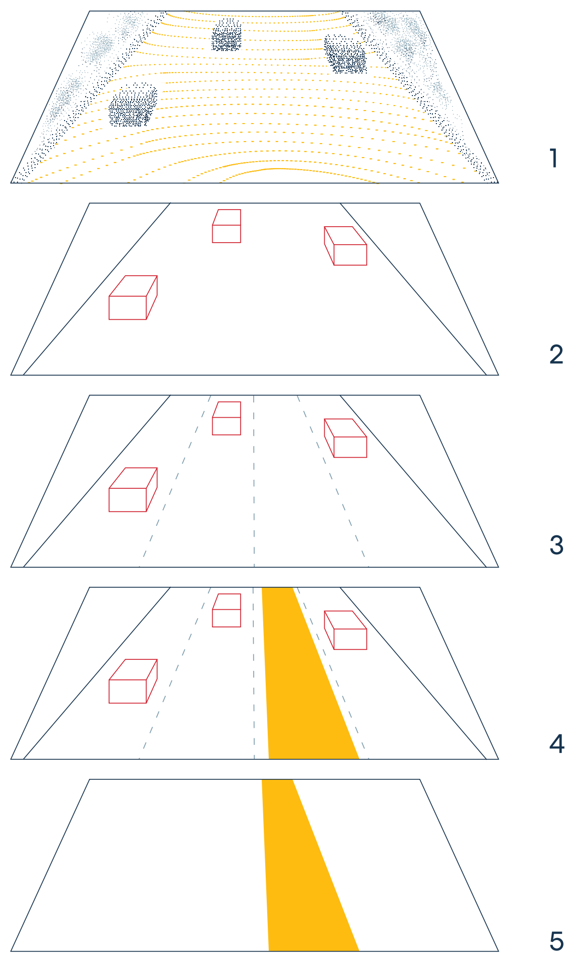
1. Sensing — how the truck "sees" what's around it, using its wide range of sensors

2. Perception — how the truck turns what it "sees" into meaningful, actionable information

3. Localization — how the vehicle places itself in the world and determines its location, orientation, and speed

4. Planning — how the vehicle decides where to drive, taking into account road conditions and the likely behaviors of other actors and objects on the road

5. Controls — actually applying the throttle or brakes, turning the wheels, and otherwise actuating the vehicle to precisely follow the plan

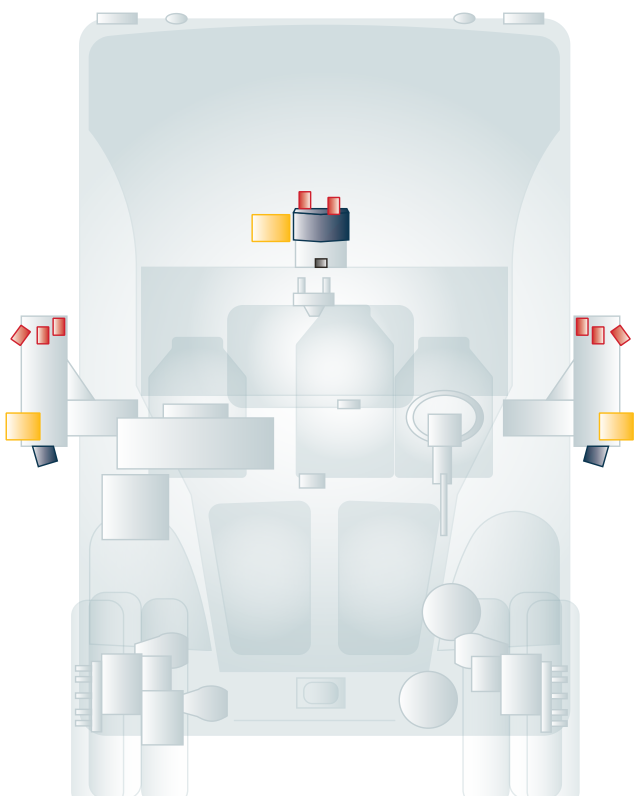


How the truck senses the world

The Kodiak Driver uses a wide array of sensors to build its sense of the world. We choose sensors that complement each other and together provide a diverse perception ability.

» **Cameras** allow the truck to detect visible objects and identify lane markings. Camera data, when processed through advanced algorithms, are best able to differentiate what an object actually is, and give the Kodiak Driver a rich understanding of the world around the truck.

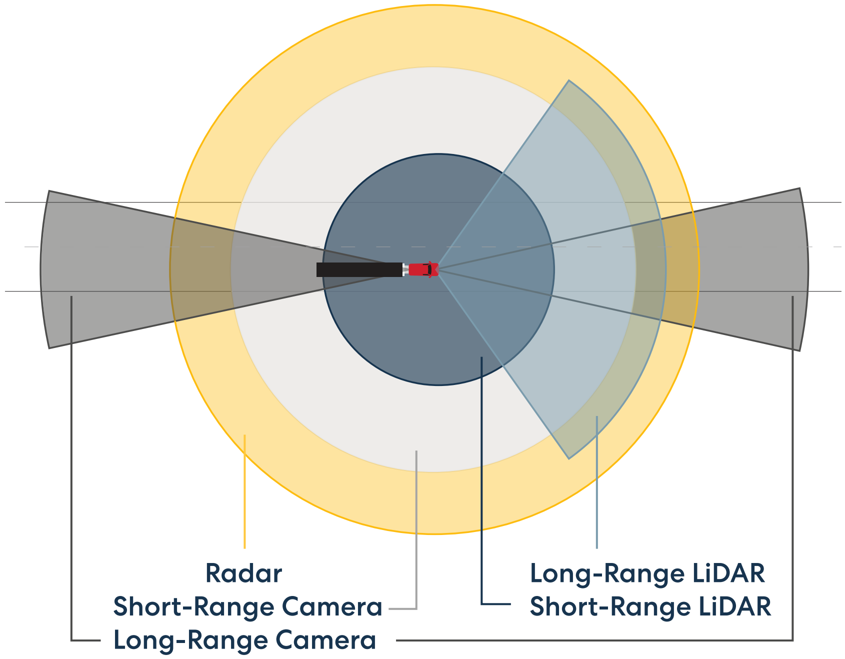
» **LiDAR** (Light Detection and Ranging) sensors bounce short laser bursts off objects to create 3D-maps of the environment around the vehicle. LiDAR sensors create detailed short- to medium-range 3D scans, and have an unparalleled ability to detect the presence of an object in a particular area. Since LiDAR sensors use their own light, they also work great in low-light conditions, but are less effective in rain, snow, and fog.



» **Radar** sensors bounce radio waves off nearby objects to determine their location and velocity. Radar is very useful for determining the location and speed of objects in conditions such as road-spray, fog, or our new friend, Texas thunderstorms. Radar generally gives a lower-resolution view of the world than cameras or LiDAR.

» The **Inertial Navigation System** (INS) uses a combination of sensors, including GPS, to help the truck determine its position and orientation. The INS is critical for helping the Kodiak Driver localize itself on the road and on the map.

Kodiak's perception model



The perception layer is responsible for turning the data our sensors collect into meaningful information the Kodiak Driver can use to understand the world around it. The perception system works by processing every sensor measurement through a series of detectors, software tools that process sensor data to identify where potential objects are and what they might be. Multiple detectors may process the same data in different ways, to further ensure that the perception system correctly identifies an object. This approach is highly diverse and redundant: since we have multiple sensors and detectors working in parallel, we can be more certain that objects will be detected.

We have built our perception layer to handle uncertainty, and be tolerant of the often less-than-perfect measurements that can happen under real-world conditions. For example it's easy to decide how to categorize an object if the camera, LiDAR, and radar detectors all agree it's a duck. In other words, if it looks like a duck, walks like a duck, and quacks like a duck, our AI can be pretty sure it's a duck.

In the real world, however, sometimes ducks look like pigeons, and sometimes detectors can disagree on whether an object is a duck, a pigeon or something else entirely. ***In these cases, Kodiak's perception system does not assume that an object is a duck, just because a single sensor says it is one.***

Using every sensory reading

Over the past decade, most self-driving systems have used LiDAR as their primary sensor, while layering-in other sensors to compensate for situations where LiDAR performs poorly. For example, they may use cameras to detect brake lights, and radar to compensate for LiDAR's lower effective range in the rain.

Our experience building self-driving systems has convinced us to take a fundamentally different approach. ***Instead of relying primarily on LiDAR then working around its limitations, the Kodiak Driver treats all its sensors as primary.*** Giving equal importance to each sensing modality allows the Kodiak Driver to build a richer understanding of the scene, and maximizes performance by taking advantage of each sensor's unique properties.

When detectors disagree about what an object is, the perception system gives a probabilistic assessment, using what we know about the relative strengths and weaknesses of each sensor. For example, in heavy rain, the perception system may choose to give less weight to a LiDAR detection, knowing that LiDAR sometimes makes false detections in the rain. But the system will never discount or ignore a detected object completely without a clear internal justification.

Localization: Using maps as a "sensor" input

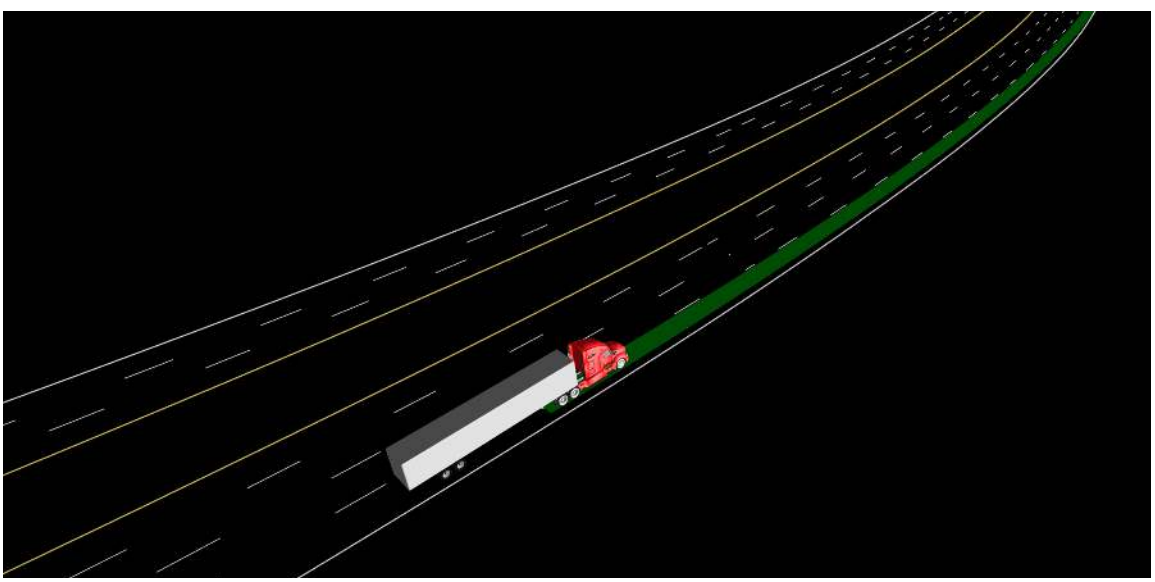
As humans, we have an intuitive sense of where our bodies are in space at any given point in time: you know where your hands are without looking. The Kodiak Driver's *localizer* is responsible for giving our truck a similar sense of location.

Many localizers place themselves in the world by comparing sensor data to highly detailed maps, created over dozens of mapping runs. Kodiak's highway-only, middle-mile ODD requires a different approach.

Most drivers rarely notice it, but highways actually change relatively frequently and rapidly due to construction and other factors. Construction can start overnight and shut down a lane with little notice, then end just as quickly. The Kodiak Driver must therefore be able to localize itself even when its map doesn't reflect what it's seeing on the road.

Given this constraint, Kodiak is building a localizer that uses maps without requiring them. Our localizer uses lane markings and other perceivable cues to place itself, relying on maps as another "sensor" input to improve performance. We call this approach *perception over priors*. The Kodiak Driver trusts its eyes, not its memory, just like a human. When the Kodiak Driver detects a new construction zone or other traffic shift, it can update its map in real-time, and share its new map with the rest of the fleet over-the-air. This mapping-light approach doesn't mean we intend to operate our trucks in unfamiliar environments, but it does mean that the Kodiak Driver has the flexibility it needs to safely drive in its ODD.

Similarly, we're building the Kodiak Driver to use GPS to aid in localization, without *requiring* GPS availability. GPS will serve as an additional layer of localization redundancy, alongside maps, perception, and inputs from the INS.



The Planner and Controls

Kodiak's *planner* is responsible for deciding where and how the truck should drive, based on the data it receives from the perception and localization systems. The planner continuously considers numerous parallel options for what the truck should do, balancing a wide range of imperatives: from safe driving policies, to predictions about how other objects on the road will behave, to the rules of the road, and the route that it wants to follow. This process is not so different from how humans think about where to drive. When you're behind the wheel, you're unconsciously considering how best to proceed, whether to switch lanes, change speeds, or continue in your lane as before.

Kodiak's planner chooses which option to take based on a lowest-cost model: the planner has to "pay" a penalty for making certain decisions, so it will always choose the action that imposes the lowest costs. For example, imagine that a car cuts the truck off on the highway. The truck has several options for how to respond. It can:

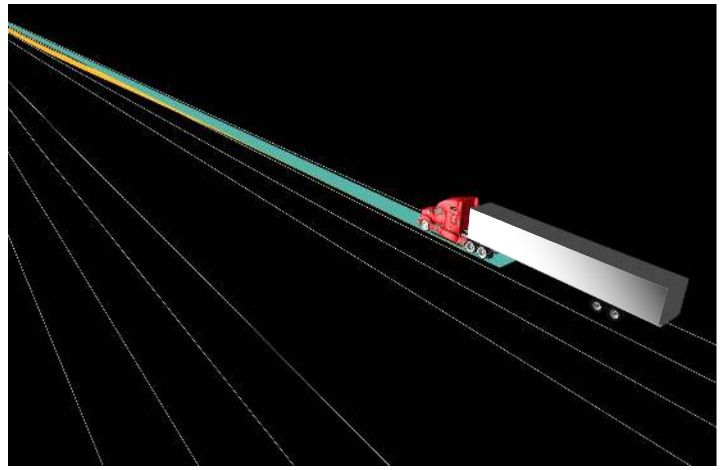
» Change lanes to drive around the car, which imposes a cost for a rushed lane change;

» Brake hard, which maintains a safe follow distance but imposes a cost for hard braking;

» Brake lightly, which imposes a cost for violating the safe follow distance but avoids the cost for hard braking.

In this case, the planner would balance the costs from these three options, taking into account other vehicles on the road, the speed of the car cutting off the truck, and other factors.

Once the planner has decided where the truck should go, the controls layer, or *controller*, is responsible for actually steering, braking, and otherwise physically driving the truck. The controls layer uses position, speed, heading, and other information from sensors to place the truck on the plan, considering the truck's desired direction and speed. The controller is also responsible for monitoring the health of the truck's systems (such as brakes and steering). If the controller detects hardware faults, it can bring the truck to a safe stop.



We've built safety limits for how strongly the Kodiak Driver can accelerate, brake, or turn the vehicle: this means, for example, that the vehicle cannot turn itself so quickly that the Safety Driver doesn't have time to prevent the truck from changing lanes dangerously. These limits ensure that the Safety Driver has time to intervene should the system do something unexpected.

One advantage of building self-driving trucks over passenger vehicles is that freight doesn't care about comfort so long as it is secure. ***While passenger car developers must balance the need for safety against the need for a smooth ride, we can optimize our driving entirely for safety.***

Planning for Uncertainty

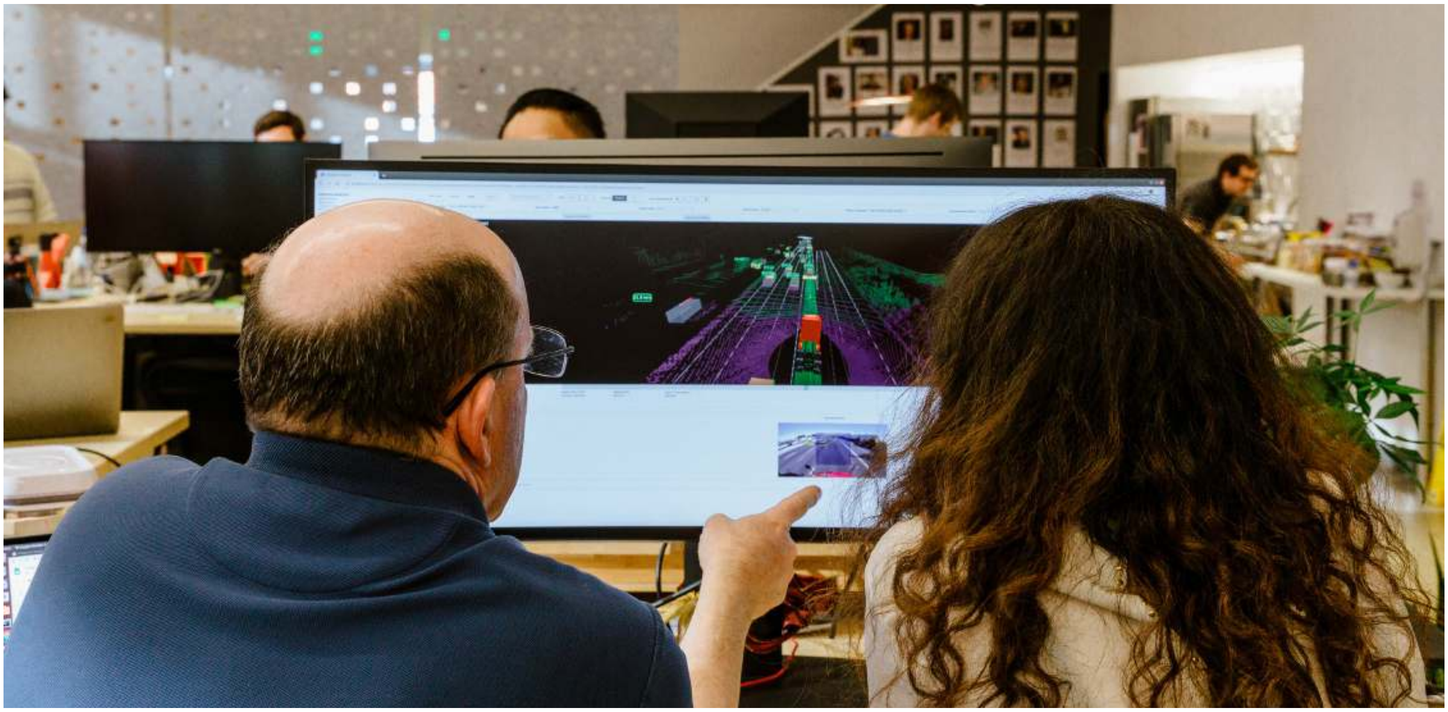
Our planner is designed to manage the inherent uncertainty of driving safely and effectively. We believe that planning for every scenario is impossible: there are too many unusual or unlikely variables to account for everything. Instead, we've built our planner so that it can adjust to the uncertainty inherent in the perception process by taking a probabilistic approach to unidentified objects. In essence, Kodiak has created a system that drives defensively when the situation calls for it, just as a person would.

When the perception system is less than fully certain about what it sees, it tells the planner to be cautious, taking into account the best- and worst-case scenarios. The planner then takes a more conservative approach, by, for example, maintaining a larger following distance or avoiding lane changes.

For example, we once saw the very unusual vehicle in the photo below on the road. Few perception systems are ever trained on how to classify a vehicle like the one in the photo. Instead of forcing the unidentified object into an existing, and possibly incorrect, vehicle type, the Kodiak Driver would proceed cautiously, slow down, and give the strange vehicle extra space. ***In other words, the Kodiak Driver will drive defensively, just like a human.***

Should the Kodiak Driver encounter a scenario it truly cannot understand, there is a backup. Rather than risk misinterpreting a dangerous situation, the Kodiak Driver is designed to assume a "fallback." This means the Kodiak Driver would safely pull to the side of the road and wait for the situation to become interpretable.

Training Kodiak's perception system



A key part of Kodiak's testing process is data recording and logging. Kodiak collects two types of data: operations data and system test data.

Operations data covers data related to typical truck operations. We work with industry-leading driver-monitoring and telematics partners to collect data regarding critical truck issues such as Hours of Service (HOS) compliance, pre-trip inspection logging, and Driver Monitoring System camera data. This data helps us ensure we remain in compliance with key safety-critical regulations, and are maintaining our vehicles to the highest standard.

More complex is our system test data, which is the data we collect on test tracks and on the roads. ***Kodiak's team actively reviews and catalogues every piece of data we collect, a process we call triage.*** We use our triage process to identify the root cause of every disengagement, or instance when the truck reverts to manual driving (either of its own accord or due to a choice made by a Safety Driver). Triaging every disengagement helps us to identify system bugs and determine the need for additional driving features. It also helps us prioritize our engineering efforts, by showing the most common reasons for disengagement.

The triage process helps improve the machine learning models that are critical to the development of the Kodiak Driver. Machine learning is an approach to software development that uses real-world data to train a system: instead of writing code that explains what cars look like, we show our perception system hundreds or thousands of photos and videos of cars, until the system "learns" how to recognize them in a myriad of weather, lighting, and other conditions. Most people assume that machine learning is largely automated, but it's actually a fairly manual process. We don't just let our data sit on hard drives: our triage team carefully considers each piece of data to determine how it can improve our machine learning models. For example, the triage team may identify an on-road object that the system may not have properly detected during a test run: this helps improve the machine learning models so the object will be detected in the future. And since these machine learning models are shared across the fleet, what one truck learns, they all learn.

Lastly, the triage process helps us to build our collection of interesting, real-world driving scenarios. We use these scenarios to help create simulations, and use those simulations to test how the Kodiak Driver would handle that situation again, given ongoing changes to its codebase. These simulations will be critical to building our safety case, our proof that our truck is fundamentally safe.

Safety, start to finish

Kodiak's safety philosophy, in theory and in practice.

Building a safe self-driving truck

As we've built Kodiak's testing and operations processes, we have thought deeply and carefully about how to put safety at the center of everything we do. After all, safety is the core, critical technology for a self-driving vehicle: building the technology and proving the technology is safe must go hand in hand.

Safety at Kodiak means many things, from running a safe testing program to ensuring the functional safety of our hardware and software components to training the Kodiak Driver to exhibit safe behaviors on the road.

We put safety first in our vehicle operations by encouraging our vehicle operators, whom we refer to as Safety Drivers, to disengage the Kodiak Driver, whenever they feel it is necessary, without needing to justify that decision.

We incorporate safety into our hardware processes by testing each piece of equipment repeatedly and ensuring redundancy and reliability throughout the system. We incorporate safety into our software by testing and retesting each piece of code to ensure it is safe and doesn't introduce new bugs or safety regressions. We even incorporate safety into how we run our company by giving everyone a say in ensuring safe operations and working hard to make sure we leave no risks unexplored or unaddressed.

Minimizing risks

At the core of Kodiak's safety program is the recognition that there is no such thing as risk-free driving: anyone who gets inside a vehicle exposes themselves to the risk of an accident. We take this risk seriously. Though no one can ever completely eliminate risk, we work actively to minimize it. Our commitment to risk minimization manifests itself in a variety of different ways. ***Perhaps most importantly, we believe it's critical that everyone at Kodiak sees safety as their individual responsibility, and that everyone is not only empowered but obligated to act to improve safety.***

Our entire testing process is built around the pursuit of safety and ensuring that every piece of data we collect is worth the risk. Putting this risk-reward tradeoff at the forefront of every test does more than promote safe outcomes: it actually speeds our development progress. This is because the imperative of maximizing safety also encourages us to focus on the most critical, high-impact data.

Safety, start to finish.

Core to Kodiak is our most important value: Safety, start to finish. Foundational, functional, and multifaceted, most of this Safety Report is dedicated specifically to the topic of safety. (After all, it's right there in the name.)

Kodiak's company culture is built around safety, and the goal of making driving safer through the deployment of our trucks at scale. Self-driving trucks will truly transform people's lives by increasing road safety. We believe that our technology will soon make the roads safer for all drivers, and that self-driving technology will allow all of us to drive on fundamentally safer highways.

At Kodiak, safety is not just something we talk about—it is something we do every day. We have embedded safety into our culture with intentionality, taking into account lessons we've learned in our collective decades of experience building self-driving vehicles and other safety-critical technologies.

Making every mile count

For years, self-driving developers have debated the merits of moving quickly vs. proceeding cautiously, balancing the desire to make life-saving technology available sooner, vs. the short-term risks speed could create. At Kodiak our experience has taught us that this trade-off is a false dichotomy. ***When implemented correctly, a strong safety process and culture actually accelerates development by forcing developers to make every mile count.***

At Kodiak, we are strategic about every mile we drive: we never drive our trucks for the sake of just logging more miles. Our philosophical commitment to disciplined innovation forces us to actively seek hard miles, or the complex driving environments that most push the capabilities of the system.

Making a mile count can mean different things: it can mean collecting a valuable piece of data that can't be collected via simulation, or it can mean delivering freight for a customer. We aim to be thoughtful and deliberate about every test run, to ensure that each piece of data we collect gets us a little closer to deployment, and that every mile is worth the incremental risk.

By being disciplined in our testing approach, we can make rapid progress while maximizing safety.

Additionally, most people assume that for machine learning, more data is always better. Our experience suggests, however, that more data does not just generate diminishing returns - it can be actively counterproductive. Once the Kodiak Driver has been trained to recognize 5,000 SUVs, it learns little from the 5,001st. And while it's important to train the system to handle unusual, dangerous circumstances, such as a vehicle fire, on-road testing is the wrong way to conduct that training—you need to drive too many miles and take too many risks to find those examples "in the wild." Instead, we rely on safer, more predictable simulations and structured testing to test system performance in those dangerous, unusual edge cases.

Of course, this disciplined approach means we will probably never log as many test miles as some of our competitors. We see our lower mileage count not as a risk, but as a sign of our commitment to safety.

Self-driving metrics

Over the past decade, many self-driving developers have focused on a single key metric: miles per intervention (MPI), or the number of miles the system can drive before a Safety Driver needs to intervene. ***At Kodiak, we think it's time we move beyond MPI, for both safety and technical reasons.***

First, we think that MPI can obscure as much as it explains. One pathway to getting a high MPI is "wasting miles," driving in simple, familiar driving environments where the system has little to learn. This just adds miles and risk, while doing little to improve the system. Additionally, a focus on MPI can encourage developers to focus on incremental improvements, instead of complex but necessary reworks—nobody wants to redesign a module if it causes a temporary drop in MPI, no matter how necessary that redesign may be.

Additionally, we think encouraging interventions actually helps us improve the Kodiak Driver. Since we carefully triage every intervention, we learn every time we take the Kodiak Driver out of autonomy. ***By maintaining a relatively low MPI, we can ensure that the system is always learning.*** In fact, we consider "learnings per mile" as a critical metric—at this stage of our development cycle, if we go too long without disengagements, we aren't learning and we need to stress the system more. We want to make sure that we're learning from every mile we drive, and that the Kodiak Driver is constantly increasing the volume of scenarios it can handle without intervention.

A focus on MPI can also be a safety risk. Safety Drivers may choose to wait to disengage the system, to see if the Kodiak Driver can recover from an issue on its own. This can be dangerous. Instead, Kodiak has a strong policy against (together with a culture of discouraging) *letting it ride*, or waiting to see if the system can recover from a mistake. Never letting it ride means we never get the chance to test the Kodiak Driver's ability to recover on public roads: instead, we use simulation and structured testing to reconstruct driving scenarios and collect the data we need about the system's ability to recover.

Kodiak values

Disciplined innovation

At Kodiak, we believe that concentrating on a solvable problem is more valuable than moonshot development. We call this value disciplined innovation, and it underlies everything we do. Our collective decades of industry experience has put the realities of business into focus and clarified the limits of existing technology—it is within these constraints that we thrive. Disciplined innovation is why we chose to build the Kodiak Driver for highways: we think highway driving is a more solvable problem than driving on city streets. In other words, ***Kodiak isn't a science experiment: from day one, we've been focused on how to build a safe, impactful business that will allow us to serve our partners and make driving a little safer and better*** for everyone.

In our software, we value elegant solutions over complicated features: disciplined innovation therefore also drives our development process from the ground up.

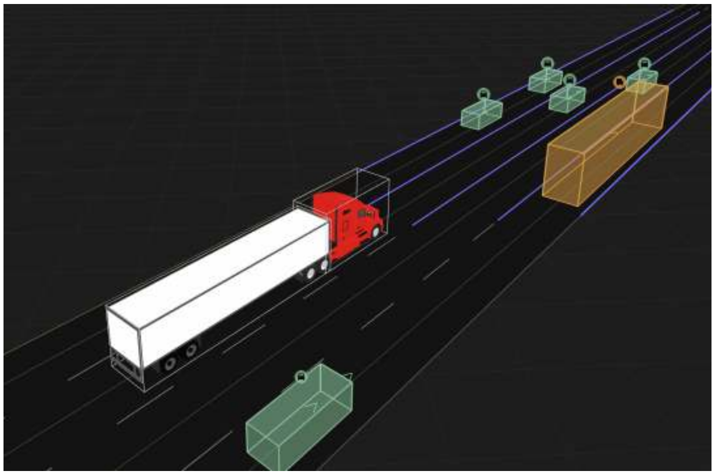
Kodiak's simulation platform

Kodiak uses a simulation-first testing approach that relies upon a detailed simulation platform as the primary test medium for the Kodiak Driver. We use this simulations-first approach for several reasons. First, simulations are obviously fundamentally safe: the worst injury people get running simulations is carpal tunnel. Second, ***we believe simulations allow the Kodiak Driver to learn more and learn faster.*** The Kodiak Driver can practice many more complex situations in simulation in a few minutes than it can in hours in the real world.

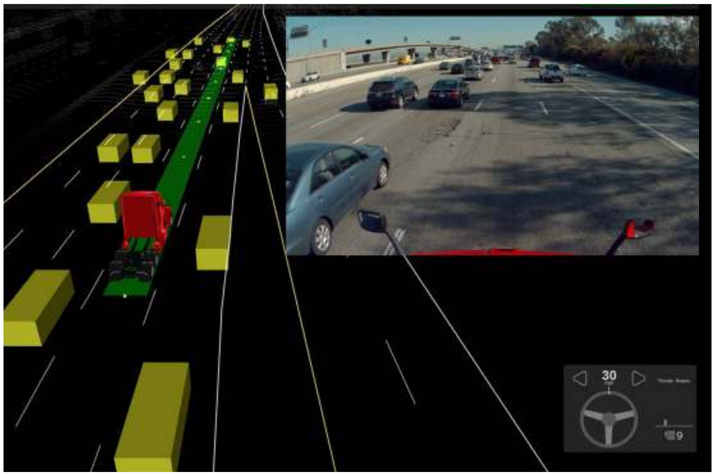
Rather than build our own simulation platform, Kodiak chose to partner with an industry-leading third-party simulation provider to co-develop a simulation platform, customized to Kodiak's unique technology stack. Our close relationship with our simulation provider has allowed us to leverage our partner's targeted technology, team, and infrastructure to build what we believe to be among the most powerful and flexible simulation platforms in the self-driving industry.

Our simulations program follows the framework identified in the draft ISO/PAS 21448 standard, which governs Safety of the Intended Functionality (SOTIF) analysis. SOTIF is a relatively new but widely accepted guide for self-driving developers on how to ensure their vehicles behave safely in the absence of a fault.

Our simulation scenarios broadly fall into two categories. We use manually created *synthetic simulations* to test the Kodiak Driver across a range of both simple and complex known driving scenarios. Since every simulation we create is kept on our simulation platform, we can ensure that once the truck has developed a certain capability, it will not regress.



Synthetic simulations



Log-based simulations

Synthetic simulations follow Kodiak's disciplined innovation approach: we don't simulate routine driving but instead run targeted tests that hone in on the key scenarios in which we need to validate the Kodiak Driver. In particular, developers use synthetic simulations to determine the effectiveness of specific software features, helping to test for, and eliminate, bugs. For example, to test the truck's ability to change lanes, we create simulations that reflect various real-world lane-change scenarios, including the presence of vehicles in the surrounding lanes, traffic ahead, or a lane-splitting motorcycle.

The second category of simulation, *log-based simulations*, are generated directly from the data we collect on-road: they are simulated versions of the interesting scenarios from our test runs. Because log-based scenarios are based on real-world driving, they are less flexible than synthetic scenarios: we can't just create a log-based simulation to test a specific function or situation. But since log-based simulations use real-world data, we know that they reflect actual driving conditions.

With a log-based simulation, we can determine how the Kodiak Driver will respond to being cut off on the highway, given previously observed, real-world driver behaviors. A similar synthetic simulation may allow us to test a specific scenario we think is important, but since it is made by a human, driver behavior will necessarily not be as realistic.

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Additionally, log-based simulations also allow testing across more layers of the Kodiak Driver. For example, log-based simulations allow us to determine whether our perception system will correctly interpret real-world sensor data collected on a previous test run. Log-based simulations will also eventually allow us to do real-world/simulation comparisons, helping to validate that the simulation reflects real-world behavior, and allowing us to further refine both the truck and the simulation platform.

Structured testing

For certain situations, there is no substitute for testing real-world performance. In those circumstances, we, when feasible, use a structured testing model to assess vehicle performance prior to taking the truck onto public roads. ***In a structured test, we test the Kodiak Driver on a closed course to stress the system in systematic, structured ways.*** Structured testing also allows us to conduct real-world tests on scenarios that are not easy to recreate on public roads.

Structured testing allows us to evaluate the performance of new features, validate behaviors we see in simulation, and identify how the truck behaves in specific, targeted scenarios. For example, to assess the system's performance in a crowded merge, we may re-create a merge in a test-track environment, so we can evaluate system performance without having to chase a crowded merge in the real world. Structured testing is particularly valuable for testing dangerous edge cases, like pedestrians on the roadway: by using a test dummy, we can test system performance without actually having people walk in front of or around our trucks while in motion.

A key part of structured testing is fault-injection testing. In a fault-injection test, we recreate real-world simulations of various edge cases and faults on a test track to see how the system behaves in practice. For example, we might create a fault-injection test in which the perception system tells the planner it identified a deer jumping into the middle of traffic, or detects the sudden presence of debris in the middle of the

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Why we test on-road

While simulations are key to Kodiak's development process, we also believe it's critical to test the Kodiak Driver on public roads. Simulations can be incredibly powerful; however, they cannot capture everything that happens while driving. By definition, simulations test the variables that you have already considered and built into the simulation model: no matter how extensive that model, the real world always finds new variables. There are therefore limits to how much the Kodiak Driver can learn without real-world data.

Kodiak uses on-road testing for a variety of reasons. First, on-road testing helps us collect data about how the Kodiak Driver behaves in the real world, from the perception systems to the planner to the controls. This data helps to validate behaviors we see in simulation and in structured testing. Second, we use our on-road testing to build new log-based simulation scenarios, thereby ensuring our real-world data helps to enrich our simulation

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highway. If the vehicle responds appropriately to virtual deer or debris, we can confirm that it will respond appropriately under real-world conditions.

Structured testing is also critical to testing Kodiak's hardware platform. We use fault-injection tests to determine how the system responds to hardware errors. For example, we may run a structured test where a camera shuts off in the middle of the run, to see if the system responds appropriately in a real-world environment, without taking the risk of turning off a camera on public roads.

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platform. Lastly, we use on-road testing has also helped us to refine our development and operations processes and procedures.

There are certain parts of the Kodiak Driver that are particularly difficult to simulate. The impact of weather conditions is difficult to model in simulation. For example, direct sunlight or haze can impact some sensors, while rain and snow can impact how tires behave. On-road testing therefore helps us determine how the Kodiak Driver handles a wide range of weather conditions. Real-world control systems are almost impossible to simulate for a variety of reasons, due to minute differences between every sensor, control system, and truck, as well as the variable latency between when the planner issues a command and when that command is executed. Lastly, real-world tests help to uncover unexpected faults, in particular potential hardware failures that we had not anticipated based on prior experience or existing data.

Whenever possible, we carry freight for commercial customers while we're testing on road, instead of hauling trailers full of sand. We see carrying freight as key to making every mile count. Because the freight needs to be delivered (either by a manual truck or one equipped with the Kodiak Driver), serving customers allows us to minimize the incremental number of miles we are adding to the overall freight network and therefore minimize the incremental risk to motorists. Carrying freight also allows us to better understand and model how the Kodiak Driver will be used in the real world: this will help us design our system to meet our customers' needs and accelerate our path to deployment. It's what's right for the freight, the environment, and our fellow motorists.

Operational Safety

How Kodiak's operations program ensures safety.

Kodiak's operations program

No matter how great our self-driving technology may be, it's still under development. This means that building a safe testing and operations program—from people processes to policies and procedures—is critical.

Our philosophical commitment to disciplined innovation forces us to actively seek hard miles, or the complex driving environments that most push the capabilities of the system. Kodiak conducts its in-vehicle tests with two-person teams: a Safety Driver and a System Operator. All Safety Drivers and System Operators are Kodiak employees—not contractors. This ensures that all of the people ensuring the safety of our vehicles are also aligned with our company values.

Once hired, all Safety Drivers and System Operators participate in an extensive training program, designed to introduce them to the operation of the truck, the Kodiak Driver, and Kodiak's safety culture. All Safety Drivers and System Operators receive extensive training on Kodiak's vehicles and system, with both formal classroom training and in-vehicle "on the job" training under strict supervision.

Safety Drivers

Safety Drivers are responsible for monitoring the road and the behavior of the vehicle. Accordingly, Safety Drivers disengage the truck's autonomy system at the first moment they deem appropriate, and then take control of the vehicle in case of a disengagement. Safety Drivers are also responsible for driving the vehicle outside of its ODD.

System Operators

System Operators are responsible for monitoring the operation of the Kodiak Driver, and communicating system intentions and status to Safety Drivers. System Operators also troubleshoot basic system behaviors, identify issues, and provide feedback on system performance through reports and comments. These reports and comments are critical to Kodiak's triage process.

Kodiak's Safety Drivers

Kodiak adheres to strict standards when hiring Safety Drivers, and still only hires a small percentage of the drivers that meet those requirements. All Kodiak Safety Drivers:

- Hold Commercial Drivers Licenses (CDLs)
- Have at least three years of commercial driving experience
- Have a sterling safety record
- Pass a preemployment drug and background check
- Pass both interviews and road tests, designed to ensure in-vehicle safety

Kodiak considers Safety Drivers to be truck drivers, which means they must comply fully with the many regulations that apply to CDL holders, from HOS compliance to inspection protocols. Kodiak Safety Drivers conduct a federally-mandated pre-trip inspection of safety-critical vehicle systems every time they take a truck onto a test track or public road. Kodiak's pre-trip inspection protocol includes both the components required by a traditional pre-trip inspection, such as brakes, fluid levels, and tire pressure, as well as a close inspection of the vehicle's sensors, their connectors and their mounts. Safety Drivers also inspect the truck and trailer every time the truck stops—at meal times, refueling stops, and rest breaks.

Kodiak's Human Machine Interface

Kodiak has designed a custom Human Machine Interface (HMI) that integrates directly into the truck and ensures that the Safety Driver is in control of the truck at all times on every test run, whether the truck is in manual or autonomous mode.

We've built the Kodiak Driver's HMI to be easy and safe for our Safety Drivers to manage during testing. A simple, easy-to-understand dashboard light communicates the state of the system: Manually Driven/Not ready to engage, Manually Driven/ Ready to Engage, Self-Driving, and Fallback. Each system state transition also has a unique audio cue, so the Safety Driver can manage system state transitions without taking his or her eyes off the road.

The Kodiak Driver has numerous safeguards to ensure it will not engage improperly. The system will not enter "Ready to Engage" mode unless it has conducted numerous self-checks, including that the autonomy software processes are healthy, that the sensors and actuators are working as intended, that the system is in its ODD, and that the vehicle's intentions and controls would be appropriate for the driving environment. For example, we do not allow engagement if the vehicle plans to suddenly or severely deviate from what the Safety Driver is currently doing. Safety Drivers engage the system by pressing the Engage/Disengage button.

We also conduct numerous verifications on the vehicles designed to ensure safe testing. These include verifications to confirm that the Safety Driver can always override autonomous control, and system checks to ensure that the Kodiak Driver always correctly communicates its autonomy state.

As the Kodiak Driver continues to improve, it will drive longer and longer stretches without requiring intervention. We are talking to our industry partners about approaches to keeping the human driver engaged, even when there is little to do.

Disengagements

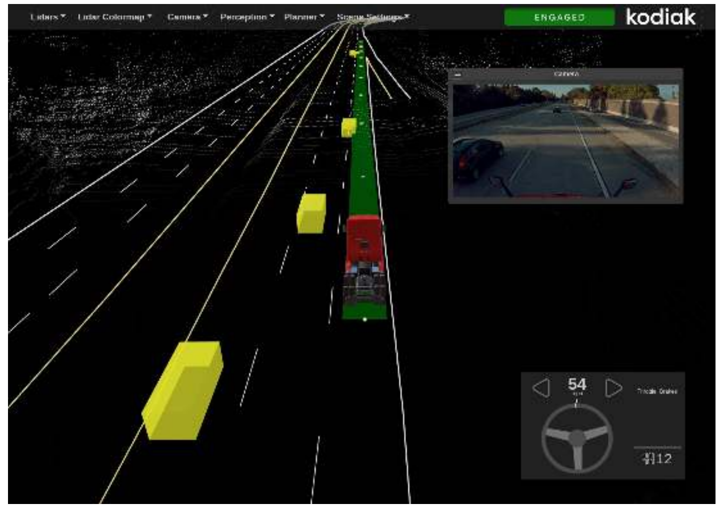
Kodiak has designed its hardware platform so that the Safety Driver can always override the self-driving system and retake control of the truck at any time. In case a Safety Driver needs to disengage, there are multiple paths to disengagement:

- Slightly turning the steering wheel
- Touching the brake
- Touching the accelerator
- Disengaging the system via the Engage/Disengage button
- Pressing the Emergency Stop Button, which shuts off power to the autonomous system and returns the vehicle to manual mode

In addition to manual disengagements, the Kodiak Driver also automatically disengages if it encounters a scenario that is outside its ODD. We've done extensive research into how to best notify our Safety Drivers to resume control over the vehicle, and use a mix of visual and audio indicators. When the Kodiak Driver disengages itself, the system automatically begins bringing the truck to a safe stop, until the Safety Driver retakes control of the vehicle.

System Operators

A System Operator on a test run



The Visualizer

System Operators also have a safety-critical role to play in testing. At any given moment, the Kodiak Driver is identifying dozens of on-road objects and making multiple plans for where it wants to go. For Kodiak's Safety Drivers to maintain control over the trucks, they must understand what the truck is seeing, and what it intends to do, while keeping their eyes on the road. ***System Operators, therefore, are responsible for helping Safety Drivers make fundamentally safe decisions by monitoring what the Kodiak Driver is planning, then communicating those plans to the Safety Driver.***

System Operators monitor the Kodiak Driver through the Visualizer, which provides a clear, graphical representation of what the system's sensors are detecting and how the system intends to react. The Visualizer allows the System Operator to ensure that the perception system isn't missing objects on the road and that the planner intends to act safely and reasonably. For example, if the System Operator sees a vehicle up ahead that the system has not yet identified, he or she can give the Safety Driver advanced warning, so the Safety Driver can prepare for a potential intervention.

At Kodiak, we expect System Operators to have a detailed understanding of how the Kodiak Driver behaves, so they can interpret how and why the vehicle is behaving the way it is. We invest heavily in building a culture of communication between our operations and engineering teams, so that System Operators understand what engineers are working on. This enables System Operators to make better risk-minimization decisions, and increases our ability to make every mile count. If at any point the System Operator is uncomfortable with the system's behavior or intended behavior, he or she can warn the Safety Driver so the Safety Driver can disengage the system and return the vehicle to manual operation.

System Operators also play a critical role in annotating the logs to provide feedback about how the Kodiak Driver behaves on the road, particularly surrounding disengagements. By enriching the data our sensors collect, System Operators help make every mile count, and allow us to make more progress with fewer miles.

Safe Policies and Procedures

Since before our first test run, we've had a strong set of policies in place to ensure the safest possible testing program throughout the organization. These include written policies that set expectations for vehicle operations, including when to disengage the system, where to scan on the road, and where drivers should keep their hands when the system is engaged. Even team members who rarely, if ever, enter a truck receive training on truck safety, including truck blind spots and how to safely enter and exit a truck. Violating certain safety-critical standards, such as touching a cell phone while driving, leads to immediate dismissal.

To enforce policies and ensure Safety Drivers remain focused on the road, Kodiak employs a sophisticated Driver Monitoring System that uses interior-facing cameras and AI-based algorithms to automatically detect when a driver may be drowsy or distracted. The Driver Monitoring System notifies a Safety Driver if it thinks he or she is losing focus, and also alerts our operations center of the potential divergence from best practices.

Test run safety

All test runs begin with an operations brief, during which the Safety Driver and System Operator learn the goals of the mission. They also learn about any changes to the system, so they know what to be aware of. These briefings are critical for ensuring safety, particularly as new features and functionality are added to the system.

Drivers are expected to report any notable events during operation—nothing goes unaccounted for or swept under the rug. Any issues related to system performance need to be included in an end-of-run report or, if safety critical, be brought up with fleet managers immediately. After each test run, the system's performance is evaluated by the Safety Drivers and System Operators, and the test logs are evaluated by the triage team.

Grounding the Fleet

One of our most important safety policies is that ***anyone at Kodiak, from a Safety Driver to an engineer, can abort a test run or even ground the fleet at any time, for any safety-related reason.*** A grounding is an unplanned event that results in Kodiak removing one or more of its vehicles from autonomous operations, manual operations, or both.

Kodiak has clear policies in place to govern groundings. These policies would be meaningless if members of the team weren't empowered to use them, but at Kodiak we encourage team members to err on the side of safety at all times. Additionally, we maintain an anonymous channel where team members can voice any safety concerns that they don't feel comfortable addressing publicly. This anonymous channel can even be used to request a grounding.

Events that automatically trigger a grounding include:

» Any unexplained malfunction of any disengage mechanisms

» Any unsolicited engagement of autonomy

» Any on-road incident regardless of state of autonomy

All groundings are communicated to team members broadly, via multiple communications channels. Once a grounding order has been issued, operations team members must immediately disengage the Kodiak system, pull to the side of the road, and make positive contact with the operations team to confirm the grounding order. If a vehicle is being operated when a grounding is ordered, the company will determine whether it is safe to return to the nearest terminal, or if it should be parked in a safe location.

A grounding only ends after a dedicated Grounding Review Team, composed of relevant members of the engineering, operations, legal, and leadership teams, has determined the root cause of the grounding and identifies the remedy in a written report. Once the identified remedy has been implemented, Kodiak's leadership team can make the decision to unground the truck or trucks.

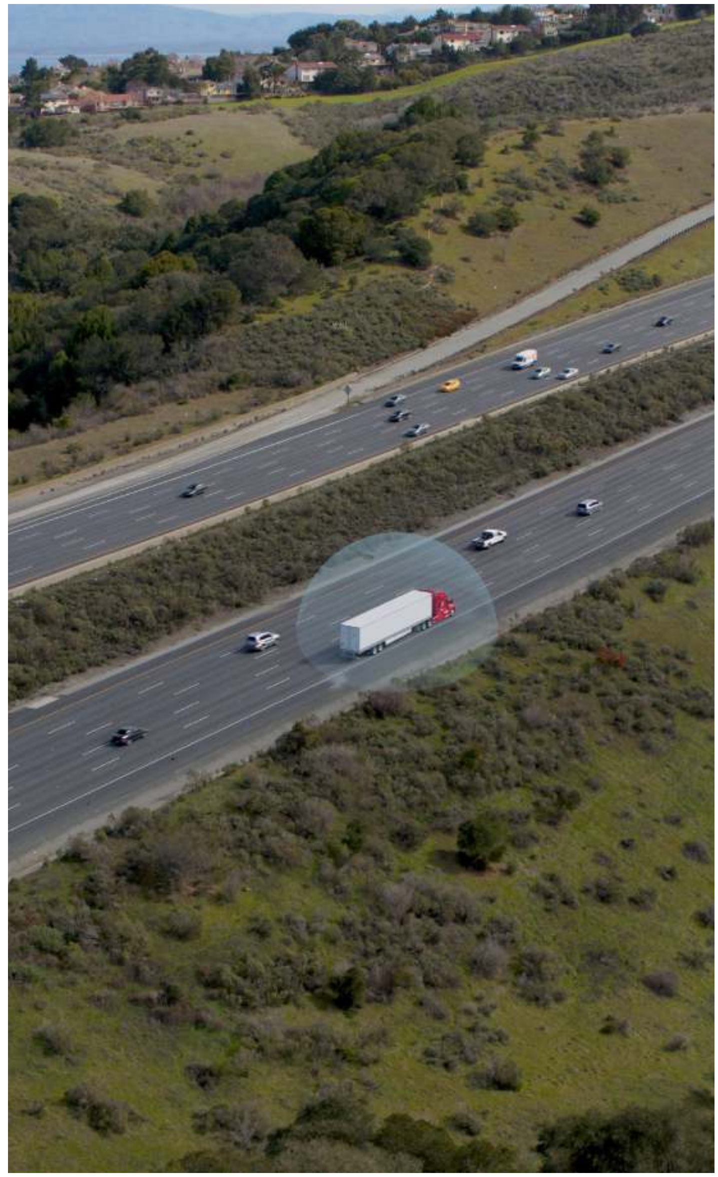
Kodiak's cybersecurity program

Protecting Kodiak's self-driving trucks from hackers and other bad actors will soon be critical to the safety of America's roads. As the Kodiak Driver develops, our cybersecurity program will continue to mature and expand to ensure the truck is always protected.

Kodiak built its cybersecurity approach based on numerous government and industry best practices, most notably the National Institute of Standards and Technology's cybersecurity framework and the National Highway Traffic Safety Administration's Cybersecurity Best Practices. We also tightly enforce physical access protocols to prevent unauthorized access to vehicles.

At a broader philosophical level, Kodiak believes that the best way to ensure the cybersecurity of our vehicles is to ensure that we minimize the number of data entry points into the vehicle. We also isolate the Kodiak Driver's safety-critical functions from external communications ports to prevent adding additional cybersecurity attack vectors. In other words, in addition to ensuring that the locks on our doors are up to standards, we've also designed the whole vehicle to have as few doors (virtual or otherwise) as possible.

Today, Kodiak's trucks do not depend on any external data sources or other Vehicle-to-Vehicle or Vehicle-to-Infrastructure communications. Should that change in the future, all connections will continue to occur over an encrypted, dedicated communications channel to establish and enforce our security policy. This methodology will enable us to further protect the trucks from intruders.



System Safety

How Kodiak's systems engineering program is helping us build a comprehensively safe self-driving truck.

Systems engineering

In the next few years, we intend to deploy the Kodiak Driver at scale. ***Preparing for deployment means developing a comprehensive and fundamentally safe software stack, but it also means building reliable, redundant, and secure hardware.*** After all, a system cannot be safe if it's not reliable or secure. This is why we began thinking about how to build a comprehensively reliable system well before we ever received our first truck.

Kodiak draws its development approach from a problem-solving philosophy known as *systems engineering*. Systems engineering is designed to eliminate safety failures from the beginning by incorporating analyses of potential failures into initial system designs.

In a complex system like a self-driving truck, faults often are interrelated: a single hardware failure may cascade across multiple systems, causing an unpredictable set of issues. In other words, a chain is only as strong as its weakest link. Systems engineering approaches focus on how the individual components of a system interact, and building so that a single-point hardware failure cannot cause a major safety failure. Every computer and sensor introduces a new opportunity for failure, so our systems engineering approach ensures that all of those potential failures are accounted for, and that processes are developed so that those potential failures do not create unmanageable safety risks.

Building redundancy

No matter how well-designed or built, all components eventually fail. To deploy commercially, the Kodiak Driver will need to be able to handle inevitable component failures. That's why we're building backups and very high redundancy into every safety-critical component of every vehicle. We never depend on a single system to accomplish a safety-critical goal, unless that system has been independently validated to the highest standard. We're also working closely with the leading technology providers in the trucking industry to make sure we are taking advantage of the latest technology as it becomes available.

While important, redundancy alone is not enough. Also critical to building a safe truck is building in robust fault detection, i.e. determining when a fault occurred. This is not always as simple as it seems: for example, it may be easier to detect that a camera's field-of-view is occluded during the daytime than at night, when an occlusion may blend into the darkness. As such, it is critical to engineer robust fault-detection capabilities into the Kodiak Driver to address faults as soon as they occur. If the Kodiak Driver detects faults, it always defaults to the safest behavior.

The Kodiak Driver is built with a core suite of redundant, high-integrity systems that are capable of fault detection and handling:

Vehicle Communication — Kodiak is building a redundant, low-latency, error-free, and secure communications network that can detect and safely handle potential faults.

Steering — Today, the Kodiak Driver steers using commercial-grade steering columns designed specifically for trucks. As we approach deployment, we plan on using dual-redundant electric motors, so that the Kodiak Driver can maintain control even if one motor should fail.

Braking — Kodiak's braking system contains redundant pressure and motion sensors that can validate that the planner's braking requests are implemented.

Sensing — The Kodiak Driver's sensors have overlapping fields-of-view, so that every region around the truck is seen by multiple sensors. This ensures the Kodiak Driver can understand its surroundings, even if a sensor fails.

Power Systems — We've built our trucks with redundant systems that can maintain power availability even in the case of a primary power failure. We closely monitor the power systems, and can execute a safe fallback maneuver in case of faults.

Compute and Controls — The Kodiak Driver actuates the vehicle on redundant, fault-tolerant computers that run independently from the main computer. These computers always know how to bring the truck to a safe stop, so that if the main computer should ever fail, they can safely achieve a Minimal Risk Condition.

Kodiak's Systems Engineering Approach

The goal of Kodiak's systems engineering program is to determine the Kodiak Driver's potential failures, then engineer the system to both minimize the risk of those failures occurring and prevent those failures from causing harm. ***To build Kodiak's systems engineering program, we have hired experts from a wide variety of safety-critical industries—from automotive to medical devices to aerospace—and organized our team so that the safety of the Kodiak Driver is part of the initial design process, not an afterthought or additional task.***

Over the last century, the automotive industry has developed comprehensive standards designed to help engineers determine the functional safety of a component, and how those components respond to hardware errors. These standards help engineers ensure they are exhaustive as they consider and document every vehicle component's functional safety. Given the newness of self-driving technology, industry has yet to develop a comprehensive functional safety standard specifically for self-driving vehicles. To fill the gap, Kodiak has chosen to develop our own functional safety approach that leverages the International Organization for Standardization (ISO) 26262 standard as a baseline, but also adopts relevant portions of a number of different standards.

Our approach follows the industry-standard V model, which is designed to ensure that everything we build is thoroughly tested and validated. We begin by identifying the functional requirements for each component, and how that that component interacts with other components in the system. This functional analysis helps to develop a list of functional requirements—what the system must be able to do—at the beginning of the design process, then use those functional requirements to drive the design and implementation of those components and systems.

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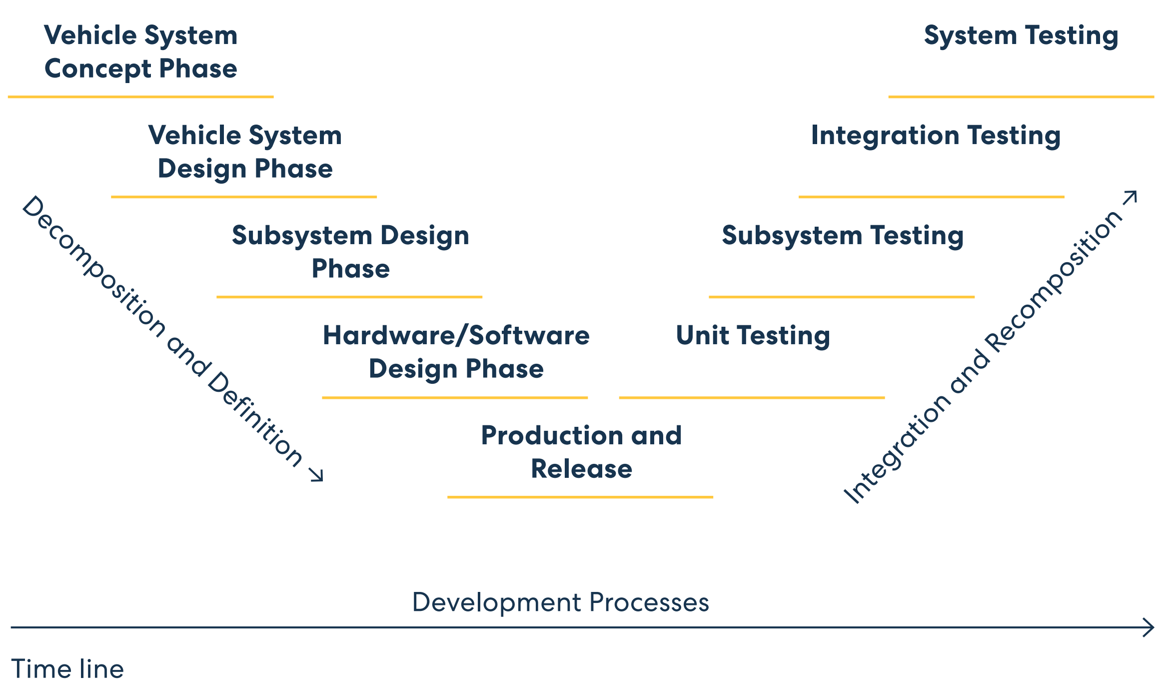
After identifying functions and functional requirements, systems engineers conduct Hazard and Risk Assessments (HARAs). HARAs assess the risk associated with each component, subsystem, system, and process along three metrics: severity (how bad a fault would be could be), exposure (likelihood of a fault occurring), and controllability (ability to mitigate a fault). Combined, these three metrics help systems engineers assign a risk score to each system and subsystem. These risk scores are known as Automotive Safety Integrity Levels (ASILs), and in turn inform the safety, reliability, and functional requirements for each item: items with the highest ASIL, known as ASIL D, must be either redundant or independently validated to an extremely high level of reliability.

After conducting HARAs, our approach moves on to developing Design Failure Mode and Effect Analyses (DFMEAs), analyses designed to identify a component's potential failure modes, and in turn drive design improvements to mitigate or eliminate those potential failures. Kodiak's DFMEA focuses on both Kodiak's hardware and software, to ensure that no single component or interaction can cause a safety issue.

Systems engineering at Kodiak is therefore an iterative process: the HARAs we are now conducting are a key input to hardware and software functional requirements: i.e. the potential faults we predict help us determine what capabilities our hardware and software need to have. As we start to build production-ready components and systems, we will be able to trace each component, process, and subsystem on the right half of the V, to ensure that we met the requirements that we set out to meet, and can validate that the system works as intended analytically, in simulation, and on the road.



Hardware testing and validation

An important part of building a self-driving vehicle is making decisions about what to build and what to buy. Whereas a decade ago self-driving developers needed to design their own sensors from scratch, today's off-the-shelf components are incredibly powerful and flexible and can be integrated relatively easily integrated into a self-driving system. ***Working closely with partners allows us to direct our internal hardware design efforts toward the most impactful technical problems we need to solve, while leveraging our partners' best-of-breed technology and expertise.*** We have chosen to partner with the leading companies in the industry to integrate world-class sensors and computers, and work with those vendors to validate these solutions for the Kodiak Driver.

Our hardware program aims to minimize the modifications we make to our stock trucks. This reduces the chance of introducing new hardware risks and helps to maintain scalable manufacturing. For those components we build or buy, we must perform rigorous hardware validation conducted on multiple levels, that correspond to the right side of the V-diagram:

1. Component level — Kodiak and its suppliers conduct rigorous tests on components such as individual sensors, actuators, valves, circuit boards, and opto-mechanical parts. These tests are typically conducted using structured methods on a lab bench or in a testing chamber to validate that these components meet their intrinsic performance requirements.

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2. Subsystem level — Kodiak tests every subassembly and subsystem to confirm that system modules that contain multiple components interact correctly, given a diverse set of inputs. Subsystem-level tests are designed to accomplish goals such as validating the performance of a set of components involved in localizing our vehicle, or detecting and handling a sensor occlusion. Subsystem-level tests include structured Hardware-in-the-Loop tests, which test system behavior on an actual truck, as well as stress tests like Highly Accelerated Life Tests and fault-injection tests.

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3. Vehicle level — Kodiak ultimately tests the system at the vehicle level to ensure that the Kodiak Driver behaves as intended. Not all of these tests happen on test tracks or public roads: we also test the vehicle hardware while stationary, to ensure that subsystems interact correctly.

Overall, this suite of tests is designed to verify the system's core functionality, resistance to environmental factors, reliability over its rated lifetime, and crashworthiness. We rely upon multiple sources for specifications for these tests, including the Federal Motor Vehicle Safety Standards and the International Organization for Standardization (ISO). We have also developed internal Kodiak specifications, derived from our own testing and real-world data.

Functional Safety and Self-Driving

Kodiak is working to apply the principles of ISO 26262 to conduct risk assessments of the Kodiak Driver's behaviors, not just its hardware components. For example, consider lane changing functionality. We conduct a lane changing HARA by considering the severity of changing lanes (how dangerous a fault would be), the exposure of lane changes (how common lane changing is), and how controllable it is (how easy it is to mitigate a fault). For any ASIL D behavior (which will certainly include complex functionality like lane changes), we will build mitigation plans to ensure redundancy and fault tolerance and mitigate risks. These analyses will be supplemented by simulations, structured tests, and real-world testing, to ensure the Kodiak Driver is able to manage, and mitigate, those risks.

In addition, we are working to integrate concepts from emerging autonomous vehicle standards into our functional safety process. These concepts include the draft UL 4600 standard, which gives guidance for how to build a safety case, taking into account major risk factors and testing needs. UL 4600 is designed to help self-driving developers create sufficiently thorough structures for their safety cases, by emphasizing repeatable assessments of safety case thoroughness. We are also using elements of the ISO/PAS 21448 Safety of the Intended Functionality standard, which helps to quantify whether the decisions an autonomous vehicle makes are safe in the absence of a fault.

Handling faults

Today Kodiak's Safety Drivers can take control of the truck in case of system fault or if the vehicle encounters a situation it isn't designed to handle. But soon, the Kodiak Driver must be able to handle faults on its own. ***Part of preparing the truck for autonomous deployment is teaching it to manage unexpected situations, from hardware faults to unforeseen and unavoidable ODD departures to unusual road conditions.***

To navigate these scenarios, self-driving vehicles typically assume a fallback state, also known as a Minimal Risk Condition (MRC)—a safe state designed to protect nearby drivers from risk. MRCs can vary, depending on the severity of the issue. For example, a truck may simply pull over during extreme weather, but if a piece of critical hardware breaks, it may need to be towed to the nearest facility. This MRC generally requires pulling over to the side of the road, not immediately but when safe. We've built the Kodiak Driver's hardware to be redundant: the trucks' redundant controls computers will be able to achieve an MRC, even if the main computer should fail. MRCs can occur due to both hardware and software errors: for example, if the perception system stops passing perception data to the planner, the truck would assume an MRC.

Critically, we use the Kodiak Driver's MRC capabilities extensively today, to stress the system's fallback mechanisms and refine the design early in the development stages. The longer the Kodiak Driver goes without a failure, the harder it is to build a comprehensive view of how the system's fallback mechanisms work.

Kodiak has strong incident response processes in place, whether the incident occurs in human-driven or autonomous mode. We have carefully thought through and rehearsed the operations protocols for how to respond in case an accident occurs, and have policies in place to ensure we keep our data to review what happened. We also have policies that require all trucks (and/or Safety Drivers) to contact our operations team and remain at the scene of the incident.

We are also working to develop processes for how to manage incidents when there are no drivers in the vehicle. While our goal is zero accidents, we are realistic enough to know that at some point, an incident will almost certainly occur. The Kodiak Driver will be designed to automatically assume an MRC after any crash, and will call the Kodiak operations center so we can take appropriate action. All data collected will be automatically protected and logged, to facilitate an investigation into why the crash occurred.

Kodiak values

Intellectual honesty, principled debate.

Our experience in the self-driving industry has convinced us that safety work is done best when it's decoupled from the pressure of milestones, demos, and features. That's why we put so much emphasis on the Safety Meeting, an open forum where team members discuss any and all safety-related issues. The Safety Meeting demonstrates to all that safety always takes precedence over deadlines or performance.

The Safety Meeting is open to all: we've learned that having a diverse set of viewpoints and opinions is the best way to ensure we operate safely. By design, it draws a cross-functional group of team members, from hardware and software to Safety Drivers and legal.

At the Safety Meeting, we encourage everyone to offer feedback on how to increase safety and reduce our risk exposure while maximizing the value of the data we gather. Team members are empowered to raise any safety-related issues or concerns, express their opinions, and work collectively to find solutions.

Every safety meeting includes a risk reflection, which gives the team a dedicated opportunity to discuss the potential risks associated with our operations, and whether the data we're collecting justifies the risks. If we can't justify an activity, we stop doing it.

Software engineering and safety

Kodiak's software development process is designed to help validate the safety of the Kodiak Driver—given that we change our code daily, we need to ensure that every change moves us towards deployment without introducing new errors.

Kodiak has built its software development process based on a systems engineering approach, designed to detect errors early. The first line of defense is using a statically-typed language that, when combined with modern development best practices, allows us to catch most errors early in the development process. Kodiak also follows a software development practice called Continuous Integration, which is designed to prevent the addition of new bugs when software is updated.

Kodiak follows a defined software release process to ensure ongoing progress. Every week, the latest build becomes a release candidate, which gets tested against the current stable release. If a release candidate shows statistically-significant safety and performance improvements over a stable release, it becomes the new stable release. This process is key to allowing Kodiak to make rapid progress on our software while keeping safety at the forefront of what we do. It also encourages developers to make longer-term investments in improving the system, by giving them the leeway they need to rewrite code even when it leads to short-term performance degradation.

Kodiak's software development process

Unit testing — To start, Kodiak conducts unit tests on each code change, both those done by humans and changes to machine learning models. These tests ensure that new code does not negatively impact basic functionality. For example, if code is designed to add two numbers, unit testing confirms that it can add 2 and 3 and get 5.

Regression & simulation testing — After conducting unit tests, we run every code change through more complex regression tests. Regression tests ensure that new code can safely perform required functionality in a simulated environment, with a focus on safety-critical components. Regression tests ensure that the code change didn't introduce any bugs or errors, and checks that the codebase performs at least as well as it did before the change.

Nightly build testing — Every night, we run a more comprehensive set of simulation tests on that day's software build. We load daily builds that pass this test onto a truck for Hardware-in-the-Loop safety testing, which tests whether a Safety Driver can safely engage and disengage the Kodiak Driver on actual truck hardware.

Closed-course and on-road testing
Code that passes Unit, Simulation, and Nightly Build tests is cleared for test track or on-road testing.

Measuring Safety

Demonstrating that the Kodiak Driver is fundamentally safe.

Building the Safety Case

Our most important goal at Kodiak is to make driving safer for everyone by building the Kodiak Driver to be safer than a human driver. Validating that the truck is safer than a human under a wide range of road conditions and fault scenarios is an incredibly complex task. The self-driving industry typically refers to this validation as a *safety case*.

Our safety case begins with a top-down approach. In 2017, trucks drove 297.6 million miles in the United States, and were involved in approximately 450,000 crashes: this suggests a crash occurs every 660,000 miles. So at the highest level, Kodiak's fleet will need to have at least as strong a safety record for us to operate without a driver.

But this high-level analysis confuses as much as it explains. Not all miles are equally complex or dangerous, so even if we could show the Kodiak Driver has a below-average accident rate, we would not necessarily be comparing apples to apples. (Statisticians call this problem sampling bias.) Additionally, this analysis would tell us nothing about the severity of the crashes: if the Kodiak Driver got into fewer crashes but more severe ones, we might not view this as a safety improvement.

Basing our safety case on real-world miles also creates technical challenges. Since every build of our software is slightly different, we would need to drive tens of millions of miles every time we made a slight change to the system. This would be highly impractical to say the least, and would discourage us from working to make the Kodiak Driver even safer after initial deployment.

Instead of solely depending on real-world data, we are building the Kodiak safety case using a variety of analytical tools, including simulations, and statistical analyses based on our real-world data. When woven together, these analyses will allow us to comprehensively demonstrate that the Kodiak Driver is safer than an average human truck driver.

While safer than a human is our minimum standard, achieving that standard doesn't mean our work is done: we will always be improving the Kodiak Driver and making it even safer. That is the promise of autonomous vehicles: while they will soon be safer than human drivers, they will only continue to get safer and safer.

The four pillars of Kodiak's safety case

Real-world driving — Real-world miles are critical to validating the safety of the Kodiak Driver. Instead of driving billions of miles, we will drive a representative sample of miles, including those we collect while hauling freight. These miles will help us both validate the behaviors we see in simulation and allow us to benchmark the Kodiak Driver against human drivers.

Scenario benchmarking — We will also use third-party data to benchmark how the Kodiak Driver performs in specific on-road situations.

Simulations — As we test, we are building a massive database of on-road scenarios, both routine and edge-cases. As we approach deployment, we will assess the Kodiak Driver's performance across our entire scenario collection to validate the system is safer than a human driver.

Functional safety analysis — Kodiak will conduct a comprehensive functional safety analysis of the Kodiak Driver, using the principles of ISO 26262. We will validate components in the lab and on system hardware, building fallback mechanisms that can safely handle any fault.

Benchmarking against human drivers

We are building our safety case on a benchmark against average human truck drivers. Until we can prove that the Kodiak Driver is safer than a human truck driver, we will keep Safety Drivers in our trucks.

Implicit in this commitment is building a deep, textured understanding of how human drivers react to different scenarios. This understanding is critical to building a clear benchmark that demonstrates that the Kodiak Driver is safer. We are building a comprehensive driver data model that considers key behavior such as following distance, reaction times, speed choices, aggressive driving, lane merges, and other factors to create realistic simulations of how humans actually behave on the roads. We will also use simulated versions of our real-world test runs to benchmark the Kodiak Driver against the actual behaviors of our experienced Safety Drivers.

In addition to using our own data, we are also building partnerships with leading trucking analytics companies. These companies have collected data on hundreds of millions of miles of driving on public roads: this data will help us understand how frequently trucks encounter specific scenarios on the road, and will provide additional inputs for our simulations collection.

While we've reached the end of our Safety Report, it's really just the beginning of our story.

More than a starting point, this safety document represents the most important foundational element of our development. There is still much left to do, but we hope you better understand our earnest enthusiasm for the great potential sitting before us.

At the end of the day, there is no substitute for experience. That's why we truly believe that Kodiak's team of experienced drivers, engineers, and professionals when paired with our dedication to safety is unbeatable, and will ensure we continue to drive down the right path.

If you have any more questions about Kodiak, please visit us at **www.kodiak.ai**.

Until next time, safe and sound journeys!

USDOT Voluntary Safety Self-Assessment Recommended Content

The table below identifies how the information in the Kodiak Safety Report addresses USDOT's recommended topics for a Voluntary Safety Self-Assessment.

Safety Design Element	Safety Report Section	Page
System Safety	Systems Engineering + Kodiak's Systems Engineering Approach	37, 39
Operational Design Domain	The Kodiak Driver: Designed for Highways	7
Object and Event Detection and Response	Kodiak's Software Stack + How the truck senses the world	14, 15
Fallback (Minimal Risk Condition)	Handling faults	43
Validation Methods	Building the Safety Case	46
Human Machine Interface	Kodiak's Human Machine Interface + System Operators	31, 32
Vehicle Cybersecurity	Kodiak's cybersecurity program	35
Crashworthiness	What we're building + Hardware testing and validation	13, 41
Post-crash ADS Behavior	Handling faults	43
Data Recording	Training Kodiak's perception system	20
Consumer Education and Training	Better together. For a better future.	9
Federal, State, and Local Laws	Federal, State, and Local Compliance	9