

ZOOX

PURPOSE-BUILT FOR SAFETY:

Introducing Zoox safety innovations



Setting the bar for safety in autonomous mobility
SAFETY REPORT VOLUME 2.0 / PUBLISHED 2021

At Zook, safety is foundational; it underlies everything we do.

In December 2020, after six years of development, we publicly revealed our purpose-built autonomous vehicle, which includes more than 100 safety innovations that do not exist in today's conventional cars. We showcased our vehicle driving on the streets of San Francisco and our test track. It is not just a concept or prototype design; it actually works.

Autonomous mobility heralds a profound transition for our society, one that is as significant as the shift from horse-drawn carriages to automobiles. To realize the potential of autonomy, we have reimagined passenger mobility by building a vehicle from the ground up—designed for riders, not drivers. Our vehicle is fully autonomous, all electric, and bidirectional. It features carriage seating with all four seats facing inwards, uses four-wheel steering and driving, and perceives the world from optimally placed sensors. This unique design will make getting around cities more enjoyable, sustainable, and safe.

Our first safety report, "Safety Innovation at Zook | Setting the Bar for Safety in Autonomous Mobility," which was published in 2018, covered our safety philosophy and focused mostly on our test fleet of hybrid Toyota Highlanders, including our approach to software and hardware testing. This second report continues the conversation, focusing on how we've designed and incorporated many safety innovations into our purpose-built vehicle.

This report also charts our efforts to evolve the automotive industry's current reactive safety approach to one that is proactive. Future reports will highlight the software and artificial intelligence functions that drive our vehicle, and introduce the operational safety efforts that will support trustworthy and reliable service on public roads.

Safety remains at the forefront of our efforts. It will define the success of autonomous vehicles. We hope this report helps to advance our nascent industry, and we look forward to the day when everyone can enjoy a Zook ride.



Aicha Evans
Chief Executive Officer



Jesse Levinson, Ph.D.
Co-Founder & Chief Technology Officer

Zoox intends to set the bar for safety in autonomous mobility.

We know that autonomous vehicle technology presents an unprecedented opportunity to save lives, reduce injuries, and minimize crashes on our roadways. But fully realizing these potential benefits necessitates a paradigm shift from reactive to proactive safety. For over 100 years, automotive safety has been reactive: i.e., we wait until there is a crash, injury, or death before we look for a solution.

Data from the National Highway Traffic Safety Administration (NHTSA) shows that 94% of crashes are caused by human choice or error. Most of these crashes are preventable or avoidable, yet in 2020 alone, 38,680 people lost their lives on U.S. roadways.¹ Globally, car crashes take the lives of 1.35 million people each year—that is more than 3,000 deaths a day.² We should not accept these casualties as the cost of mobility. As a society, we can do better.

At Zoox, safety is foundational, and our safety philosophy is made up of two distinct pillars: "Prevent and Protect." The ultimate proactive safety strategy is to prevent incidents from occurring in the first place, so we analyze potential safety risks and address them before they happen. Our vehicles also protect riders and other road users with an array of safety innovations—for example, we intend to provide the equivalent of a five-star safety rating for every occupant in a Zoox vehicle.

The safety innovations featured in this report reflect our commitment to setting the bar for safety in autonomous mobility.



Mark R. Rosekind, Ph.D.

Chief Safety Innovation Officer
Former Administrator of the National Highway Traffic Safety Administration (NHTSA)
Former Member of the National Transportation Safety Board (NTSB)

¹ "2020 Fatality Data Show Increased Traffic Fatalities During Pandemic" National Highway Traffic Safety Administration <https://www.nhtsa.gov/press-releases/2020-fatality-data-show-increased-traffic-fatalities-during-pandemic>

² "Road Traffic Injuries" World Health Organization
<https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries>

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Zoox safety report 1.0: a recap

A lot has happened since we published our first safety report in 2018, but the fundamentals haven't changed. Zoox is building an all-electric, one-of-a-kind autonomous vehicle, an AI software stack to make it drive, and the mobility service it will enable. Our Prevent and Protect safety strategy consists of analyzing potential safety risks to prevent incidents from occurring in the first place and deploying innovative safety tools and traditional protections to minimize harm if an incident does occur.

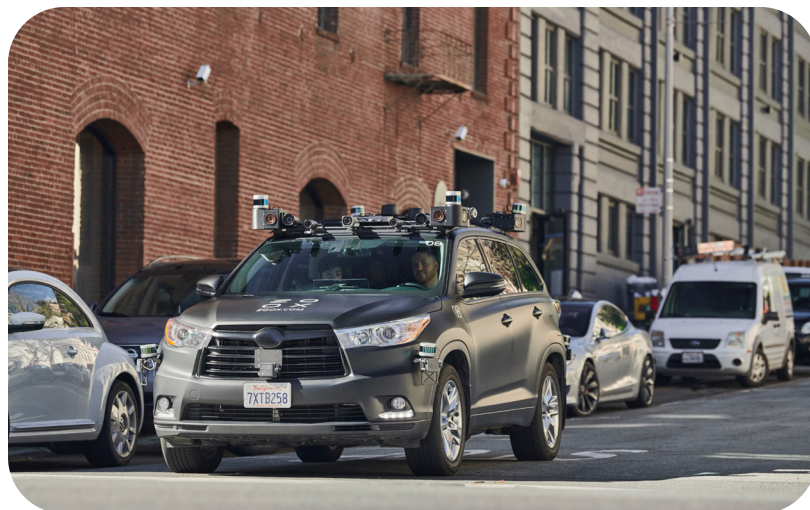
Our autonomous vehicles use a localization and mapping system to know exactly where they are at all times, and they navigate the world using a physical sensor suite and sophisticated autonomous driving software. Our sensor suite includes multiple cameras, lidar (Light Detection and Ranging) sensors, and radar (Radio Detection and Ranging) sensors that create a 360-degree, overlapping, and redundant field of view. These sensors provide the data that our autonomous driving software uses to accurately perceive the vehicle's surroundings, predict the behavior of other road users, plan a path, and control the vehicle.

Our design objective is for our vehicles to be free of any single point of failure from a safety perspective. So we've designed a number of innovative and redundant features that allow the vehicles to continue to operate safely even if certain safety systems become unavailable. We rigorously test and validate our autonomous driving technology to ensure safe operations within our operational design domain (ODD). Before tires ever hit pavement, we test our autonomous technology via simulation and an integrated hardware/software system affectionately called LabBot.

Then we test on closed tracks and private roads before moving into the final stage: real-world testing on public roads. Each of these tests contribute to a continuous feedback loop, ensuring that our vehicles are constantly learning and operating at the highest level of safety. Human operators provide ongoing safety oversight for all testing and stand by to assist if a vehicle encounters an unknown situation that needs human intervention.

We engage with stakeholders who are likely to interact with our vehicles on the road or who could benefit from our autonomous technology. For example, Zoox is working with law enforcement and first responders to develop an integrated education and training program about autonomous technology and specifics of our vehicle. We also work with a diverse group of advocacy organizations to design features that will improve accessibility, inclusivity, and ease of use for passengers.

Our Prevent and Protect safety strategy consists of analyzing potential safety risks to prevent incidents from occurring and deploying innovative safety tools to minimize harm if an incident does occur.



Mission

Zoox was founded in 2014 to make personal transportation safer, cleaner, and more enjoyable—for everyone.

- › Fully autonomous
- › All-electric
- › Designed for riders, not drivers



Vision

We're reinventing
personal transportation

SAFER STREETS

94% of all U.S. crashes are caused by human error. Removing these mistakes will save thousands of lives.

GROUND-UP AUTONOMY

Zoox isn't an updated car—it's a whole new form of transportation. With every detail designed around riders, not drivers.

JOURNEYS TO ENJOY

No driving means less stress—and more time to get things done in a spacious, comfortable cabin.

FEWER CARS, LESS POLLUTION

Our shared fleet of all-electric Zoox vehicles will reduce congestion and pollution in our cities.

Zoox vehicle safety innovations



01/ Driving control

02/ No single point
of failure

03/ Rider protection

Complementing the December 2020 reveal of our purpose-built vehicle, this Safety Report 2.0 will illustrate some of the safety innovations in this next generation design.

A safety innovation is a novel feature intended to prevent crashes or protect vehicle occupants and other road users. We have designed over 100 safety innovations to improve safety in ridesharing, the automotive industry, and autonomous vehicles. Here we detail a sampling of these safety innovations across three categories: "driving control," "no single point of failure," and "rider protection." Driving control and no single point of failure are proactive safety innovations to prevent incidents from occurring in the first place. With rider protection, if an incident does occur, our vehicle will deploy traditional protections as well as new safety tools to minimize harm.

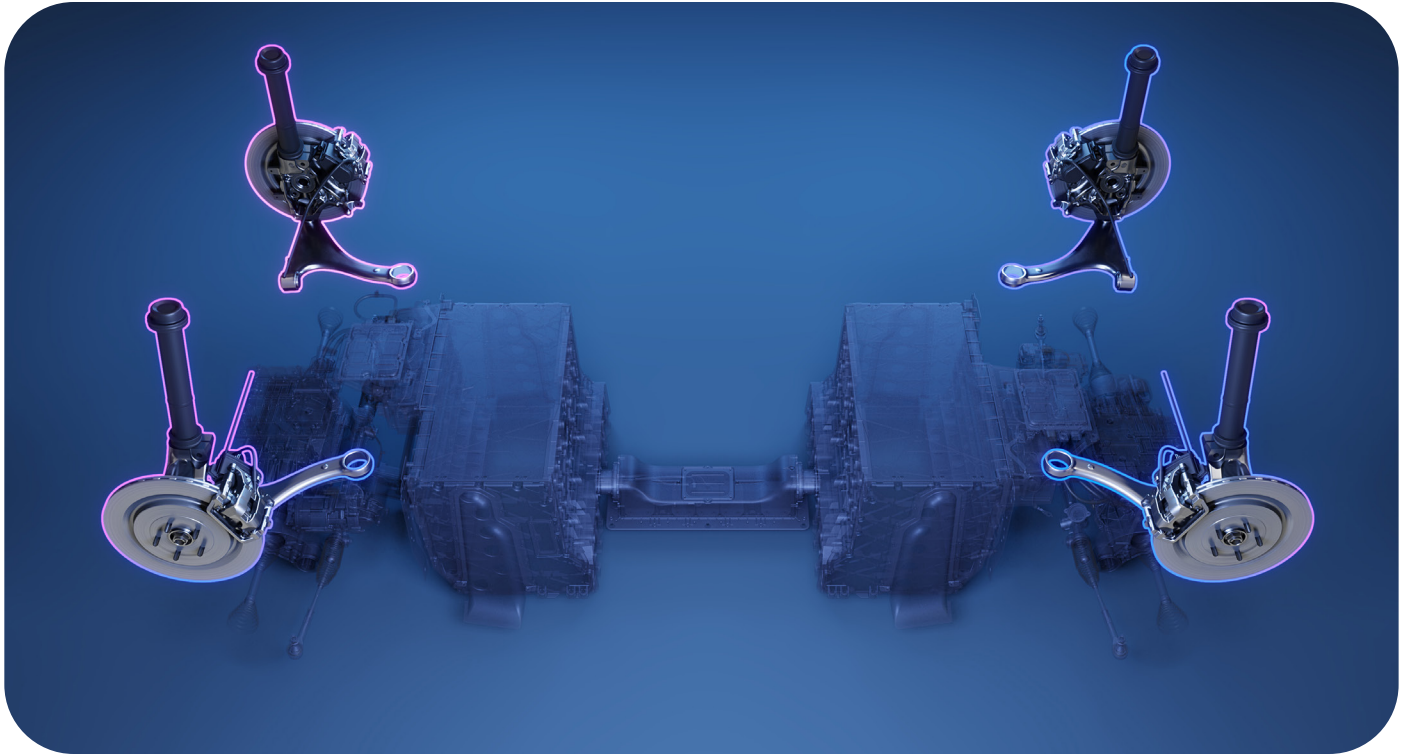


01/

Driving control

- › Shorter stopping distances means safer braking
- › Four-wheel steering and control are all about precision
- › Bidirectional: no back or front

Shorter stopping distances means safer braking



Highlighted are both the independent braking system and active suspension.

The Zoox vehicle has a unique safety-focused braking and active suspension system that helps it avoid potential crashes and minimize the impact of unavoidable collisions. This system is made possible by the independence of the vehicle's four wheels, each of which can adjust to driving conditions and react accordingly.

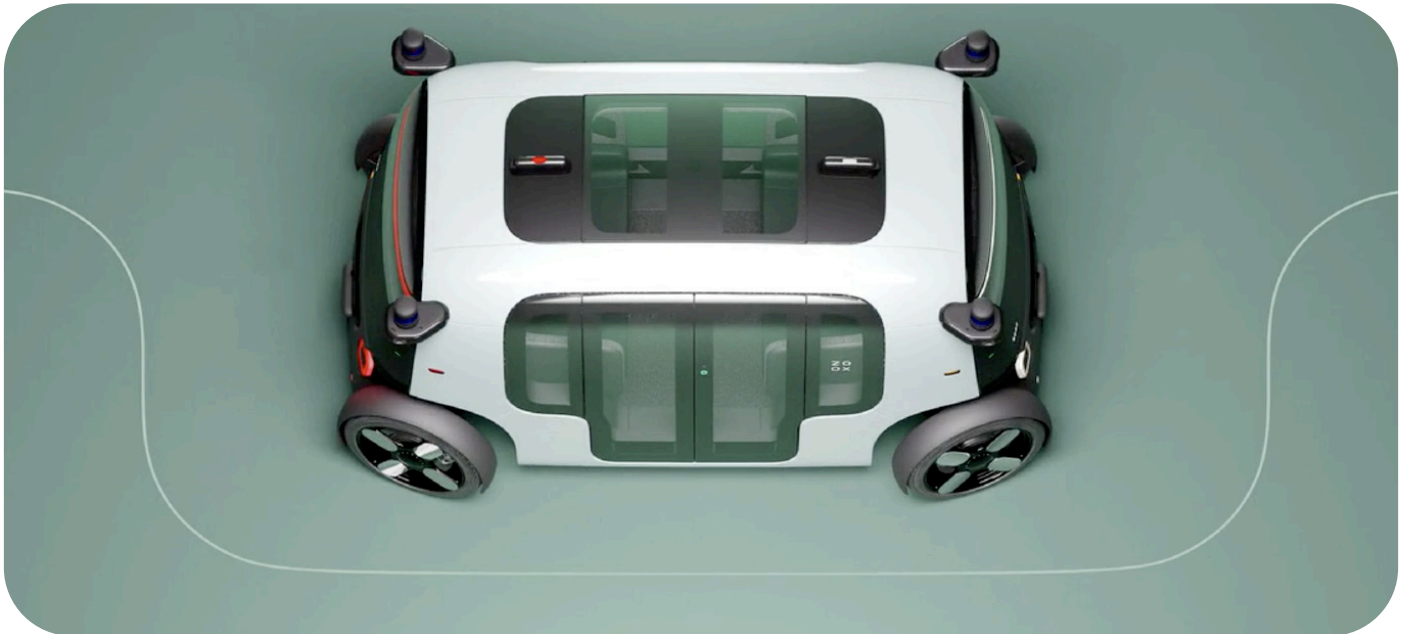
Like most new vehicles today, the Zoox vehicle can adjust each wheel's anti-lock brake system to increase stability and traction. Our innovation builds on this function with electronic control units that manage each wheel's suspension, meaning our vehicle can adjust ride height and spring stiffness, add stability for turns, and quickly compensate for road conditions like bumps. The independence of these controls makes the traditional live axles that link left and right wheels together unnecessary.

Together, our independent braking and active suspension systems create better tire traction and weight distribution, which translates to more braking control and shorter stopping distances. These features give Zoox vehicles more time to react and perform safety maneuvers when needed.

In addition to improving safety, the independent braking and active suspension systems provide greater ride comfort. For example, if one wheel hits a pothole, our vehicle can compensate for the impact so that passengers hardly even notice a bump.

These systems also cooperate with our fully automated regenerative braking system that improves performance while charging our vehicle's batteries.

Four-wheel steering and control are all about precision



One of our vehicle's unique attributes is its ability to individually control the speed, power, and direction of all four wheels. Four-wheel steering enables more precise control on the road, whether the vehicle needs to stay inside a driving lane or avoid an obstacle. We have also customized the physical steering racks and their control algorithms for dramatically superior precision. Together, these innovations enable unprecedented accuracy in vehicle control, which represents a fundamental improvement in safety—especially in dense urban environments.

The upshot of this technological breakthrough is that each time our driving software calculates a path, the physical hardware and control algorithms on the vehicle ensure that it does not deviate more than a few centimeters from the desired trajectory—even when taking curves at speed.

The ZOOX vehicle is the first automobile with comprehensive four-wheel steering capability.

While vehicles like large fire trucks have some rear steering capabilities, they are typically only able to make slight adjustments. Vehicles that steer with only the front wheels must take lateral offset into account and compromise between heading and position adjustments. The ZOOX vehicle can do both independently, meaning it can adjust where it is headed while simultaneously adjusting its position within the lane.

Four-wheel steering also enables tighter turns and driving maneuvers other vehicles cannot manage. For example, the ZOOX vehicle can access smaller loading zones and tighter spaces than typical cars, so it can get riders closer to the curb and more quickly enter and exit traffic and bike lanes.

Beyond the safety benefits of precise four-wheel steering and control, these innovations also translate into greater comfort and convenience for riders—the carriage is almost like a gentle turntable that glides smoothly through lane changes and turns.

Bidirectional: No back or front



Four-wheel steering and symmetrical design means the front and back of the vehicle are the same. It can navigate either way as needed, which reduces the need for complicated, time-consuming, and sometimes dangerous three-point turns or U-turns.

This innovation is the first of its kind and has great safety and versatility implications. Our vehicle can pull into a parking space to pick someone up and then

pull out and leave in the opposite direction without needing to turn around, providing an easier, smoother, and safer passenger experience.

To signal intent and direction to other road users, our vehicle uses illuminated turn signals and special lights that can switch between white headlights and red tail lights depending on which way the vehicle is heading.

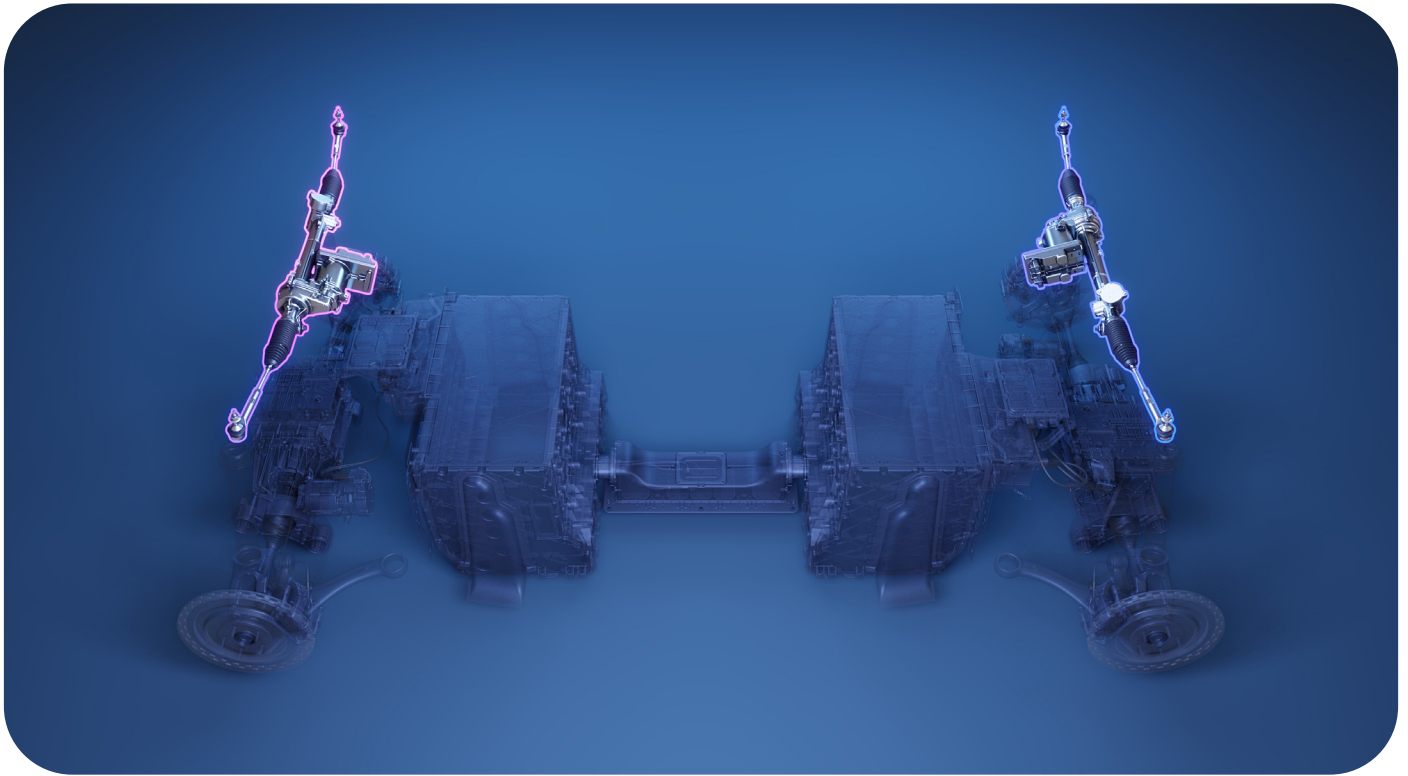


02/

No single point of failure

- › Redundant steering and driving controls
- › Fail-operational power supply keeps our vehicles moving
- › Vehicle self-diagnostics: comprehensive safety monitoring

Redundant steering and driving controls



Highlighted are the steering gears.

Our vehicle is engineered with the design objective to eliminate single points of failure in safety-critical systems.

Redundant systems ensure that our vehicles can safely and effectively operate no matter what happens on the road. Our vehicle is engineered with the design objective to eliminate single points of failure in safety-critical systems. Even if confronted with a major system failure, our vehicles can continue to operate with safe limited abilities, navigate to an appropriate place to stop, or come to a quick emergency stop. This approach to our vehicle architecture draws inspiration from aviation levels of safety, and Zoox is the first to apply them to automotive design.

The Zoox vehicle has two batteries and two separate powertrains with drive motors. The two powertrains typically act together, but the vehicle can operate using only one if necessary. For example, our vehicle normally steers with both the front and back wheels, but if steering for one end of the vehicle fails, the other will

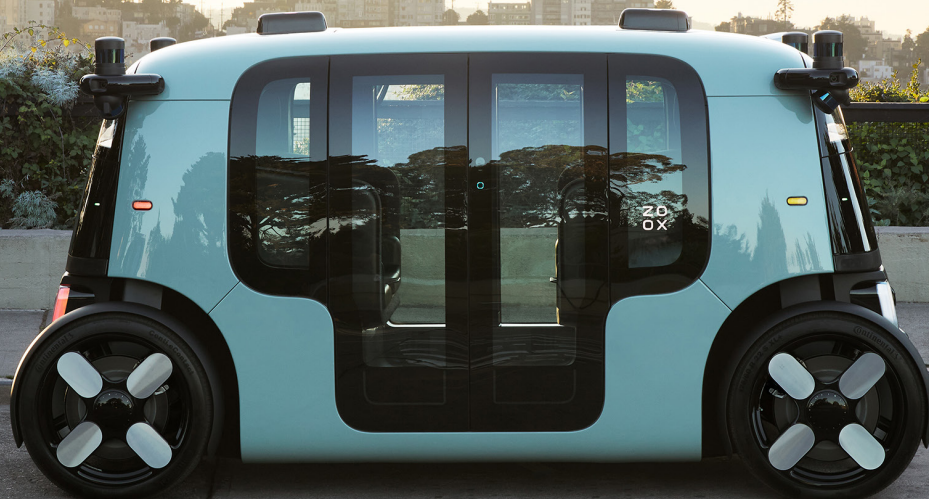
still be able to drive the vehicle safely. All four parts of this drive system are wired together, so either battery can power either drivetrain and motor. For example, if the front battery and rear motor fail, the rear battery and front motor will still work together and allow the vehicle to move.

Our braking system is also built to be resilient. Each of the two separate electronic control units that manage the braking system can work on its own. We've also added a third level of redundancy with an electronic parking brake managed by a separate system that can be activated to bring the vehicle to a stop in an emergency.

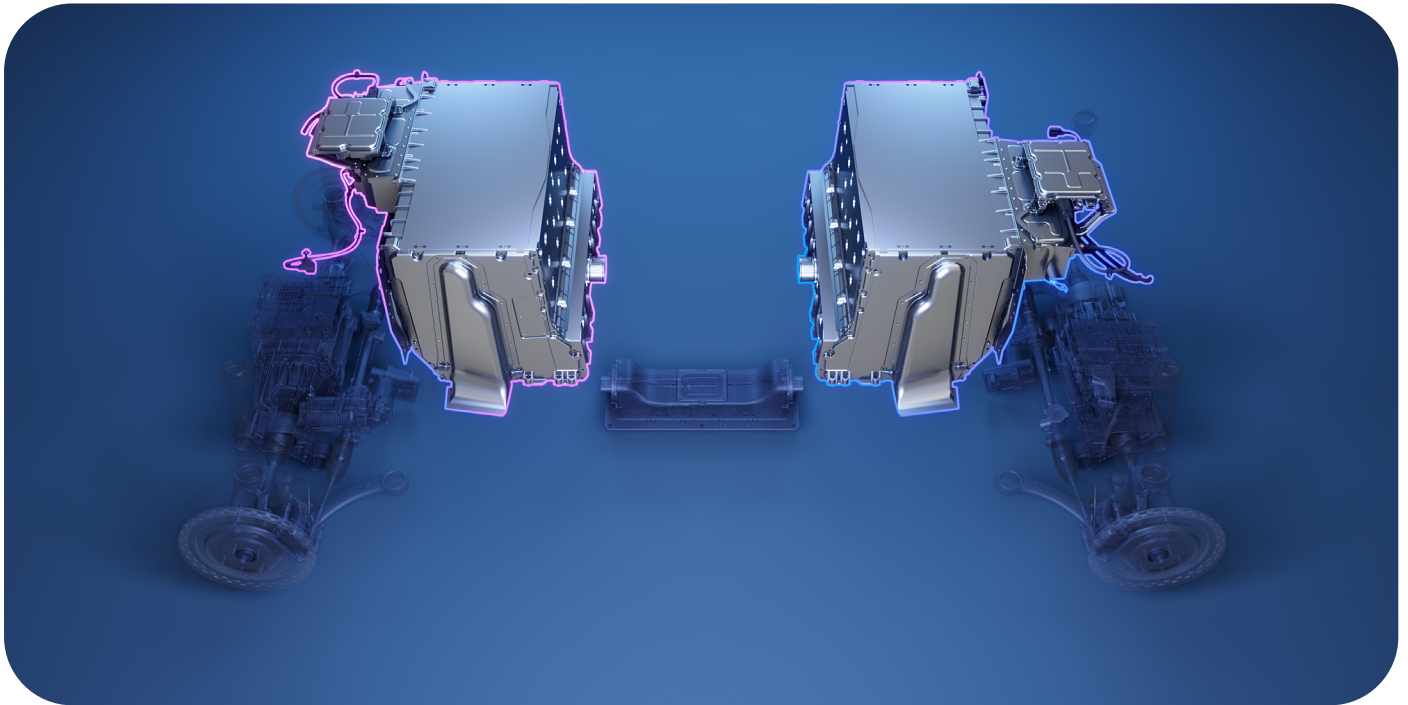
FAIL-SAFE VS. FAIL-OPERATIONAL

In safety and engineering disciplines, a system or device is generally considered fail-safe when, in the event of a problem, it is able to ensure that no damage is done to the device, the users, or the surrounding environment. A device or system is considered fail-operational when it is not only safe, but can continue to function, even when facing multiple problems.

We've incorporated fail-safe responses throughout the vehicle, but at Zoox, our aspiration is to be fail-operational as much as possible. We work to ensure that our vehicle can deliver riders to their destination safely by switching to a back-up system.



Fail-operational power supply keeps our vehicles moving



Dual batteries equip Zoox vehicles with the power to drive all day and ensure a backup power supply.

The all-electric Zoox vehicle is powered by a fail-operational high-voltage battery system that allows the vehicle to either continue operating safely or come to a safe stop if it experiences a system fault. This battery system is larger than virtually any other on the market, and it keeps our vehicle running all day on a single charge.

Our battery system consists of two separate but connected batteries, one on each side of the vehicle beneath the passenger seats. When operating normally, these two batteries function in parallel, behaving like a single battery. The power generated by the high-voltage battery system is directed through power converters on both sides of the vehicle and converted into a lower voltage that powers all of the vehicle's systems—including safety-critical systems such as steering and braking.

This battery architecture makes the vehicle's power system tolerant of single-point failures in several important ways: If one high-voltage battery malfunctions, it can decouple itself from the rest of the system, and the other operational high-voltage battery will continue to power all systems with no loss in vehicle function. This mitigation will allow the vehicle to safely complete its journey or plan an alternate route and then return to base for servicing.

In the very unlikely event that both high-voltage batteries fail or both converters malfunction, the two 12-volt battery packs provide an additional layer of redundancy and ensure that the vehicle can pull over into a safe location and still turn on hazard lights and open doors.

Vehicle self-diagnostics: comprehensive safety monitoring



The Zoox vehicle is equipped with a robot monitor that maintains a global view of the health of all its various parts and systems.

This monitoring system goes far beyond a typical car's check engine light; it can precisely detect fault-states across the vehicle's hardware, software, and firmware, and manage them using the many redundant systems that make up the vehicle's software and hardware architecture.

For example, using a suite of redundant sensor monitoring systems, the robot monitor can determine if a specific sensor has degraded performance—this could be caused by an internal failure or some environmental factor like debris or damage.

When a sensor degradation or failure is noted, the robot monitor will respond and mitigate the effects by doing any or all of the following:

- Attempt to clean the exterior of the sensor with active cleaning systems
- Transition the vehicle from bidirectional to unidirectional so that the sensor issue has a minimized effect on driving capability
- Reduce speed or stop driving

The robot monitor itself has a redundant architecture distributed across multiple systems. There is an Executive Motion Unit (EMU) and a Backup Motion Unit (BMU), both of which are considered high-integrity hardware—i.e., they have very high expected uptime and an extremely low likelihood of undetected failure—and each is capable of coordinating all necessary steering and speed functions via separate power systems. The EMU and BMU are redundant and constantly monitor each other for failures.



03/

Rider protection

- › Equivalent safety for each rider
- › Reimagining the airbag for a new kind of vehicle
- › Seat belts: a new take on a classic life-saving tool

Equivalent safety for each rider



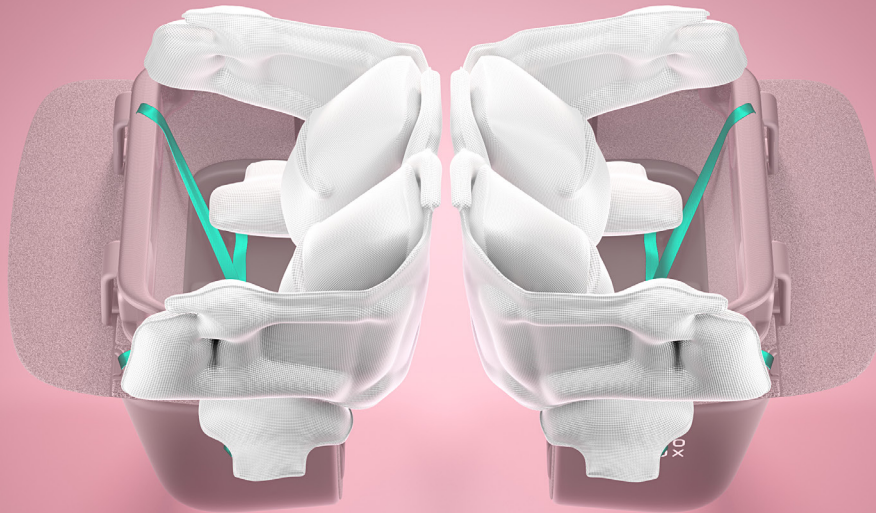
Zoox is transforming the transportation paradigm, including the way we think about occupant safety. In conventional automobiles, occupant safety is optimized for the driver and front passenger seats, which have the highest occupancy rates. Because the ZOOX vehicle is symmetrical and bidirectional, no seat is more likely than any other to be occupied by a passenger, so our goal is to ensure the highest level of safety for each seat.

Building autonomous mobility from the ground up creates many opportunities for us to set the bar for safety expectations, which is why we evaluate each of the four seats in our vehicles according to the United States New Car Assessment Program (USNCAP) five-star performance metrics. We utilize USNCAP performance metrics as part of our goal to set the bar for what customers of ride-sharing services should expect; that is one of the unique opportunities building autonomous mobility from the ground up presents.

To achieve this level of safety for all of our passengers, regardless of where they are seated, we rely on both traditional and innovative safety features.

The USNCAP is an educational, consumer-focused program created and run by the National Highway Traffic Safety Administration (NHTSA). NHTSA established a five-star crash rating rubric that has been recognized as foundational to evaluating crashworthiness and car safety. Every year, NHTSA selects a subset of newly released passenger vehicles to evaluate in a series of crash tests. The goal of the program is to help consumers understand and compare relative vehicle safety across different manufacturers.

Reimagining the airbag for a new kind of vehicle



Depicted here are the horseshoe curtain airbag, frontal airbag, and seat side airbag.

We have designed a new generation of airbags built for a vehicle interior without a traditional steering wheel and dashboard surface from which to deploy.

The unique inward-facing carriage seating arrangement in the Zook vehicle has required a radical rethinking of the occupant restraint system. Our novel airbag system is managed by an Airbag Control Unit (ACU) that incorporates sensor data to detect the vehicle's direction and velocity, as well as the severity of a collision. Because Zook vehicles are bidirectional, our ACU detects collisions in both directions.

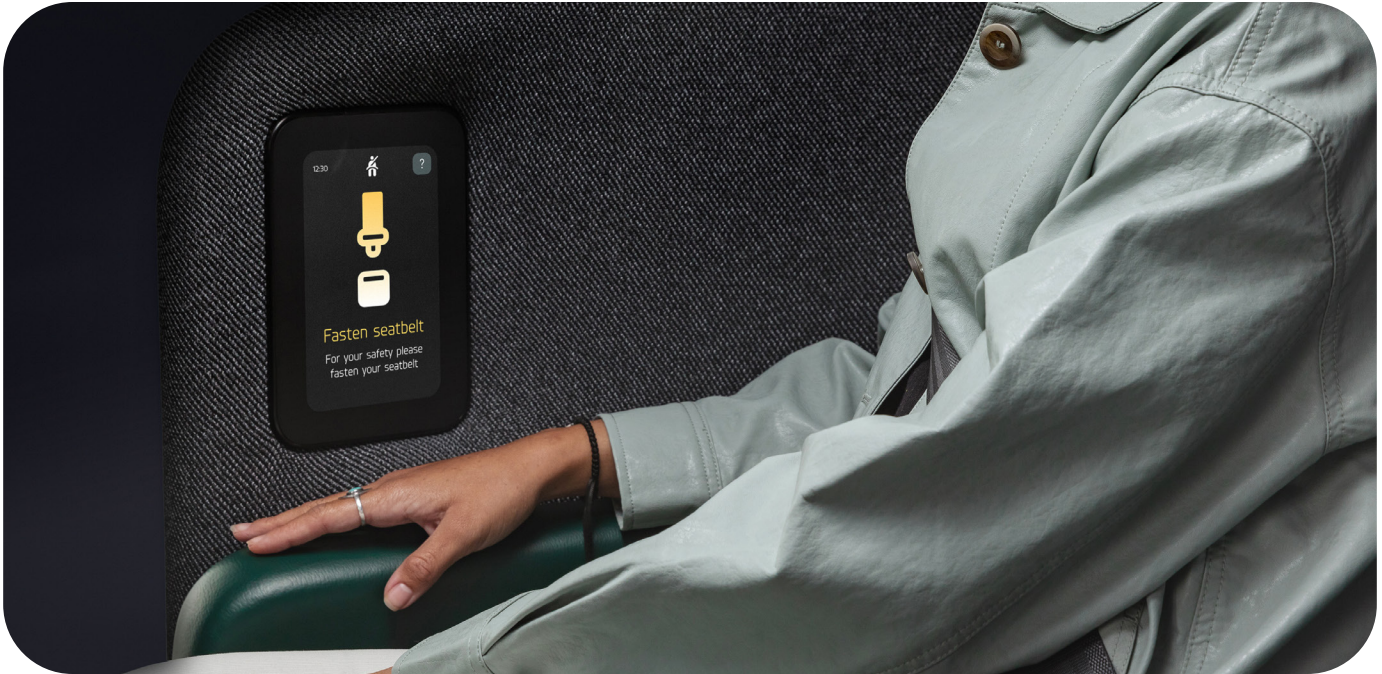
We have designed a new generation of airbags built for a vehicle interior without a traditional steering wheel and dashboard surface from which to deploy. Our system consists of several distinct airbag types: horseshoe curtain airbags, frontal airbags, rear airbags, side head airbags, and seat side airbags. Depending on the direction and severity of a crash, the ACU will determine which airbags to deploy and in what sequence to maximize passenger protection.

- **Horseshoe Curtain Airbag:** This airbag provides a reaction surface (i.e., a stable surface) for the frontal airbags that passengers make contact with in the event of a collision at either end of the vehicle.
- **Frontal Airbag:** This system deploys from the ceiling, dropping down in front of each seat. The airbag is divided into two sections that are separated by an indented pocket, which provides greater protection and support for passengers' heads, necks, and chests.
- **Rear Airbag:** This airbag deploys behind the passenger headrest on the side of the vehicle involved in the collision, preventing debris from entering the passenger cabin.
- **Side Head Airbag:** This airbag deploys from the ceiling if the vehicle is struck from the side, dropping down between the seat and window to protect passengers' heads and necks.
- **Seat Side Airbag:** This airbag is embedded within the side of each passenger seat. When it deploys, it presses against the interior of the seat, which pushes the seat surface closer to the rider's body, holding them more securely in the seats. This airbag deploys in a high speed side crash event.

A set of instructions for first responders is printed visibly on the side of the airbag system that faces out the window. The instructions detail how to enter the vehicle and assist passengers inside post-crash.



Seat belts: a new take on a classic life-saving tool



A communication device for each seat.

We know seat belts save lives, and we ensure our riders are buckled up before their trip with us begins.

Zoox is taking this fundamental safety feature to a new level of performance. The Zoox vehicle is allowed to begin its journey only when all passengers have properly and securely fastened their seat belts. We know seat belts save lives, and we ensure our riders are buckled up before their trip with us begins.

Our system verifies appropriate seat belt usage via three different inputs:

1. Sensors in the seat that detect a rider's presence.
2. A switch within the seat belt buckle itself that monitors whether the belt is fastened.
3. An in-vehicle camera that ensures seat belts are fastened and secured properly (for example, to ensure the chest strap has not been moved behind the passenger). This camera is infrared-enabled and detects specific coding on the seat belt to ensure it is worn properly—even at night or in other low-visibility conditions.

Our system combines the information from all of these sensor inputs to confirm that all passengers are safely secured in their seats.

If our automated driving system detects a potential or imminent collision, the seat belt system will proactively tension the seat belt webbing to bring occupants into the optimal position for airbag deployment and protection. This capability maximizes seat belt safety performance for all riders at all times.

The seat belt is one of the most powerful safety technologies available. Though it was first invented in the late 1800s, it wasn't until the 1950s and 1960s that it became widespread in the United States.³ In 1954, the Sports Car Club of America mandated that race car drivers would be required to wear seat belts. In 1968, the first federal seat belt law—Title 49 of the United States Code, Chapter 301, Motor Vehicle Safety Standard—came into effect, requiring all vehicles (with the exception of buses) to have seat belts for all designated seating positions.⁴

The safety benefits that seat belts provide are clear. In the U.S., about 90% of occupants wear their seat belts, but more than half of those who have been killed in car crashes were not wearing them. For occupants in the front seats, seat belts reduce the risk of serious injury and death by about a factor of two.⁵



³ "A Seat Belt History Timeline" Northeast AAA

<https://magazine.northeast.aaa.com/daily/life/cars-trucks/a-seat-belt-history-timeline/>

⁴ "From Scorn to Worn: The curious history of seat belts" Columbus Air Force Base

<https://www.columbus.af.mil/News/Article-Display/Article/936880/from-scorn-to-worn-the-curious-history-of-seat-belts/>

⁵ "Seat Belts: Get the Facts," Centers for Disease Control

https://www.cdc.gov/transportationsafety/seatbelts/facts.html?CDC_AA_refVal=https%3A%2F%2Fwww.cdc.gov%2Fmotorvehiclesafety%2Fseatbelts%2Ffacts.html

Moving forward



In this Safety Report 2.0, we've highlighted nine safety innovations that are actually made up of over 30 novel safety features. In future reports, we will discuss our Collision Avoidance System that is able to predict and avoid other objects' trajectories; our External Lighting and Sound System that can communicate intent to other road users; our Emergency Vehicle detection and response system; and the structural energy absorbers that dampen impacts in the case of a collision.

Autonomous vehicles create a once-in-a-generation opportunity to enhance safety, mobility, and sustainability for our society. At Zoox, our intent to set the bar for safety in autonomous mobility means pursuing safety innovations that move beyond the features that exist in cars on the road today.

In December 2020, we revealed our vehicle built from the ground up for autonomous mobility, and this report is an introduction to just a few of the 100+ safety innovations we've designed and built into our vehicle to prevent incidents and protect riders.

We are working on additional reports that will focus on other technical and operational Zoox safety innovations that further demonstrate our commitment to safety. As this journey progresses, we're excited to help advance the conversation around safety in autonomous mobility.

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