TORC

Innovating Safety and Efficiency

Torc Safety Report


#SENSINGWHATSAHEAD
FREIGHTLINER

Contents


FREIGHTLINER
TORC

Our Mission is Saving Lives

Since 2005, Torc Robotics has developed and commercialized automated driving system (ADS) technology in vehicles with safety-critical applications. In 2019, the company became a subsidiary of Daimler Truck, the undisputed global market leader in truck manufacturing, with a legacy that traces back to the invention of the combustion engine and the world's first truck in 1896. Together, we are focused on the deployment of level 4 ADS-operated trucks[1] (hereafter referred to as level 4 trucks), with the goal of preventing crashes related to human error while also enhancing efficiency, productivity, sustainability, and economic competitiveness in the trucking industry.

Torc recognizes that this endeavor is a marathon, not a sprint, and our overarching principle must be safety. Torc is leveraging our 16 years of deep domain expertise in automated vehicle technology to achieve optimum integration and a superior product. The outcome of this process will provide a solution that supports and enhances trucking – the backbone of our economy – while simultaneously contributing to improved safety on the road.

The deep-rooted safety culture at Torc permeates all personnel and activities, including our established Safety Driver Training Program. We at Torc have a clear understanding of the steps required to guarantee safety as our development moves us closer to on-road deployment of level 4 trucks.

Our framework for safety contained in this report is founded on a relentless institutional safety culture and embodies the 12 safety elements delineated in the National Highway Traffic Safety Administration's *Automated Driving Systems 2.0: A Vision for Safety*.[2] Torc is committed to developing level 4 trucks at scale – when, and only when it's safe to do so. As this document outlines, our full focus is on safe development and testing of this technology.

Sincerely,

Michael Fleming
CEO, Torc Robotics

Safety Elements

1. System Safety p. 32

Design and validation process based on a systems-engineering approach with the goal of designing an ADS free of unreasonable safety risks.

2. Operational Design Domain (ODD) p. 42

Define and document the ODD for the ADS available on the vehicles as tested or deployed for use on public roadways, as well as document the process and procedure for assessment, testing, and validation of ADS functionality within the prescribed ODD.

3. Object and Event Detection and Response (OEDR) p. 46

Process for assessment, testing, and validation of their ADS's OEDR capabilities. When operating within its ODD, an ADS's OEDR functions are expected to be able to detect and respond to other vehicles (in and out of its travel path), pedestrians, bicyclists, animals, and objects that could affect safe operation of the vehicle.

4. Fallback (Minimal Risk Condition) p. 52

Process for transitioning to a minimal risk condition when a problem is encountered, or the ADS cannot operate safely.

5. Validation Methods p. 58

Validation methods to appropriately mitigate the safety risks associated with their ADS approach. Demonstrate the behavioral competencies an ADS would be expected to perform during normal operation, the ADS's performance during crash avoidance situations, and the performance of fallback strategies relevant to the ADS's ODD.

6. Human Machine Interface (HMI) p. 60

Define the interaction between the vehicle and the driver. Document the process for assessment, testing, and validation of the vehicle's HMI.

7. Crashworthiness p. 64

Present how possible scenario of another vehicle crashing into an ADS-equipped vehicle and how to best protect vehicle occupants in that situation. ADSs intended for unoccupied use scenarios should consider appropriate vehicle crash compatibility given the potential for interactions with vulnerable road users and other vehicle types.

8. Post-Crash ADS Behavior p. 65

Methods used for returning the ADS to a safe state immediately after being involved in a crash.

9. Vehicle Cybersecurity p. 68

Define the systems engineering approach to minimize risks to safety, including those due to cybersecurity threats and vulnerabilities.

10. Data Recording p. 69

Documented process for testing, validating, and collecting necessary data related to the occurrence of malfunctions, degradations, or failures in a way that can be used to establish the cause of any crash.

11. Consumer Education and Training p. 72

Develop, document, and maintain employee, dealer, distributor, and consumer education and training programs to address the anticipated differences in the use and operation of ADSs from those of the conventional vehicles. Provide target users the necessary level of understanding to utilize these technologies properly, efficiently, and in the safest manner possible.

12. Federal, State and Local Laws p.73

Procedure on how to account for all applicable federal, state, and local laws in the design of the vehicle and ADS.


DAIMLER
SELF-DRIVEN BY TORC

Why Innovate Trucking?

According to the American Trucking Associations, nearly 12 billion tons of freight were transported as part of primary shipments in the U.S. in 2019, representing 72.5% of all domestic freight tonnage nationwide.[3] The Bureau of Transportation Statistics expects the tonnage of goods shipped by trucks in the U.S. to continue to increase, with the tonnage nearly doubling over the next two and a half decades.[4] These statistics highlight the growing need for safe, reliable, cost-effective trucking solutions.

Torc believes that level 4 trucks can reduce crashes and make our roads safer while also helping address the ever-growing volume of freight. Torc has more than 16 years of experience in developing and commercializing ADS technology in heavy-duty, safety-critical applications. Torc began its legacy as one of only three finishers in the 2007 DARPA Urban Challenge, a prestigious competition demonstrating the real-world possibilities of ADSs. Since then, Torc has developed full-stack software and tirelessly worked with industry leaders to advance solutions for safety-critical, heavy-duty applications in the relentless pursuit of using automated vehicle technology to save lives. Since 2007, Torc has been safely testing these solutions on public roads and highways across the country.

Trucking Statistics

Revenue

The trucking industry collects annual revenues of **$792 billion**[3]

Growth

Freight volume in the U.S. is expected to grow **29%** by 2026[5]

Freight

11 billion tons of freight are transported by truck each year[3]

Highways

Nearly **50%** of truck vehicle miles are traveled on interstate highways[6]

Trucks

Class 8 trucks (those with gross vehicle weight ratings over 33,000 lbs) transport **>70%** of all freight in the U.S.[3]

Miles

The average professional long-haul trucker logs more than **100,000 miles** per year[3]

Distance

60% of goods are moved over 100 miles between the origin and destination[7]

Goods

70% of agricultural, food, lumber, wood, paper, and paperboard products are transported to rural America by truck[8]


TORC

An Uncompromising Safety Culture

Torc's culture is built on the foundation of a safety-centered mindset and meeting the needs of industry. In support of this, Torc is developing a comprehensive validation approach for the deployment of ADS operations in total alignment with federal policy for the testing and commercial deployment of level 4 trucks.

The U.S. Department of Transportation (USDOT) Safety Council defines safety culture as "the shared values, actions, and behaviors that demonstrate a commitment to safety over competing goals and demands."[9] The National Transportation Safety Board (NTSB) has cited an inadequate safety culture as a contributing factor in incidents involving ADS-operated vehicles and has provided guidance on how a safety culture should be developed, promoted, and maintained.[10]

The safety culture at Torc permeates all departments and activities (from concept design to the ultimate deployment of ADS-operated vehicles), furthers our mission, and helps to uphold our core values. Torc's critical elements provide the foundation for safe operations, reflect basic good business practices, and are based in USDOT and NTSB[6] principles:

Torc's Foundation for Safe Operations

01

Leadership

Leadership is clearly committed to safety.

02

Communication

Open and effective communication exists across the organization.

03

Responsibility

Employees feel personally responsible for safety.

04

Learning

The organization practices continuous learning.

05

Work Environment

The work environment is safety conscious.

06

Reporting Systems

Reporting systems are clearly defined and not used to punish employees.

07

Decisions

Decisions demonstrate that safety is prioritized over competing demands.

08

Trust

Employees and the organization work to foster mutual trust.

09

Fairness

The organization responds to safety concerns fairly and consistently.

10

Training

Safety efforts are supported by training and resources.


DAIMLER
AUTONOMOUS
SENSING WHAT'S AHEAD
DAIMLER
SELF-DRIVEN BY TORC
DAIMLER

The Vision for Level 4 Trucks

Torc is working toward level 4 truck technology with a vision for transforming safety and efficiency in the trucking industry. To reduce the potential for crashes while mitigating risks for vehicle occupants and other road users, Torc's ADS operates like a defensive and attentive driver. Torc's ADS has been integrated and safely tested in multiple platforms on public roads.

ADS-operated vehicles will constantly monitor the driving environment and respond appropriately and safely to changing conditions. Torc is working to incorporate system safety into vehicle design, development, testing, and validation in consideration of the 12 safety elements defined by the National Highway Traffic Safety Administration.[2]

Defining Levels of Driving Automation

OVERVIEW OF AUTOMATION LEVELS

The SAE J3016 standard[1] details defines the varying levels of driving automation systems. These levels are briefly introduced below.

Level 0 — Manual Driving

All driving maneuvers are performed by the driver. Support may be provided by warning or assistance systems.

Level 1 — Assisted Driving

The driving automation system, when engaged in defined scenarios, performs either longitudinal or lateral vehicle motion control. The driver continuously monitors the system and takes over the delegated tasks if required.

Level 2 — Partially Automated Driving

In suitable scenarios, the driving automation system performs part of the dynamic driving task by driving the vehicle laterally and longitudinally. The system disengages immediately upon driver request, and the driver continuously monitors the system and takes over the delegated tasks if required.

Level 3 — Conditionally Automated Driving

In suitable scenarios, the ADS performs the entire dynamic driving task and disengages immediately upon driver request. The driver no longer has to continuously monitor the system and perform non-driving-related tasks. If the system sends a takeover prompt to the driver, the driver must take over in a short period of time.

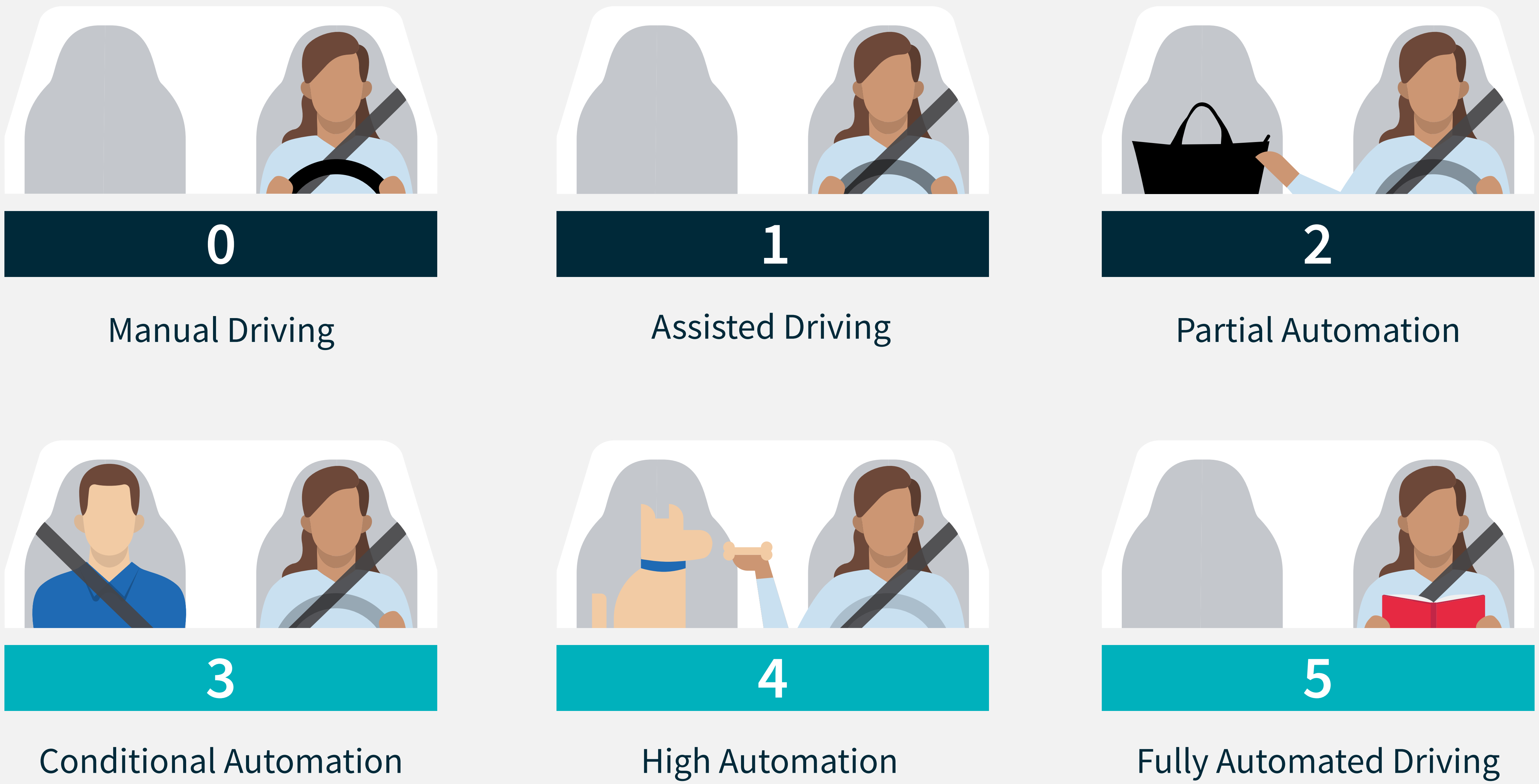
Level 4 — Highly Automated Driving

In suitable scenarios, the ADS performs the entire dynamic driving task. The ADS disengages, if appropriate, if a driver takes over. In these scenarios, the vehicle does not send a takeover prompt to the driver/user as it can handle the scenario completely.

Level 5 — Fully Automated Driving

The ADS can drive on all mapped roads that are navigable by a human driver. The user simply inputs a destination, and the vehicle automatically navigates to that destination. The system can handle all scenarios independently and performs the entire dynamic driving task. It disengages, if appropriate, if a driver takes over.

Levels of Driving Automation



Why Level 4?

Torc is working toward building a level 4 truck because we believe that this level of driving automation will be the safest for heavy-duty trucks and will offer enormous advantages in many areas. Level 4 trucks will:

- make considerable contributions toward safer roads and more sustainable transport solutions;
- enhance traffic safety thanks to a redundancy of systems and multiple sensors that can consistently achieve high performance – thereby helping to prevent the great majority of crashes that today result from human error;
- improve efficiency and productivity by, among other avenues, higher utilization of the vehicles – practically around the clock;
- avoid traffic jams by intelligent route management, making it possible to travel during light traffic times.

This will be beneficial for fleet customers and the entire economy: the competitiveness of an economy is strongly correlated with the efficiency of logistics.


DAIMLER
SELF-DRIVEN BY TORC
#SENSINGWHATSAHEAD

ADS-Operated Truck Design and Testing

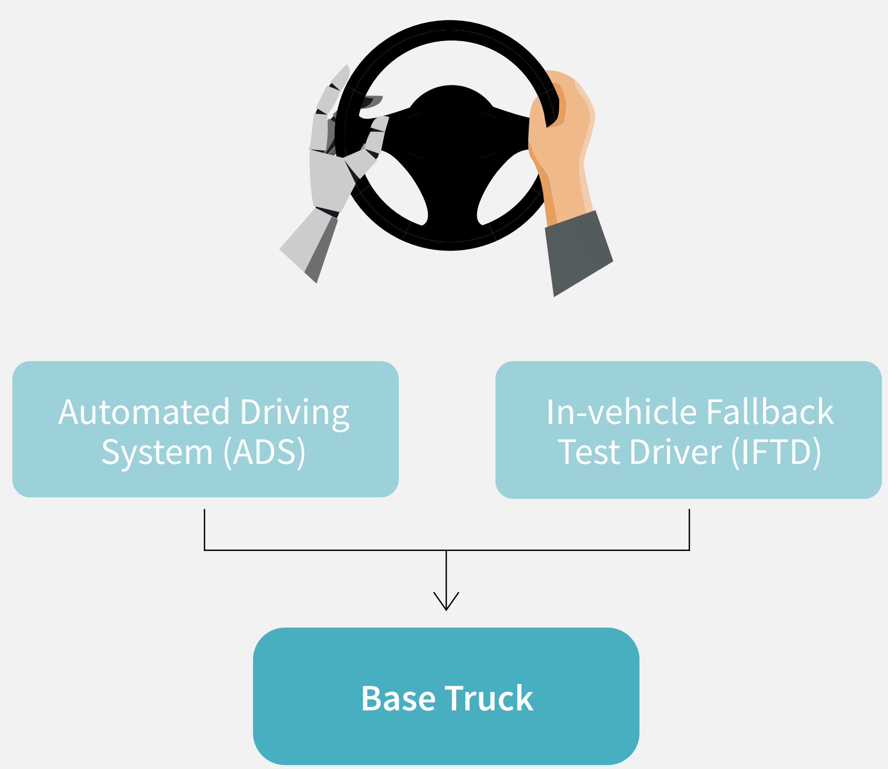
The design aspects for an ADS-operated vehicle involve multiple important components. The ADS itself represents the "eyes" (sensors) and "brain" (decision making) of the vehicle. These are the key components that allow the ADS to see, think, and act:

- SEE: Perception (what the truck sees) and localization (where the truck is in the world)
- THINK: Behavior and planning (what the truck should do in a specific situation to navigate along a route)
- ACT: Controls (what the truck does to implement the dynamic driving task)

Considering safety from design to deployment is paramount. This process includes many key aspects of vehicle design and required ADS-related redundancies in addition to the testing process.

The Human Element of Testing

Driving Safety through the Testing Process



The people performing the testing are of utmost importance to establishing the foundation for safety in the development of an ADS-operated truck. The In-vehicle Fallback Test Driver (IFTD) sits in the driver's seat and drives the vehicle manually when needed. When the ADS is engaged, the IFTD is prepared to serve as a fallback during testing and validation. The IFTD goes through a robust program of training and testing to become a certified professional. Thus, the IFTD is the primary line of defense for the safe operation of the vehicle if the ADS fails or another vehicle performs an unsafe maneuver the ADS is not yet prepared to encounter.

The process of developing an ADS that serves the needs of a Class 8 truck is unique. Heavy trucks differ from passenger cars in terms of the vehicle dimensions, vehicle dynamics, and the amount of time it takes the vehicle to respond to driver inputs. Thus, the behaviors and decision-making capabilities of the ADS must be engineered in a way that allows it to understand the truck's capabilities and limitations (e.g., braking depending on vehicle load and road conditions) and communicate effectively to the base truck. The IFTD is indispensable to ensuring the safety of the surrounding traffic and the vehicle occupants during testing, where critical feedback is provided to evolve and improve the ADS.

Safety Driver and Safety Conductor Training

Torc has created an intensive program that allows for a supervised testing process with a highly trained IFTD and a critical partner: a Safety Conductor. During testing, the Safety Conductor is responsible for the leadership and safe execution of tests related to the development of ADS-operated vehicles within the prescribed operational design domain. Moreover, all truck drivers responsible for interacting with one of our vehicles undergo a rigorous screening, training, and evaluation process. We are committed to safety on our roadways.

For the near future, the IFTD and Safety Conductor will be critical for ensuring the safe operation and testing of prototype vehicles. The roles and responsibilities of the different types of Safety Drivers and Safety Conductors are summarized in the following sections.

SAFETY DRIVER

The Safety Driver is responsible for the safety of the vehicle, occupants, and other road users and may not fulfill any other role while the vehicle is in motion. To be considered a Safety Driver, the driver must be certified at one of four levels, each of which authorizes the driver for different types of operations. This certification is divided into two main categories: IFTD and ADS-equipped Vehicle Manual Operator (AVMO). Note that the IFTD certifications have a location restriction, whereas the AVMO certifications have a task-type restriction. The top Safety Driver certification type (Type 1) authorizes the Safety Driver to complete the responsibilities of the subsequent lower certification levels (Types 2–4), but not vice versa. For example, a Safety Driver certified as Type 1 (IFTD Public Road) could perform Type 4 (AVMO Transportation), but a Type 4 Safety Driver could not perform ADS-related testing, which requires Type 1 or Type 2 certification.

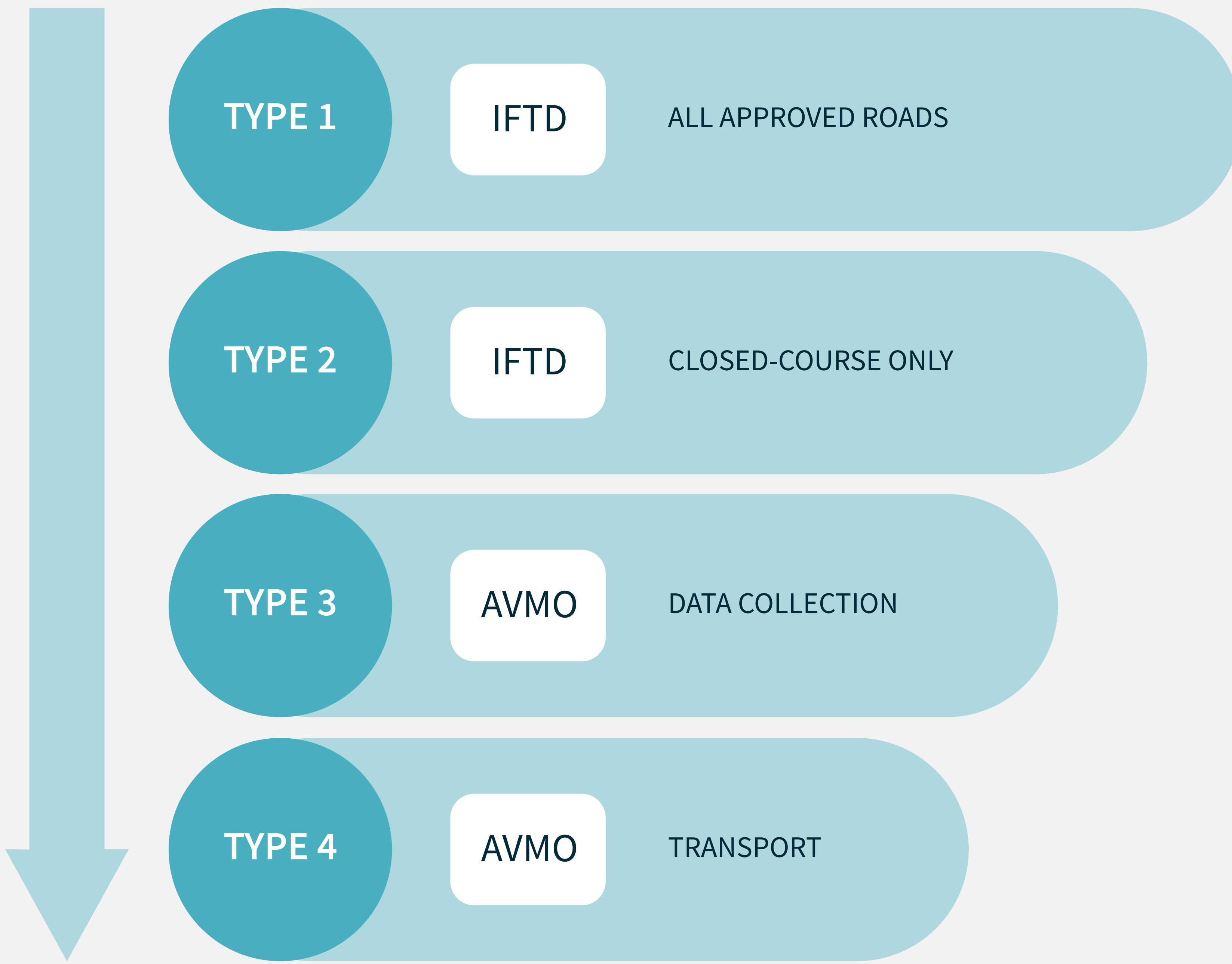
SAFETY CONDUCTOR

Depending on the state of ADS engagement, a Safety Conductor might be needed in addition to the appropriate Safety Driver within the vehicle. For example, when the ADS is engaged, both an IFTD (a type of Safety Driver) and a Safety Conductor must be present. The Safety Conductor is responsible for the leadership and safe execution of tests related to the development of ADS-operated vehicles within the prescribed operational conditions. A certified Safety Conductor is required for all tests where the ADS is engaged. The Safety Conductor leads and/or coordinates the remaining activities in the vehicle. Safety Conductor testing tasks include: 1) ensuring environment and maneuvers remain within the test objectives and testing conditions; 2) monitoring IFTD performance; 3) pausing or stopping test execution when necessary; 4) performing designated Incident and Emergency Response Plan responsibilities; 5) ensuring data and notes are captured during safety-relevant events; 6) serving as primary contact for any external communications; and 7) serving as the primary line of communication to the IFTD. The objective for the Safety Conductor is to allow the IFTD to operate the vehicle in a distraction-free, safe, and secure manner.

TRAINING AND MONITORING

Torc Safety Drivers as well as Torc Safety Conductors undergo a very rigorous selection and training process. For public road testing, drivers are vetted using a demanding behind-the-wheel driver assessment as well as the extensive trucking experience and driver record review. The comprehensive curricula include in-classroom training and scenario-based in-vehicle testing (e.g., simulated ADS failure, extreme vehicle dynamics). During this process, safety instructors coach and evaluate candidates. This three-tier certification program (classroom, closed course, public road) provides a comprehensive approach to safety training and evaluation. Once the training learning objectives and testing acceptance criteria are met, they are approved for their intended role (i.e., Safety Driver, Safety Conductor). Once they are assigned to their role, performance is constantly monitored, and periodic evaluation audit processes are followed to ensure the highest level of performance is maintained.

Categorization of Safety Drivers



This IFTD is certified to engage, disengage, and perform safety-related tasks to control the ADS-equipped vehicle. This type of IFTD oversees the ADS while it performs the dynamic driving task, takes over as needed, and drives the vehicle as a manual operator where necessary. This is the only certification that allows for a Safety Driver to be in the driver seat while the ADS is engaged on public roads.

This type of Safety Driver is certified as a manual operator with ADS powered on but not engaged. This Safety Driver type is only for data collection purposes when the ADS is not performing the dynamic driving task.

This type of Safety Driver is certified only as a manual operator with the ADS powered off. A Type 4 Safety Driver mainly moves vehicles for non-test-related tasks or in preparation for a test (e.g., staging, vehicle maintenance appointment, and fueling).

Safety Assurance and ADS Test Approval

Various Torc teams, including Safety and Mission Assurance, Fleet Operations, and Engineering, work together to ensure safety is considered at every level of testing. Collaboratively, these teams identify hazards and feasible mitigation strategies, improve the inherent reliability and safety of software, and define the operational design domain and training needs to maintain testing safety. The Fleet Operations team coordinates test resources to operationally evaluate test plans and provide approvals and/or recommendations for additional controls required to maintain test safety. Torc's process of safety assurance and test approval includes:

- Verifying the operating conditions for testing (i.e., where and under what conditions the ADS-operated vehicle will be tested);
- Securing safety approvals for each test mission; and
- Training and managing the IFTDs and Safety Conductors who directly support each vehicle test, as described in the Safety Driver and Safety Conductor Training section.


ThinkPad

Designing for Safety

Ensuring a rigorous process to guarantee safety at each step in this process is paramount. We accomplish this by applying known industry standards and best practices along with our own procedures designed specifically for ADS-related features.

Safety Element 1: System Safety

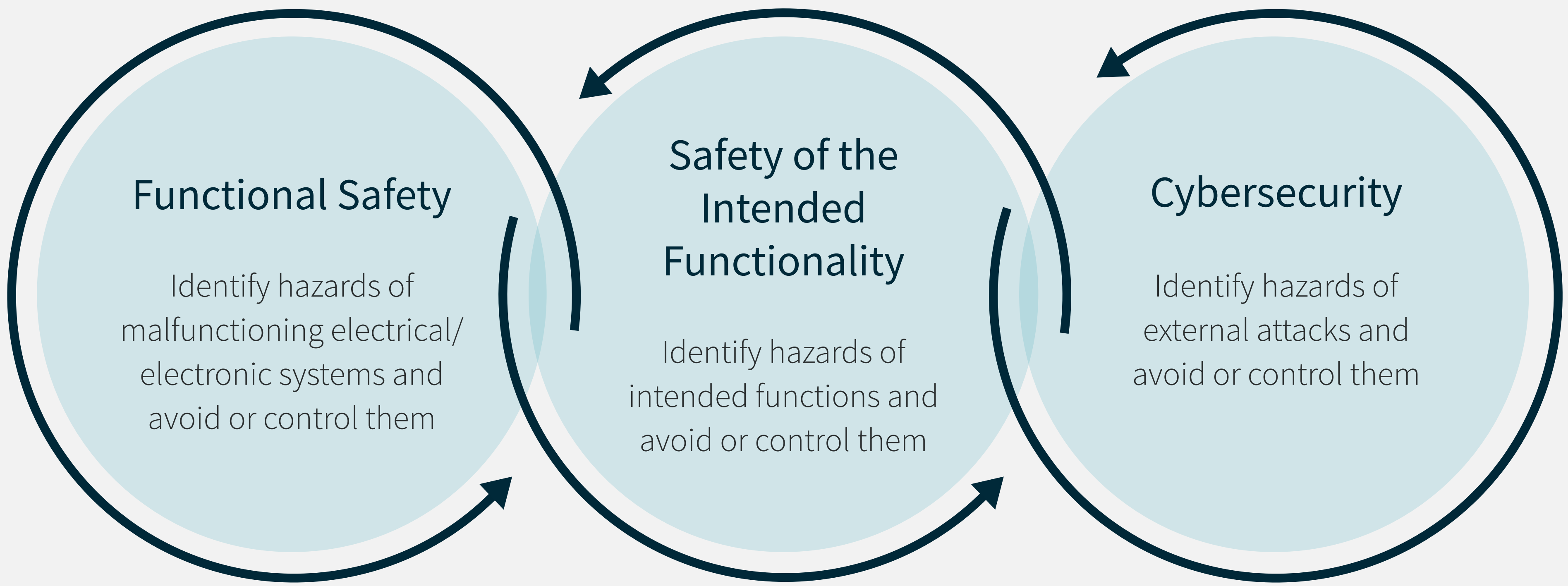
To implement a holistic safety approach, Torc incorporates its own procedures and will adhere to industry standards, including those focused on functional safety,[11] intended functionality,[12] cybersecurity engineering,[13] design, verification, and validation with respect to the safety and cybersecurity of ADSs.[14]

In the development of an ADS-operated vehicle, a system safety approach provides structure and guidance regarding the necessary compliance to standards.

SAFETY FROM DEVELOPMENT TO PRODUCTION

Torc will carry this system safety approach throughout all efforts from advanced development to preparing ADS-operated vehicles for production. To do this, it is necessary to distinguish between system safety activities needed to test ADS-operated vehicles under IFTD supervision and those necessary for ADS-operated vehicles during production.

System Safety



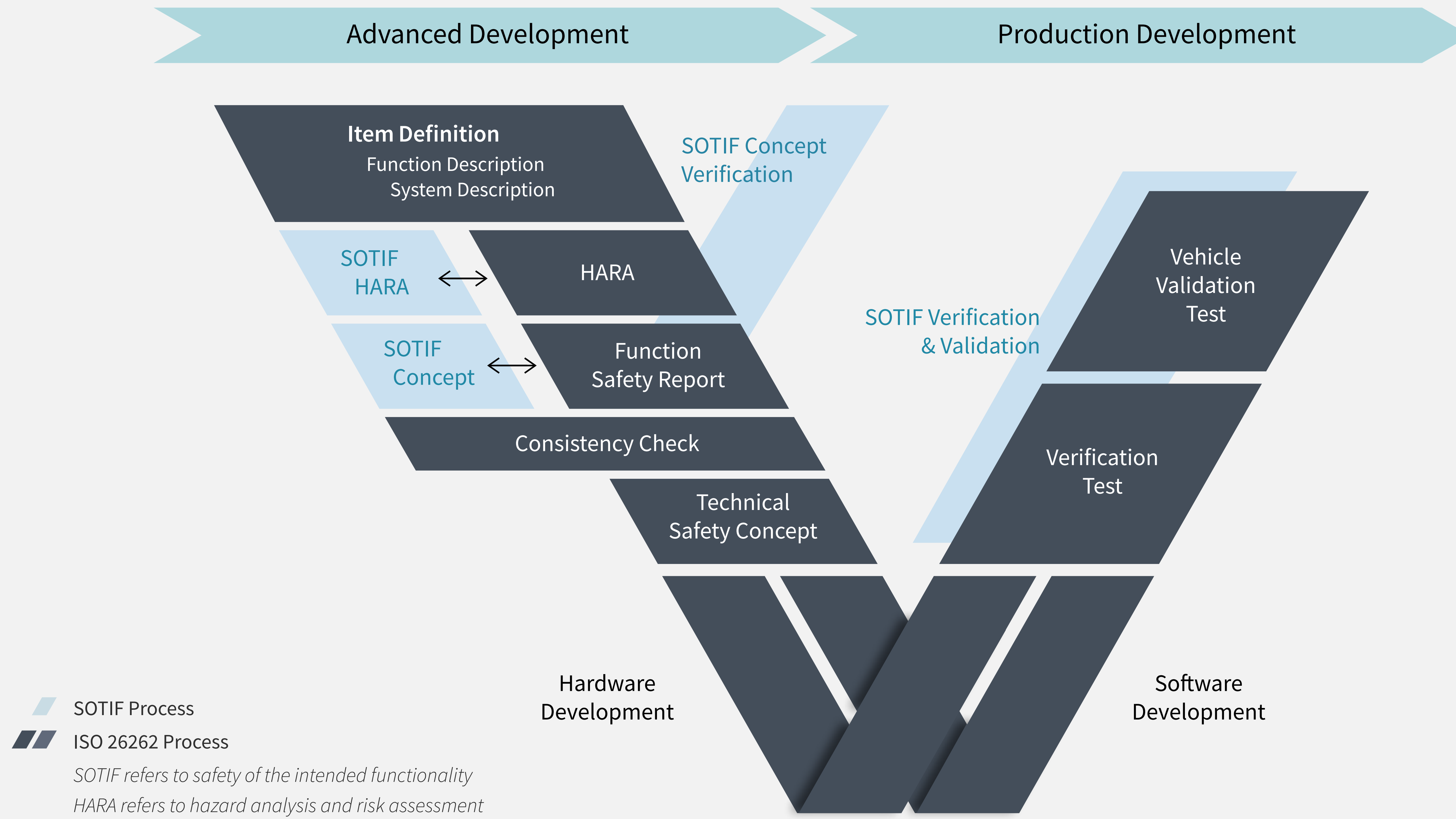
Random Failure
Safety Culture
Safety Management
Systematic Failures
...

Artificial Intelligence
Automated Driving System
False Positive
Performance Failure
...

Encryption
Firewall
Key Management
Threats Intelligence
...


CASCADIA

Ensuring Safety from Development to Production



Interaction between SOTIF and Functional Safety (Pegasus, n.d.; Mariani, 2017) [15, 16]

SAFETY WHILE IN DEVELOPMENT

Extensive testing on closed courses and on public roads is critically important in developing an ADS-operated vehicle. To ensure the highest level of safety, Torc established a safety process during the early phases of development and has adapted it to testing needs.

The goal of the system safety approach is to ensure that potential ADS malfunctions do not have implications at the vehicle level which have not been accounted for (e.g., risk assessment). Since the ADS itself is under development, the functional safety concept is based on two safety pillars and one functional pillar:

Torc's Functional Safety Concept

System Under Test
↓
Hazard Analysis
↓
Risk Assessment
↓
Safety Concept Test

Vehicle

The vehicle is developed according to safety processes.

- Vehicle and its Driver Assistance Systems based on Regular Production Processes
- IFTD Takeover
- Actuator and its Limitations based on Regular Production Processes and IFTD Qualifications

Safety Pillar 1

ADS

ADS development release process (i.e., the process required to release the next ADS version as the ADS evolves).

- Development Release Process

Functional Pillar 1

IFTD

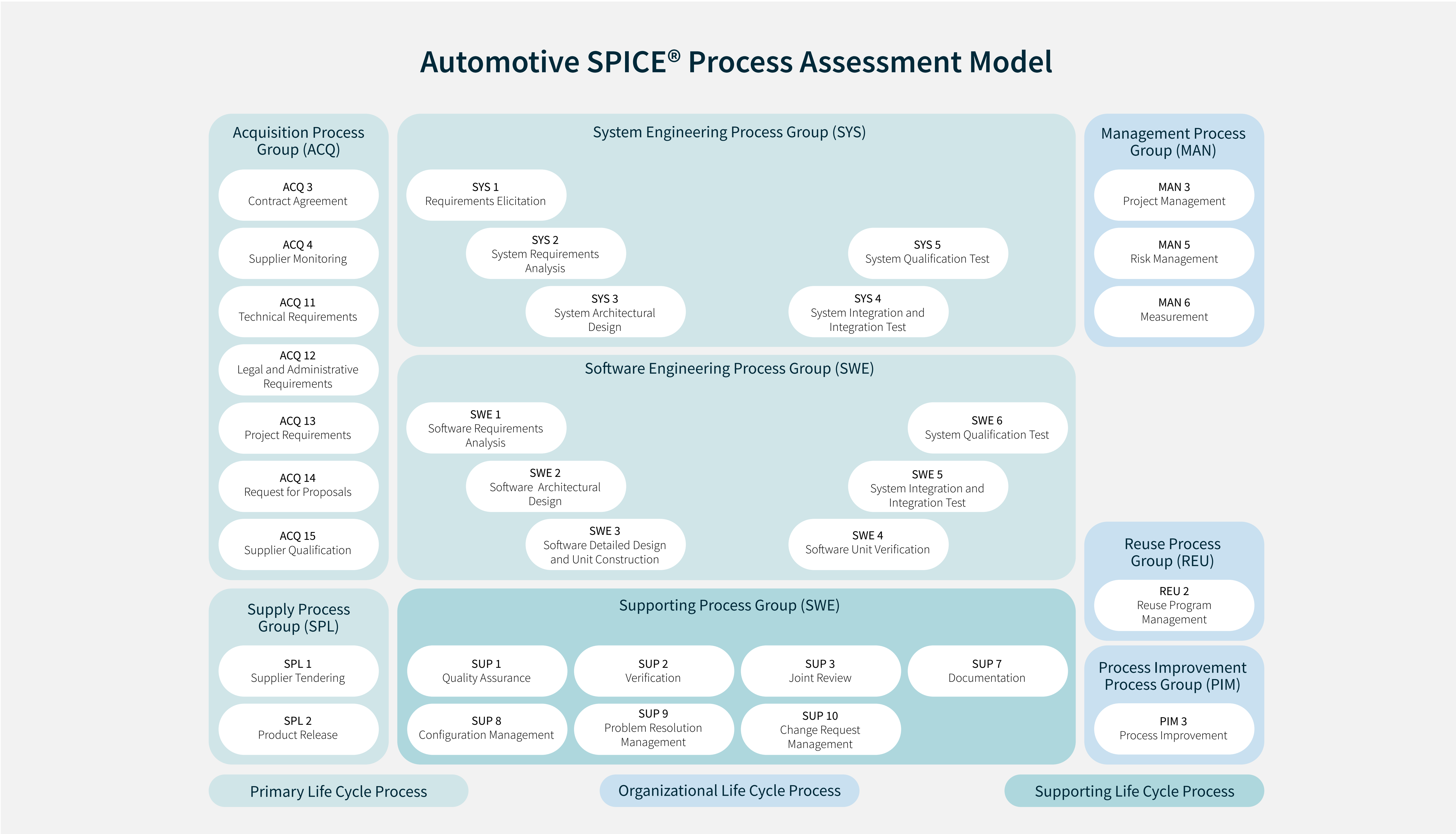
The IFTD supervises the ADS and can take over full control of the vehicle.

- Qualification
- Responsibilities
- Further Training

Safety Pillar 2

SAFETY IN PRODUCTION

To ensure the highest level of quality from the development of the ADS-operated truck to its production, we will implement a set of discrete steps, each designed to ensure the safety of the prototype being tested. The Automotive SPICE® Process Assessment Model will be implemented to assess software capabilities during the development of automotive systems in accordance with the requirements of international standards.[17]



Adapted from Automotive SPICE Process Reference Model Overview [17]

Safe Highway Driving

While Torc has demonstrated its software in a myriad of weather conditions and road types, we believe that the best, most efficient approach to commercialization is to first focus on developing our ADS system for structured long-haul highway routes in the U.S. to meet the most pressing needs for freight delivery.

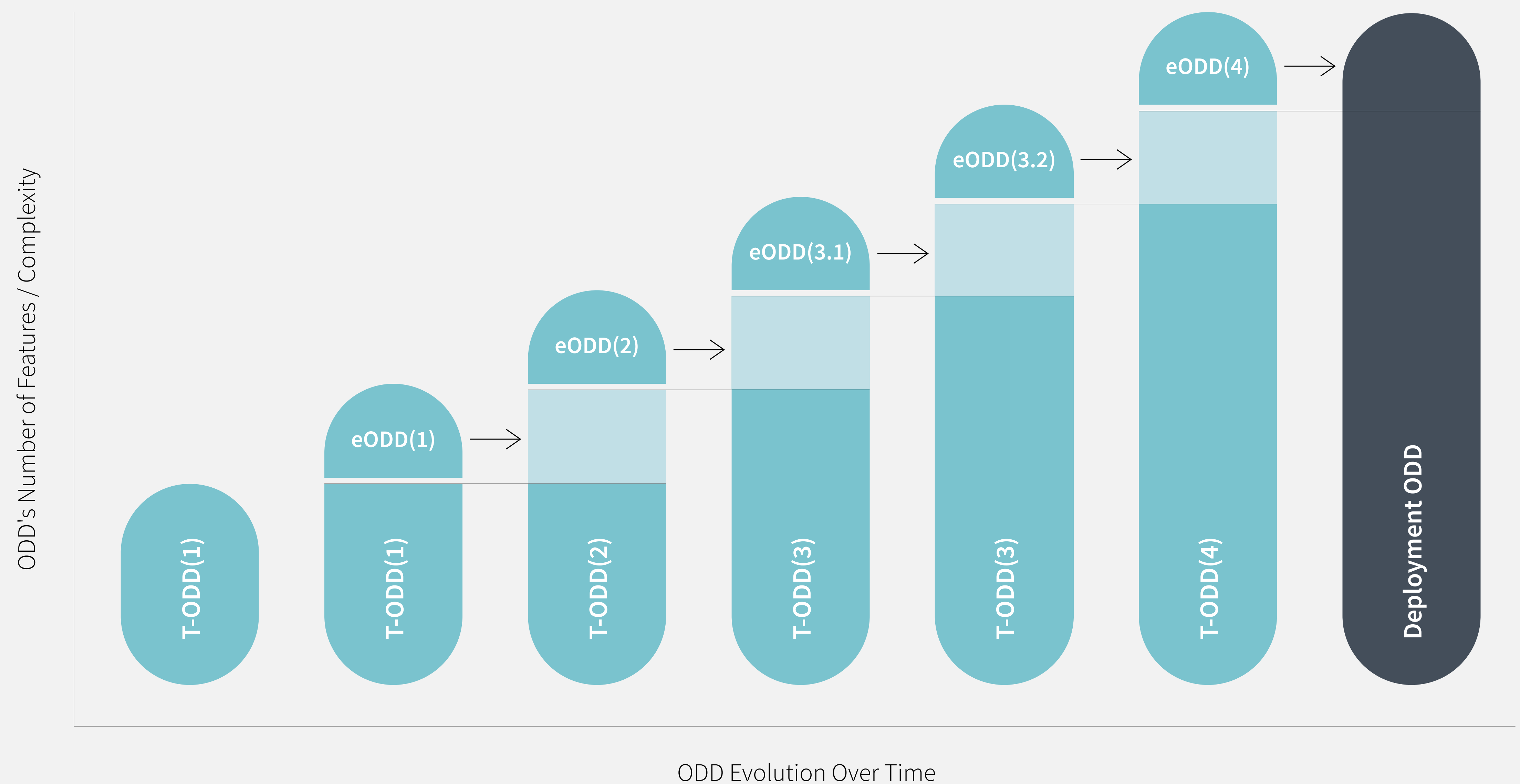
Safety Element 2: Operational Design Domain (ODD)

To understand the system capabilities and limitations as well as the relevant safety implications, the Operational Design Domain (ODD) needs to be clearly defined for the ADS-operated system. SAE defines the ODD as the "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics."[1] The ODD for our level 4 truck is characterized in the elements defined by the Automated Vehicle Safety Consortium.[18] The testing ODD (T-ODD) and ODD expansions (eODDs) are implemented via a stepwise evolution as the ADS evolves and as the testing results suggest the need for an eODD.

The T-ODD is currently focused on the following elements, although multiple eODDs are planned as part of the stepwise evolution process:

- **Route:** Highway operation for specific routes.
- **Environmental Conditions:** Mildly adverse weather factors related to light and moderate rain with winds up to category 6 on the Beaufort Wind Force scale.
- **Lighting Conditions**: Any type of lighting condition (e.g. daytime, nighttime, and overhead lighting).
- **Roadway Alignment and Profile**: Predetermined routes characterized by grade as well as horizontal and vertical curves that the ADS-operated vehicle is capable of navigating.

Operational Design Domain Evolution




#SENSINGWHATSAHEAD
FREIGHTLINER

Safety in Action:
See, Think, Act

All driving decisions can be broken down into the following actions:

- Perceiving and localizing: contextualizing the world around us and understanding where we are in it
- Thinking: calculating the best choice based on all known factors
- Acting: the actual behavior of navigating the environment.

Torc's ADS continually performs all three of these tasks in real time as the vehicle traverses the roadway. The ADS driver – like a human driver -- is able to detect and recognize a myriad of different objects (e.g., passenger vehicle, motorcycle) as well as events as they evolve (e.g., traffic decelerating, vehicle entering highway). Some of the events might even need responses tailored to the event characteristics, usually referred to as behavioral competencies, or the way the ADS is expected to act depending on the encountered situation.

Safety Element 3: Object and Event Detection and Response (OEDR)

Object and Event Detection and Response (OEDR) describes the various tasks that must be performed for the vehicle to operate in live-traffic conditions and includes monitoring the driving environment and responding to events and objects. Torc's ADS-operated vehicle complies with the relevant behavioral competencies suggested in NHTSA's *Automated Driving Systems 2.0: A Vision for Safety*.[2] We design the vehicle's OEDR capabilities by analyzing relevant scenarios the vehicle will encounter within its ODD, including both commonly and rarely encountered situations. How the vehicle handles any given traffic situation is determined by both traffic laws and by principles of safe and defensive driving. Torc will use a well-designed system of sensors, actuators, computing resources, and redundancies so that the vehicle responds appropriately, even in the case of a malfunction. Within the current evolution process of ADS development, an IFTD is always present in the vehicle to ensure safety redundancies during testing and validation. The various components responsible for the OEDR are described here in more detail.

OBJECT AND EVENT DETECTION

Sensing What's Ahead

Torc's ADS uses an innovative sensor suite to perceive and analyze relevant traffic and roadway conditions around the vehicle. Raw detection data from multiple asynchronous sensors (radar, lidar, and camera) are fused into a comprehensive view of the targets around the vehicle and their respective pose, kinematics, extension, and class. The ADS uses these targets and characteristics, which are re-evaluated and processed by algorithms in real time, to identify appropriate behaviors and plan the truck's motion.

Torc's use of overlapping sensors is critical to provide redundant perception capabilities because each type of sensor has strengths and limitations. For example:

- Lidar uses infrared light to develop a 3D image of the environment around the vehicle, which means it is not hampered by low-light conditions or bright reflective surfaces. Lidar can be used to define an object and its distance from the vehicle (e.g., a passenger vehicle in an adjacent lane).
- Cameras allow the ADS to identify signs or traffic control devices containing information that needs to be processed
- Radar provides important information about the speeds of other vehicles around the truck, especially in precipitation like rain, snow, or sleet, which can hamper other sensors.

In the event of a sensor failure, redundant perception will allow the ADS-operated vehicle to function appropriately. If the failure exceeds the capabilities provided by the existing sensor redundancy and fusion, the IFTD safety driver is present as a fallback. The interface between the IFTD and ADS provides an alert if the ADS disengages. Even if an alert is not generated, the IFTD is trained to take over the driving task as needed based on failure conditions.

Torc's ADS Sensor Suite

Lidar

Returns 3D detailed view of the environment
Performs regardless of ambient light

Radar

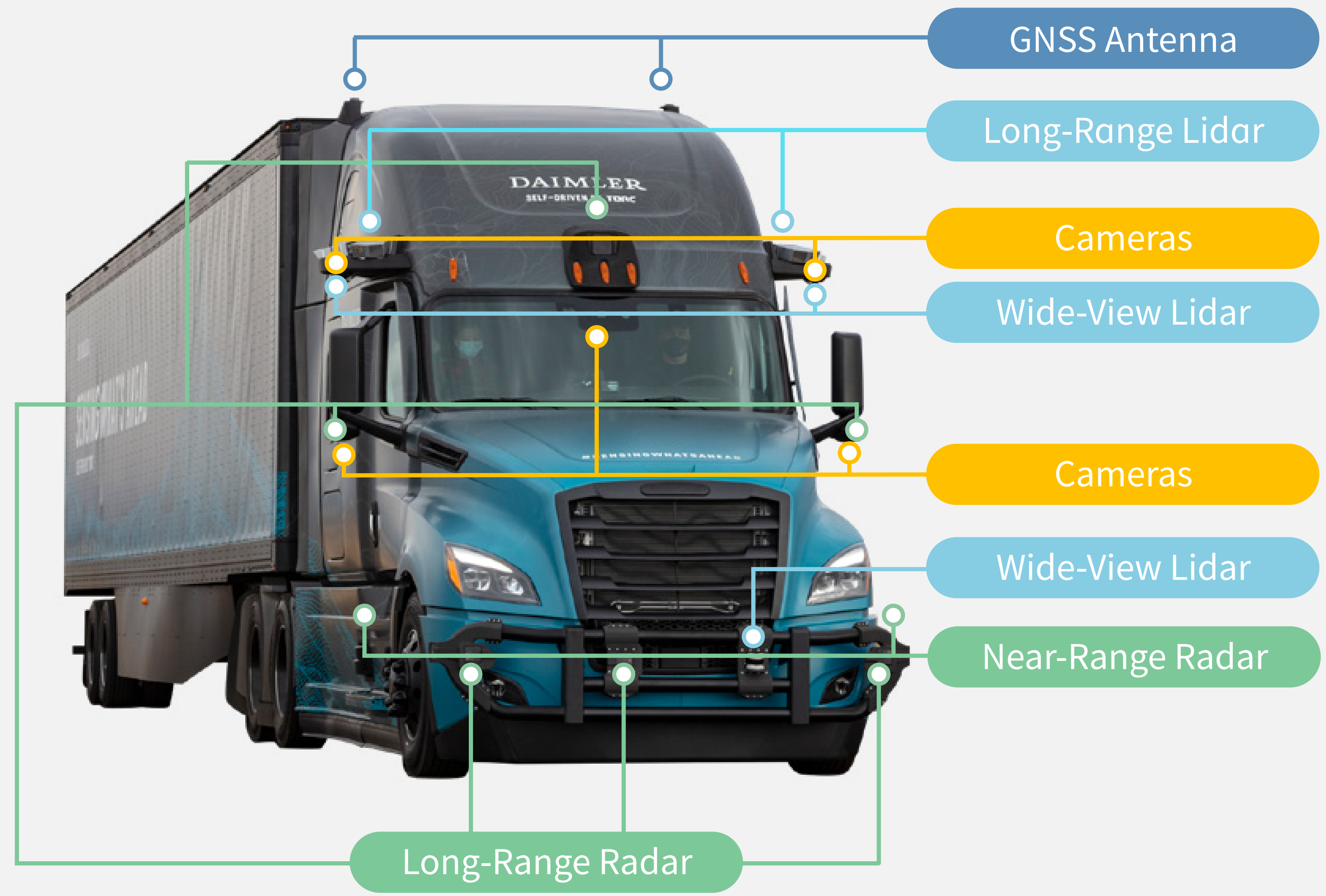
Tracks velocity and speed of objects around the vehicle
Offers strong performance in precipitation

Camera

Provides high-dynamic-range images with color information necessary for perceiving traffic control devices intended for human drivers

Positioning and Localization

Uses Global Navigation Satellite System (GNSS), inertial measurement unit, high-definition map features, and perception sensors to localize the vehicle



Design of the Sensor Setup

Torc has developed an optimized sensor array allowing the ADS to completely "see" around the vehicle. This optimization is extremely important, particularly because trucks usually present multiple known blind spots for the human driver. Under the current and planned evolutions of the sensor setup, which are designed to minimize these zones, the ADS provides a significant advantage over the human driver.

MAPPING AND LOCALIZATION

Similar to a human driver, the ADS uses integrated maps to understand where it is in the world in relation to driving lanes, drivable surfaces, road signs, etc. These maps are carefully crafted to produce the most accurate depiction of the surroundings and key objects of interest . The ADS-operated vehicle is then able to navigate using knowledge of where it is "in the map" (i.e., localization).

BEHAVIORS, PLANNING, AND CONTROLS

The ADS considers many factors that affect its decisions and actions while performing the driving task, such as where the vehicle is located with respect to other objects (e.g., other vehicles and pedestrians), roadway conditions, and its planned path. Based on all this information, the human driver would use the steering wheel and pedals to exert control over the vehicle and continue the intended path. The ADS accomplishes these subtasks through a set of three distinct but interrelated tactical and operational functions: behaviors, planning, and controls.

As different on-road behaviors are identified and engineered in the ADS software, the tasks that can be executed by the ADS expand, including interactions with different objects around the truck in different situations. For example, reacting to a speed limit change, changing lanes, or performing actions related to highway courtesy are considered ADS behaviors. As the ADS and its ODD evolve, data are collected as the ADS interacts with different situations and analyzed to ensure the appropriate behaviors are selected. This catalog of behaviors is developed and constantly refined, improved, and expanded.

The IFTD and Safety Conductors are critical in these verification and validation tasks. Although the ADS behaviors are executed digitally and extensively tested on closed test tracks, the real test is when the ADS-operated vehicle must select a particular action and interact with other components of the behavior catalog during real-world, public road operations. During this process, health checks are constantly conducted to ensure the driving task is appropriately executed. At the current stage of the ADS development and testing, the IFTD verifies that the driving task is performing as expected based on the current behaviors catalog, and the Safety Conductor annotates points in time that would merit review and potential refinement.

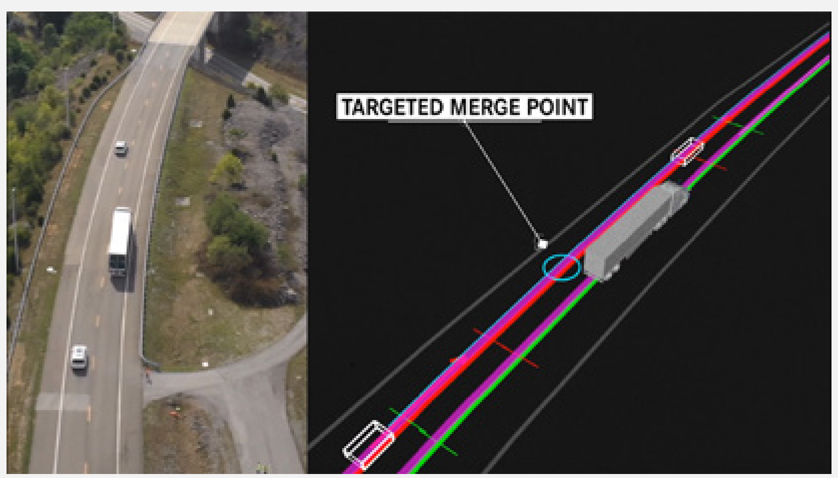
At the current stage, the ADS's operational functions related to the lateral and longitudinal portions of the driving task are planned considering aspects such as roadway characteristics, adjacent vehicle locations, and any other factors of relevance. These plans are implemented by the truck, which carries out the actual actions based on the behaviors selected and the planned testing. Many iterations and checks occur during this process. However, as a simplified example, consider an ADS that has identified that it is approaching an entry ramp on a highway and has sensed that a vehicle could be merging into its lane of travel. In this case, the ADS would "recall" several behaviors (e.g., lane change and highway courtesy) and "look" at adjacent traffic as well as traffic in front to decide if it should:

- decelerate and let the vehicle in the entry ramp pass;
- change lanes since a sufficient gap is available; or
- perform a combination of the first two behaviors.

This decision is communicated to the physical components of the vehicle to implement the appropriate operational functions (i.e., lateral and longitudinal functions) and perform the associated controls for the suggested behaviors and planning for the given scenario.

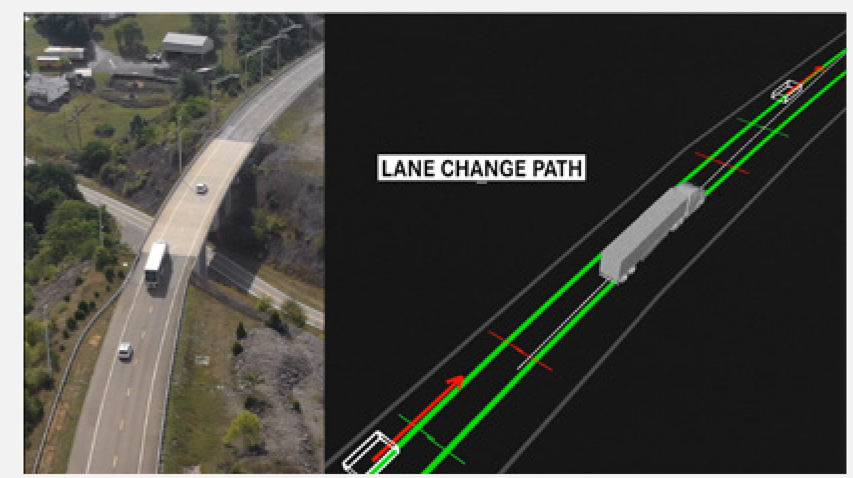
Example ADS responses to a vehicle merging into its lane of travel

1. Decelerate and let the vehicle in the entry ramp pass



2. Change lanes since a sufficient gap is available

3. Perform a combination of the first two behaviors



Safety Element 4: Fallback and Minimal Risk Condition

During the current development and testing process, the IFTD will be considered as the fallback. The goal of the next stage of the ADS (production-ready) is to not require the presence of an IFTD.

Even after the production-ready point, the ADS could potentially malfunction due to subsystems failure, which might cause the ADS-operated vehicle to operate in a degraded state (limp mode) or cause the ADS to cease operation. At that point, the IFTD will not be present. For an SAE level 4 ADS-operated vehicle, the minimal risk maneuvers will ensure the ADS-operated system can recover from potential malfunctions, degraded states, and/or the departure of the ADS from its ODD. As the maneuvers are developed, they will be formally documented, tested, and validated. Each update that could potentially affect the outcome will be tested and evaluated to ensure the minimal risk condition is successfully achieved.

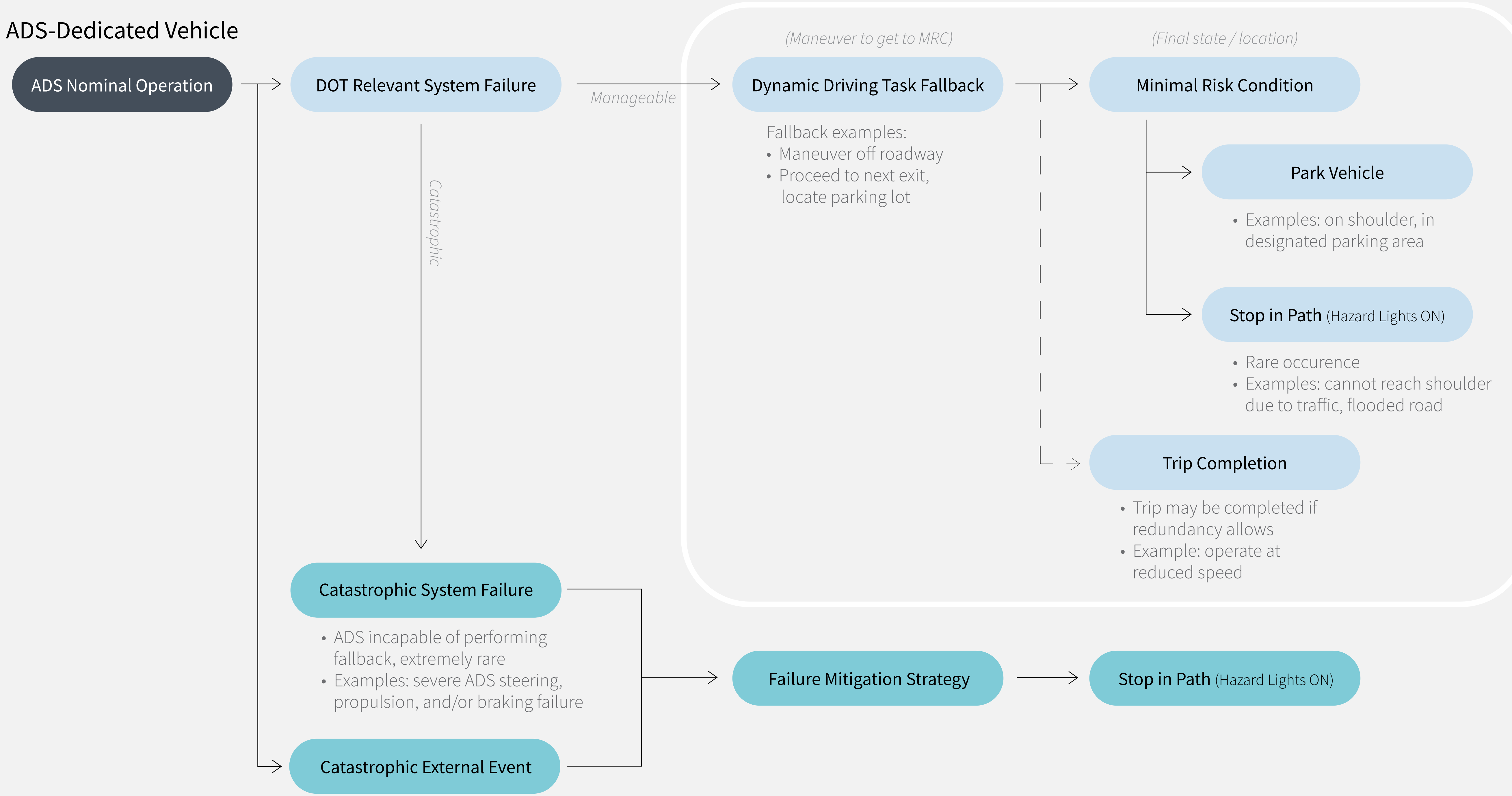
The minimal risk condition can be divided into two broad categories:[19]

1. Parked vehicle. The ADS cannot perform the driving task sufficiently to complete the trip but has enough operability (i.e., steering, braking, propulsion, and OEDR capability) to exit the driving lane and park the vehicle.

2. Stop-in-path. While the ADS is unable to complete the trip or exit the driving lane to park the vehicle (e.g., because of vehicle or environmental conditions such as flooding or a broken axle), the ADS is able to perform a controlled stop in its current lane of travel.

Torc is currently developing and testing these two categories of minimal risk condition. The diagram on the following page depicts the possible outcomes in the event that nominal ADS operation is interrupted. Note that a stop-in-path condition can result either from ADS fallback leading to minimal risk condition achievement or a failed mitigation strategy in the event that the ADS has been incapacitated (e.g., loss of backup power to the ADS after an initial power failure) and is thus unable to achieve a minimal risk condition.

Minimal Risk Condition Procedure



Adapted from CAMP's ADS Failures and Stopping Procedures [19]


AUTONOMOUS
SENSING WHAT'S AHEAD
DAIMLER
SELF-DRIVEN BY TORC
DAIMLER


Daily Vehicle Inspection Checklist
Class A Vehicles

Training the ADS Driver

Safety Element 5: Validation Methods

To perform the necessary validation tests on public roads, Torc follows a rigorous process to evolve software and hardware in a systematic manner for unit testing, component testing, software integration testing, system verification integration testing, and system validation. The plans for each of these steps relate back to their design counterparts and delineate the tests that are performed to ensure each individual software component meets the requirements. Currently, the focus of the ADS evolution is ensuring safe testing steps are taken:

Unit Testing

White-box tests to verify that software meets the functional requirements. These tests support the development process by quickly identifying any functional issues at the unit level.

Component Testing

Black-box tests that verify the software meets the functional requirements and interface specifications independent of the functionality of other components. These tests typically require component-specific simulators or custom evaluation tools.

Software Integration Testing

Closed-loop simulations and open-loop regression tests to verify that the software components communicate with each other properly and the configurations are appropriate for the target application.

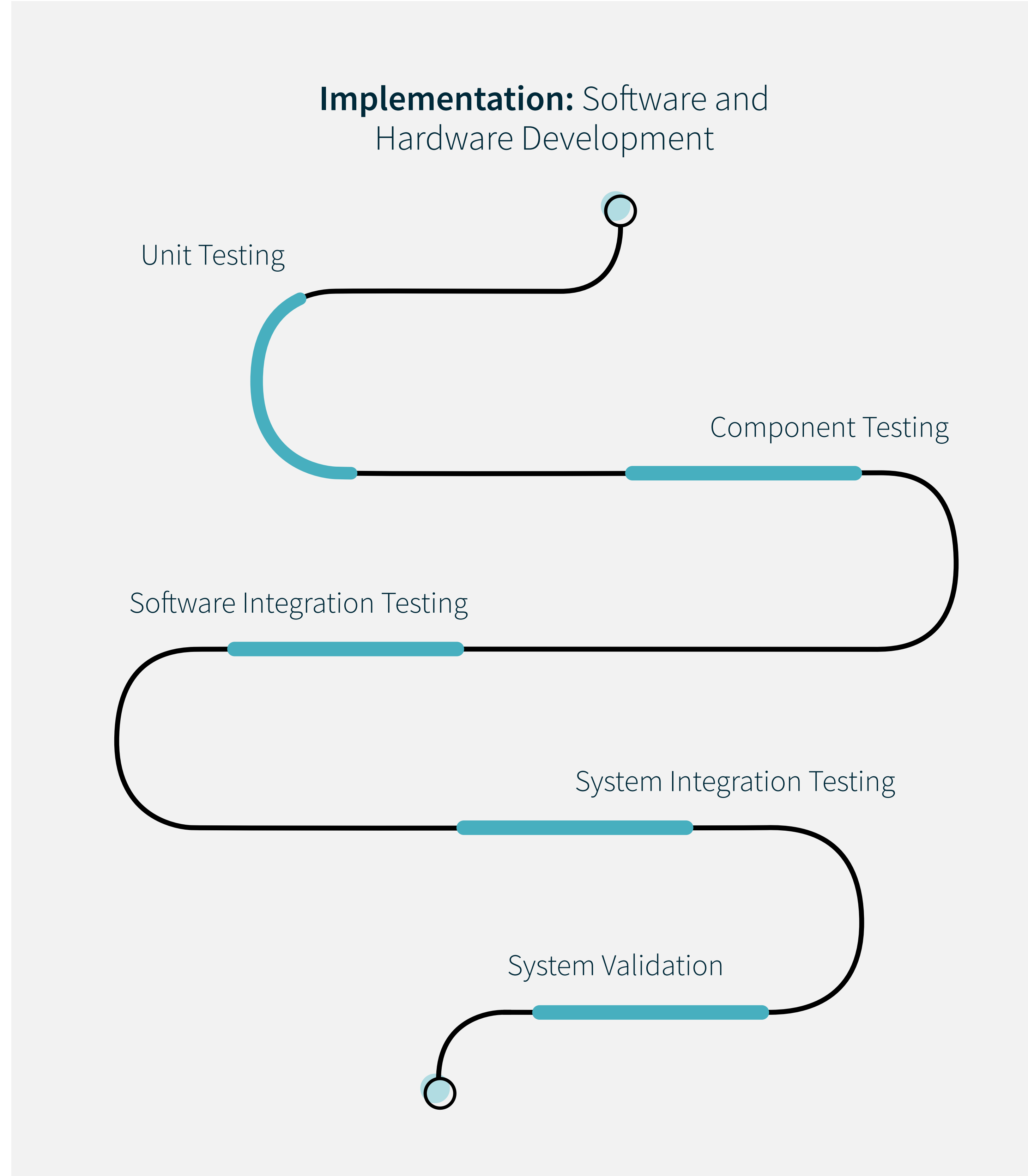
System Integration Testing

A combination of simulation-in-the-loop, closed-course, and limited on-road testing to ensure compatibility between the software, hardware, and base vehicle and verify their performance in real-world situations.

System Validation

A comprehensive system validation with a fleet of ADS-operated trucks under regular day-to-day operations in which the vehicles exercise all elements of the ODD. These on-road tests will drive the refinement of system specifications and identify any additional needs for closed-course or simulation test cases.

Current assessment, which occurs through simulation along with closed-course and on-road testing, is helping build the library of tests that will be used for a final validation. New software will only be released after proper validation through simulation and public road testing.



Safety Element 6: Human Machine Interface (HMI)

Torc's design intent is a level 4 truck that operates between designated highway locations. As mentioned, a human IFTD is involved during the current stage of verification. As with any software system, the human machine interface (HMI) is a critical component for Torc's process because it serves as the direct link between the IFTD and ADS status.

The HMI for the IFTD is simple to minimize distractions and is focused on showing ADS status (i.e., not available, not engaged, engaged). If the ADS transitions from engaged to not engaged or vice versa, the HMI issues an auditory component to emphasize the transition. The HMI also allows the IFTD to disengage the ADS by using the brake or accelerator pedals, manually turning the steering wheel, or depressing the disengage button.

For external communication, the external lighting signals that are commonly used in conventional vehicles (e.g., turn signals and vehicular hazard warning signals) are used and recognized by both the ADS and the IFTD. Detailed information about ADS malfunctioning is housed in the Safety Conductor testing unit interface; to minimize distraction, this information is not presented to the IFTD.


FREIGHTLINER


DAIMLER
SELF-DRIVEN BY TORC
#SENSINGWHATSAHEAD
DAIMLER
TORC
DAIMLER
TORC
DAIMLER
TORC
ANIKA
WHEELER

Beyond Testing

Safety Element 7: Crashworthiness

The base vehicle used for the ADS-operated truck will include manually operated driving controls similar to existent production vehicles. Thus, the base vehicle will have dual operation capability (i.e., capable of both manual driving and ADS-operated driving). Therefore, all current occupant protection, safety standards, and regulations applicable to a Class 8 vehicle will also be part of the ADS-operated vehicle crashworthiness.

Safety Element 8: Post-Crash ADS Behavior

Torc has an appropriate post-crash procedure that includes measures based on a truck self-assessment as well as the deployment of other vehicles to assist in roadway. The IFTD and Safety Conductor undergo extensive in-classroom training and live exercises on incident and emergency response procedures for multiple scenarios. This training involves assisting first responders with information needed about the ADS-operated truck and appropriate interaction with the public. During current testing situations, in the event of a crash, a supervisor may request the IFTD to perform an assessment of the drivability of the vehicle and initiate necessary steps to retrieve the vehicle and testing personnel, while the Safety Conductor will alert emergency services if required.


TORC
TORC
ThinkPad

Data Safety

Safety Element 9: Vehicle Cybersecurity

Torc's primary goal is to provide the absolute safest vehicle possible, including security against the very real threat of interference and manipulation by malicious cyber-attacks. Cybersecurity is an essential component of maintaining control of the vehicle for the safety of its passengers and other traffic participants. Torc follows a defense-in-depth approach to reduce security-related risks and defend against cyber-attacks, incorporating guidance from NHTSA's *Cybersecurity Best Practices for Modern Vehicles*,[20] ISO/SAE DIS 21434,[13] and ISO/IEC 27001:2013.[21] In addition, we will incorporate standards such as Automotive SPICE[17] and ISO/IEC 33020:2019[22] to provide guidance for good software development processes supporting cybersecurity.

Cybersecurity begins with a comprehensive information security management system, which incorporates a risk-based approach to the implementation of technical and organizational controls protecting its facilities, personnel, vehicles, components, source code, design artifacts, development pipeline, and log data. These cybersecurity practices are applicable to all phases of the engineering process and integrated into the validation and verification processes. Thus, cybersecurity protections encompass the entire safety path for the base vehicle platform, ADS, and over-the-air service software.

Safety Element 10:
Data Recording

All ADS-operated trucks are equipped with multiple sources of data logging. For the purposes of reliability and resilience, the Torc data logger employs a redundant video platform and solid-state data storage. The video platform is always on to ensure visual sensor data are always available. By design, the vehicle will actively collect and record the full ADS dataset before it is able to engage the ADS. The designed ADS data logger is based on SAE J3197[23] as well as Automated Vehicle Safety Consortium best practices.[24] The objective is to be able to recreate aspects of vehicle control (i.e., what the ADS did), saliency (i.e., what the ADS thought was important), sensing (i.e., what the sensors saw), and general parameters of interest for proper crash reconstruction.


DAIMLER
DAIMLER
SENSING WHAT'S AHEAD
SELF-DRIVEN BY TORC

Our Commitment to a Safer Society

In the past century, trucks have served as catalysts to evolve the way we do business, deliver goods, build our homes, and grow. Torc works with our customers and partners to deliver the next level of efficiency and productivity to their businesses. However, our commitment extends beyond a single group to society as a whole: we strive to provide a safer solution for the millions of people on our roads every day.

Important to that commitment is inviting everyone to join our journey to develop technical advancements. Torc is committed to listening and establishing strong partnerships not only with customers but also with those who create and enforce policy around ADS-operated vehicles.

Safety Element 11: Consumer Education and Training

Automated vehicles are the subject of intense scrutiny from the public and the media, and Torc is committed to being a thought leader and innovator in helping to educate on the value and the benefits of autonomous trucking.

Torc also participates in a variety of associations, partnerships, and organizations that help further education and advocacy regarding automated vehicles. Torc's partners include the American Trucking Associations, Partners for Automated Vehicle Education, and various local, state, and federal organizations to whom we offer our expertise as leaders and pioneers in this industry.

Training and education for participating fleets is outside of the scope of this version of the document but will be included in the future. The transition from product development to validation with revenue-producing fleets will be carefully pursued in collaboration with the fleets adopting the field-operational test program as a key component of educating and training the field. Torc's test program will include a detailed training curriculum that provides information about Torc's level 4 truck, the ADS, and other vehicle and system features available as they are integrated into the fleet's operation. Torc is currently focused on the training needed for verification stages and IFTD training described in previous sections.

Safety Element 12: Federal, State, and Local Laws

Maintaining good standing, continuous conversation, and transparency regarding testing activities with local governmental bodies is of utmost concern and importance to Torc. Prior to performing any testing or data collection, we share the necessary information and timing to all pertinent regulatory bodies.


DAIMLER
SELF-DRIVEN BY TORC
DAIMLER
YAJH663

Our Journey Forward

This Voluntary Safety Self-Assessment presents the methods and procedures that Torc has implemented for the safe development, testing, and validation in our work towards safer roads and saving lives with level 4 trucks.

We are committed to the safety of our colleagues conducting the testing and validation as well as all other road users. We hope that the information presented herein clearly demonstrates this commitment to safety.

Torc general contact information:
Website: torc.ai
Media inquiries: press@torc.ai

Acronyms & References

ADS	Automated Driving System
AVMO	ADS-equipped Vehicle Manual Operator
eODD	Operational Design Domain Expansions
HMI	Human Machine Interface
IFTD	In-vehicle Fallback Test Driver
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
T-ODD	Testing Operational Design Domain
USDOT	United States Department of Transportation

1 SAE International (2018). *Taxonomy and Definitions for Terms Related to on-Road Motor Vehicle Automated Driving Systems* (J3016_202104). Retrieved from: https://doi.org/10.4271/J3016_201806

2 NHTSA (2017). *Automated Driving Systems 2.0: A Vision for Safety.* Retrieved from: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

3 American Trucking Associations (2020). *Economics and Industry Data*. Retrieved from: https://www.trucking.org/economics-and-industry-data

4 Bureau of Transportation Statistics (2020). *Growth in the Nation's Freight Shipments - Highlights*. Retrieved from: https://www.bts.gov/archive/publications/freight_shipments_in_america/growth_in_the_nations_freight_shipments

5 FreightWaves (2020). *2020 closes with plenty (of freight) left in the tank.* Retrieved from: https://www.freightwaves.com/news/2020-closes-with-plenty-of-freight-left-in-the-tank

6 Federal Highway Administration (2020). *Highway Statistics 2019.* Table HM-18. Retrieved from: https://www.fhwa.dot.gov/policyinformation/statistics/2019/hm18.cfm

7 Bureau of Transportation Statistics (2018). *Freight Facts and Figures 2017.* Retrieved from: https://www.bts.dot.gov/sites/bts.dot.gov/files/docs/FFF_2017_Full_June2018revision.pdf

8 United States Department of Agriculture (2010). *Study of Rural Transportation Issues.* Retrieved from: https://www.ams.usda.gov/sites/default/files/media/RTIFullReport.pdf

9 Morrow, S., and Coplen, M. (2017). *Safety Culture: A Significant Influence on Safety in Transportation* (DOT/FRA/OR-17/09). USDOT: Washington, DC.

10 NTSB (2013). *Safety Culture: Enhancing Transportation Safety*. Retrieved from: https://www.ntsb.gov/news/events/Pages/2013_Safety_Culture_FRM-Presentations.aspx

11 ISO (2018, December). *Road vehicles — Functional safety — Part 1: Vocabulary.* (ISO 26262-1:2018). Retrieved from: https://www.iso.org/standard/68383.html

12 ISO/PAS (2019, January). *Road vehicles — Safety of the intended functionality.* (ISO/PAS 21448:2019). Retrieved from: https://www.iso.org/standard/70939.html

13 ISO/SAE. (2020, February). *Road Vehicles - Cybersecurity Engineering*. (ISO/SAE DIS 21434). Retrieved from: https://www.iso.org/standard/70918.html

14 ISO/TR (2020, December). *Road Vehicles — Safety and cybersecurity for automated driving systems — Design, verification and validation.* (ISO/TR 4804:2020). https://www.iso.org/standard/80363.html

15 Mariani, R. (2017). *An Industry (And Standardization) Perspective: Can We Trust Autonomous Systems?* Retrieved from: http://www.icri-sc.org/fileadmin/user_upload/Group_VCI/Events/Kickoff_2017/Mariani_Intel_ICRI-CARS_kickoff_v1.pdf

16 Pegasus (n.d.). *Social Acceptance of HAD*. Retrieved from: https://www.pegasusprojekt.de/files/tmpl/Pegasus-Abschlussveranstaltung/11_Social_Acceptance.pdf

17 VDA QMC Working Group 13 (2017). *Automotive SPICE Process Assessment / Reference Model, Version 3.1.* Retrieved from: http://www.automotivespice.com/fileadmin/software-download/AutomotiveSPICE_PAM_31.pdf

18 AVSC (2021). *Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon.* AVSC00002202004. Retrieved from: https://avsc.sae-itc.org/principles-02-5471WV-44074RU.html?respondentID=26884177#our-work

19 Automated Driving Behavior Consortium (2019). *Minimal Risk Condition Behaviors.* Retrieved from: https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2019/07/Minimal-Risk-Condition-Behaviors-June-2019-FINAL.pdf

20 National Highway Traffic Safety Administration. (2016, October). *Cybersecurity best practices for modern vehicles.* (Report No. DOT HS 812 333). Washington, DC. Retrieved from: https://www.nhtsa.gov/staticfiles/nvs/pdf/812333_CybersecurityForModernVehicles.pdf

21 ISO/IEC. (2013, October). *Information technology – Security techniques – Information security management systems – Requirements.* (ISO/IEC 27001:2013). Retrieved from: https://www.iso.org/standard/54534.html

22 ISO/IEC. (2019, November). *Information technology — Process assessment — Process measurement framework for assessment of process capability.* (ISO/IEC 330 20:2019). Retrieved from: https://www.iso.org/standard/78526.html

23 SAE (2020, April). *Automated Driving System Data Logger.* (SAE J3197_202004). Retrieved from: https://www.sae.org/standards/content/j3197_202004/

24 SAE (2020, September). *Automated Vehicle Safety Consortium Best Practice for Data Collection for Automated Driving System-Dedicated Vehicles (ADS-DVs) to Support Event Analysis.* (SAE AVSC00004202009). Retrieved from: https://www.sae.org/standards/content/avsc00004202009/

TORC


DAIMLER
SENSING WHAT'S AHEAD
SELF-DRIVEN BY TORC
AUTONOMOUS
(AU-TON-O-MOUS)
ADVANCING TRANSPORTATION SAFETY, SUSTAINABILITY, AND EFFICIENCY FOR ALL WHO KEEP THE WORLD MOVING
#SENSINGWHATSAHEAD
AT06
DAIMLER
SELF-DRIVEN BY TORC
Great Dane