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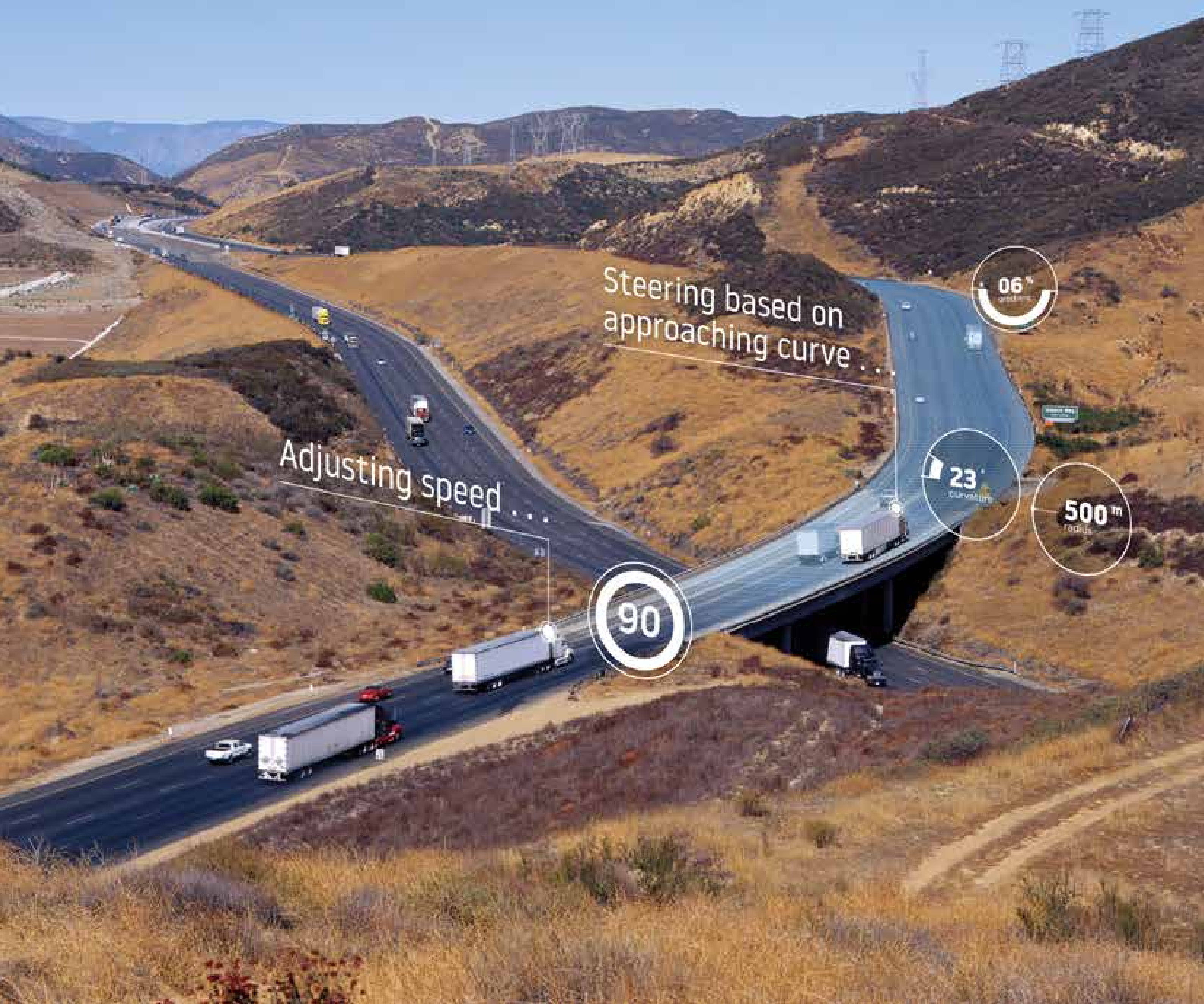
Elektrobit

Extending the vision of automated vehicles with HD Maps and ADASIS



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Automated driving and its use cases

Automated driving is not a future vision, but a reality today. Level 2 automation as defined by the Society of Automotive Engineers (SAE International) is ubiquitous and can be found in many advanced driver assistance systems (ADAS) such as traffic jam assistants, efficiency or emergency assistants. In higher-end cars, first implementations of Level 3 are already in the market and mostly waiting for the legal foundation to be put into practice. Level 4 and Level 5 are still limited to test projects on closely constrained roads and environments, but developers are actively working on their deployment as well.

Benefits of ADAS and HD Maps

Starting already with Level 1 ADAS functions such as adaptive cruise control (ACC), the corresponding systems often rely on digital map data which are highly specialized and surpass the navigable maps used in GPS satnav systems in aspects such as resolution, level of detail, and depth of information. When it comes to ADAS and AD, the requirements which map data has to fulfill are much higher and much more distinct than providing road geometry, labeling, and attributes. Therefore, there are specialized maps available focused to the use in ADAS functions, which can be labeled as "ADAS Maps".

However, even these specialized "ADAS Maps" have their limitations when it comes to Level 2 or even Level 3 driving automation functions. For such systems, an even more precise and detailed generation of digital maps is necessary. They are commonly referred to as high-definition (HD) maps.

ADAS and AD systems based on high-definition maps will also profoundly increase the safety of the car and its passengers, actively assisting the driver in challenging situations, such as heavy rain or snow fall.

ADAS Maps can be deployed standalone or as part of navigation maps, and prove accuracy of several meters. HD Maps narrow this accuracy even further to resolutions of only a few centimeters and furthermore provide a high degree of attribution. For example, they include detailed information such as road network mode, lane-level information, localization objects, traffic signs, road furniture, and lane geometry. HD Maps enable automated and autonomous vehicles to become location-aware, environment-aware and path-aware.

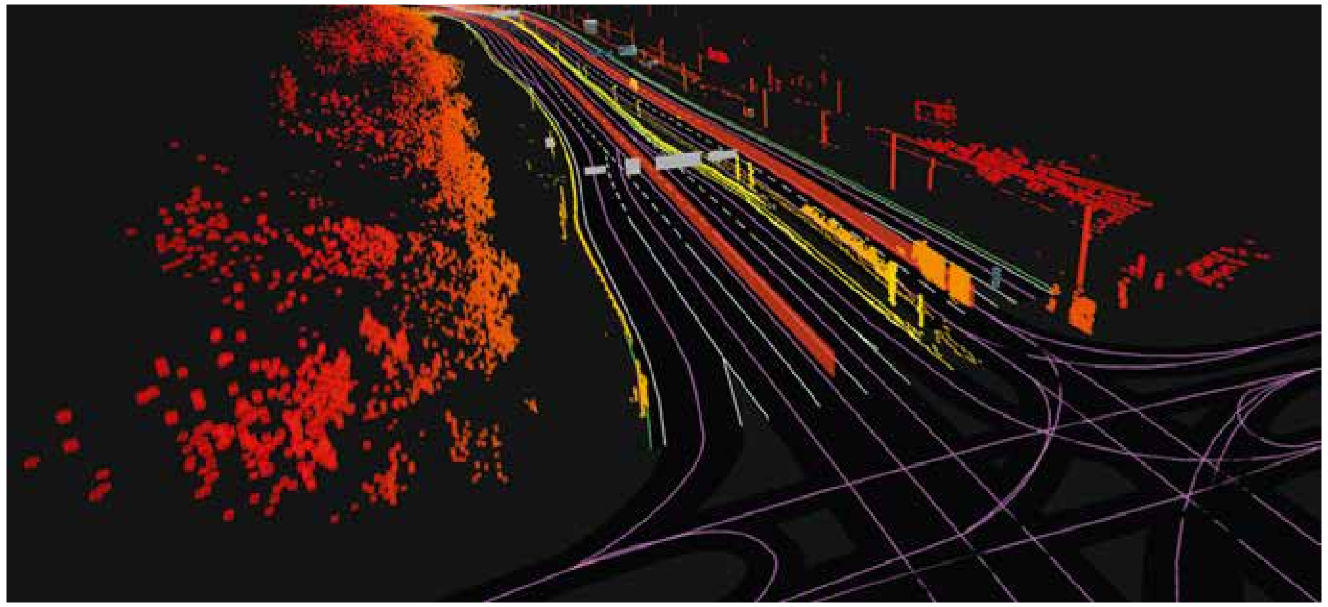

Figure 1: TomTom High Definition (HD) Map

These are the three main fields of application for TomTom HD Maps:

Localization:
GPS is only accurate down to a few meters and suffers from poor reception in tunnels and urban canyons, where accuracy can drop to tens of meters. In contrast, for automated and autonomous driving a vehicle must determine its position relative to its surroundings. To precisely position itself, the vehicle has to correlate HD Map data with the data obtained by its sensors in real time, resulting in a highly precise lateral and longitudinal position. This accurate localization allows a vehicle driving in ADAS/AD mode to keep a comfortable distance to road barriers, for example, in curves, increasing the reliability and safety of the function and thus also raising the comfort of the driver.

Environment perception:
Cameras, radars, laser/LiDAR, and ultrasonic sensors enable a vehicle to perceive the environment around itself, including other vehicles, pedestrians, traffic signs, objects on the road, and lane markings. However, the car's systems need to put the identified environmental elements into the right context. For example, in dense urban environments or on extensive highway crossings, a car needs to know which lane it is driving on. Equally, on an intersection with multiple traffic lights, an HD Map can help the vehicle's sensors to correctly identify the relevant traffic light for the lane the car is traveling on.

Path planning:
Automated vehicles need to be able to plan their path at a very granular level, anticipating maneuvers across lanes. Relying only on the vehicle's limited sensor rage can lead to inefficient path planning, as a vehicle might frequently change lanes to stick to the intended direction of travel. An HD Map helps improve path planning for automated vehicles by providing a longer horizon to the path planning entity. Thus again, the use of high-definition maps in ADAS and AD systems aims at increasing the safety of vehicle operation and increasing the trust that the driver puts into these systems.

A common application is also whitelisting roads that a system has tested and approved. This approach allows a functional-safety-aware approach to introducing Level 3 and higher systems into the marketplace.

Actually, maps can be comprehended as an addition the to the car's sensors. With the help of map data, a car's systems can anticipate the road ahead, far beyond the vehicle's sensor range. Especially when traveling at high speeds, such as on highways, having a sensor range of just a few hundred meters or having their sensors blocked by large vehicles such as trucks may not be sufficient for a safe and comfortable experience. An "HD Map horizon" enables the vehicle to anticipate the road ahead and can even "see around corners" or compensate for poor visibility, for example, in rainy or foggy weather conditions. Moreover, this extended horizon can support more successful strategies, for example, in efficiency assistants.

Furthermore, map data can also leverage safety and convenience features which OEMs can use for differentiation, such as predictive curve light systems, NCAP-targeted car safety systems, or advanced climate control.

In order to enable the described applications, HD Maps do not only have to be highly accurate, but also absolutely up to date. When traffic signs are added and removed or lane markings are altered, HD Maps need to reflect these changes quickly.

TomTom's maps portfolio for ADAS and AD

As a world-wide renowned specialist for digital maps, TomTom has been fueling this development for some time. The company was the first to introduce HD Maps in 2015 and was the first digital map provider to offer HD Map coverage across Europe, North America, and Asia. Over one million vehicles belonging to SAE's Level 1 and 2 equipped with TomTom's specific ADAS and HD Maps are already on the road today – both private and commercial. Also, TomTom ADAS Map can help car makers to achieve higher Euro NCAP ratings.

To address the localization challenges of ADAS and AD as described before, TomTom developed RoadDNA – a set of localization layers in the TomTom HD Map that enables accurate and precise localization for autonomous vehicles supporting a variety of sensor architectures.

TomTom's RoadDNA suite includes information about traffic signs, complementing camera sensors, a highly optimized point cloud of LiDAR roadside patterns, a model in individual lane markings in order to support cameras, a layer of reflection points where radar signals hit, LiDAR data describing the reflectivity of the road

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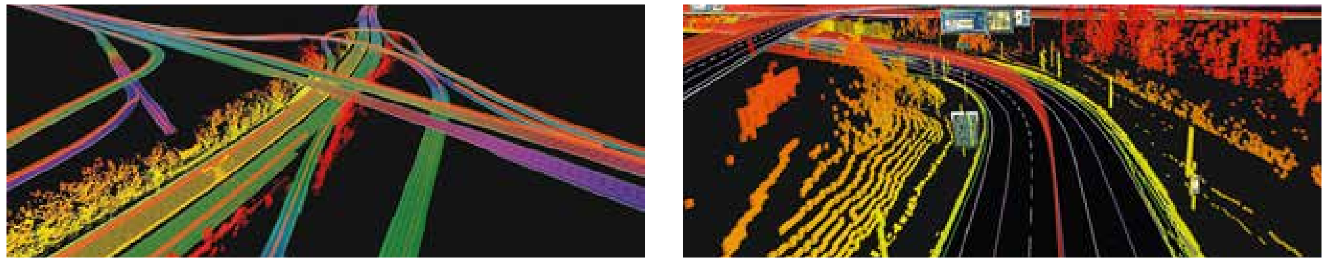

Figure 2: Visualization of HD Map, RoadDNA-RoadSide and RoadDNA-Signs in the TomTom HD Map

surface as well as a collection of vertical poles along the side of the road, working with all sensors.

By offering this broad suite of localization data, TomTom's RoadDNA gives car makers the freedom to use different sensors and different localization techniques, achieving precise localization in a storage-friendly and processing-friendly format.

Building, maintaining, and delivering HD Maps

TomTom is going to great lengths in order to offer the precise and reliable HD Map data which the car industry needs for the reasons explained before.

For HD Map making, TomTom is leveraging a combination of automated data fusion tools, a fleet of intelligent mobile mapping vehicles equipped with state-of-the-art mapping sensors, and its transactional map making platform which can efficiently process large volumes of data an update the map database in almost real-time. This platform enables TomTom to update and maintain a map database in an always "releasable" state.

Depending on the use case and desired function, the customer can decide what data to use. For example, TomTom's HD Map can be chosen to power a Highway Pilot system, while the system uses the TomTom ADAS Map for Predictive Powertrain Control and SD map for navigation functions. For delivering the map data to the vehicle, TomTom offers three different approaches: Map Content API, NDS, and AutoStream.

The Map Content API is an API that enables car makers to have TomTom map data delivered directly from the TomTom cloud to their own clouds.
This allows customers to query the data as needed and enables them to compile it into the format of their choice.

TomTom can also deliver its HD Maps and SD maps in NDS (Navigation Data Standard) format, allowing customers to have a full map on-board, in a standard format.

TomTom AutoStream automatically streams the latest map data from the TomTom cloud to the car. AutoStream comprises an online map data service and an on-board software client with smart logic, which significantly simplifies and shortens development time for companies building autonomous driving systems. TomTom AutoStream allows customers to adapt the map data stream to their needs, based on e.g. sensor data or horizon length. It can stream ADAS Map features such as road gradient and curvature, and HD map features such as detailed lane level geometries. AutoStream provides a map access API and ensures the ADAS/AD system always has the latest map data to power advanced driving applications.

How to keep these maps up to date: Connected cars themselves contribute to the correctness and reliability of map data by sending selected sensor perceptions as so-called "Roadagrams" back to the TomTom cloud. TomTom partners with sensor vendors such as Denso and Hella Aglaia for this. Here, they are evaluated, interpreted, and combined with various other sources such as government data, stationary roadside sensors, or the results of targeted mapping vehicle surveys. TomTom has already completed several proof of concepts with partners where they update the TomTom HD Map with data from Roadagrams.
Thus, TomTom offers and operates a whole ecosystem of map-making and map-delivering solutions in order to deliver the necessary resources for advanced driver assistance systems and automated driving.

ADASIS – a specification for vehicle-wide map distribution

TomTom and Elektrobit jointly implement first ADASIS application of HD Maps

TomTom and Elektrobit signed a partnership agreement in 2017 and have since been closely cooperating, following multiple development tracks in parallel. Their main goal is to jointly define and develop an HD Map horizon, to facilitate reference implementations accordingly and to bring them to mass production.
As a protocol and interface specification for these implementations, they have selected the ADASIS (Advanced Driver Assistance Systems Interface Specification) standard. As ADASIS v3 they also work on a stand-alone ADASIS v2 provider that is independent of navigation and comes with OTA support for the integration of map streaming solutions such as TomTom's AutoStream.

The purpose of ADASIS is to make map data available to various ADAS and AD applications distributed over a vehicle's systems. The standard is developed and maintained by a non-profit international organization – the ADASIS forum. In this organization, significant actors from the global vehicle industry and suppliers joined forces in order to define and promote the ADASIS interface.

An important benefit for OEMs is that the common standards ease sourcing and tier handling. Instead of defining long request lists, OEMs can refer to the official specifications of the standard and, for example, only designate differences or subsets based on them.

There are two major versions of interest: ADASIS v2 and v3. Both are not compatible to each other and focus on different use cases. The ADAS Map supports ADASIS v2 whilst the TomTom HD Map fulfills v3 specifications. The following table compares the main characteristics and specifications of ADASIS v2 and ADASIS v3:

	ADASIS v2	ADASIS v3
Purpose	Standard and ADAS Map with road-level data for advanced driver assistance applications	High-definition map with lane-level data for automated driving
Vehicle bus	Designed for CAN bus	Broadband connection (Ethernet, TCP/IP)
Communication scheme	Broadcast communication: > One provider, n clients	Bi-directional communication mechanisms supported: > Broadcast for most probable path (MPP) > Publish-Subscribe (P2P) for additional attribute information > Multiple sub-provider
Vehicle Horizon road network representation	Single tree support	Support for multiple independent trees
Most probable path (MPP) and tree length	Up to 8190 m (13-bit)	Roughly up to 43 000 km (32-bit)
No. of possible profile types	31 attribute profiles	Room for up to 2^{32}-bit possible profiles, 45 types currently specified
Profile attribute value range	Profile short: 10-bit Profile long: 32-bit	64-bit for all profile attributes
Attribute resolution	Meter [m]	Centimeter [cm]
Content	> Standard map attribute profiles on link level > Traffic data	> Map attribute profiles on lane level > Extended road lane model/detailed intersection model > Road boundaries/furniture/land marks

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ADASIS version 2

The ADASIS forum had been developing a first specification of ADASIS until 2007. Optimization and simplification led to the publication of "version 2". Since 2011, ADASIS v2 has been implemented in various systems and ECUs, targeted at advanced driver assistance applications. ADASIS v2 is in production and turned out to become the most important and widely accepted standard for the deployment of map data to ADAS and AD systems in Europe and the U.S.

ADASIS v2 is designed to communicate over the industry-standard CAN bus. The underlying architecture relies on broadcast communications: A central map data provider distributes the necessary map information to variable number of clients. The source of the map data typically is either the car's navigation system or a stand-alone implementation. Especially the latter is implemented at increasing numbers in the truck market.

Typical use cases of ADASIS v2 comprise applications such as traffic-sign recognition or predictive powertrain control. Furthermore, non-driving functions such as climate control (e.g. automatically switching to recirculating air in tunnels) or head-beam forming systems are valid use cases. In the context of providing a vehicle horizon, the implementation relies on on-board maps which are manually updated only at very low frequencies. For higher-end ADAS applications, a "connected vehicle horizon" can be provided by amending the on-board map data with dynamic additions such as traffic, road work, or accidents data. Also, for these use cases map updates would be provided more frequently.

Targeted at this entry-level and mid-level of ADAS applications, the accuracy and attribution of the provided map data is based on road-level "ADAS Map" (as opposed to lane-level HD Maps). An ADASIS v2 map data set can be attributed with information from up to 31 profiles and can also include current traffic data. This dynamic attribution can also be used by a system to decide whether it should be activated or turned off – for example, an AD system could inform the driver that it will have to suspend operation in a road construction area because it cannot reliably recognize temporary lane markings.

ADASIS version 3

The version 3.0 of ADASIS was released in 2018. This new specification is targeted at high-end ADAS as well as Level 2+ and Level 3 automated driving applications. A common perception of the unofficial "Level 2+" is that this designation extends Level 2 functionally in a way which feels like Level 3 to the customer, but at the same time limits this functionality in time and domain, and the driver still is liable.

ADASIS v3 is designed for handling HD Map data with lane-level accuracy and due to this different objective has not been designed to be backwards compatible with ADASIS v2. While ADASIS v2 only describes a road as a single line with attributes, the ADASIS v3 protocol is able to depict lane-level geometries of the road surface.

Considering the larger volumes of data necessary for these fields of application, ADASIS v3 relies on broadband connections, typically Ethernet wiring. But ADASIS v3 additionally supports bi-directional communication mechanisms including a peer-to-peer publish-subscribe model for map attribute data as well as multiple sub-providers.

ADASIS v3 is being rolled out into series production at the time of writing this whitepaper. The specifications of ADASIS v2 are available for every interested party via the ADASIS webpage). V3 is available for non-members of the ADASIS forum with a one-year time delay.

Figure 3: TomTom ADAS Map attributes

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ADASIS v3 map attribution profiles

The following table gives an overview of the attribution profiles available in ADASIS v3 map data as well as a roadmap for additional profiles which are scheduled for furnishing during 2020:

	Profile	Description
Intersection profile	Node	The node profile is used to describe intersections.
Basic geometry profile	Heading change	This profile represents the heading angle change of the path at the points of a polyline representation of the path.
Basic geometry profile	Curvature	This profile represents the curvature of the path.
Basic geometry profile	Slope	This profile represents the slope information of a path.
Road model profile	Road geometry	This profile provides the geometry of the road reference line, usually as a polyline. Typically, the road reference line is the road centerline, but this is dependent on the underlying road map.
Road model profile	Lane model	A lane is part of a carriageway that is designated for use by a single line of vehicles, to control and guide drivers, and reduce traffic conflicts. A lane is usually a laterally delimited area as part of a carriageway.
Road model profile	Linear objects	Linear objects describe various kinds of real and virtual objects that can be represented by a line roughly in the direction of the lane: lane boundaries, lane markings, lane center lines, physical lane dividers, curbs, guard rails, fences, walls
Road model profile	Lane geometry	A lane geometry description defines the geometry of all lanes for a section of a path (a section being defined as a range of offsets).
Road model profile	Lane connectivity	The lane connections between one road segment and the following road segment are described by the LaneConnectivity Profile.
Road model profile	# Lanes (per direction)	This profile represents the number of lanes on a specific path in a specific relative driving direction.
Road model profile	Lane width	The lane width profile provides the width of the drivable area on a lane in centimeters.
Road model profile	Location object	This profile provides information on objects near the road that can be used to precisely locate the ego vehicle.
Speed profiles	Effective speed limit	The effective speed limit describes the speed limit that currently applies to the ego vehicle.
Speed profiles	Extended speed limit	The extended speed limit profile can describe speed limits that might apply to a road (or set of lanes), possibly depending on a variety of conditions.
Other profiles	Complex intersection	This is a Boolean flag marking a part of a path that is inside an intersection.
Other profiles	Link identifier	This profile gives the ID of the map database link to which a specific part of the path belongs to.
Other profiles	Traffic sign	The traffic sign profile conveys information about roadside traffic signs.
Other profiles	Traffic light	The traffic light profile describes traffic lights along a path.
Other profiles	Road accessibility	This profile represents the information about which classes of actors can access the path.
Other profiles	Tunnel	The road is in a tunnel.
Other profiles	Divided road	There is a division between the lanes of opposite driving directions.
Other profiles	Functional road class	This is a classification of the road with respect to its importance for routing. Lower values correspond to higher importance. The actual range of numbers is dependent on the map provider, as is their exact definition.
Global data profiles	Driving side	The legal driving side (right-handed or left-handed traffic).
Other profiles	Form of way	This profile represents the type or form of a path; a path can be a tunnel, a bridge, a divided road, etc.
Other profiles	Access restriction	Driving restrictions for a path.
Other profiles	Overtaking restriction	Overtaking restrictions for a path.

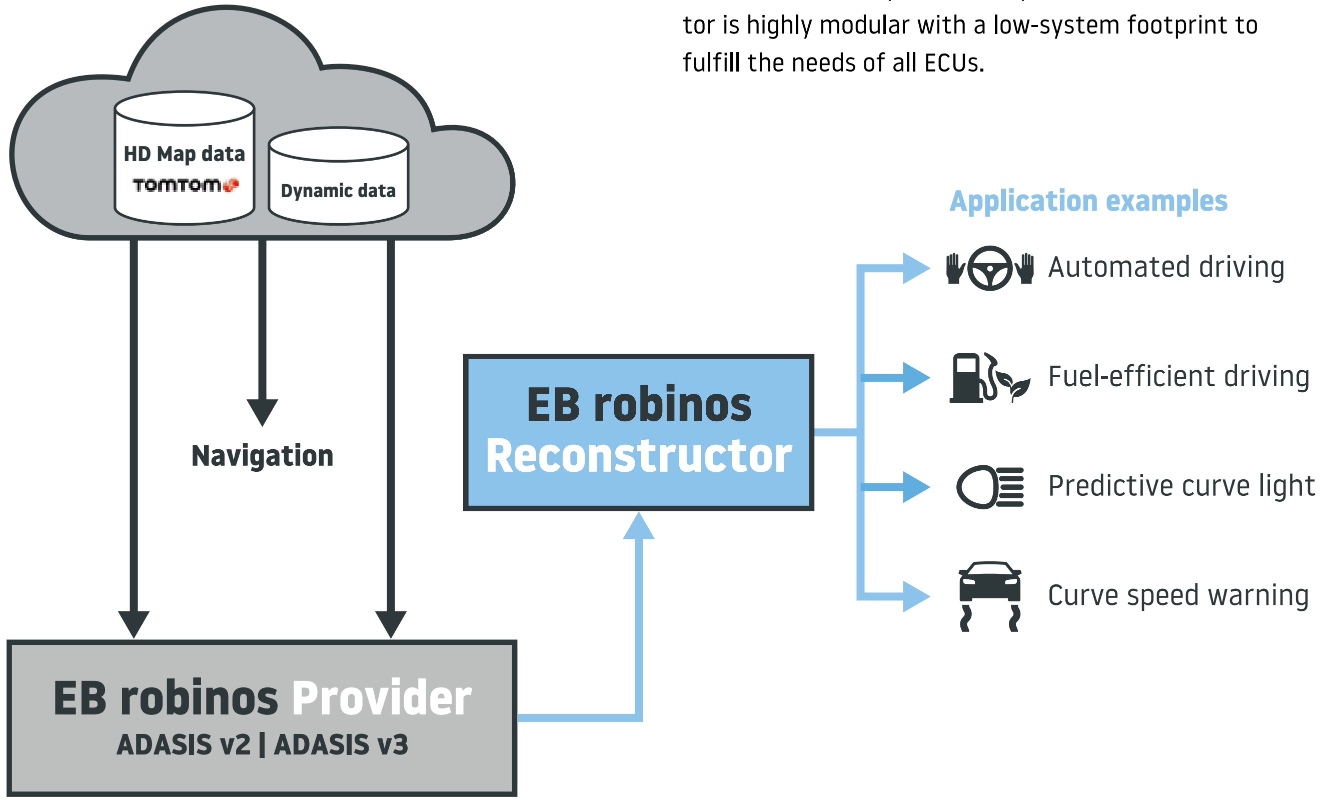

Figure 4: EB robinos Predictor – HD vehicle horizon solution

TomTom's and Elektrobit's joint first ADASIS v3 implementation

In the context of vehicle horizons, ADASIS v3 supports automated driving (Levels 2+ and 3) with on-demand map downloads, map streaming from the cloud to distributed in-vehicle systems, and the provision of live layers of map attributes. In their streaming-based reference implementation, TomTom and Elektrobit therefore use TomTom's AutoStream map delivery, feeding the map stream into EB robinos Provider.

This map data provider predicts the upcoming driving path by considering the current vehicle position, driving conditions, and road data. If necessary, the calculated route of a satnav system can also be imported. Based on the calculated path, it will create the so-called map horizon tree out of the HD Map data and fuse the dynamic data into it. Depending on the predicted paths, multiple trees are generated, so that an up-to-date HD Map horizon can be quickly provided should the vehicle leave its current path.

The map data is then provided as an ADASIS-compliant data stream to all attached ADAS ECUs. Here it is received by the EB robinos Reconstructor which deserializes the data stream back to a data structure that can be stored and processed by the ECU. The Reconstructor is highly modular with a low-system footprint to fulfill the needs of all ECUs.

Co-existence of ADASIS v2 and v3

As existing ECUs using ADASIS v2 will not immediately be upgraded to ADASIS v3, a co-existence of both implementations not only in the market, but within the same vehicle will be standard for some time. ADASIS v3 use cases are typically add-ons to systems based on v2. They do not only facilitate automated driving functions but can also include "lower level" functionality such as predictive curve light systems, NCAP-targeted car safety systems, or convenience features such as advanced climate control. Furthermore, the co-existence of ADASIS v2 and v3 can – but doesn't have to – comprise the vehicle's navigation system.

A vehicle's legacy often makes the parallel use of ADASIS v2 and v3 a necessity. This provides challenges to developers as the map sources are disjunctive: ADASIS v2 currently uses the static NDS format, while ADASIS v3 needs streaming map data such as Autostream. Therefore, there are efforts and approaches aiming at aligning these requirements, with TomTom and Elektrobit being two important players who are clearly prepared for this challenge.

Figure 5: TomTom AutoStream delivers HD Map tiles

Safety considerations

Safety in automotive means preventing harm to human health due to machine misbehavior. To manage the needed functional and conceptional work, the concept of "Automotive Safety Integrity Levels" (ASIL) as defined by ISO 26262 is widely accepted. The ASIL is established by performing a risk analysis of potential hazards by looking at the severity, exposure, and controllability of the vehicle operating scenario. The standard defines four ASILs from ASIL A to ASIL D, with ASIL D demanding the highest integrity requirements and ASIL A being the lowest level. Additionally, a fifth level is defined with the designation "QM" (quality management).

With HD Maps becoming an essential part of the environment sensor platform, their input is often viewed and required by OEMs to be ASIL instead of QM – as it is nowadays. However, the nature of a map as a sensor implies using "old data" (at least older than a few minutes) and hence cannot be considered as "reality". With this and due to the definitions in the standard, ASILs cannot be assigned to map data per se. Still, the transport of the map data from the cloud source to the ADAS function needs to ensure data integrity. Furthermore, the receiving part, the reconstructor, must be able to coexist in an ASIL environment – with mechanisms to ensure the absence of interference, fast data access, and further safety-critical technical requirements. The EB robinos Reconstructor fulfills these prerequisites. It adheres to ASIL B and is located in the same environment that also hosts the ASIL software.

The implementation of safety concepts on different client platforms touch various safety aspects which must be considered in architecture and design decisions of ADASIS functions. TomTom and Elektrobit are happy to discuss this with our clients considering their actual use cases and operation scenarios.

The concrete realization of such concepts depends on the actual use case and operation scenario. It can be refined in further discussions with the respective client.

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Figure 6: EB robinos Predictor Eval Kit, out-of-the-box ADASIS provider for R&D

Getting started with development

TomTom and Elektrobit support automotive customers to get started with their research and development right away by offering an ADASIS Provider as an evaluation kit. The EB robinos Predictor evaluation kit is based on a Raspberry Pi which can be connected to a GPS signal.

It then supports performing and recording test drives and plays them back later in the development environment. drives and plays them back later in the development environment.

Figure 7: EB robinos Predictor Eval Kit web application for desktop and mobile

The eval kit supports ADASIS v2 and ADASIS v3 and comes with pre-installed maps and an evaluation license from TomTom for Europe (EU plus Switzerland, Norway, and UK) and North America. It supports CAN connectivity for ADASIS v2 and LAN/Wi-Fi connections for ADASIS v3. A web app is used for configuration and control which can be accessed from any PC, tablet, or mobile phone also via LAN or Wi-Fi.

Additional information and the option to order can be found under https://www.elektrobit.com/products/automated-driving/eb-robinos/predictor/eval-kit

If an ADASIS v2 and/or v3 reconstructor is needed as a counterpart, corresponding evaluation kits are available from Elektrobit as well.

Conclusion/key take-aways

TomTom as a world leader in HD Map technologies and Elektrobit as a leading supplier of automotive software and development solutions have jointly been offering map-based vehicle horizon solutions since 2017.

ADASIS v2 vehicle horizons based on TomTom's ADAS Map are industry standard today and can be found in many implementations in the marketplace. TomTom and Elektrobit work on the next-generation OTA-based stand-alone ADASIS v2 product.

ADASIS v3 provides a standardized way to supply and distribute HD Map data to on-board units responsible for high-level (autonomy Level 2+ and Level 3) advanced driver assistance systems as well as automated and autonomous driving functions.

In a joint effort, TomTom and Elektrobit offer convenient ways to implement an ADASIS v3 horizon and to provision an ADASIS v2 map data source for legacy applications.

Via either partner, evaluation toolkits for an ADASIS v3 provider including evaluation map data of the EU and North America, and if needed also for an ADASIS v3 reconstructor, are available for research and development purposes.

Figure 8: The HD Map horizon by TomTom and EB ensures a smooth automated ride

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Notes

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About TomTom

TomTom is the leading independent location technology specialist, shaping mobility with highly accurate maps, navigation software, real-time traffic information and services.

To achieve our vision of a safer world, free of congestion and emissions, we create innovative technologies that keep the world moving. By combining our extensive experience with leading business and technology partners, we power connected vehicles, smart mobility and, ultimately, autonomous driving.

Headquartered in Amsterdam with offices in 30 countries, TomTom's technologies are trusted by hundreds of millions of people worldwide.

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About Elektrobit (EB)

Elektrobit (EB) is an award-winning and visionary global supplier of embedded and connected software products and services for the automotive industry. A leader in automotive software with over 30 years serving the industry, EB's software powers over one billion devices in more than 100 million vehicles and offers flexible, innovative solutions for connected car infrastructure, human machine interface (HMI) technologies, driver assistance, electronic control units (ECUs), and software engineering services. EB is a wholly owned subsidiary of Continental.

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