Towards Zero Faster

Zenseact's path to safe automation

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Towards ZERO faster.

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I. The rise of autonomous driving technology

WHO estimates that more than 1,35 million people die in traffic accidents every year, and more than 50 million people get injured. While significant advancements in road safety have been made over the years, inattentiveness, drowsiness, reckless driving, or inaccurate situation awareness still present the most critical threats to traffic safety. In fact, a National Highway Traffic Safety Administration report shows that in 94 % of traffic accidents worldwide, the driver is the critical reason for the crash.[1] Human driving is flawed, and therein lies one of engineering's great challenges.

However, during the last decade, the automotive industry has undergone a major structural transformation, powered by breakthroughs in electrification, connectivity, and automation technologies. Recent advances in sensor technology, vision systems (perception), and compute technologies, combined with strong market demand for advanced safety and comfort features, have led to a critical reshaping of the automotive landscape. This shift has brought enormous expectations and attention to the development of autonomous driving systems and future driverless vehicles.

Today's popular view is that vehicle autonomy can change the world as we know it. It's expected to offer substantial societal benefits, including time savings, increased personal safety, mobility options for nondrivers, and decreased environmental footprint. Several analysts even believe that transportation advancements will change our conception of mobility, with the most significant impact ever seen on car ownership and public transportation use.

1 The critical reason is the immediate reason for the critical pre-crash event and is often the last failure in the causal chain of events leading up to the crash. Although the critical reason is an integral part of the description of events leading up to the impact, it is not intended to be interpreted as the cause of the collision nor as to the assignment of the fault to the driver, vehicle, or environment. Other risk factors, such as poorly designed roads and dangerously high speed limits, can play an important role, making accident causation a very complex problem. See "Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey," National Highway Traffic Safety Administration (NHTSA), 2015.

But with its implications for safety, comfort, efficiency, and sustainability, the development of autonomous driving has proven to be a challenge. Solving it requires considerable technology investments and divergent thinking about how vehicles are designed, deployed, and continuously updated.

It is against this backdrop that Zenseact was created. With the ambition to accelerate the transition to zero collisions and create safer roads through autonomous driving technology, our platform comprises a series of software technologies and a computing infrastructure both onboard the vehicle and in the cloud. And our ambition is to get there faster: through faster improvement loops, faster development cycles, and faster deployment of high-capacity sensing and vehicle platforms.

This paper describes the evolution of vehicular road safety technology from hardware to software, focusing on some of the most important aspects of advanced driver assistance systems and autonomous driving development. We discuss the need for automated safety features and our approach and technological offer for this collective journey, outlining our Towards Zero Faster" vision and its implications for our products, development processes, and safety notions and principles.

II. From passive to active safety

Product development in the automotive industry is a story of evolution. Starting in the 1950s, car manufacturers focused on safety-incorporated targets, analyses, and countermeasure design in their development process. Accidents and resulting injuries were typically studied by crash investigation teams that tried to understand the mechanisms and causes of injury.

Volvo Cars' Accident Research Team is one example of such a team, at the forefront of accident investigation since 1970. Countermeasures such as vehicle body structure or new devices like seat belts and airbags were conceived and optimized in laboratories by leveraging crash test dummies. Finally, a new product platform carrying the improvements was launched to the market, and the latest product would set a new baseline to improve on.

But the rate of progress was relatively slow due to several factors. First, only a limited number of accidents were investigated. This is a manual and labor-intensive process, requesting a considerable amount of time to build a statistically significant database. Second, safety performance was achieved predominantly by hardware characteristics. Therefore, most improvements were not realized until the next vehicle platform, equipped with new hardware/sensors. Third, produced vehicles would have a continuous level of performance until their end of life.

Although slow, there was nevertheless remarkable progress in terms of road safety. For instance, Volvo Cars reported that the injury rate was reduced by a factor of three between 1970 and the following 30 years; see Figure 1.

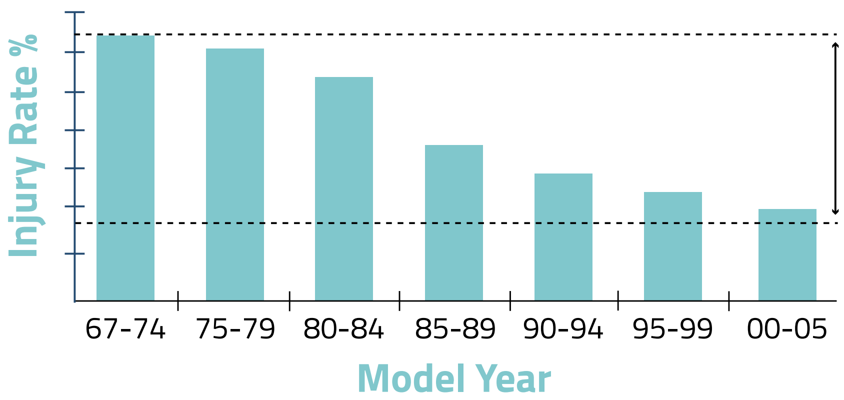

Fig. 1 Evolution of injury rate for Volvo Cars vehicles between 1967-2005

Now, among the essential elements of automotive safety are two “passive” safety elements: the seatbelt and the airbag. Overall, the National Highway Traffic Safety Administration has estimated that using seatbelts and airbags can reduce the risk of death from a head-on collision by 61%.

But during the last 20 years, active safety technologies, commonly referred to as Advanced Driver Assistance Systems (ADAS), have flourished and become a new cornerstone of traffic safety. These safety technologies focus on pre-collision systems that use, among other technologies, radar sensors and cameras to help prevent accidents – unlike passive systems that help mitigate imminent collisions.

For instance, Electronic Stability Control has reduced severe injury/fatal run-off-road accidents by more than 30 %, and autonomous emergency braking systems, nowadays standard in most new cars, have proven to be highly effective, particularly in the more frequent, lower severity accidents. Nevertheless, road traffic safety worldwide is still far from perfect. Indeed, deaths and accidents remain high, and economic losses due to traffic incidents are estimated to reach 2–3 % of a country’s gross domestic product.2

However, the distribution of deaths and injuries is uneven around the globe. According to WHO, around 93% of the world’s fatalities on the roads occur in low- and middle-income countries, even though these countries have approximately 60% of the world’s vehicles.3 Such countries also present specific traffic characteristics, such as a large number of pedestrians, bicycles, and motorcycles, that represent significant challenges to autonomous solutions given their unpredictable human nature.

The development of autonomous driving solutions will thus be subject to different societal and behavioral aspects worldwide. What’s more, data collection, software development, and system validation processes are bound to be reexamined at the dawn of the democratization of cloud solutions and artificial intelligence (AI) technologies.

2 Global Status Report on Road Safety 2018”, World Health Organization, 2018.
3 Global Status Report on Road Safety 2018”, World Health Organization, 2018.

III. From hardware to software: a new definition of vehicles

Autonomous vehicles are expected to provide an entirely new user experience within the following decades. The development will inevitably lead to drastic shifts in value chains and required capabilities, including software and cybersecurity expertise. Most likely, new industries and technology pools will emerge.

Powered by the increasing deployment of advanced sensing, AI, and software solutions, the "software-defined vehicles" concept has become increasingly prevalent in the automotive industry.[4] "Software-defined vehicles" broadly refers to new vehicle models for which software and electronic hardware are considered more important than mechanical hardware.

This concept reflects today's transformation of cars from complex, yet simple electromechanical platforms, to intelligent, adaptive, and expandable mobile electronic terminals that can be continuously upgraded. Several automakers have recently decided to equip their vehicles with advanced hardware upon vehicle production. At the same time, the functions and value of the software are gradually activated and enhanced via over-the-air technology (OTA) throughout the vehicle's life cycle.

While computation, storage, and communication technologies offer new horizons, two of the most remarkable impacts of software-defined vehicles will be:

- Network functions decoupled from the car's proprietary appliances, enabling the parallel development of physical and digital elements of the vehicle, making the software a differentiation factor,
- Automotive software as a commercial product, optimizing the vehicles' life and value cycles.

Such technologies will certainly attract third-party innovators to develop intelligent automotive functionalities, helping improve the connected vehicle ecosystem and fostering new business models and cycles of value creation.[5]

It's important to realize that while AD technology represents a revolutionary change for society, its adoption will be evolutionary. Indeed, such a journey will start with increasingly more intelligent and complete ADAS systems **until fully autonomous solutions are deployed and operate within pre-defined geographic/domain boundaries.**


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IV. Zenseact and the safety loop

The road traffic system has indeed evolved to be a backbone of our society, with significant importance for the world economy, individual freedom, and overall quality of life. On an abstract level, road traffic can be viewed as a transportation factory where efficiency and quality can be applied to improve its competitiveness. In this analogy, traffic accidents can be seen as quality problems that should be avoided. Industrial methodologies to do so are well known in the literature, and several frameworks are available today.[6] For instance, the Six Sigma DMAIC iterative cycle proposes to:

- Define the problem and opportunity for improvement,
- Measure the current performance,
- Analyze the process to determine the root causes of variation and poor performance,
- Improve process performance by addressing and eliminating the root causes,
- Control the improved process and future process performance.

Similar methodologies have also been applied to traffic safety over the years, and there are many encouraging examples of successful implementations and improvements made. It is worth highlighting, though, that when compared to industrial plants and processes, the global road traffic problem is arguably more challenging due to the high number of factors and actors involved: traffic users (qualified and non-qualified), vehicle producers, infrastructure owners, lawmakers, law enforcers, governments bodies, and international organizations.

6 Sarah E. Burke, Rachel T. Silvestrini, "The Certified Quality Engineer Handbook - Fourth Edition", American Society for Quality (ASQ), 2017.

Hence, the issue of road safety remains a cornerstone aspect of today's society and, therefore, of recent regulatory and infrastructure initiatives in a joint effort to improve safety standards worldwide.

Now, by providing safe automation solutions that combine onboard software modules and cloud-based services for supervised driver assistance features as well as unsupervised autonomous driving, Zenseact's vision is to ultimately realize autonomous driving and further reduce road-traffic fatalities and human-error-based accidents. The system is designed to automate the process of continuous data-driven development and the deployment of autonomous driving features across an entire vehicle fleet.

In striving toward our vision, we have bet on the implementation of a fast continuous loop for developing, verifying, and validating safety-critical features by collecting road data and safety information from the fleet and the OTA deployment of the software features to the vehicle fleet.

By dynamically probing and analyzing data from the fleet of consumer vehicles, one can learn how to improve safety and automated driving capability based on real-world data. This unlocks the capacity to gradually expand the autonomous vehicle driving task by seamlessly adding driving abilities and expanding the vehicle's operating domain.

This endless stream of development, deployment, and data and performance monitoring is the basis for the Zenseact Safety Loop. See Figure 2.

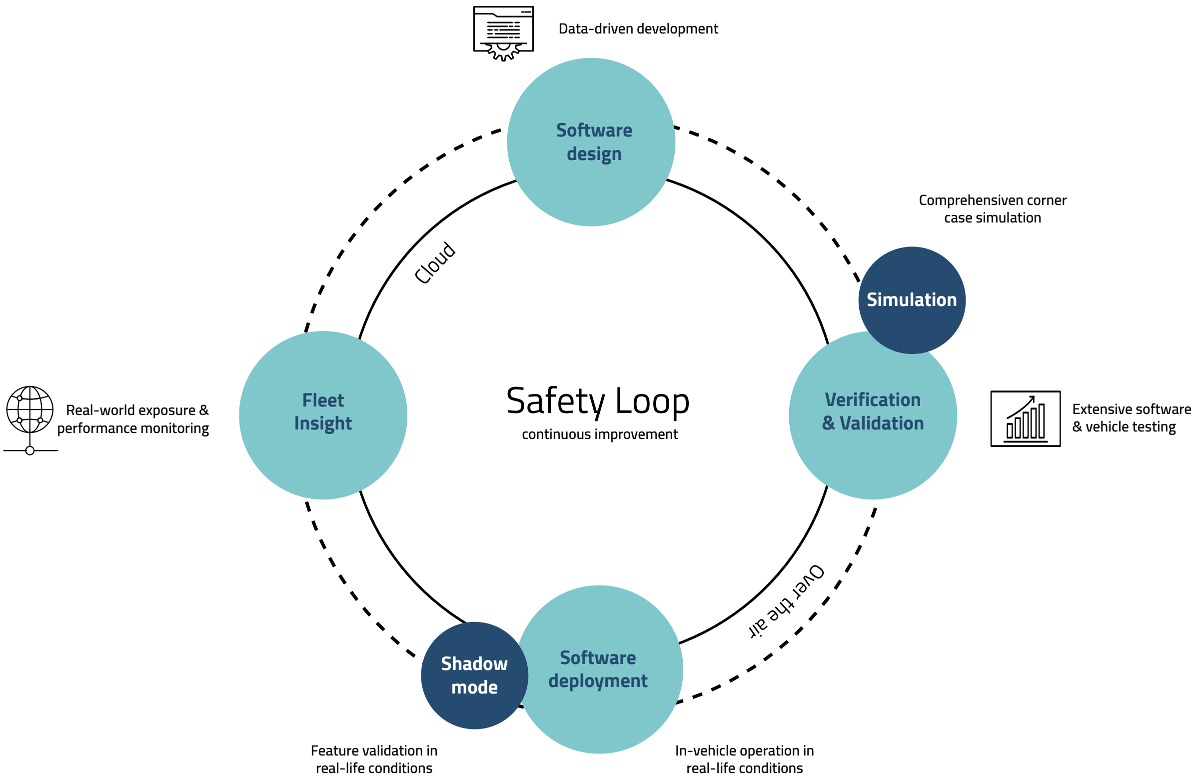


Fig. 2 **Zenseact's Safety loop, powered by data-driven design, over-the-air updates, and cloud technology**

Powered by connectivity and OTA capabilities, our automation solutions are developed around four key pillars:

- Development,
- Functionality growth,
- Data,
- Knowledge.

By embracing the digital transformation of vehicular, localization, and communication technologies, it is possible to accelerate the validation procedures through OTA software deployment or leverage shadow-mode operation to enrich data sets for design, validation, and training purposes.

In shadow mode (see Figure 3) the vehicle isn't taking any action, but it registers when and how it would have acted. Hence, shadow mode is crucial, allowing the gathering of statistical data on the false positives and false negatives of the software, and allowing the development teams to analyze incidents and predict and ultimately optimize the autonomous system response.

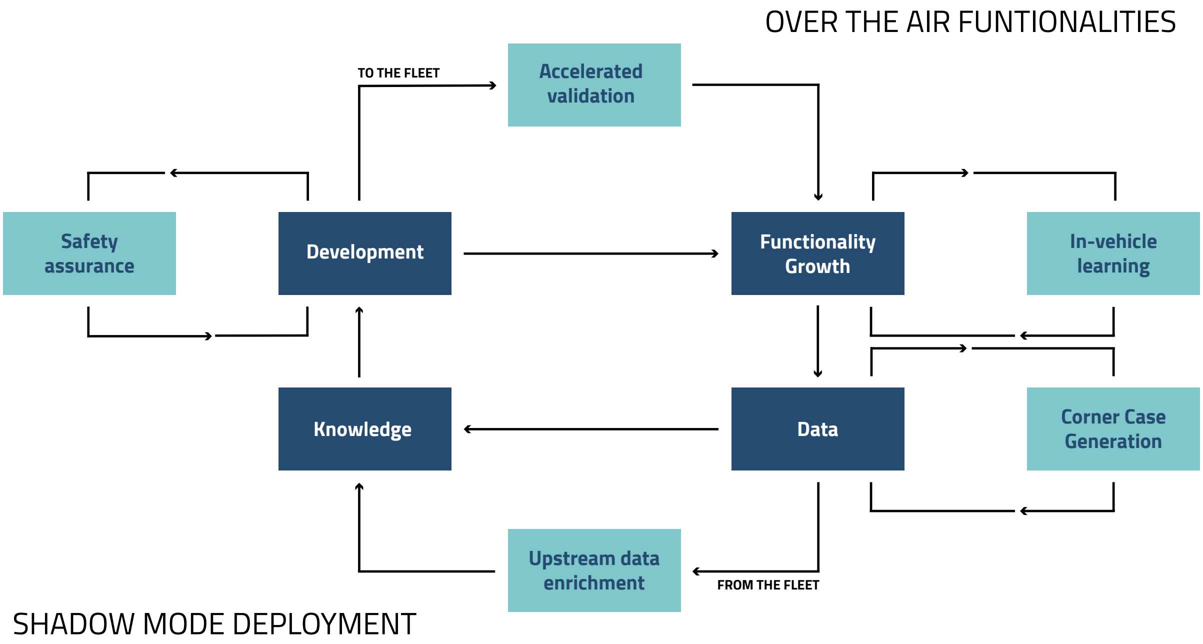


Fig. 3. Zenseact's Circular Safety pillars

The speed at which one can iterate such a loop, defining how fast one can deliver services to customers and monitor their performances, is one of Zenseact's advantages. We have industrialized this continuous data-driven development loop, where the platform components are tightly integrated to ensure maximum efficiency end to end.

Furthermore, for validation and verification purposes, the quantity and quality of data needed for the design of future AD solutions will require new ways of working, as well as data mining. Even if the design and validation of autonomous features already leverage field-test data from all over the world, it will be crucial for the AD development to collect large quantities of traffic data and monitor the automation performance within the fleet in multiple locations worldwide. Such capabilities will allow the deployment of autonomous solutions that can ultimately be optimized for different markets and driving cultures.

V. Driving, cruising, or riding?

To navigate the transition towards autonomy and driverless vehicles, it is crucial to propose a set of efficient and distinct functionalities and capabilities in alignment with the targeted market position and customer base.

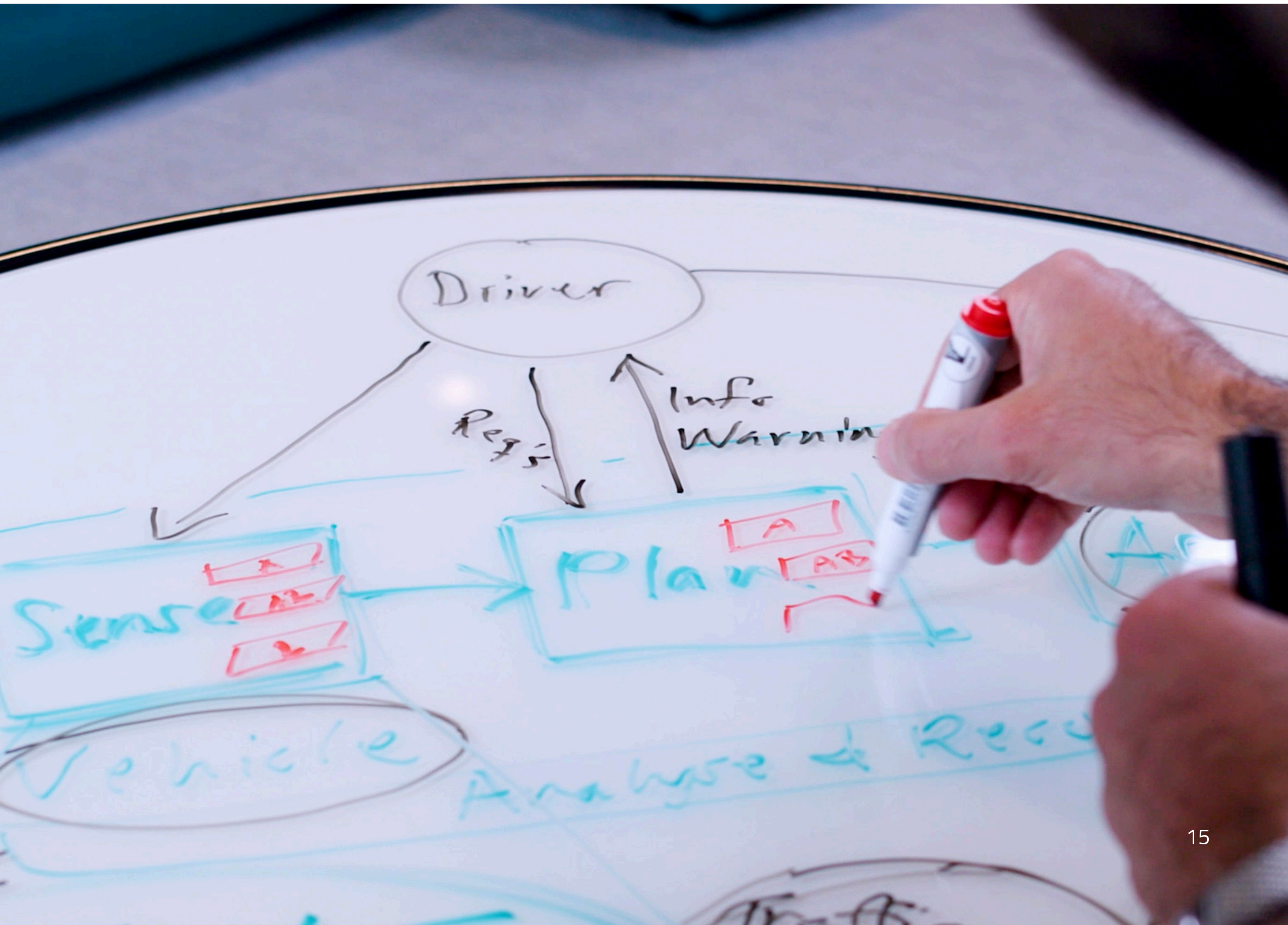
For Zenseact, the targeted customer base includes car manufacturers, and OnePilot is our market offer. It's the flagship service of Zenseact Autonomy Services. It offers a combination of on-board software modules and off-board cloud services that enable both advanced driver assistance and autonomous driving. OnePilot offers the customer three different modes of operation:

- Drive – OnePilot helps the driver avoid collisions by providing information, warnings, and automatic braking and steering interventions during manual driving,
- Cruise – OnePilot controls the vehicle's motion but is under the driver's supervision,
- Ride – OnePilot is unsupervised (a proper AD system) and provides the driver freedom to do something else behind the steering wheel.

The primary difference between these modes is their supervised and unsupervised nature, with their respective performance and safety assurance consequences: cruising features only support the driver and rely on human supervision. AD systems, however, are designed to operate the vehicle safely without human supervision. Thus, Ride is the only unsupervised driving mode.

With increasingly complex and connected functionalities, the development of advanced ADAS and AD systems places higher demands on performance and safety assurance. This inevitably leads to stricter requirements on the system, architecture, hardware, and software components, especially those responsible for planning and decision making.

Hence, one of the challenges for ADAS and AD systems is to become robust and consistent concerning changing environmental conditions and behaviors from other road users, such that trajectory planning and decision making can be adapted to the vehicle's capabilities, external conditions, and knowledge on human mistakes to satisfy ambitious requirements on accident-, injury- and fatality rates.



VI. The Precautionary Safety framework

Safety assurance and safe trajectory planning are among the most challenging aspects of developing AD systems. Many solutions have been proposed in the last few years, both from an academic and an industrial perspective.

For instance, NVIDIA described its Safety Force Field concept as a safety layer for obstacle avoidance which guarantees that the AD vehicle does not expose other road users to dangerous behaviors.[7] Similarly, Mobileye has proposed a white-box, interpretable, mathematical model for safety assurance, denoted as Responsibility-Sensitive Safety.[8] Waymo has also built up its Safety by Design approach, leveraging a combination of system-level testing and component and subsystem testing.[9]

Zenseact's Precautionary Safety framework will play a crucial role in designing, developing, and validating its systems to satisfy the strict safety and performance requirements expected for autonomous vehicles. Precautionary Safety provides a set of threat-assessment, decision-making, and verification principles that enhance traffic safety while maximizing the availability of autonomous driving functionalities by driving with precaution and accounting for unexpected events.

7 D. Nistér, H.-L. Lee, J. Ng, and Y. Wang, "The safety force field," NVIDIA, Tech. Rep., 2018.
8 S. Shalev-Shwartz, S. Shammah, and A. Shashua, "On a formal model of safe and scalable self-driving cars," arXiv:1708.06374, 2018.
9 N. Webb, D. Smith, C. Ludwick, T. Victor, Q. Hommes, F. Favaro, G. Ivanov, and T. Daniel, "Waymo's safety methodologies and safety readiness determinations," 2020; "Waymo safety report", Waymo, Tech. Rep., 2021

To enable the development and deployment of safe autonomous driving systems, Precautionary Safety provides a set of principles and methodologies such that autonomous vehicles can adjust their trajectory planning and decision-making to the platform's sensing and actuation capabilities, external conditions, and knowledge of human mistakes, to satisfy overall requirements on low accident-, injury- and fatality rates, see Fig.4.

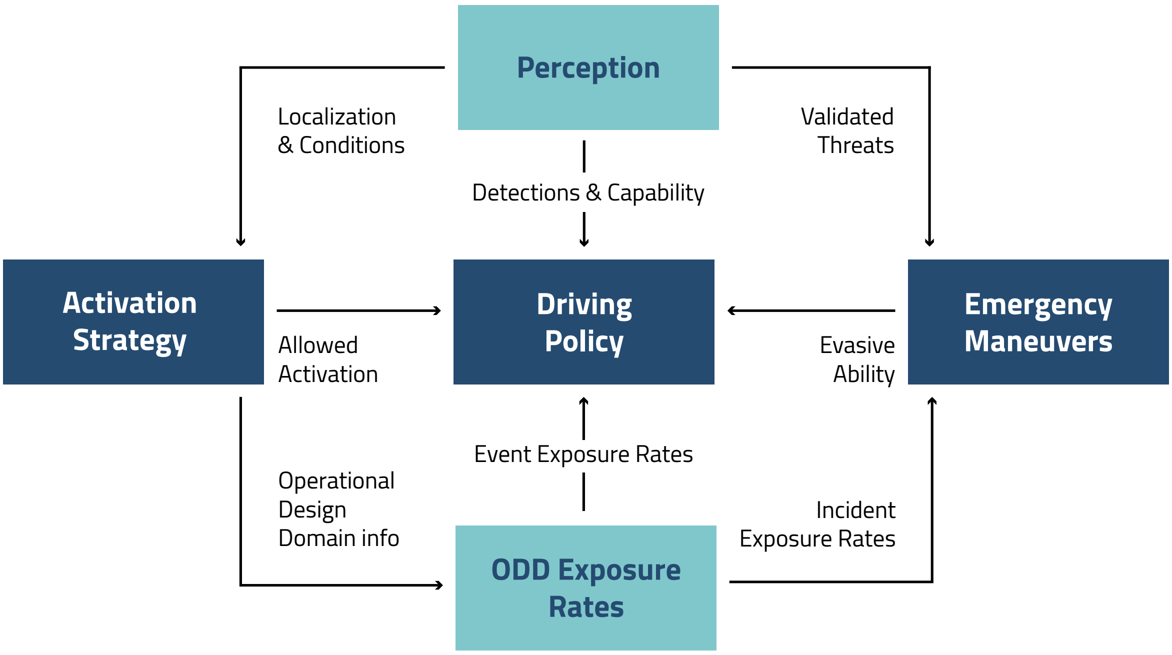


Fig. 4. Precautionary Safety driving policies adapt trajectory planning and decision making to the ability to perform evasive maneuvers, given the knowledge on the exposure to specific incidents.

Precautionary Safety focuses on safe trajectory planning and decision-making for unsupervised autonomous driving often referred to as a safe driving policy. Some researchers define safe driving as legal safety, i.e., in the sense that AD systems are considered safe if they always obey a set of rules.[10] From a legal safety perspective, it's easy to conclude that there would be no accidents if everyone just followed the rules.

However, the underlying assumption that other road users always follow the rules is questionable. Many people violate traffic rules, either on purpose or by mistake: driving faster than the speed limits, getting distracted, taking away when changing lanes, or going through intersections. Fortunately, the infrastructure is built to be resilient to human errors. Other road users are also relatively good at counteracting others' mistakes by using a combination of proactive and reactive actions.

It's therefore essential to acknowledge that people do make mistakes and to design AD systems that are resilient to human errors and other external incidents, e.g., weather, road infrastructure conditions, or exposure to wild animals, to name a few.

Instead of using the legal safety concept alone, our Precautionary Safety proposes safe driving policies defined as a low accident rate with low severity, no matter whose fault it is. Simply put, AD systems are set to adapt their driving policies to their abilities such that they can satisfy any given quantitative safety requirement.

10 S. Shalev-Shwartz, S. Shammah, and A. Shashua, "On a formal model of safe and scalable self-driving cars," arXiv:1708.06374, 2018.

VII. Enabling technologies

However, the need for rapid progress in safety performance technology and feature growth doesn't come for free. Indeed, the quest for autonomous vehicles is a long-term, investment-intensive journey, which has led to an impressive re-organization of the automotive industry – through partnerships, acquisitions/mergers, and joint-venture deals. While autonomous driving represents a paradigm shift, its development will be enabled by several different factors and disruptive technologies. Some of them are worth highlighting.

Software at the kernel of new vehicles

Even if the transformation of new vehicle development is already ongoing, it is now clear that future systems' functionality will need to be defined primarily by the software to enable the continuous improvement of the vehicles already sold and on the roads. This would allow a shift to recurring revenue streams and asset deployment optimization.

Flexible vehicle platform

The underlying hardware platform will need to be adequately flexible and sufficient to support functionality and performance growth over time, as hardware limitations could become bottlenecks for future development. In practice, vehicles will have to be produced with overcapacity in hardware and sensing capabilities – an expensive yet necessary investment for future functionality and capability growth.

Data collection at the fleet level

Flexible data capture procedures and data analysis systems will be needed in each vehicle, enabling fleet-wise performance monitoring and, most importantly, identifying challenging scenarios and domains for future, data-driven functionality development.

Performance and user experience feedback loops

To improve the feedback loop illustrated in Zenseact's Safety Loop model, there is also a need for metrics quantifying the user experience and system performance. For instance, for safety analysis purposes, it is essential to identify metrics that can capture the margins of unsafe events and incidents. While actual collisions should be rare, finding and leveraging metrics representing risk exposure is essential.

Safety assurance in run-time

Even if safety assurance is traditionally a design-time activity, there will also be the need to introduce safety assurance capabilities in run-time. This requires monitoring systems that can assess each component's safety and performance arguments in real-time, allowing for the Operational Design Domain to be adjusted to the system's current performance. Such real-time estimations could also be used for software components updates or system configuration adjustments for particular environments or geographical areas.

Reliable verification and validation procedures

AD development will naturally require establishing reliable verification and validation procedures, processes, and ways of working to enable safe solutions and the revision of previous deployments (recalls, SW roll-back, etc.) given the real-world behavior.

Sensing platform

The vehicle's sensing system will be crucial for developing high-performing AD systems. Therefore, future vehicle and sensing platforms will likely be composed of several high-resolution vision sensors and high-resolution, long-range lidars, and multiple radar sensors that provide a 360-degree perception of the vehicle. This hybrid configuration will offer significant redundancy and performance optimization advantages in diverse, challenging conditions. (e.g., adversarial weather conditions, obscurity, etc.).

Mapping and localization technologies

High-precision and reliable localization and mapping solutions will also represent critical enabling technologies for AD solutions. As any map remains a model of reality at a given point in time, it can be incorrect over a certain period. Mapping solutions should therefore be able to be updated to minimize errors and uncertainties. The metric "time to reflect reality" (TTRR), commonly used to denote the lag time between the world and the world as it is known to machines, is of crucial importance for intelligent mapping solutions. Powered by connectivity technologies, probe-sourced fleet data represents a rich source of information, allowing the reduction of TTRR values at a reasonable cost.

Artificial intelligence

Artificial intelligence, in the form of deep neural networks combined with rule-based logic, is already used in several parts of the functional elements in modern vehicles. But AI's footprint and reach within the software stack and supporting functionalities/tools are expected to expand significantly in the coming years to perception capabilities as well as decision-making and tactical logic. Additionally, the usage of lidar sensors could allow automatic vision annotations performed locally in the vehicle, enabling the creation of local training data on each vehicle. Leveraging the combination of the local learnings from different vehicles in a federated learning architecture, it will be possible to improve AI training processes at a local and global level and increase the improvement speed of AI-based elements when compared to off-vehicle, centralized training methods.

VIII. Towards Zero Faster

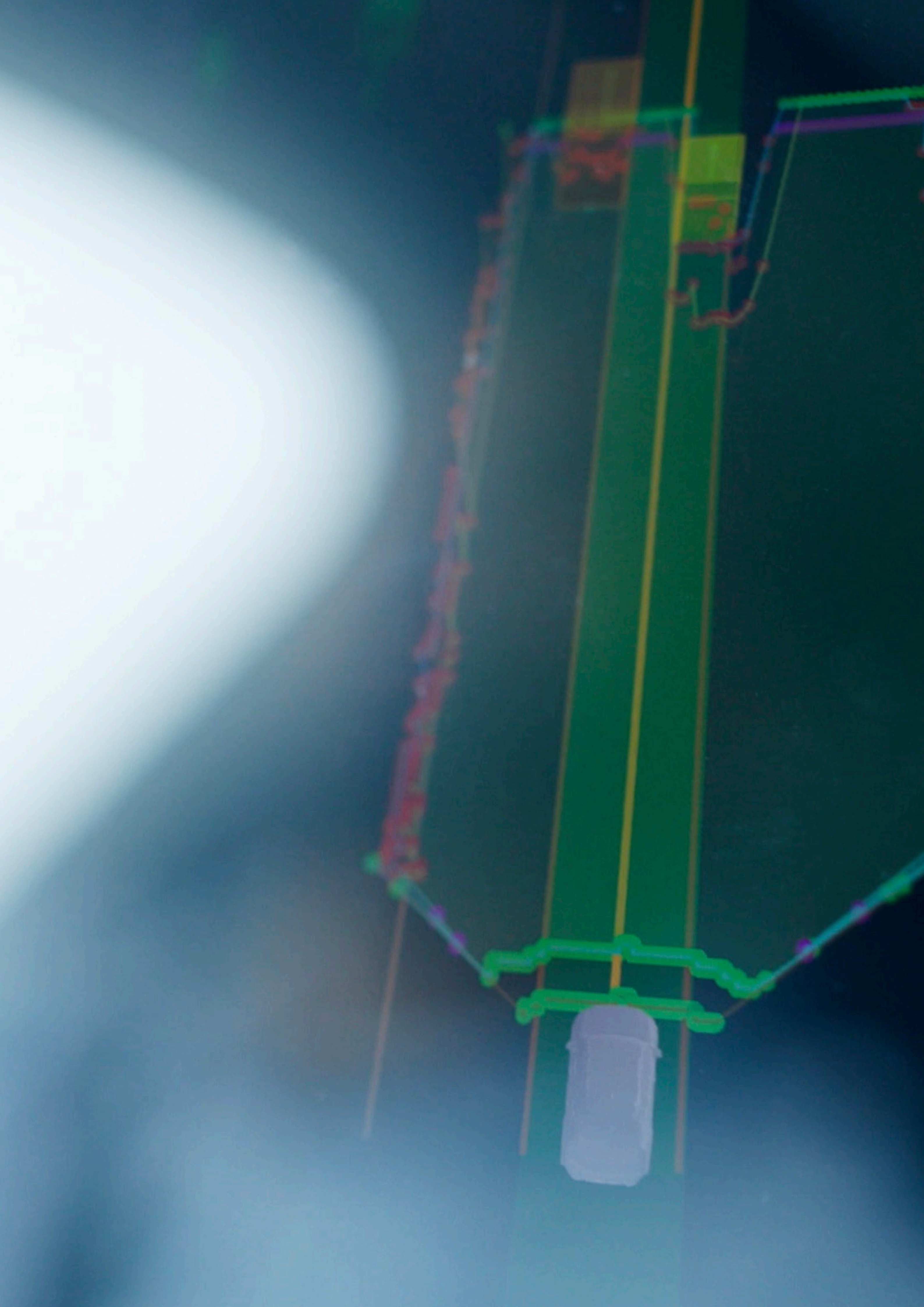
Road safety has been studied for more than 75 years to prevent traffic accidents, injuries, and fatalities. As a result, proper road design, standards, traffic rules, driver education, and law enforcement have been continuously improved to reduce the crash risk. While significant advancements have been made, over 1,35 million people still die every year worldwide, and over 50 million people get injured.

Engaged in the technological revolution around autonomous vehicles, the automotive industry has become the center of a fierce war of new-tech, intelligent driving features. This quest represents a long-term and investment-intensive journey, which has led to a fundamental re-organization of the automotive industry – through partnerships, acquisitions, mergers, and joint-venture deals. Piggybacking on this collective journey, road safety technology has also evolved – from passive and reactive features to increasingly more proactive and predictive solutions.

Fig. 5. Zenseact's reference vehicle platform is equipped with a central computing unit, and lidars, radars, and cameras providing 360 degrees of perception around the vehicle.

This paper has discussed this paradigm shift along with the development of automatic driving assistance systems and autonomous driving. It has also outlined Zenseact's approach and technological offer.

By providing safe automation solutions that combine onboard software modules and cloud-based services for supervised driver assistance features and unsupervised autonomous driving, our vision is to ultimately realize autonomous driving and further reduce road-traffic fatalities and human-error-based accidents. Our ambition is to get there faster, through faster improvement loops, development cycles, and faster deployment of high-capacity sensing and vehicle platforms.



IX. References

Articles

[1] D. Nistér, H.-L. Lee, J. Ng, and Y. Wang, "The safety force field," NVIDIA, Tech. Rep., 2018.

[2] Jennifer N. Dang. "Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems – Final Report", U.S. Department of Transportation National Highway Traffic Safety Administration 2007.

[3] G. Rodrigues de Campos, R. Kianfar, and M. Brännström, "Precautionary Safety for Autonomous Driving Systems: Adapting Driving Policies to Satisfy Quantitative Risk Norms", IEEE Intelligent Transportation Systems Conference, 2021.

[4] N. Webb, D. Smith, C. Ludwick, T. Victor, Q. Hommes, F. Favaro, G. Ivanov, and T. Daniel, "Waymo's safety methodologies and safety readiness determinations," 2020.

[5] S. Shalev-Shwartz, S. Shammah, and A. Shashua, "On a formal model of safe and scalable self-driving cars," arXiv:1708.06374, 2018.

Sarah E. Burke, Rachel T. Silvestrini, "The Certified Quality Engineer Handbook - Fourth Edition", American Society for Quality (ASQ), 2017.

Reports and surveys

[1] Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey", National Highway Traffic Safety Administration (NHTSA), 2015.

[2] Global Status Report on Road Safety 2018", World Health Organization, 2018.

[3] Software-Defined Vehicles – A Forthcoming Industrial Evolution", Deloitte.

The Abbreviated Injury Scale (Revision)", Association for the Advancement of Automotive Medicine (AAAM), 2015.

[4] Waymo safety report," Waymo, Tech. Rep., 2021.

About Zenseact

We develop software for safer driving with the ambition to help reduce traffic collisions all the way to zero. With approximately 600 engineers, we design the complete software stack for advanced driver-assistance systems and autonomous driving. We were founded by Volvo Cars in 2020 and operate out of Gothenburg, Sweden, and Shanghai.

We use our white papers to share knowledge and help the industry move faster towards safety standardization and a future of zero accidents.

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