intetics
Where software concepts come alive™
Mapmaking for Automotive Industry
White Paper

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Introduction

In the realm of modern automotive technology, onboard navigation systems have evolved into sophisticated entities intricately connected to cloud technologies. These systems offer a spectrum of functionalities, including autonomous location search, route planning, turn-by-turn voice guidance, real-time traffic and weather updates, and insights into parking and charging stations, all geared towards optimizing navigation and driving experiences. In contemporary vehicles, these systems seamlessly integrate with driver assistance or autopilot capabilities, relying on satellite signals for precise positioning and leveraging highly detailed digital navigation maps.

Maintaining the accuracy and relevance of such detailed maps involves a technologically complex production process. We will delve into the foundational elements of digital navigation, explore prevailing trends, dissect industry standards, and navigate through the essential stages of navigation map development. From initial field data collection and mapping road conditions to utilizing crowd-sourced data and artificial intelligence, this review aims to shed light on the intricacies involved in ensuring that navigation maps stay consistently up-to-date.

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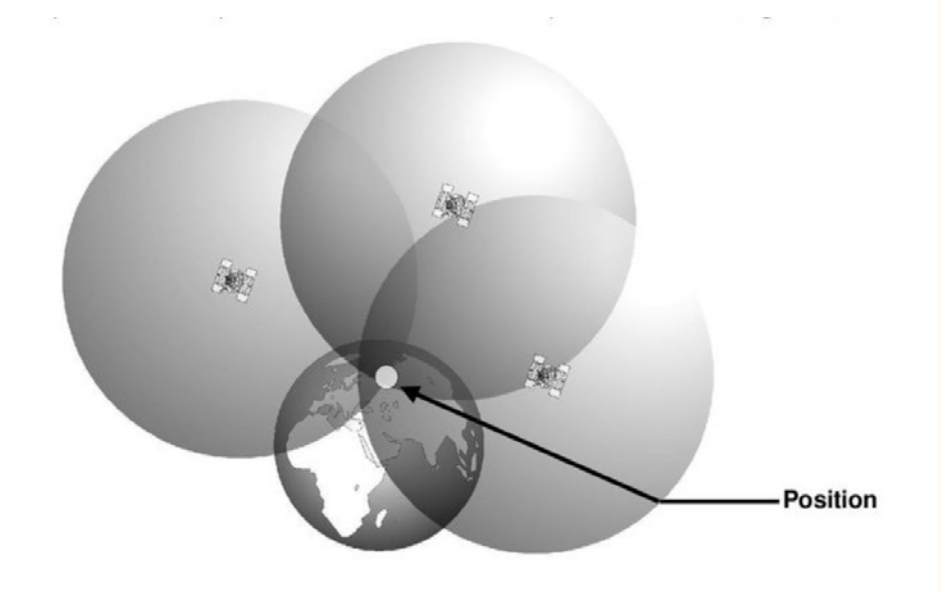
1

About Navigation Maps

The First Navigation Systems and Maps

Location knowledge is important information for both the development and use of navigation maps. In use, we need to determine where we are, estimate the route, and orient ourselves while driving. When creating maps, we need to determine the location of all road objects and conditions in order to build an accurate digital model according to their location.

One of the most critical data sources for solving this problem is data obtained from Global Navigation Satellite System (GNSS). Each GNSS satellite circles the Earth in a precisely known orbit. In doing so, it constantly transmits a synchronization signal using several built-in atomic clocks. The receiver's sensor equipment then estimates the radio wave's travel time. At least three transmitter satellites are needed to localize the receiver on the earth's surface. The more satellites the receiver has in its field of view, the more accurately it can localize itself on the earth's surface.



GPS receiver determines its position using three satellites to triangulate its 3D position

Source

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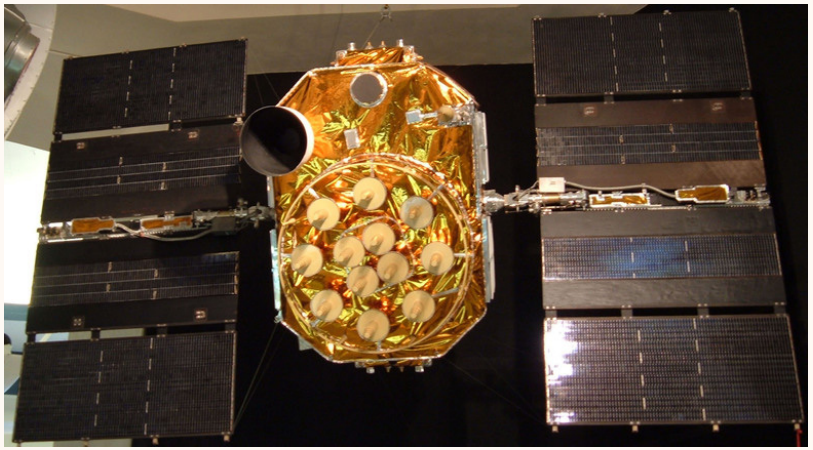
The first global satellite navigation system, the GNSS, was the Global Positioning System or GPS, which remains the leader in accuracy and coverage. In 1978, the United States launched the first Global Positioning System satellite.

The accuracy of location determination for commercial use increased from 100-200 meters at the beginning of the system's operation to up to 15 meters in 2000 and beyond.



Positioning system satellite

Source

In 1985, the first mass-market car navigator using GPS—The Etak Navigator—was already available. The image on the display was green. Maps for it were stored on cassettes.

Etak GPS Navigator (1985)

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Mazda Eunos Cosmo became the first production car with a built-in GPS navigation system in 1990. In 1991, General Motors also created its computerized built-in car navigation system.

By 1998, Garmin introduced its first portable StreetPilot GPS navigation system for automotive use. It had a black and white screen, and used cartridges with mapping. One cartridge could cover a fairly small area like Atlanta. This was a huge advance, because now "anyone" could buy a GPS navigation system – if they could afford it. The list price was initially about $550. Best of all, it could be moved from car to car at will, so people could actually pack it, fly to a location, and use it in rental cars.

StreetPilot GPS Navigator (1998)

Source

Subsequently, we have seen rapid growth in the development of the digital mapping industry, which has provided massive navigation device owners with updated digital maps on a regular basis within countries and continents. Navteq (now Here Technologies) and TomTom, two early digital mapping vendors, were founded about 30 years ago. They concentrated on field data collection and released digital map updates on a quarterly basis. Hundreds of vehicles drove around all the roads and mapped their characteristics and the characteristics of important objects in detail.

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Navigation systems are also undergoing development. In addition to the leader GPS, five additional satellite navigation systems have already been deployed: GLONASS (Russian Federation), Beidou (China), Galileo (European Union), IRNSS (India), and QZSS (Japan). Today, the vast majority of receivers in smartphones, navigators, and built-in positioning systems of modern cars can work with all of these systems, which allows for increased positioning accuracy and determination of the car's location on the ground and the map with the accuracy of several meters.

With the introduction of mobile communication capabilities inside vehicles, more time-efficient and wireless update mechanisms were developed. The ability to update wirelessly also made it possible to provide additional traffic and weather information. Map providers began collecting data on driving speed and user location. This data made it possible to estimate the actual speed of traffic on roads at different times of the day, as well as to identify new or unused roads and improve their own maps. And then, as the number of historical GPS records grew, as well as the capacity and coverage of mobile networks, navigation application developers began to share traffic information with users in near real time.

Over the 30 years of development of digital navigation maps, their accuracy and relevance have been increasing. Originally designed to help drivers, these maps have evolved and are now integrated into the latest vehicles to assist human drivers effectively.

1990	2000	2013
Digital Maps	**Enhanced Digital Maps**	**High-Definition Maps**
2D	2D	2D/3D
Road level	Lane level	Lane level
Static data	Static data	Static & dynamic data
Navigation	ADAS	ADAS/AD
Precision 5-10m	Precision 50cm	Precision < 10cm

History of navigation maps development

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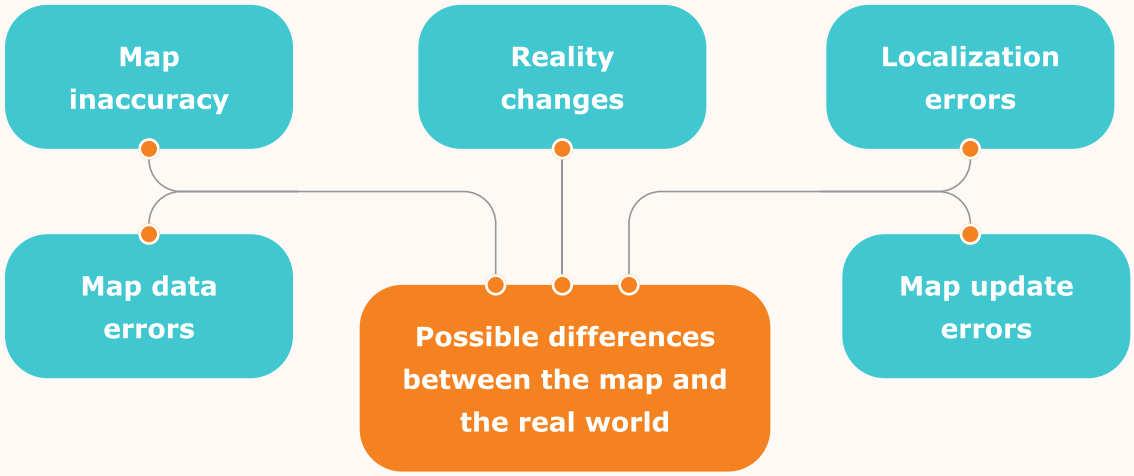
Map Accuracy

"Map accuracy" refers to the "positional accuracy" of the map. For instance, with a two-meter "map accuracy," confidence in the road curvature and sign positions is within a two-meter range. While suitable for many navigation tasks, detecting changes like altered lane markings or moved stop signs may pose challenges.

The data quality of HD maps extends beyond lane-level detailedness and centimeter-level locational accuracy. It involves various aspects, and assessing it can be guided by ISO standards for geographic information, with examples for clarity:

- **Completeness:** Ensuring all features of every feature class are present. For instance, verifying if all road signs, lanes, and intersections are accurately represented.
- **Logical Consistency:** Validating the correctness of the road network topology, including the accurate digitization of one-way streets in the correct direction.
- **Positional Accuracy:** Assessing the accuracy of absolute location, ensuring that the map reflects real-world coordinates with precision.
- **Correctness (or Thematic Accuracy):** Ensuring correct attribute values, such as accurately attributing a path for pedestrians as opposed to mislabeling it as a road for cars.

A map can become a threat to our comfort and security if it has errors. In general, the map may differ from the real world in the following cases:



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Map Updates

The accuracy of a map depends on when it was created. Given the constant changes in the real environment, a certain level of discrepancy between the map and the dynamic reality it is intended to represent is inevitable. In this case, we talk about the temporal accuracy of the map: how up-to-date the data set is and whether there is a time lag.

The refresh rate is not absolute and depends on the environment's change (or activity), with highly dynamic environments typically requiring more frequent map updates.

The map update process can occur through various methods, ensuring customers can access accurate and current information. Here are four ways in which the update process can take place:

- **Updates from Authorities:** The infrastructure provider (Government) initiates an over-the-air update directly to the automated vehicles. This method is utilized when there is a known change in the environment, such as road works, construction, or maintenance of infrastructure, electronic, and dynamic restrictions, and the government sends immediate updates to all customers (vehicles).
- **Map Producer Updates:** The producer of the map (typically a private company) collects new data by the regular field surveys and updates their map, which is then transmitted to the customers (vehicles). Private companies responsible for map production regularly gather new data to ensure maps are up-to-date, and they transmit these updates to customers (vehicles).
- **Authorities Updates to Map Producer:** The infrastructure provider (Authorities) sends a message to map suppliers, detailing known changes. This information is then used to update the map on the cloud before being transmitted to customers (vehicles). Authorities collaborate with map suppliers to communicate changes in the environment, allowing for cloud-based updates that reach customers (vehicles).
- **Crowdsourced Data Update:** Several drivers or smart-vehicles detect changes in the environment compared to the prior map. This data is communicated back by crowd map-app or directly to map provider, validated, and then transmitted by map provider as an updated map to all other customers (vehicles). Drivers and smart-vehicles act as sensors, detecting real-time changes in the environment. This information is crowdsourced, validated, and used to update maps for the entire fleet (or customers/vehicles).

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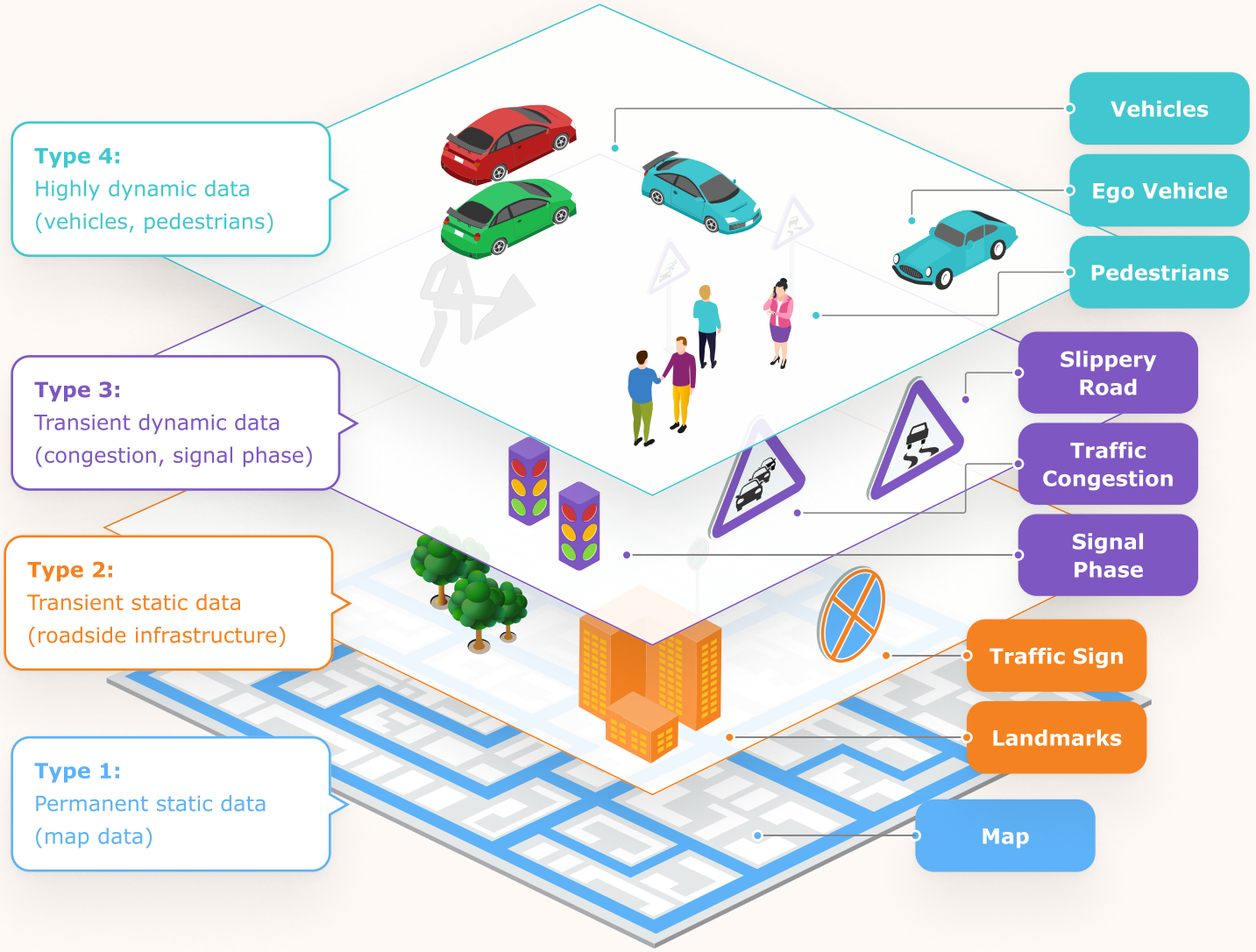
The update process can be categorized into two main types: dynamic data and static data. Dynamic data involves rapidly changing situations like accidents, traffic jams, or roadworks. On the other hand, static data represents more permanent road changes, such as the installation of new traffic lights, a yield sign or an additional lane on a motorway.



Different types of data are updated on the map at different frequencies

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Updating static data requires specialized field mapping vehicles with special sensors to move around and collect data. The data received from the field teams is then transferred to the offices, where a specialized team of map editors processes it. The map editors can use satellite and aerial photography data as additional sources for updating maps. Crowdsourced data may be an additional source of data, but such data requires careful quality control and revision. Another solution for mapping refinement involves close cooperation between government agencies and map developers, especially for updating data related to road works.

Maps Metadata

Maps are inherently imperfect, and acknowledging this, it's essential to include quality metadata in the map information. The quality metadata encompasses various aspects:

- **Existence Probability:** Represents the likelihood that a feature exists in reality. In cases where mapping conditions were challenging, such as poor lighting or sensor faults, the map acknowledges uncertainty by assigning a low existence probability to a specific object.
- **Location Accuracy (Centimeters):** Reflects the potential magnitude of error in the location of mapped objects. This metadata provides an indication of how precisely an object's location is known, considering possible errors in the mapping process.
- **Object Classification Accuracy:** Indicates the accuracy of the classification of mapped objects. For instance, the mapping software might recognize a traffic sign but may be uncertain about its specific classification, such as distinguishing between "30mph speed limit" and "80mph speed limit." The map includes metadata for the probability of correct classification, potentially incorporating a probability distribution across various classes.

Including these quality metadata elements in the map information enhances its transparency and utility. It not only communicates the confidence level in the data but also enables users and systems to make informed decisions based on the reliability of the mapped features. The map can also contain information related to the source of the data: which sensors were used to get the information when the map was last updated.

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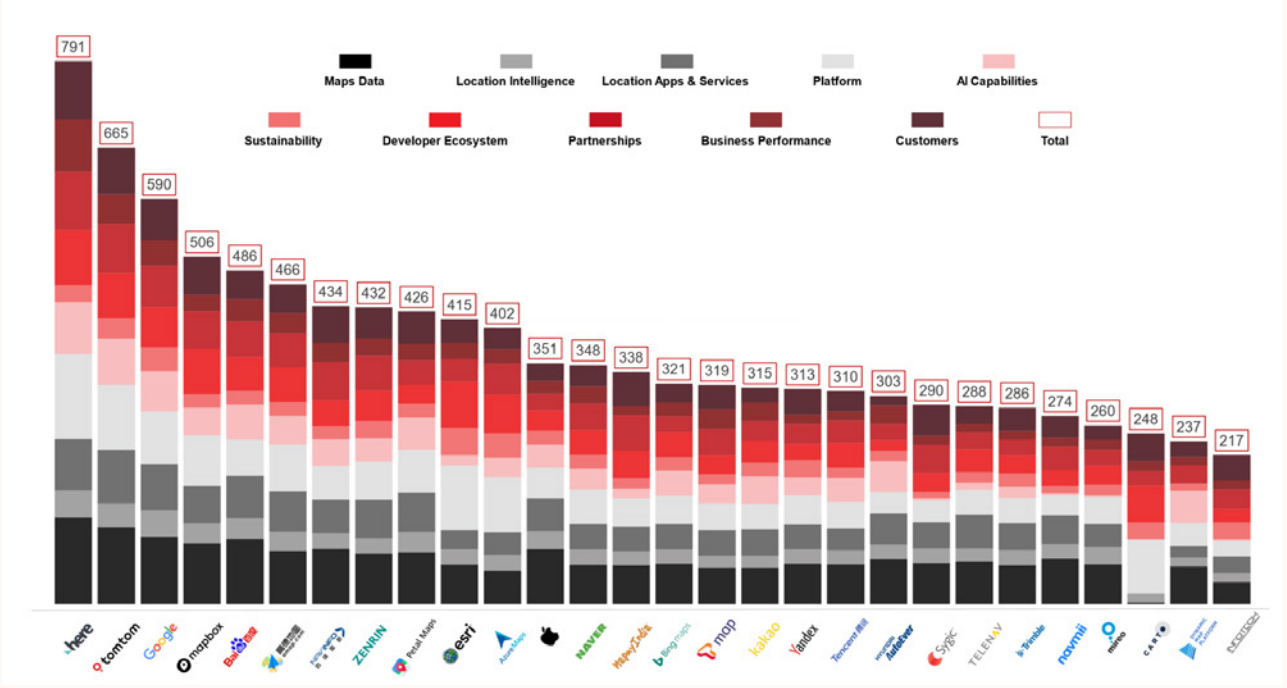
Largest Manufacturers

Numerous self-driving car companies are developing their proprietary maps, while specific companies specialize in providing mapping services.

Drivers who use navigation maps for localization, routing, and turn-by-turn navigation are recognized as the main users of maps. Driver assistants use accurate maps of road shapes to improve driving safety and comfort. A new growing segment of consumers is vehicles with a high level of automation, which requires increased accuracy and speed of updating times.

According to various sources, the global HD maps market size is estimated to grow at a CAGR of 15.06% to 28.63% between 2023 and 2030, reaching a value of USD 9.67 billion by 2030. The major factors driving the growth of this market are the rapid developments in autonomous vehicles, the rise in the number of start-ups for the development of HD maps, and the increasing demand for high-precision mapping services.



Location Platform Effectiveness Index 2023

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According to a Counterpoint study, HERE remains at the pole position of location platform rankings for the seventh consecutive year. TomTom maintained its second position, inching closer to its industry peer HERE with a growing portfolio of offerings, capabilities, and customer wins. Google secured the third rank among location and mapping platform providers worldwide.

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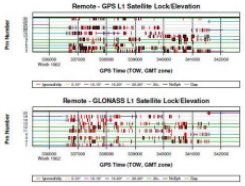
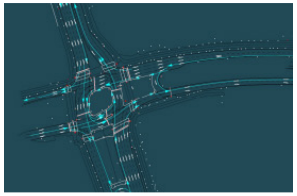
Mapmaking

To ensure reliable navigation, manufacturers control the entire lifecycle of map creation and updating, from collecting source data to maintaining the quality and up-to-date maps. Maps are created using various data sources, including field data, open data, crowdsourced data, satellite and aerial imagery. The mapping process using these sources is as follows:

Mobile Mapping	Data Processing	Data Analysis	Ultra HD Map
			
• Mission Planning • Mapping of Any Kinds of Roads • Digitalization of the 360 Degree Road Corridor with max. 10 Cameras and 2 Laser Scanners	• Post-Processing • Quality Management • Homogenization • Scanner and Image Data-Processing	• Object Data Extraction • All Elements in One "As-Built-Plan"	• Traffic and Connection Logic • Precise, intelligent HD Map in appropriate formats, e.g. OpenDrive, which is most widely used as ultra HD Map format for testing and simulation

Continuous development of our own software + customer support during the entire project

The main stages of navigation map production

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Field Data Collection

Field data collection is the most important basic step in the creation of navigational charts, the purpose of which is to collect actual data on road conditions and to model the road corridor. It usually consists of the following tasks:

- Clearly define goals and geographical scope.
- Define the technology and tools to accomplish the challenge: GNSS, INS/IMU, Sensors (Optical, Laser, Thermal etc).
- Develop a comprehensive plan and routes.
- Train field personnel on tools, standards, and safety.
- Establish and communicate standardized data collection protocols.
- Strategically deploy equipped field teams based on defined areas.
- Implement real-time quality control measures.
- Data Classification & Extraction – All road Elements (surface, lanes, lane boundary, lane connectivity, lane markings, splines, intersections, parking spaces, building facade), complex break lines (curb lines, pavement, sidewalk, pedestrian crossings, dividers), road furniture (signs, traffic signals, poles, trees and green area).
- Attribution & Labeling – Labeling & auto attribute transfer, assign/remove navigation attributes, attribute integration to street/lane network.
- Ensure data security and privacy compliance.
- Plan for seamless integration of collected data with existing systems.
- Map Data Output – Detailed map based on NDS format or other client-specific data model.
- Maintain detailed documentation and generate regular progress reports.

Intetics regularly conducts fieldwork to meet the needs of its clients. One such project involved surveying a significant road network across 20 European countries. The collected data enabled the client to update their geospatial information and enhance the quality of their services.

Let's take a closer look at some important aspects of the collection stage.

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Equipment

Depending on the scope of the mapping project, different collection strategies and corresponding equipment and techniques can be applied. For example, to update the POI characteristics in the dense urban area of the old part of the city, field teams of cartographers using smartphones and tablets with the possibility of interactive refinement of location in conditions of unstable GPS signal are carried out. And to update data on traffic conditions and road surface types in the newly built housing estates, high-traffic vehicles with 360° cameras for panorama collection will be used. To collect data on the new motorway ramps, high-speed economic passenger cars with specialized high-precision cameras will be used.

Equipment categories for mobile mapping projects

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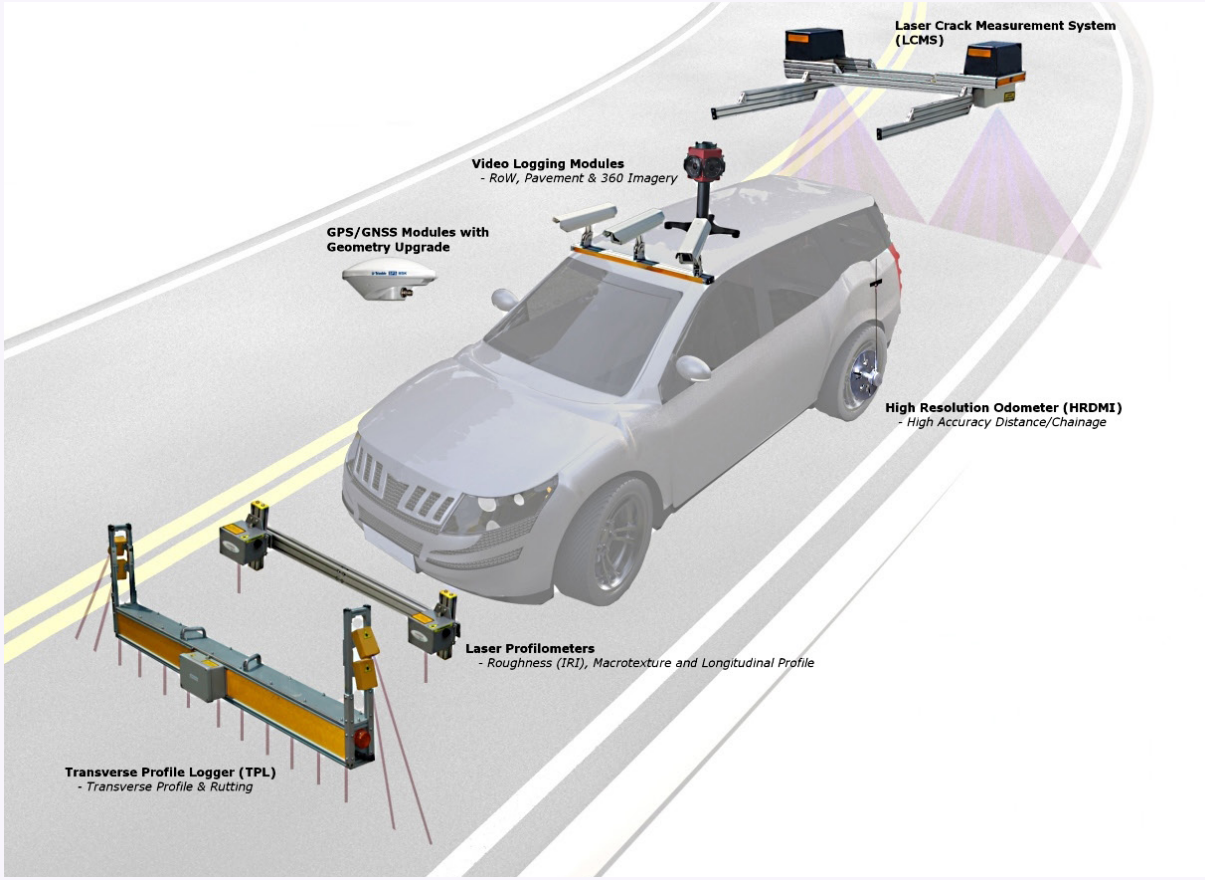
Mobile Mapping Systems

Specialized **Mobile Mapping Systems (MMS)** are used to comprehensively collect all road conditions data. MMS integrate several tech and sensor types for swift and thorough data collection on a mobile platform. The main types of platforms are automotive, but there are also options for pedestrian, bicycle and motorcycle use, as well as aviation or UAV solutions. MMS generates detailed 3D point clouds and high-resolution images, capturing dynamic environments, traffic-related information, and mobile positioning data.



Pavement inspection equipment set

Source

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Key tech components of MMS is:

- positioning system (GPS/GNSS, inertial measurement units, odometer)
- RGB cameras for precise image capture
- LiDAR for laser-based Earth range measurement

Pro solution: 360º camera system (Mosaic 51) plus LiDAR

Source

Light solution: Front/rear action cameras and supplemented equipment

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An additional type of data that is collected in the field is the technical notes of field analysts who work in the field and collect additional semantic data in the form of notes or audio recordings using a smartphone, tablet, or laptop. Notes may include observations about a new road sign, change of road surface type, parking lot hours, POI names, useful data that is out of sight of cameras, and other observations that will help in the next stages of map development.

Positioning via GPS/GNSS and inertial units ensures continuous and accurate data recording.

RGB cameras equipped with CMOS global shutters or CCD sensors capture colored images of people and objects. Camera images provide location information through additional methods like reconstruction and photogrammetry.

LiDAR, using pulsed laser light, is a pivotal remote sensing method. Its mobility allows effective mapping of inaccessible areas, drastically reducing survey times from weeks to days. Widely applied in road and rail maintenance, mapping projects, and infrastructure safety enhancement, LiDAR stands out as a crucial geospatial technology.

Global companies like HERE, TomTom, and Google have entire fleets of these cars. Recent trends involve shifting from single specialized vehicles to multiple vehicles with cost-effective sensors, promoting a cooperative approach. Multiple vehicles working simultaneously create local maps, which are then merged into a single global map. This not only reduces costs but also enhances flexibility and robustness. In case of one vehicle failure, others can continue, minimizing accumulated errors. This approach can extend to crowdsourcing, compensating for low-fidelity data through aggregation.

After fieldwork is completed, all field service logs are merged and processed to improve the positional accuracy of the data collected. As a result of this postprocessing step we will receive accurately positioned sets of data, ready for further processing by cartographic teams in the office.

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Map Coding

At the next stage, field information, along with supplementary details like government records on road repairs, satellite and aerial imagery, open cartographic information, and niche data, is integrated into specialized GIS software for map updates.

Field data processing by cartography teams in the office is a pivotal stage in the navigation map update process. During this phase, raw field data is acquired and transformed into refined navigation data, involving the selection of precise positions and characteristics of road elements and conditions. The tasks typically encompass:

- Implement collaboration tools for efficient communication among cartographers.
- Establish a secure and organized system for receiving field data from teams.
- Standardize data formats, ensuring uniformity for integration.
- Implement rigorous validation processes to ensure accuracy and completeness.
- Map Feature Classification & Extraction based on field data (roads, landmarks, etc.).
- Prioritize updates based on urgency, relevance, and user demand.
- Utilize Geographic Information System (GIS) software for detailed mapping.
- Integrate quality assurance and quality control processes into every stage.
- Establish version control to track changes and updates.
- Maintain comprehensive documentation for future reference and audits.
- Create a feedback loop with field teams for iterative improvements.
- Plan for seamless integration with existing navigation systems.

An example of such a project, which involved fieldwork, geoprocessing, and data extraction, was the successful implementation of detecting and updating speed limits on 250,000 km of European roads.

Let's take a closer look at some important aspects.

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Map Features/Types of Data

Since there is no common standard format for navigation maps, each map vendor supports its own set of features in its maps. In the table, we have included all the components that are common to most publicly distributed navigation maps. The data was obtained from product descriptions.

The maps encode street structure, road speed limits, road curvature, lane structure, road signs, street names, addresses, and POIs:

- **Lane positions and widths:** A vehicle needs precise information about the location of all lane markings to ensure safe driving. The 2D position of lane markings, along with the lane type (solid line, dashed line, etc.), is stored. This includes markings at intersections, road edges, and off-ramps. Lane markings encompass arrows indicating whether a lane is for turning or traveling straight. Explicitly marked lane markings, implicit lanes (e.g., a country road with no lines but two directions of travel), navigable spaces adjacent to lanes (for emergency responses), and a representation of the lane network structure (lane logic) enabling the vehicle to plan a legal route from its current location to a target destination.
- **Speed limits by road type in accordance with the boundaries of settlements:** Allows you to drive within the permitted limits, increases the functionality of cruise control.
- **Road signs:** Provides data on existing traffic restrictions, permits, and information. A map must store the precise position of significant road signs in relation to the map and vehicle. Road signage includes stop signs, traffic lights, yield signs, one-way road signs, traffic signs, and any other relevant signage. This task becomes challenging when signage conventions and road rules vary by country. Typically, a sign's position is encoded using a centroid (an imaginary point in the exact middle of the sign) and a bounding box (a set of coordinates defining the sign's size).
- **Special road features:** This category encompasses pedestrian crossings, school zones, speed bumps, bicycle lanes, and bus lanes.

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Map Feature	Description
Speed Limit Signs	Maps include both the designated speed limit for each section of the road along with the expected position and sign text of all speed limit signs.
Electronic Speed Signs	A subset of speed signs that are electronic and can be dynamically modified by road transport departments. These signs have been noted as causing major recognition difficulties for existing traffic sign recognition systems.
Road Warning Signs	Road warning signs include those indicating stop and give-way instructions, changes to the road's surface or condition, and merging and added lanes (and more). The position and semantic meaning of all these types of signs must be encoded in any map.
Lane Structure	Maps include detailed data concerning the number of lanes, lane types, and exact positions of all lane markings.
Traffic Lights	The location of traffic lights in the network is stored in the map, both as an approximate position (i.e., which intersections have lights) and exact 3D position. Traffic lights also need to encode the design of the light—i.e., whether the light is a single column of red, yellow, green, or has turning arrows as well.
Road Edges	While this may seem like a trivial element, to account for all possible situations, a prior HD map needs to encode the exact position of the road edges. This can be considered as a form of geofencing, which helps guarantee that the automated vehicle never drives off the road, risking the safety of off-road vulnerable road users.
Pedestrian Crossings	Crossings, along with other high-risk areas like school zones and shared zones, need to be encoded in an HD map.
Environment Appearance	Using a detailed map around the road, the autonomous vehicle can localize itself relative to the map. Some map providers and autonomous car companies use a LiDAR point cloud (e.g., Waymo), some use a depth image (e.g., TomTom), and some use the position of road features to localize (HERE). Some map providers do not provide this feature at all (Mapbox).
Road Slope	The slope of the road. This data can improve the performance of an automated gearbox and throttle, especially for heavy vehicles.
Road Surface	Whether the road is bitumen, gravel, or dirt. May also include a measure of whether the road is in good or poor maintenance condition.

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Summary of what (HERE) Map Database provides

Source

260 Attributes

Unique Road Classification

- 5 Functional Classes
- Globally consistent
- Based on the actual usage of the roads

Relevant Content

- Speed limits
- Speed categories
- Road type
- Road surface
- Turn restrictions
- Lane markings
- Traffic lights
- Driver alerts
- Truck restrictions
- Traffic (historical and real-time)

POI

Dynamic POI Content Features

Air Travel Status

- Offers an array of details ranging from airport weather conditions to flight arrival and departure information, to overall airport status

Fuel Prices

- Provides continuously updated fuel costs, allowing consumers to search for the lowest fuel prices while in-transit

Movie and Event Listings

- Gives consumers access to information for movie times, sporting events, concerts, cultural and other entertainment-related events

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Parking Preview

- Provides travelers with a preview of parking space availability, forms of payment acceptance, pricing by time and lot opening times

Pedestrian Content

- Public transit information such as stop and access point locations
- Neighborhood boundaries to enable local and proximity search
- Crosswalks, sidewalks, and stairs
- Tunnels and bridges
- Virtual connections (where physical connections do not exist)

Traffic

- Sensor
- Probes
- Incident-Flow
- Traffic Local Flow
- Traffic Region/Country Flow
- Predictive Feed

Routing

Green Routing

Truck Routing

- Physical Restrictions
- Legal Restrictions
- Warning Information
- HAZMAT

The layers in the HERE Map Content catalog can bethematically grouped as follows:

- Roads layers
- Lanes layers
- Places layers
- Buildings layers
- Cartography layers
- Administrative Areas layers
- Rules & Regulations layers
- Addressing & Postal layers
- Visuals map-references layers
- Other Layers

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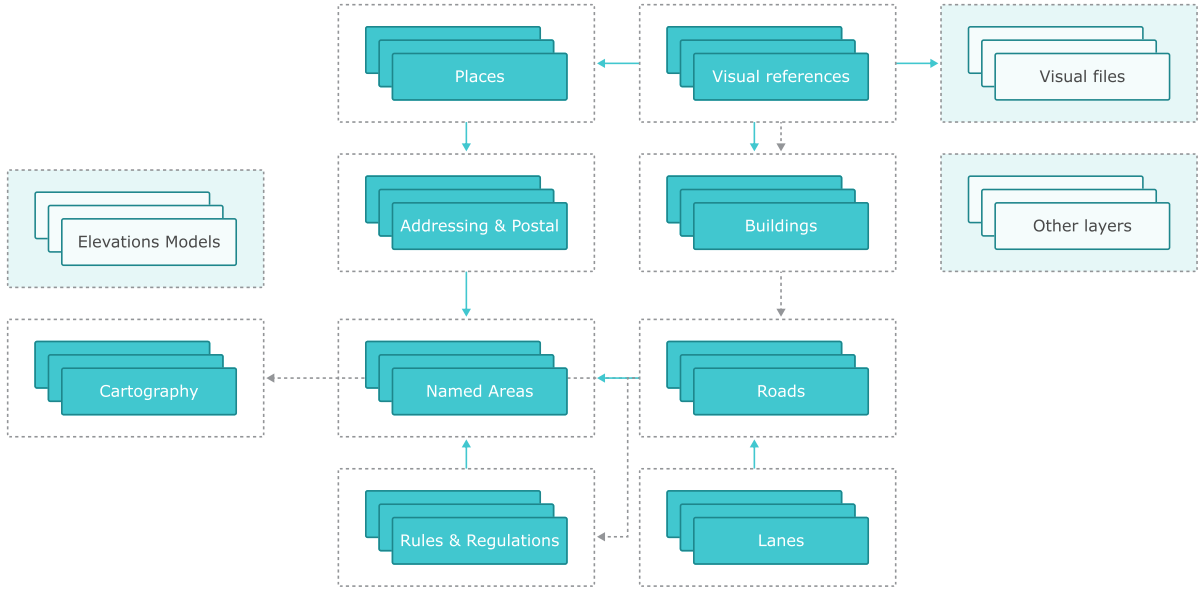

Schematic representation of spatial layers

Source

Visual representation of spatial layers

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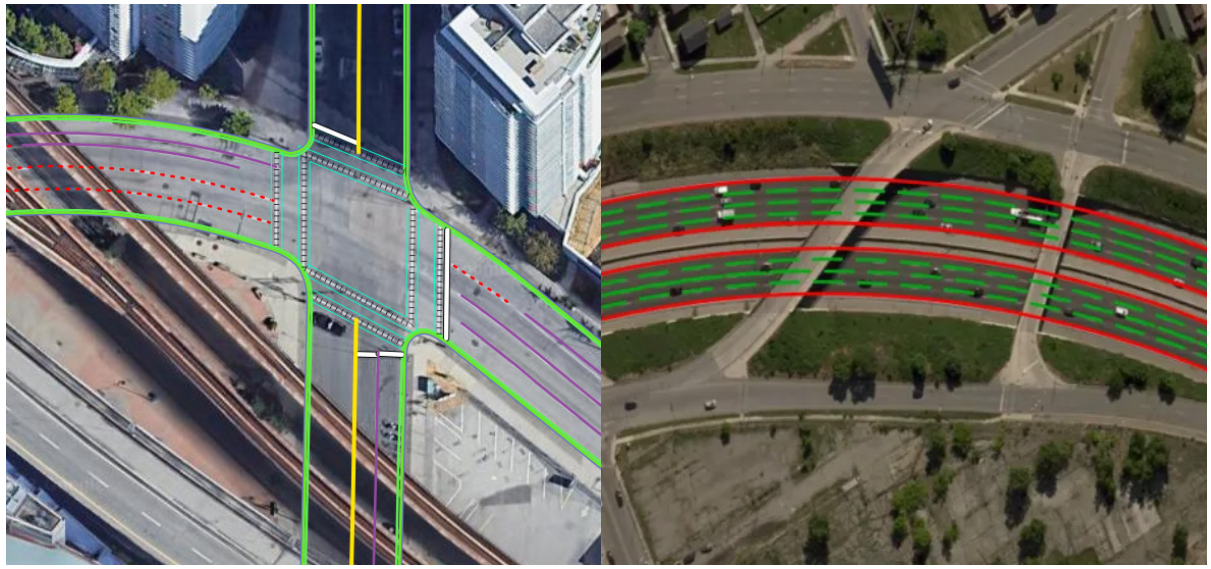
Aerial and Satellite Imagery Sources

Aerial platforms that complement MMS offer an additional data stream. MMS focuses on road and linear features, while aerial photography captures surrounding landscapes and objects, as well as major road infrastructure. Aerial images tend to have better global accuracy and are less affected by GNSS signal quality. Unmanned aerial vehicles (UAVs) provide an inexpensive and flexible tool for obtaining important information, including lane markings and major landmarks.

To process satellite and aerial images, cartographers use specialized methods and tools. First, several images of the same area over a certain period of time are compared, and then those map elements that have changed, such as new road markings, infrastructure, or buildings, are automatically extracted from them. At the next stage, the mapper compares the current version of the map with data from field teams, the most recent imagery, and other sources, and updates the map based on this.

Here are some map features that can be updated using imagery:



Road Markings, Pedestrian Crossings, Road Edges

Source

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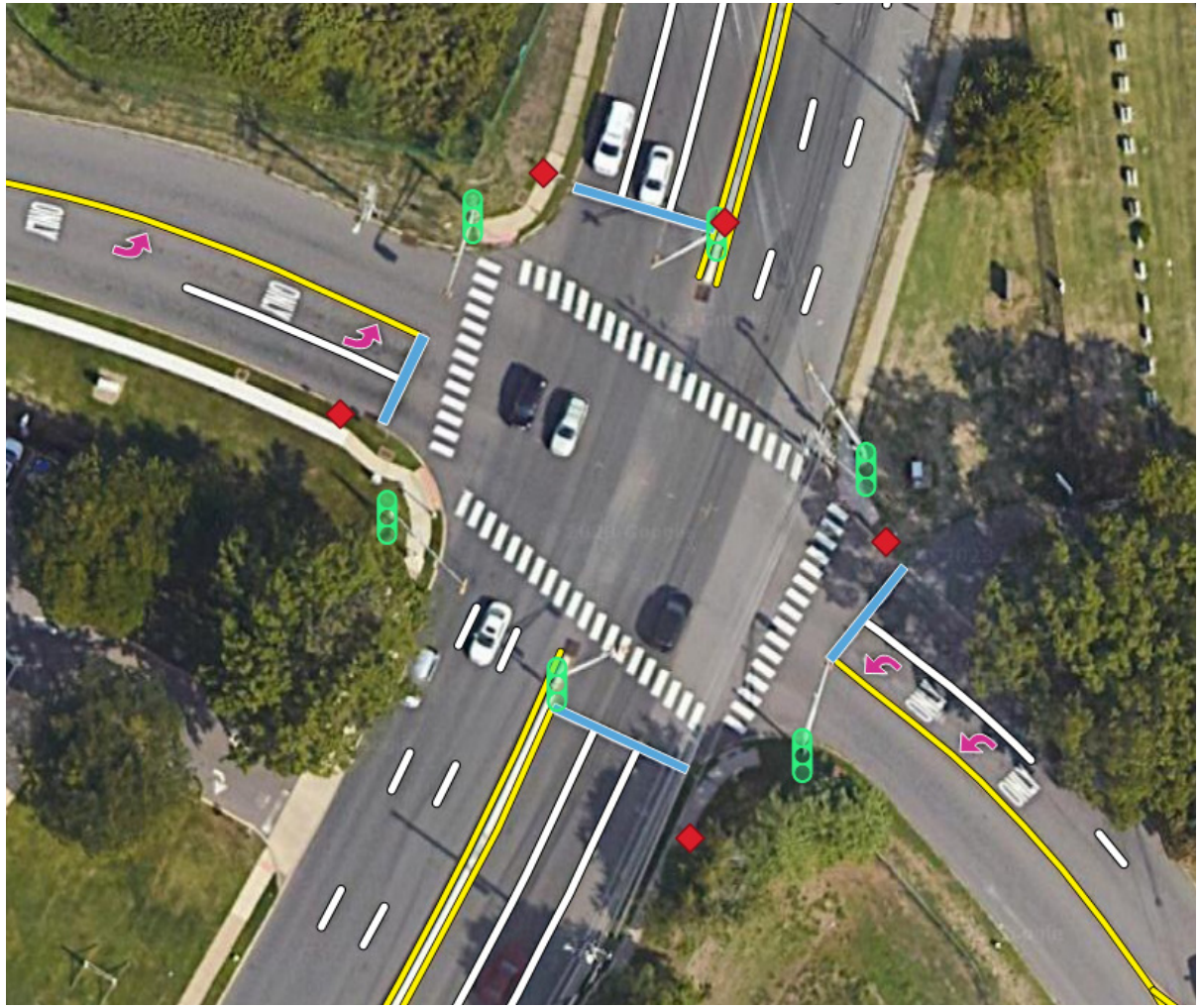
Combination of MMS, UAV and Satellite imagery can produce more advanced maps, which can feature objects which are hard to detect using only one type of data collection.



Road features, including Signs, Traffic Lights, and Road Marking digitized from UAV oblique imagery

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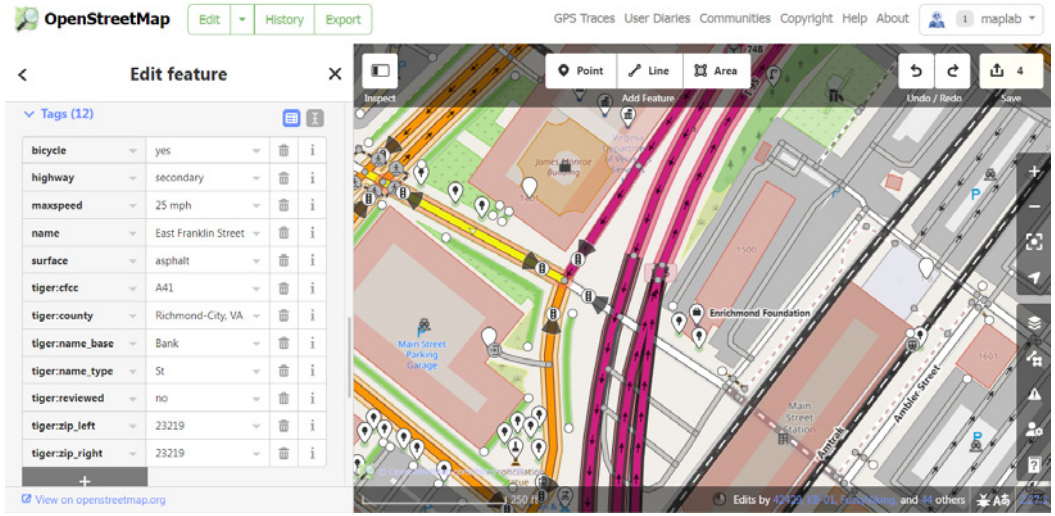
Additional Open Data Sources

Two related open source geodata sources such as OpenStreetMap and Mapillary are also often used to update maps, which, in combination with our own field and statistical data, allows us to obtain higher map accuracy.

OpenStreetMap

Aimed at developing open geodata, the OpenStreetMap volunteer community has become one of the largest and most active free communities in the world, along with the Wikipedia community.



OSM Editor App

OSM data is available under an open license. Due to its free access and global coverage, OSM has become a popular source of up-to-date geospatial information, and in regions with an active community of project participants, OSM data is of higher quality than other sources.

Large companies not only use OSM data but are actively involved in its development: they provide satellite imagery, create editing applications, create specialized mapping teams that improve the coverage and quality of OSM data (with nearly 17% of the global road network edited by corporate data-team members as of March 2020), and invest in infrastructure and global community development.

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Overture Maps

In 2022, the Linux Foundation announced the creation of the Overture Maps Foundation, a non-profit association aimed at creating a platform independent of specific companies for the joint development of tools and a unified map data storage scheme, as well as maintaining a collection of open maps that can be used in their own mapping services. The founders of the project include Amazon Web Services (AWS), Meta, Microsoft, TomTom, and Esri.

Overture Maps aims to aggregate existing open maps from various sources, including OpenStreetMap as the main source, and maps that are willing to be shared by various companies and organizations. At the same time, since both projects use the same license, Overture Maps' work can be transferred to OpenStreetMap, and Overture Maps participants intend to actively participate in the development of OpenStreetMap data.

Mapillary & OSM

Mapillary empowers users globally to contribute their street photos and panorams using their smartphones, action cameras, or 360° cameras. Additional key to Mapillary's success lies in its innovative use of computer vision technology, allowing users to capture sequences of images that, when uploaded, are processed and interconnected with other users' contributions.

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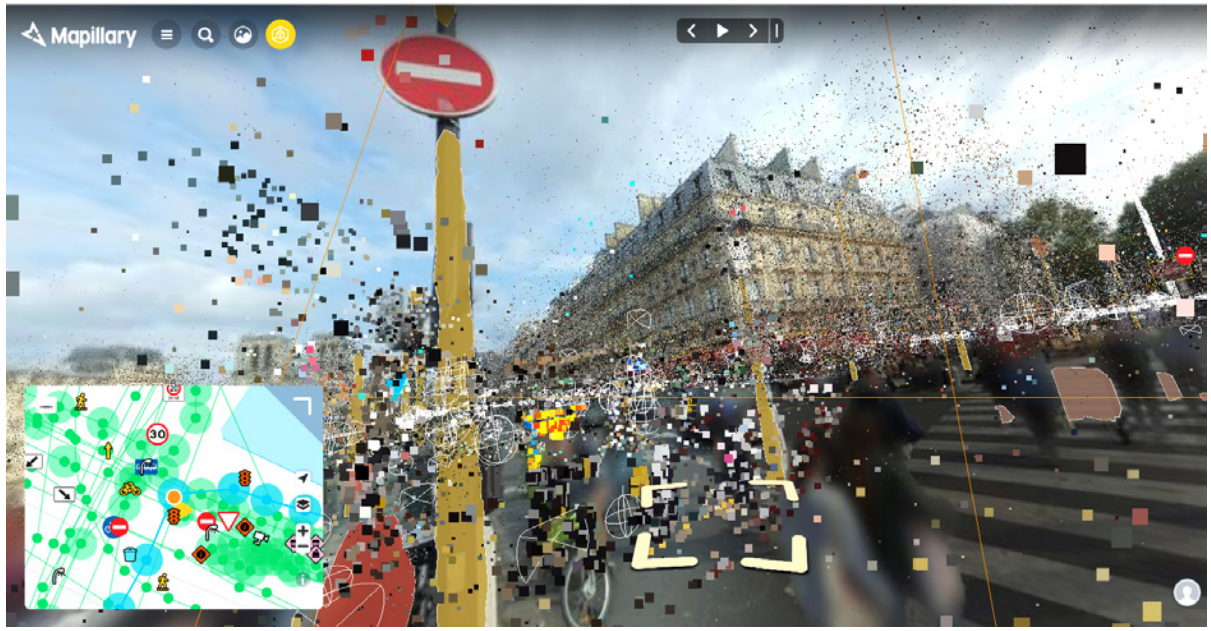
The platform provides a rich source of geospatial information derived from street-level images, which can be used to edit maps and enhance geospatial datasets. Mapillary images are available under an open license.

Mapillary is committed to OSM, offering free access to its imagery and data for OSM contributors. Integrated with popular OSM editing tools, Mapillary supports the verification of map data, addition of attributes, and real-world insights. Such attributes could be street numbers, road signs, street names, building descriptions, road conditions etc. Derived data may be published directly to OpenStreetMap. Actively collaborating with the OSM community, Mapillary's data is used in various community tools, and the company participates in conferences and events to support OSM initiatives. This commitment underscores Mapillary's role in empowering the OSM community with dynamic street-level imagery for accurate and up-to-date mapping.



Photogrammetric model and classification of road signs in Mapillary

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HERE Map Creator

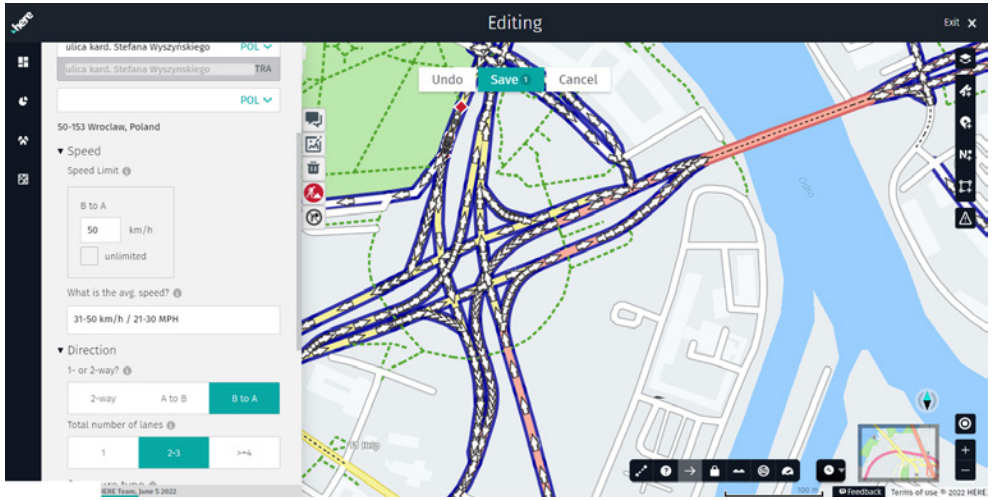
HERE supports its own community of volunteer cartographers through its navigation platform HERE Map Creator, employing a crowd community approach. This method entails leveraging user collective intelligence for actively refining and updating maps.

Users play a crucial role by contributing updates and additions, such as new road data, landmarks, points of interest, and other relevant geographical details. This direct involvement guarantees that maps remain current and accurately depict the evolving real-world landscape. The volunteer edits make their way to HERE's maps and the governments, citizens, companies, and vehicles around the world that rely upon them.

To uphold data integrity and quality, HERE implements a meticulous verification process. This involves cross-referencing user-contributed data with authoritative sources and utilizing validation mechanisms. The synergy between user contributions and the technical validation process ensures that the information aligns with industry standards.

Mapillary is also available in HERE Map Creator as a source for imagery and data. This help guide walks you through the map editing process using Mapillary as a data source.

The ability to utilize multiple sources such as field data, open data, and aerial imagery allows for more accurate detection of changes in road conditions. This ensures scalability and the ability to update city and regional maps with the required frequency.



HERE Map Creator Editor App

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Thematic Map Creation

The integration of imagery data, existing vector sources, and field collected data allows the creation of informative, dynamic maps that contribute to informed decision making. Additionally, thematic mapping plays a crucial role in data analysis and our understanding of spatial patterns.

Such an example is a POI map with tourist information, which was enhanced with additional data: building footprints, roads, and city areas.

Example of buildings and residential areas digitization for Tourist information POI map

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Another example is a map which shows a digitized road network and collected from open sources POIs of emergency services for certain areas. This map helps with emergency route planning and workload distribution.

Example of Road Network Connectivity with main Emergency Services (police, hospitals, fire departments)

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Advanced Mapping for ADAS

Improved driver assistance maps include more accurate road shape modeling:

- **Curvature:** the curvature of the road in degrees around corners. This usually includes a recommended safe speed for navigating the curve and may also include multiple speed options depending on weather conditions.
- **Steepness:** the incline of the road, especially details like this are very important for trucks where the wrong gear selection can lead to excessive brake wear.
- **Curvature at the intersection:** essentially describes the "sharpness" of the intersection. Knowing this property in advance allows you to accelerate at the correct speed to overcome the turn at the intersection to ensure both passenger comfort and vehicle safety.

Coding according to the ADASIS v3 standard

Attribute	Profile	Description
Node	Intersection profile	Describes intersections.
Heading change	Basic geometry profile	Represents the heading angle change of the path at the points of a polyline representation of the path.
Curvature	Basic geometry profile	Represents the curvature of the path.
Slope	Basic geometry profile	Represents the slope information of a path.
Road geometry	Road model 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.
Lane model	Road model profile	A lane is part of a carriageway designated for use by a single line of vehicles, controlling and guiding drivers, and reducing traffic conflicts. Usually, a laterally delimited area as part of a carriageway.

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Linear objects	Road model profile	Describe various kinds of real and virtual objects represented by a line roughly in the direction of the lane, including lane boundaries, markings, center lines, dividers, curbs, guard rails, fences, and walls.
Lane geometry	Road model profile	Defines the geometry of all lanes for a section of a path (a section being defined as a range of offsets).
Lane connectivity	Road model profile	Describes the lane connections between one road segment and the following road segment using the LaneConnectivity Profile.
# Lanes (per direction)	Road model profile	Represents the number of lanes on a specific path in a specific relative driving direction.
Lane width	Road model profile	Provides the width of the drivable area on a lane in centimeters.
Location object	Road model profile	Provides information on objects near the road for precise location of the ego vehicle.
Effective speed limit	Speed profiles	Describes the speed limit currently applying to the ego vehicle.
Extended speed limit	Speed profiles	Can describe speed limits that might apply to a road or set of lanes, possibly depending on a variety of conditions.
Complex intersection	Other profiles	Boolean flag marking a part of a path that is inside an intersection.
Traffic sign	Other profiles	Conveys information about roadside traffic signs.
Traffic light	Other profiles	Describes traffic lights along a path.
Road accessibility	Other profiles	Represents information about which classes of actors can access the path.
Tunnel	Other profiles	Indicates that the road is in a tunnel.
Divided road	Other profiles	Signifies 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.

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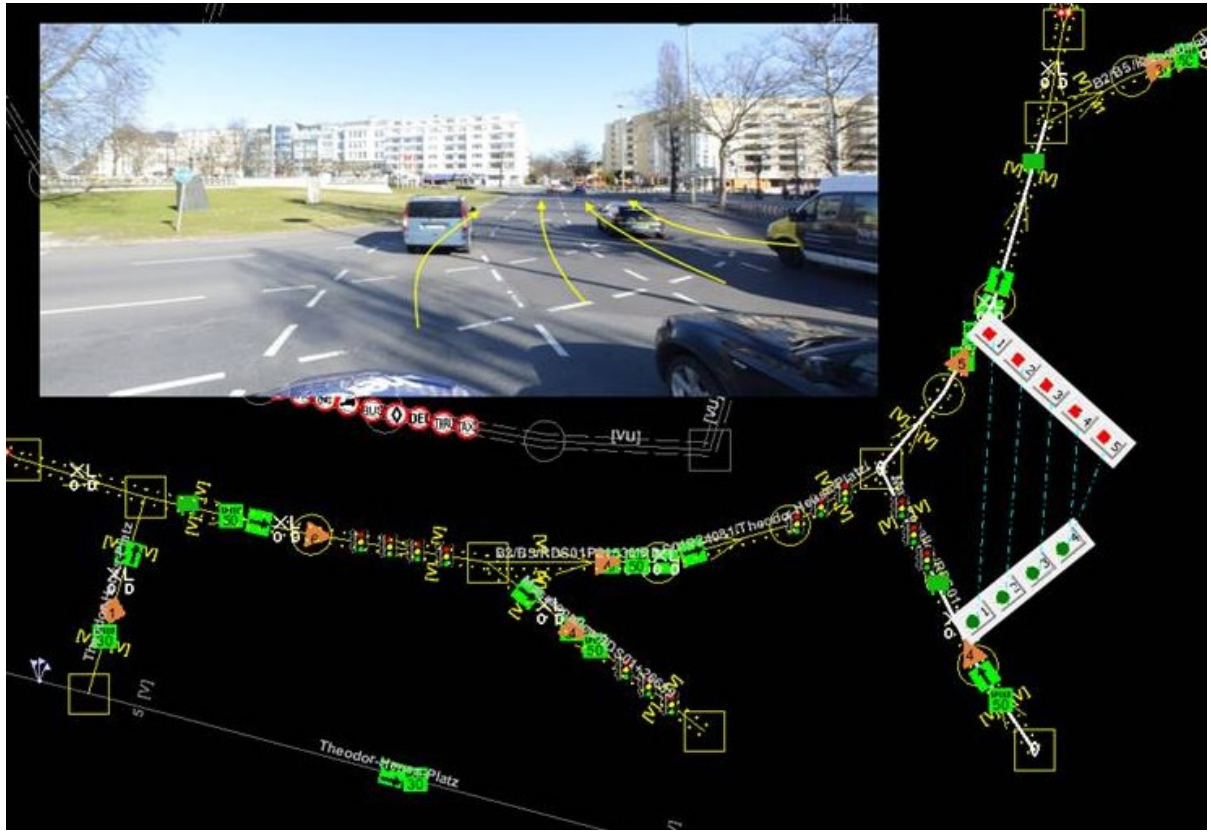
Global data profiles	Driving side	The legal driving side (righthanded or left-handed traffic).
Other profiles	Form of way	This profile represents the type or form of a path; a path can be a tunnel, a bridge, a divided road, etc.
Other profiles	Access restriction	Driving restrictions for a path.
Other profiles	Overtaking restriction	Overtaking restrictions for a path.



Lane coding sample of ADAS features

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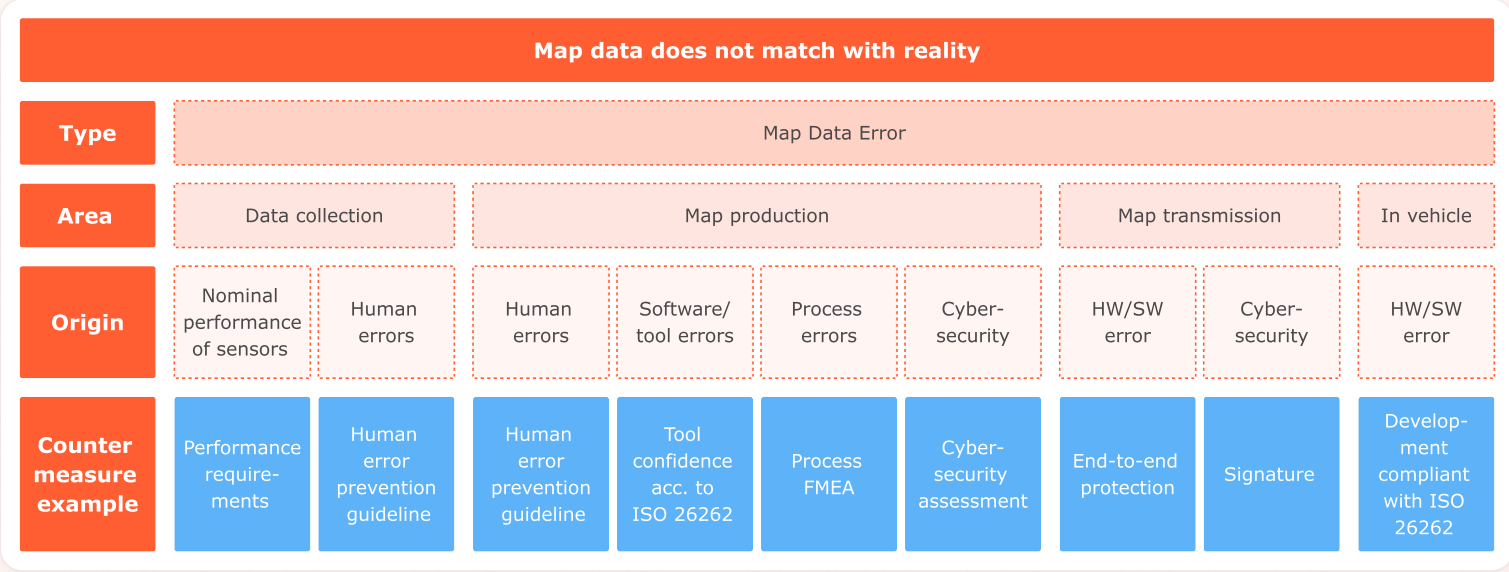
Quality Assurance & Crowd Control

Quality Assurance (QA) and Crowd Control (CC) processes are integral to navigation map production. In QA, data collection adheres to stringent standards, employing advanced surveying technologies like LiDAR and GPS. Metadata undergoes thorough validation, ensuring accuracy and completeness. Positional accuracy is assessed, and automated verification algorithms continuously monitor data for errors. Cross-referencing with other datasets enhances overall accuracy.

In CC, user feedback is actively integrated, encouraging real-time updates on road closures, traffic conditions, and infrastructure changes. User reports play a pivotal role in error identification. The process involves real-time map updates based on user-contributed data, ensuring maps reflect the latest changes. Verification mechanisms include validation algorithms, community-driven verification, and a continuous feedback loop for prompt issue resolution. Iterative updates and technological advancements contribute to continuous improvement in map accuracy.

Map data errors indicate potential failures in the map creation process. For instance, a road may be missing from the map due to human, hardware (HW), or software (SW) errors.



Possible map data errors

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AI and ML

In the field of mapping, AI applications are often used to:

- Optimize field collection routes for walking teams or a fleet of vehicle crews. (Algorithms generate optimal routes, reducing data collection time by 25%, resulting in a 30% increase in daily coverage and fuel savings).
- Classify map features in aerial or satellite imagery by recognizing objects such as roads, buildings, road markings, vegetation, etc.
- Detect and pinpoint specific objects or elements on maps, such as vehicles, pedestrians, or road signs.
- Identify land cover by distinguishing between different types of surface, such as water bodies or forests surrounding roads.
- Recognize changes in maps over time, making it easier to update and maintain accurate and up-to-date geographic information.
- Data quality control at the collection stage and during processing. (Automated checks enhance data quality by evaluating image clarity, GPS accuracy, and route alignment, improving overall accuracy by 20% and reducing manual review time by 70%).

By leveraging AI in mapping applications, the industry benefits from enhanced automation, improved accuracy, and the ability to process vast amounts of spatial data efficiently.

At the data stage of postprocessing field data, AI helps to quickly combine data from different sensors such as cameras, LiDAR, and positioning sensors.

Dynamic objects during data collection, such as vehicles and road users, sometimes block sensors and cause "noise" in the data, and the automatic use of AI speeds up the removal of these objects from the point cloud.

Field images are processed by an image recognition system, most often a convolutional neural network trained to recognize road signs. This system categorizes the types of signs in the image and defines a polygon with the minimum number of vertices needed to cover each road sign in the image. This speed up the mapping of map features such as road signs, lane markings, and other important elements.

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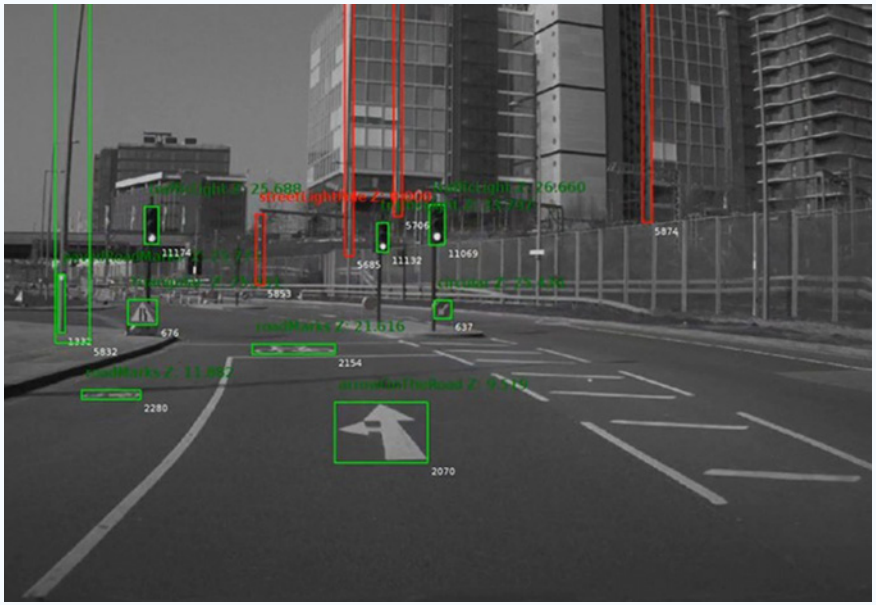
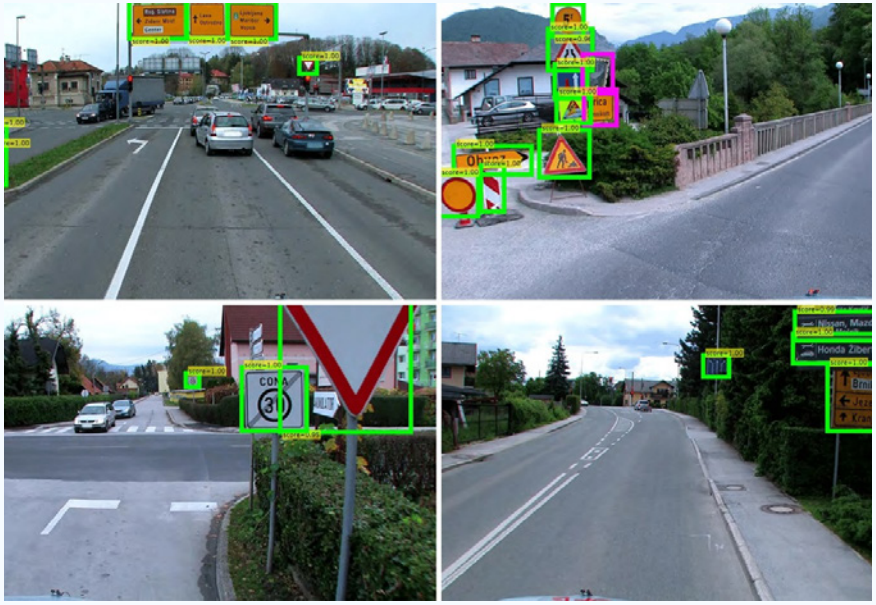


Traffic sign detection and recognition based on AI/ML

Source



Traffic sign detection and recognition based on AI/ML

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Intetics also actively utilizes ML capabilities in its data collection and map content creation projects. For example, in one of such projects Intetics built an ML pipeline to detect parking signs and extract all information from them.

LiDAR data is processed using Deep Learning algorithms to classify objects, including buildings, roads, and vegetation. Natural Language Processing (NLP) is utilized for non-visual data, extracting relevant details from textual information or spoken instructions to update map databases.

Artificial Intelligence algorithms classify objects on satellite and aerial imagery, such as: new parts of road network, bridges, construction sites, gas stations, rest areas, buildings and landscapes around the road.

AI/ML building footprints extraction and rooftop classification

Source

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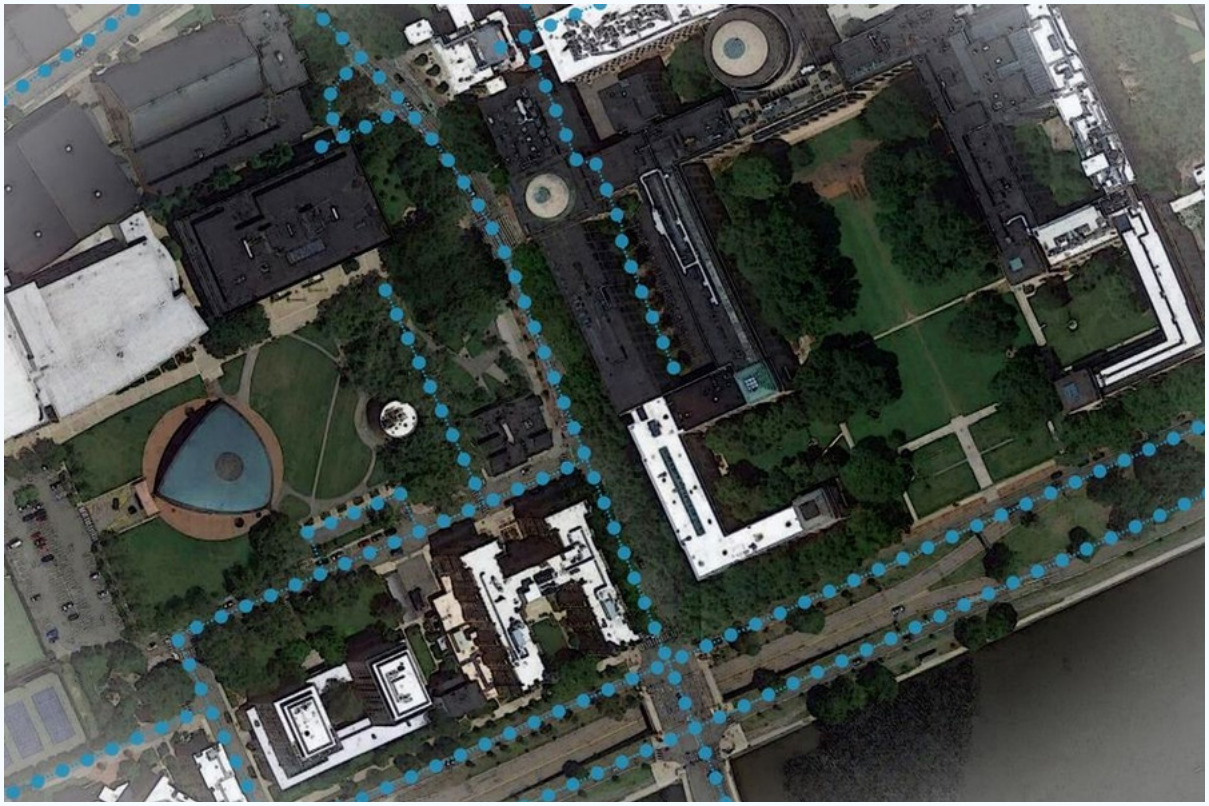

AI model uses satellite imagery to tag road features

Source

AI helps not only collect map data but also generate it. Based on sets of field images, a convolutional neural network (CNN) can predict road types and lane structure even in the presence of visual obstacles.

Automated combination of different map data sources allows you to maintain greater accuracy when processing your own field sources such as LiDAR and street level photos.

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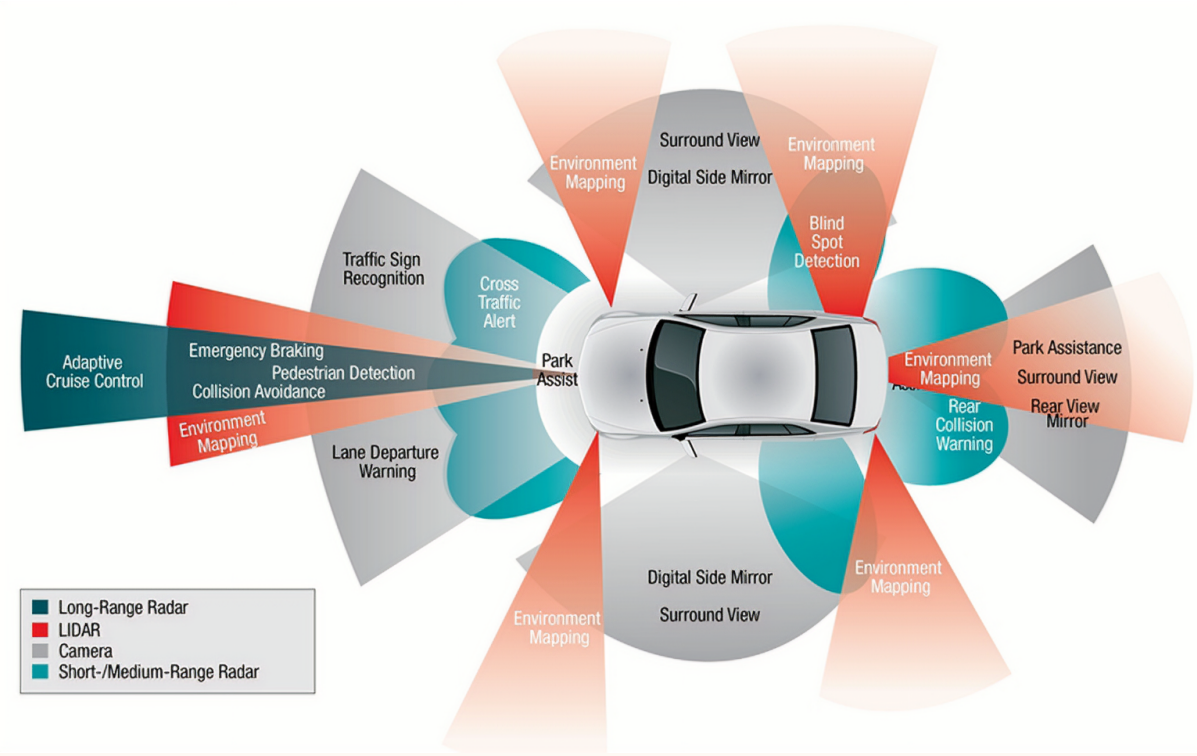
Automated Vehicles & HD Maps

Automated Vehicles

Automated vehicles (AV), also known as self-driving cars, is a technology that promises to eliminate some or all driving tasks from human control.

An autonomous car uses a variety of sensors, such as radar, ultrasonic sensors, cameras, LiDAR, and global navigation satellite communication systems and their intelligent combination. As a result, it can anticipate and avoid critical situations on the road, providing reaction times and visibility far beyond those of any human.



Various sensors in an autonomous vehicle

Source

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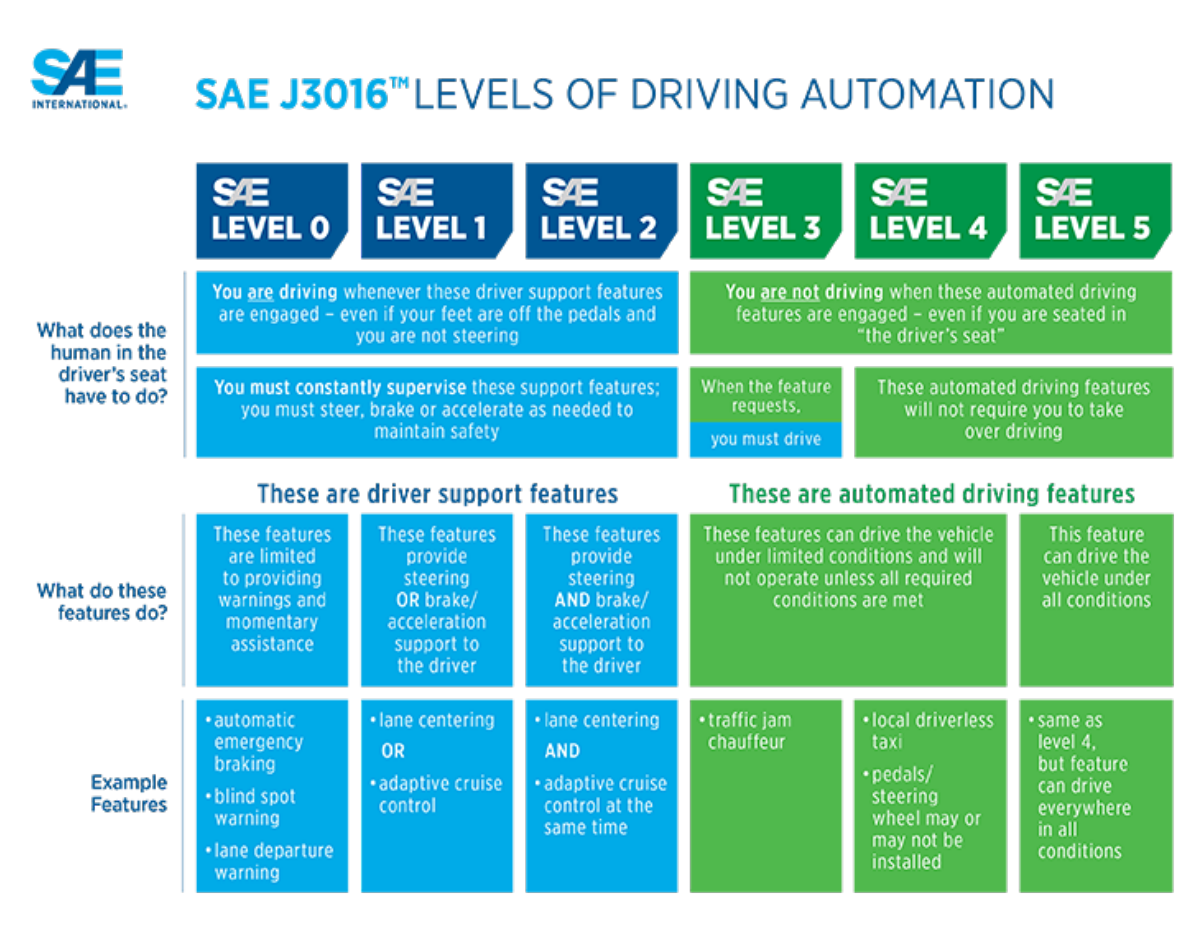
Levels of Driving Automation

The Association of the Automotive Industry (Verband der Automobilindustrie) has defined five different levels to classify the degree of automation of autonomous vehicles. These levels range from Level 0: Driver-only, where the driver must perform all normal driving tasks by himself, to Level 5: Driverless, where the car can perform all driving tasks by itself, and a human driver is no longer required. Accurate navigation is useful at all levels of autonomy, but becomes extremely important as the level of automation increases.



Levels of Driving Automation

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HD Maps for AV

The definition of an HD Map varies from vendor to vendor. There is no hard and fast guideline as to which components make up an HD map. However, all vendors agree that an HD map for autonomous driving requires high positional accuracy and precision, on the order of approximately 10-15 centimeters.

By relying on the HD map, the autopilot car increases its ability to obtain information about the current traffic situation around it and ahead of its route, beyond the range and capabilities of its own sensors. This additional information allows the driver assistant or autopilot to make more accurate decisions and plan the journey based on the additional data available, just as a driver would do with a traditional navigation map.

The array of sensors on modern cars—cameras, radars, and LiDARs—function as the "eyes" to detect other vehicles, pedestrians, road signs, traffic lights, and landmarks. However, unlike humans, machines lack contextual understanding. Humans can adjust in real-time and drive confidently in novel situations. Maps bridge this gap for automated cars. They offer additional layers of data, supplying the machine with a human-like context to complement the sensors' observations. This three-dimensional view of the environment requires maps to be both up-to-date and accurate down to centimeters.

> [Our maps] are any geographic information that we can tell the car in advance to make its job easier. We tell it how high the traffic signals are off the ground, the exact position of the curbs, so the car knows where not to drive. We'd also include information that you can't even see, like implied speed limits.
>
> ***Google's self-driving car team's mapping lead***
> ***Andrew Chatham, 2014***

According to Lyft, an HD Map is organized into five layers:

1. They are a base map (standard definition map), geometric map, the semantic map, map priors, and real-time knowledge.
2. The Geometric Map relies on raw sensor data from LiDAR, cameras, GPS, and IMUs, generating a dense 3D point cloud. This information undergoes postprocessing to create derived map objects stored within the geometric map.

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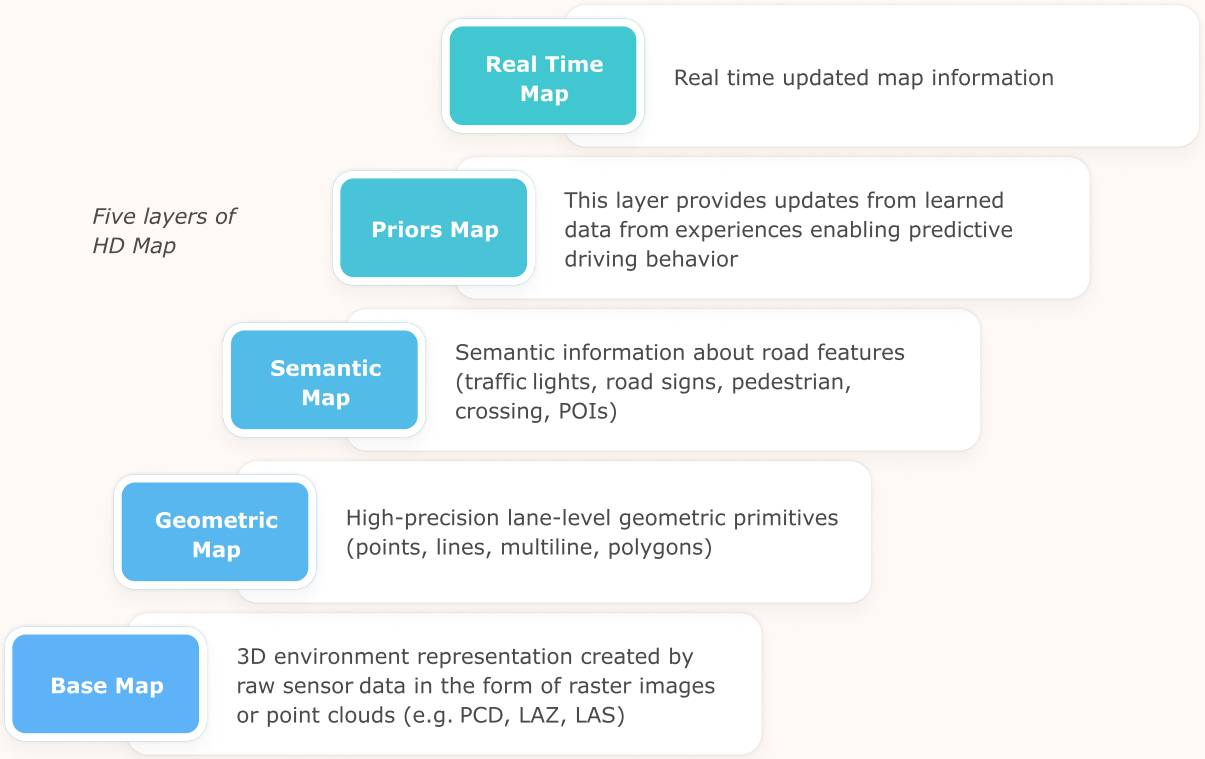
3. Built upon the geometric map layer, the Semantic Map Layer incorporates semantic objects, whether 2D or 3D, such as lane boundaries, intersections, parking spots, stop signs, and traffic lights. These objects include detailed data like traffic speeds and lane change restrictions, contributing to safe driving.
4. The Map Priors Layer integrates dynamic information and human behavior data, encompassing details like the sequence of traffic light changes, average wait times, probabilities of vehicle presence at parking spots, and average speeds at parking spots. Autonomy algorithms often use these priors as inputs, combining them with real-time information.
5. At the top-most layer, the Real-time Knowledge Layer dynamically updates with real-time traffic information, facilitating real-time sharing among autonomous vehicles in the fleet.



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Amount of data to store a map can be enormous. Note that the accuracy of an HD map may be deliberately limited by the map producer at the publication stage to reduce data storage requirements and computational costs. Some providers choose a map accuracy of approximately 15 cm as a compromise between data storage requirements and application requirements.

Requirements for the HD map:

- Lane level detailedness for mapped features.
- Locational accuracy around 5-10 cm: the car must be able to drive autonomously and stay in the lane in straights and curves (lateral control).
- Actual locations for traffic lights and stop lines.
- For longitudinal speed control, velocity must be mapped.
- For routing the topology must be correct.
- Features that must be mapped: curbs, lanes, white lines, traffic lights, pedestrian crossings, intersection, road signs, stop lines.
- Smooth curvature of the trajectories so the drive would be smooth (lateral control).
- Usage of indicator lights.

The most important tasks for AV that are provided by HD Map:

Tasks AV	Using HD Map in AV
Definition of road signs	When environmental conditions deteriorate (rain, night, etc.), traffic sign detectors may make mistakes or operate slowly. However, if there is an accurate and up-to-date map and precise localization, when a traffic sign detection fails, the map can be used as an emergency application system for safety.
Confirmation of line markings	Although automated vehicles have built-in lane detection systems, they are prone to error. A map allows the vehicle to verify the line markings detected by the system and reject any erroneous markings.
Line structure	One of the key requirements for a map for an automated vehicle is to detail lane logic. This is because lane logic describes the direction of travel in a lane or whether a lane is intended for straight travel or for turning. This information can be provided by markings, but if there are errors or mislabeling in the real world, the consequences can be potentially serious.

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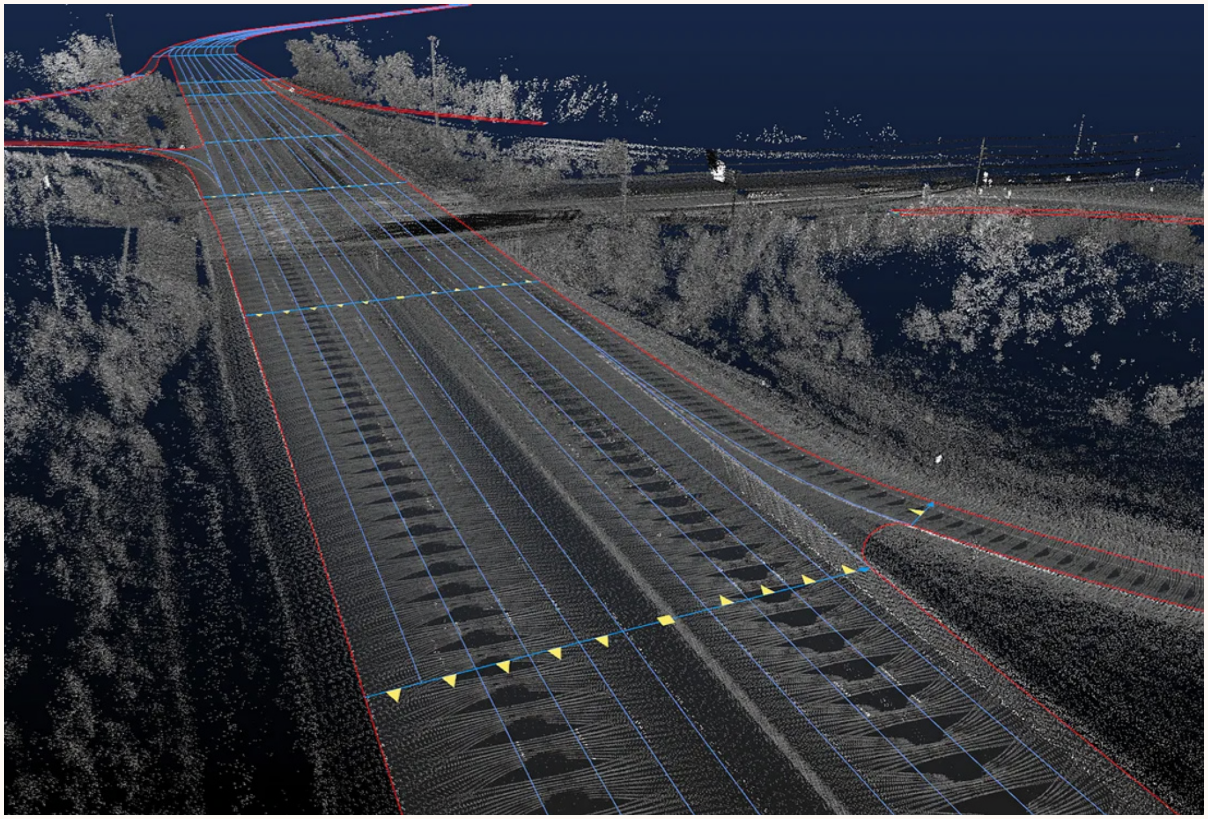
Localization	One of the biggest challenges in using an HD map is the localization element. With increasing details about the position on the map, it becomes important to know the exact location of the vehicle on the map. The accuracy required is higher than what GPS can provide, so software is needed to localize the vehicle on the map by comparing the sensor input with an existing accurate map. This task becomes even more challenging when you consider that there are usually numerous dynamic and temporary objects on the road; the localization system needs to have some understanding of which objects are temporary to avoid using them as landmarks for localization.



Road lines mapping

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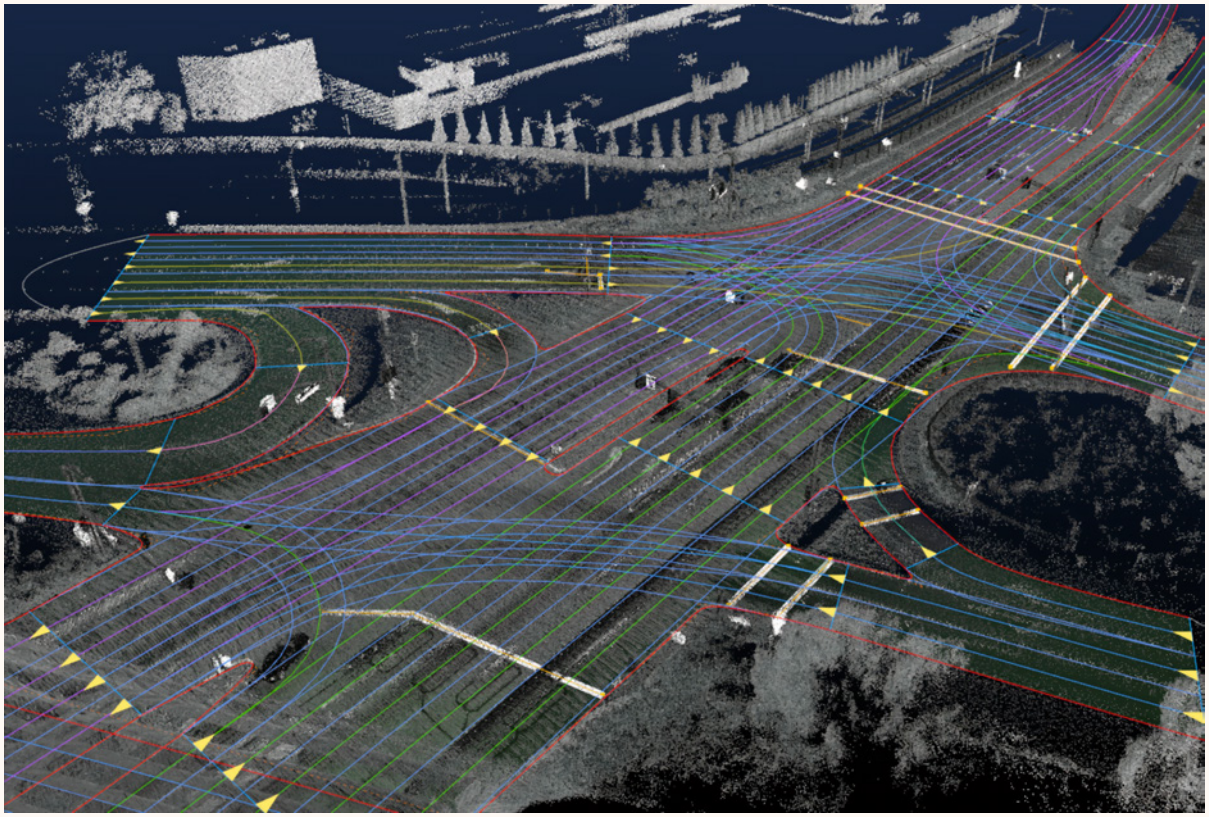

Road lines mapping

Examples of HD maps creation are well described on the following articles:

https://arstechnica.com/cars/2017/03/the-most-detailed-maps-of-the-world-will-be-for-cars-not-humans/

https://www.here.com/learn/blog/here-introduces-hd-maps-for-highly-automated-vehicle-testing

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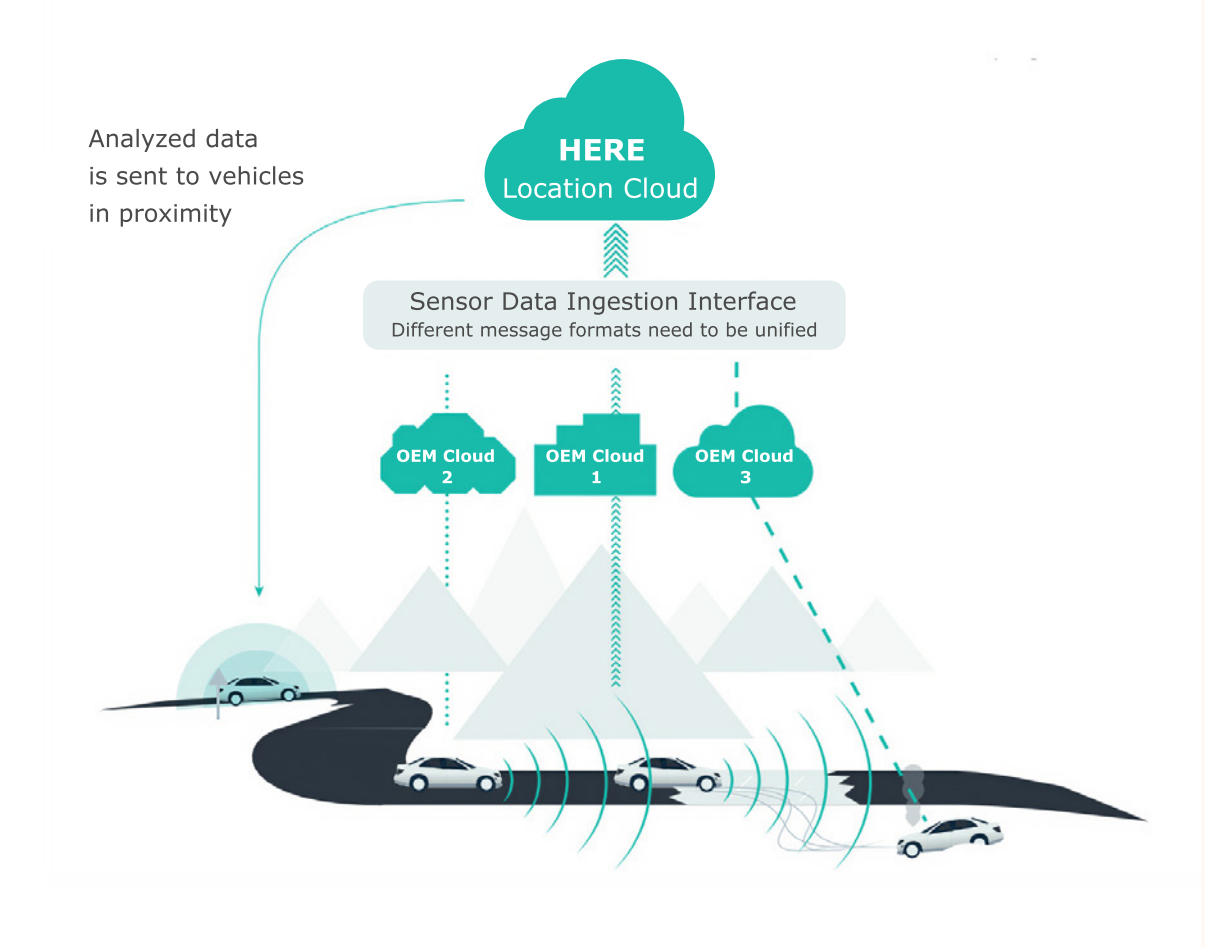
Updating of HD Map

Due to the high accuracy and time-criticality of the information for AD, the HD map needs to be updated faster. Autopilot vehicles must always be able to rely on the most up-to-date map data to properly execute decisions while driving on the road. As a result, the HD map needs to be constantly updated, and the updates need to be delivered wirelessly. In addition, self-driving cars themselves collect information about the current traffic situation around them and provide it to the overall navigation platform. See HERE self-healing map.



Connected vehicles exchange information wirelessly

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Connected vehicles (CVs) allow vehicles to communicate with each other and the world around them. In addition to HD Map and their own sensors, connected vehicles can use information from other connected vehicles. For example, the first car to detect a new obstacle on the road can quickly warn all subsequent vehicles long before they reach the area, increasing travel comfort and overall safety.

To efficiently access the various geo-referenced objects within the map for updating and maintaining them, the navigation is structured on different levels. These different levels are organized in terms of temporal dynamics and the required accuracy of the included objects. For example, traffic lanes require precise localization on the map to the level of centimeter accuracy, and changes do not occur very often. Weather conditions, such as fog, rain, or snow, on the other hand, cover several kilometers of the route and therefore do not require such high localization accuracy, but change frequently. The cost of an error can be different for different map layers. The highest quality requirements apply to the mapping of road signs and lanes.

Challenges for AD and HD Maps

Challenges for AD include developing reliable solutions for autonomous driving in conditions such as heavy traffic, snow, and rain, as well as reliable detection and interaction with road users such as pedestrians and cyclists. The aforementioned difficulties can be partially eliminated by providing automated vehicles with HD map. This allows the car to compare the data received by its sensors with the map and "fill in the gaps" where the data coming from the sensors is limited.

In the pursuit of scalable HD maps for autonomous mobility, significant research and development efforts have emerged in the past decade. Despite progress, there are persistent challenges in achieving the full potential of HD maps, falling into the following categories:

Data Collection:

- HD map data collection is time-consuming and labor-intensive, involving sensors like GPS, IMU, LiDARs, and cameras.

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Data Communication:

- Transferring mapping data from collection to processing and consumption, especially in real-time, poses challenges due to the large volume of data generated by mapping vehicles.

Data Processing:

- Creating HD maps involves complex data processing, aggregating and aligning information from various sources while ensuring accuracy and real-time synchronization among multiple mapping vehicles.

Map Maintenance:

- Continuous efforts are required to keep HD maps up-to-date with changes in the road environment, including construction sites, road blockages, and modifications.

Data Security and Privacy and Ownership:

- HD maps often contain sensitive information, necessitating robust measures to ensure data security and privacy.

  Despite the widespread availability of digital maps, many countries strictly regulate and even prohibit the export of geospatial data, a challenge present in traditional navigation maps:

  - The emergence of HD Maps intensifies this challenge due to unclear government regulations. Sensitivity issues arise from high-resolution LiDAR in cars and continuous camera scanning, including private areas. Addressing privacy, adhering to security regulations, and robust data encryption are critical.
  - Ownership aspects of data, whether by the car owner, manufacturer, or government, require resolution. These concerns, inherent in maps, gain prominence with dynamic map development.

Mapping Cost:

Building HD maps at a large scale requires numerous mapping vehicles equipped with expensive mapping devices. The cost becomes a significant factor, particularly when mapping extensive areas. While the use of consumer-grade sensors is possible, it may compromise the sophistication of mapping algorithms.

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HD Map for Other Needs

HD maps primarily serve the purpose of aiding autonomous vehicles in comprehending and safely navigating their surroundings. With their detailed and precise depiction of the environment, HD maps extend their utility to enhancing the quality of services provided by conventional digital maps. Additionally, these maps can play a crucial role in digital assistive technologies tailored for individuals with disabilities. For visually impaired individuals equipped with suitable sensors, having access to a highly accurate, detailed, and semantically rich representation of the environment could significantly improve mobility and safety.

When precisely localized, a digital assistive device can interpret and understand the surroundings, generating vocal navigation instructions for secure navigation. Integrating real-time information, such as the status of traffic lights and other relevant traffic details, into HD maps for pedestrians becomes pivotal to enhance the functionality of these devices. The development and continuous updating of HD maps encompassing all participants will pave the way for a comprehensive and inclusive range of autonomous and non-autonomous applications.

Accurate maps are essential for engineers and planners to maintain and develop road and urban infrastructure. Needed to navigate autonomous last mile delivery vehicles. To ensure safety on the road and investigate traffic incidents.

Accurate photorealistic models obtained in the process of lidar and photogrammetric surveying are needed by urban planners and for tourist purposes. It is important for municipalities to have up-to-date models of public buildings for proper management.

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8 Conclusions

In this review, we have navigated through the intricate process of digital navigation chart production, providing insights into the essential stages—from meticulous field collection planning to rigorous quality control and the seamless integration of new data into the navigation platform.

A noteworthy shift in the consumer landscape is the growing demand for vehicles with a high level of automation. This trend necessitates heightened precision and efficiency in updating times, reflecting the dynamic requirements of an evolving automotive market.

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Standards

ADAS (Advanced Driver Assistance Systems) represent a cutting-edge suite of technologies primarily dedicated to enhancing collision avoidance capabilities, exemplified by features like lane departure warnings and blind-spot applications. In addition to collision prevention, ADAS encompasses a spectrum of driver aids, including but not limited to night vision, driver alertness monitoring, and adaptive cruise control. The core strength of ADAS lies in its real-time responsiveness, swiftly reacting to diverse inputs while intelligently prioritizing information to avert potential accidents.

The integration of ADAS extends beyond the vehicular realm into navigation systems, where intricate details are embedded within the maps. These maps not only provide the geographical context but also incorporate ADAS geometry and precise attributes essential for optimal system functionality. A key component of this integration is the ADAS Attributes layer, which encompasses crucial parameters such as height, slope, curvature, and heading attributes meticulously assigned to the road network. This layer serves as a foundational element, enriching the overall ADAS capabilities by ensuring a comprehensive understanding of the road environment, thereby contributing to a safer and more intelligent driving experience.

Product features Using HERE ADAS Map provides access tothe following features:

- **Warning and traffic signs:** roadside signs warning drivers about special conditions, such as speed limit signs for trucks, use of trailers, bad weather, and time-related situations.
- **Curvature:** angles on a road and over intersections to prevent drivers from making turns that are too sharp.
- **Slope and elevation:** to aid appropriate acceleration and deceleration on an incline. Supports fuel economy.
- **ADAS quality & source flag:** quality parameters included to indicate reliability of ADAS attributes.
- **Average speed:** measures average speed of cars driving along a section of road in a specific direction.
- **Speed limit metadata:** Country-wide speed limits for specific road and vehicle types.

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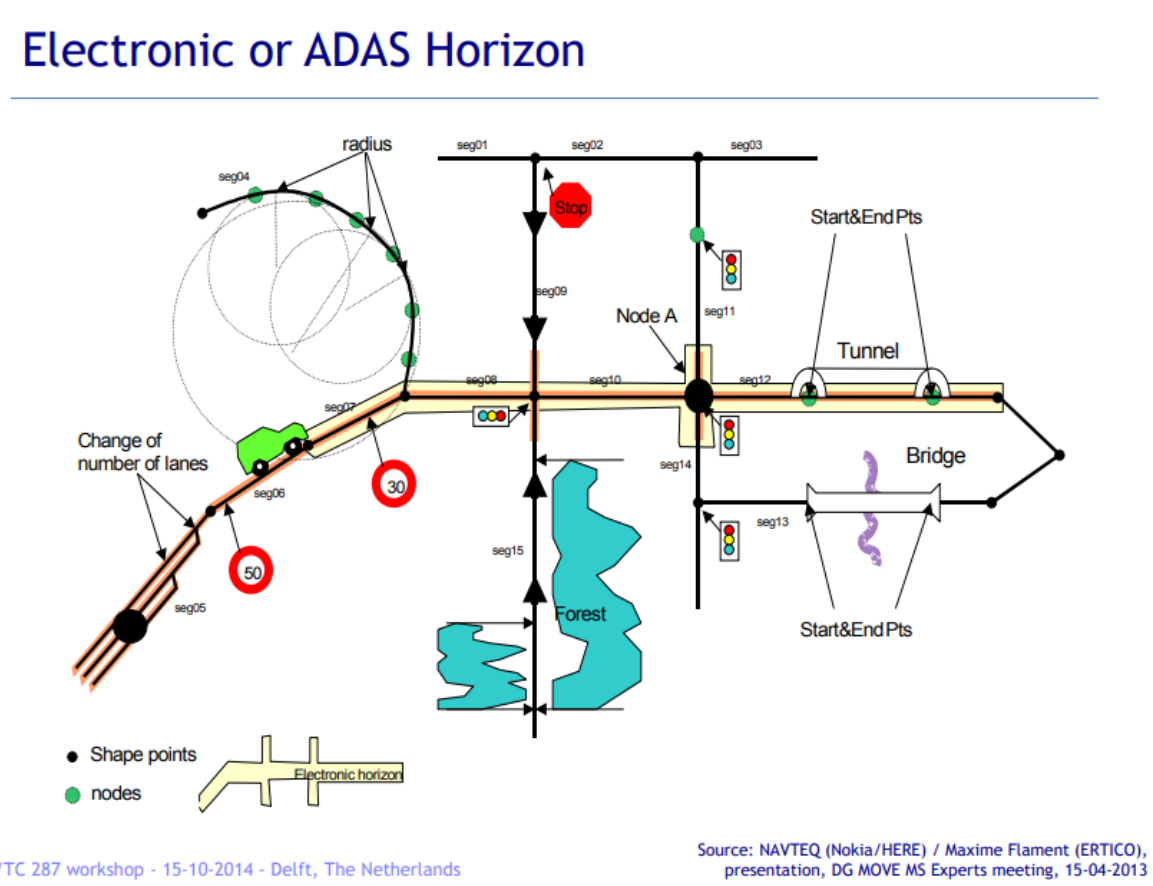
- **Enhanced geometry:** indicates when the geometry is suitable for HAD purposes.
- **Truck speed limits:** speed limits with truck-specific attributes.



HERE ADAS Map

TomTom, HERE Maps, and Nvidia publish their maps in proprietary formats, but the true potential of HD mapping for autonomous vehicles lies in standardization. Standardization is crucial for ensuring map integrity and reliability. Recognizing this need for consistent data specifications, the Navigation Data Standards (NDS) Association was established to promote standardization in HD mapping.

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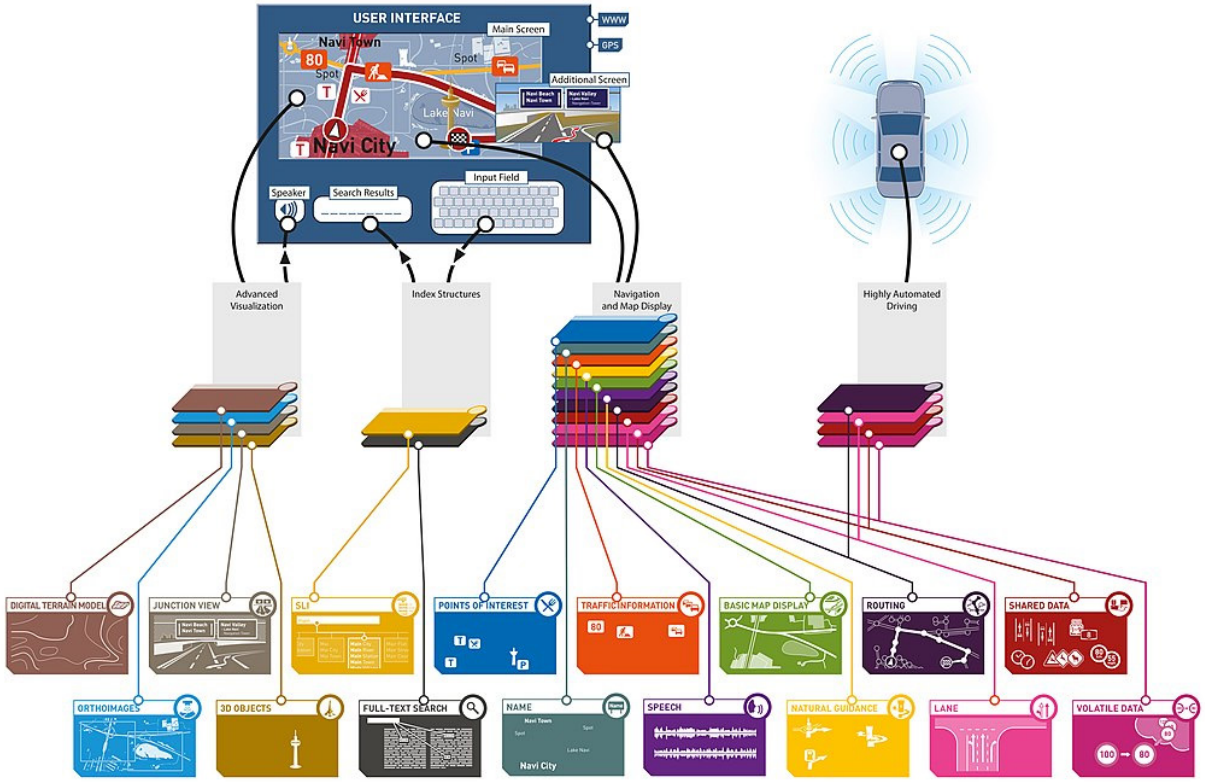
NDS (The Navigation Data Standard) is a standardized data storage format for maps, which is shared amongst all member corporations of the NDS association (founded in 2008). It is continuously being evolved to meet the map requirements for cars manufactured by member corporations. Currently NDS maps include lane level data, localisation data, obstacle data and road topology.

NDS uses the SQLite Database File Format. An NDS database can consist of several product databases, and each product database may be divided further into update regions. This concept supports a flexible and consistent versioning concept for NDS databases and makes it possible to integrate databases from different database suppliers into one NDS database.



Building blocks of Navigation Data Standard

Source

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ADASIS (Advanced Driver Assistance Systems Interface Specifications) acts as an important interface that connects map data, such as the NDS standard, to the vehicle's electronic control unit. This ensures seamless communication by integrating accurate mapping information into vehicle control systems. The standard requires centimeter-level accuracy for lane-level map data, including details of road geometry. Access to accurate map data improves location accuracy, environmental perception and route planning, significantly increasing safety and helping drivers in difficult situations. ADASIS v3 standardizes the delivery and distribution of map data for in-vehicle devices to support advanced driver assistance systems and automated driving functions.

OpenDrive. The standard was originally published in 2005 by VIRES Simulationstechnologie GmbH, but in 2018 the standards were adopted by Association for Standardization of Automation and Measuring Systems. OpenDrive is an open file format organized in a hierarchical structure and serialized in an XML format. The format is technology and vendor independent.

The format describes exact road geometry, includes surface properties, markings, signposting and logical properties such as lane types and directions. OpenDrive has one reference line and lanes are built around that.

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Glossary

0-9

3D Map Modeling
Creating three-dimensional representations of the environment for enhanced spatial awareness and visualization.

A

Absolute Accuracy
A term using in spatial maps to define the proximity of a measured map feature to the true position (in global coordinates) of that map feature (the difference between a map and the real world).

ADAS (Advanced Driver Assistance Systems)
Defines automation systems that assist the human driver in performing the dynamic driving task.

AV (An acronym for Automated Vehicle)
A vehicle which may perform all of its actions autonomously. An automated vehicle is capable of performing the entire dynamic driving task without human input, either with human supervision (SAE level 3 autonomy), without human supervision but limited ODD (SAE level 4 autonomy), or under all possible conditions (SAE level 5 autonomy).

C

Change Detection Algorithm
Automated algorithms identifying changes in the physical environment from various data sources.

Completeness
Evaluates how well a digital map includes all essential information about a geographic area. It ensures that the map provides comprehensive details, minimizing gaps or missing data, and covering various elements such as roads, landmarks, and boundaries.

Connected Vehicle
A vehicle which has built-in real-time communications with the world outside the vehicle. This could include internet access, communications with other vehicles and communications with roadside infrastructure.

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	CNN (Convolutional Neural Network)	Is a regularized type of feed-forward neural network that learns feature engineering by itself via filters (or kernel) optimization.
	Crowdsourced Mapping	Gathering map data collaboratively from a large number of users to enhance and update mapping information.
D	**Data Harmonization**	Ensuring consistency and compatibility among different datasets integrated into the map.
	Dynamic Map Updates	Real-time adjustments and additions to map data reflecting changes in the physical environment.
F	**Fleet Management System**	Assisting companies in managing vehicle fleets, optimizing routes, and monitoring vehicle performance.
G	**Geocoding**	Converting addresses or place names into geographic coordinates for mapping and location purposes.
	Geofencing	Creating virtual boundaries triggering specific actions when a device enters or exits predefined areas on a map.
	Geotagging	Adding geographical metadata to media like photos or videos to associate them with specific locations.
	GIS (Geographic Information System)	Is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface.

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	GNSS (Global Navigation Satellite System)	A network of satellites enabling precise location determination worldwide. It is used in navigation, mapping, surveying, and timing synchronization.
H	**HD Map Generation**	Creating High-Definition maps with detailed information, often used in autonomous driving.
L	**Lane-Level Navigation**	Providing detailed information about individual lanes on a road, essential for advanced driver assistance systems and autonomous vehicles.
	LiDAR (Light Detection and Ranging)	A sensor that uses low energy laserlight to record distances to objects in the environment.
	Localization Data	Information used to adapt maps for specific regions, including language, cultural nuances, and local preferences.
M	**Map Compilation**	Aggregating and integrating various geographic data sources to create a comprehensive digital map.
	Map Conflation	Resolving discrepancies and ensuring alignment between multiple datasets to create a unified and accurate map.
	Map Enhancement	Continuous efforts to improve map features, visualizations, and user experience.
	Map Matching	Aligning real-world vehicle trajectory data with corresponding positions on a digital map to ensure accurate positioning information.

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	Map Metadata Management	Handling additional information about map features, such as creation date, update history, and attribution details.
	Map Validation	Assessing the accuracy and reliability of map data through testing and quality assurance measures.
	Map Versioning	Managing different versions of maps to track changes over time and provide users with up-to-date information.
	Mapillary	Is a service for sharing crowdsourced geotagged photos. It officers open licensed street level imagery similar to Google StreetView.
	MMS (Mobile Mapping Systems)	Advanced technology that integrates various sensors, cameras, and LiDAR on a moving platform, typically a vehicle, to capture geospatial data.
N	**Navigation Attributes**	Data attributes used for routing, such as speed limits, turn restrictions, and road classifications.
	NDS	The worldwide standard for map data in automotive eco-systems nds-association.org.
O	**OpenStreetMap**	Is a free and open geographic database updated and maintained by a community of volunteers via open collaboration. Contributors collect data from surveys, trace from aerial imagery and also import from other freely licensed geodata sources.
P	**Point Cloud**	Is a collection of points in a 3D space. Each point has its own x, y, and z coordinates and typically is very dense (i.e. a very large number of points in a given area).

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	Positional Accuracy	Assesses how accurately map features represent their real-world locations. It measures the precision and correctness of geographic coordinates on a map.
R	**Relative Accuracy**	Is the positional accuracy of a point on a map, when compared to other points on the map. In other words, a high relative accuracy means that the distance between two points on the map is equivalent to the true distance between those two points if they are measured in the real world.
	Routing Algorithm	An algorithm determining the optimal path or route between locations on a map, considering factors like distance, time, and traffic conditions.
	Routing Engine	Software calculating the best route between locations considering factors like traffic and road conditions.
S	**Spatial Temporal Data**	Information including both spatial and temporal dimensions, crucial for dynamic mapping.
T	**Telematics**	Integration of telecommunications and informatics for applications like vehicle tracking, fleet management, and navigation systems.
	Traffic Data	Information about current traffic conditions used by navigation systems for real-time updates and route optimizations.
V	**Voxel**	A voxel is analogous to the 3D version of a pixel; it is a cube within a 3D model and may be either an occupancy voxel (binary, denoting the presence or lack of a solid object) or colour voxel.
W	**Waypoint**	A specific point on a route defined by geographic coordinates to guide navigation systems.

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Events and Communities

- International Conference on Location-Based Services (LBS): Explores the latest trends and applications in location-based services, including mapping and navigation. https://lbsconference.org/
- Geospatial World Forum: A global platform for geospatial industry leaders, discussing the impact of geospatial technology on various sectors. https://geospatialworldforum.org/
- Intelligent Transportation Society (ITS) World Congress: Focuses on intelligent transportation systems, including discussions on mapping and navigation technologies for smart mobility. https://itsworldcongress.com/
- Connected & Autonomous Vehicles (CAV) America: Addresses the latest developments in connected and autonomous vehicles, with a focus on mapping and navigation solutions. https://www.autonomous-vehicles-conference.com/
- Automotive Tech.AD: A conference dedicated to the latest advancements in automotive technology, including discussions on mapping for autonomous driving. https://www.autonomous-driving-berlin.com/
- HERE Directions: An event hosted by HERE, covering innovations in mapping, location-based services, and technologies shaping the future of mobility. https://www.here.com/here-directions-2023
- CES® is the most powerful tech event in the world—the proving ground for breakthrough technologies and global innovators. https://www.ces.tech/
- ADAS & Autonomous Vehicle Technology Expo—most influential hub for automotive innovation, research and development. https://www.autonomousvehicletechnologyexpo.com/
- HERE Map Creator Community. https://forum.mapcreator.here.com/
- OpenStreetMap Community Forum - OSM Community Forum. https://community.openstreetmap.org/
- Mapillary Community Forum. https://forum.mapillary.com/
- GIM International a global magazine and online platform that focuses on geomatics, surveying, and related spatial technologies. https://www.gim-international.com/

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- ITS International is the leading media platform for the intelligent transportation systems industry worldwide, who are holding a conference ITS World Congresses and ITS America Annual Meetings. https://www.itsinternational.com/
- GPS World is a publication and online platform that focuses on GNSS, including the Global Positioning System (GPS) and other satellite navigation technologies. https://www.gpsworld.com/
- LiDAR News is a platform and publication dedicated to LiDAR technology, providing information, news, and insights about Light Detection and Ranging (LiDAR) applications, industry trends, and developments. https://lidarnews.com/
- GeoConnexion is a platform covering geospatial technologies, GIS, mapping, surveying, and location-based services, offering insights into industry developments and trends. https://www.geoconnexion.com/
- GeoWeek is a conference that brings together professionals, experts, and enthusiasts in the geospatial industry. It provides a platform for networking, sharing knowledge, and exploring the latest advancements in GIS, mapping, and related technologies. https://www.geo-week.com/
- GeoBusiness is a leading geospatial event that connects professionals, businesses, and innovators in the geospatial industry. https://www.geobusinessshow.com/
- Inside GNSS is a platform that provides news, insights, and analysis on global navigation satellite systems (GNSS) and related technologies. https://insidegnss.com/

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