THE FUTURE OF MAPS: TECHNOLOGIES, PROCESSES, AND ECOSYSTEM

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1. MAPS: BACKGROUND AND MARKET TRENDS

1.1 INTRODUCTION

Maps remain critical elements across all consumer, mobility, and Internet of Things (IoT) use cases, powering a range of transformational paradigms, including location-based search, social networking, end-to-end freight tracking, and autonomous driving. Maps are at the heart of the smartphone, driverless vehicle, and IoT revolution. Maps are ubiquitous and taken for granted. However, new demands in terms of accuracy, attributes, functional safety, freshness and continuous updates, and quality requirements are turning map making into increasingly complex, high-tech, and expensive processes. While a growing ecosystem of new entrants and mapping startups are emerging, longstanding expertise and deep insight into data formats and local requirements remains critical.

1.2 KEY TRENDS

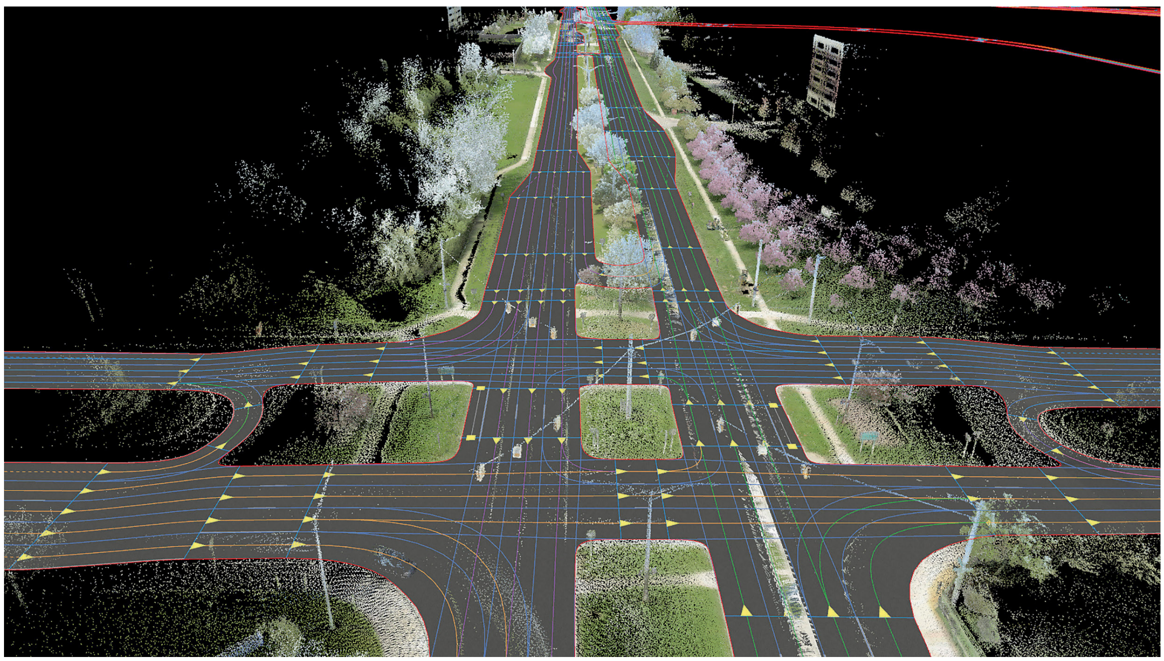
The main trends in the role and use cases of maps are outlined below.

1.2.1. NEW MAPPING USE CASES

Maps have traditionally mainly been used for outdoor road-based turn-by-turn navigation as part of automotive infotainment systems. A range of new use cases is now emerging:

- **Safety and Mission-Critical Autonomous Vehicle (AV) Use Cases:** The use of maps will be extended to more mission-critical applications like informational safety (Electronic Horizon), active safety, and Advanced Driver Assistance Systems (ADAS) (Level 2+, semi-autonomous driving, and lower levels of automation), as well as advanced levels of automation (Level 4 to 5), from positioning to humanized driving, providing visibility to vehicles beyond the reach of their onboard sensors in order to make autonomous driving more comfortable and reliable, based on advanced path planning and information redundancy, and the use of maps in driverless simulation and training.
- **Pedestrian Navigation and Guidance:** Key mapping use case for smartphones and wearables.
- **Indoor Navigation:** Emergence of indoor maps for in-building human and robotic navigation, guidance, delivery, and tracking in venues, airports, manufacturing plants, and warehouses.
- **Non-Automotive IoT Use Cases:** Non-automotive IoT use cases are also on the rise across segments like supply chain (goods location tracking), government, and smart cities (urban planning and management).

Figure 1: HD Maps for Autonomous Vehicles *(Source: HERE)*



1.2.2. NEW MAPPING CONTENT

Closely linked to the new use cases described above, a range of new map content categories is added through separate map layers and attributes:

- **3D Maps:** The addition of 3D representations of building and various types of landmarks and content caters to a more intuitive and user-friendly navigation and guidance for both vehicles and pedestrians. This is culminating in the concept of High-Definition (HD) maps for driverless vehicles, including an accurate Three-Dimensional (3D) representation of the entire environment.
- **Imagery:** Street level, aerial, and satellite imagery are fast becoming essential components of maps, providing additional visual information for improved confidence and convenience. One of the major drawbacks of image-based content is the very low update frequency, which can be offset, to some extent, through community-based crowdsourcing of images. Imagery is also increasingly used for the (automated) generation of traditional maps and/or the addition of new map content categories like 3D buildings (see Figure 1), green spaces, and lane boundaries.

1.2.3. GLOBALIZATION TREND

Technology suppliers and car Original Equipment Manufacturers (OEMs) are increasingly launching global platforms, driving the need for global map coverage and the one-stop shop sourcing of global content. This requires map companies to extend their coverage into challenging regions like China and other countries in Asia.

1.2.4. DEVELOPING MAPPING ECOSYSTEM

A range of startups prioritizing automated crowdsourcing and the use of Artificial Intelligence (AI) and deep learning technologies have emerged over the past year. At the same time, a wave of partnerships across the technology ecosystem can be observed, aimed at increasing coverage, building HD maps for AVs, or acquiring AI-based mapping technology.

1.2.5. NEW BUSINESS MODELS

Business models for monetizing map content are evolving, with pressure on map pricing resulting in new monetization paradigms, such as maps-as-a-service, embedded in larger solutions sets and packages (indirect monetization), marketplaces, and advertising.

1.2.6. OPEN (SOURCE) LOCATION AND MAPPING PLATFORMS

Linked to some of the previous points, open platforms are increasingly seen as critical enablers to support a wider ecosystem play, new mapping use cases, and content categories. Location platforms will also be integrated and embedded in hardware and semiconductor components. Open source maps and community crowdsourcing approaches are also emerging with OpenStreetMaps (OSM) used by some vendors as a basis for navigable maps with additional navigation-related attributes generated *via* AI tools. In some cases, dedicated low-cost aftermarket automotive camera rigs are installed in consumer or rideshare vehicles for accelerated crowd-sourced map-making.

2. BUILDING MAPS: DATA SOURCES, TECHNOLOGIES, STANDARDS, AND PROCESSES

2.1 TECHNOLOGY TRENDS

The main technology trends that are transforming map generation processes are listed below, many of which are mutually interdependent.

2.1.1. SENSOR DATA CROWDSOURCING

The use of a wide set of fixed, mobile, and vehicle sensors, including Light Detection and Ranging (Lidar), image sensors, and even radar (*e.g.*, Bosch radar road signature), as well as remote sensor data *via* Vehicle-to-Everything (V2X) communication to build continuously updated maps based on real-time data. Camera sensor-based map-generating technologies retain the advantage of leveraging an already large installed base of vehicles equipped with camera sensors used for ADAS features, hereby accelerating the scale of the crowdsourcing effort.

2.1.2. MAPS AS A SENSOR

Maps are becoming integrated into the wider sensor fusion concept, complementing and enhancing onboard vehicle sensors and allowing off-loading on the fly computing to maps for lane keeping, traffic sign recognition, and other functionalities.

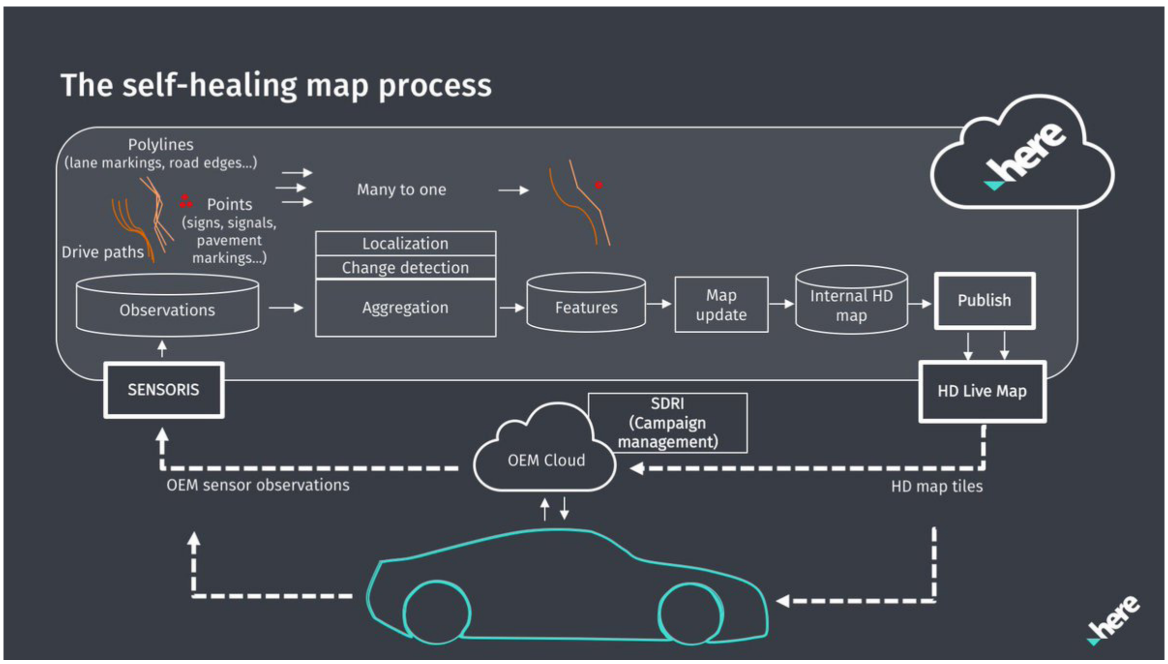
2.1.3. STREAMING MAPS

Maps are evolving from static-based maps to dynamic content repositories based on real-time sensor data streamed in real time to devices and vehicles.

2.1.4. SELF-HEALING MAPS

Maps are increasingly updated automatically based on AI and deep learning techniques to identify modified features, allowing automated, closed loop map generation and update processes.

Figure 2: Self-Healing Maps *(Source: HERE)*



2.1.5. AI AND DEEP LEARNING

This refers to the use of AI to build detailed maps from high-resolution image sensors, as opposed to using AI to interpret image sensor images in real time

2.1.6. CLOUD-BASED STORAGE AND PROCESSING

The dynamics in terms of real-time processes and computing described above de facto mandate the use of cloud-based technologies. This will be driven by low-latency 5G connectivity in the future and edge cloud capabilities in particular, allowing reliable and low-latency uploading, processing, and streaming of mapping content, while still allowing for intelligent caching of local content to hedge against predictable loss of connectivity (i.e., hybrid approaches).

2.1.7. HD MAPS AND SIMULTANEOUS LOCALIZATION AND MAPPING

This refers to the use of high-accuracy HD 3D environmental maps for relative positioning based on Simultaneous Mapping and Localization (SLAM) and Time-of-Flight (ToF) measurements. HD maps provide accurate (10 cm to 20 cm) and dynamic 3D renderings of the road environment, including details like slope and curvature of roads, lane markings, and roadside objects, such as sign posts, obtained using Lidar-equipped data capture vehicles. While the need for maps is still questioned by some technology vendors, touting the universal operation benefit of map-less systems, they represent a huge burden on onboard computing power and have a lack of redundancy of information, which is relevant for highly reliable operation.

2.1.8. INCREMENTAL OVER-THE-AIR UPDATES OF MAPS

As described above, streaming map updates are becoming a key requirement for keeping critical onboard vehicle maps up-to-date. This is increasingly challenged by the cloud-based maps-as-a-service paradigm, continuously streaming content from the cloud, as opposed to updated maps stored locally in vehicles.

2.1.9. VECTOR AND TILE-BASED MAP FORMATS

New map coding standards based on vectors and tiles are instrumental in reducing file sizes and enable incremental updates.

2.1.10. INTEGRATION OF LOCATION AND MAPPING INTO CHIPSETS

Location and mapping will be embedded at a chipset hardware level, enabling additional efficiencies and seamless integration.

2.2 MAPPING STANDARDS

2.2.1. NAVIGATION DATA STANDARD

The Navigation Data Standard (NDS) is a standardized binary database map format for automotive-grade navigation databases, co-developed by car OEMs and suppliers. NDS supports compatibility and interoperability, separation of application software and map data, and incremental updates. The not-for-profit NDS Consortium is headquartered in Germany. Members include automotive OEMs, map data providers, and navigation device and application providers (Daimler, BMW, VW, Hyundai, Nissan, Renault, Volvo, HERE, TomTom, Zenrin, AutoNavi, NavInfo, Baidu, Bosch, Harman, Elektrobit/Continental, *etc.*).

2.2.2. SENSORIS

Initially proposed by HERE as part of the Sensor Data Ingestion Interface specification, the Sensoris standard is now managed by ERTICO as a standardized interface specification. The first vehicle-to-cloud data standard was released recently. The data specification covers input on weather environment, road infrastructure, traffic regulation, traffic events, and behavior, as well as the in-vehicle status.

2.2.3. ADASIS

ADASIS is a map-based ADAS standard, specifying how maps can be used to enrich and improve ADAS services. The ADASIS v3.0 standard aimed at automated driving was released recently by ERTICO.

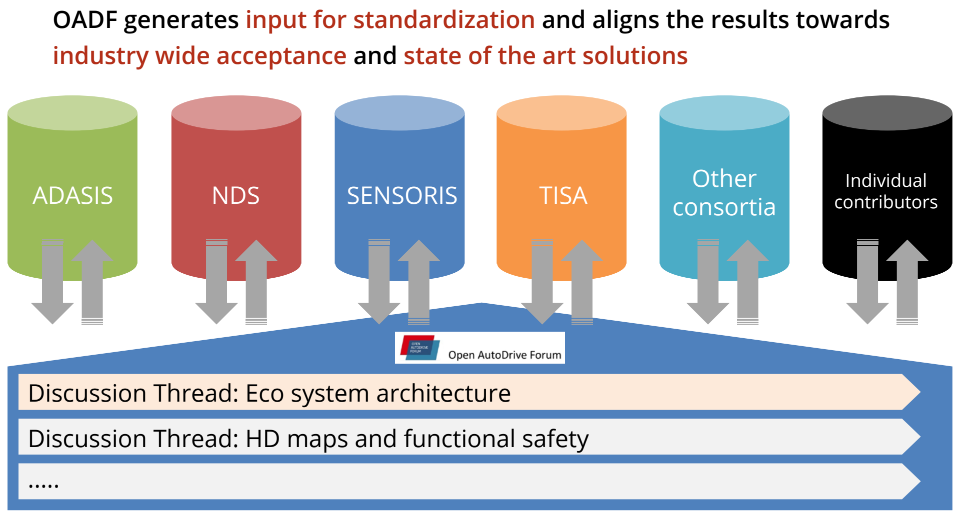
2.2.4. VECTOR TILE 3

Mapbox's Vector Tile 3 (VT3) specification is an open standard for powering HD vector maps.

2.2.5. OPEN AUTODRIVE FORUM

The Open AutoDrive Forum (OADF) is the overarching organization overlooking multiple map standard initiatives, including NDS, Sensoris, and ADASIS, and aims to harmonize data flow and allow interoperability between data formats.

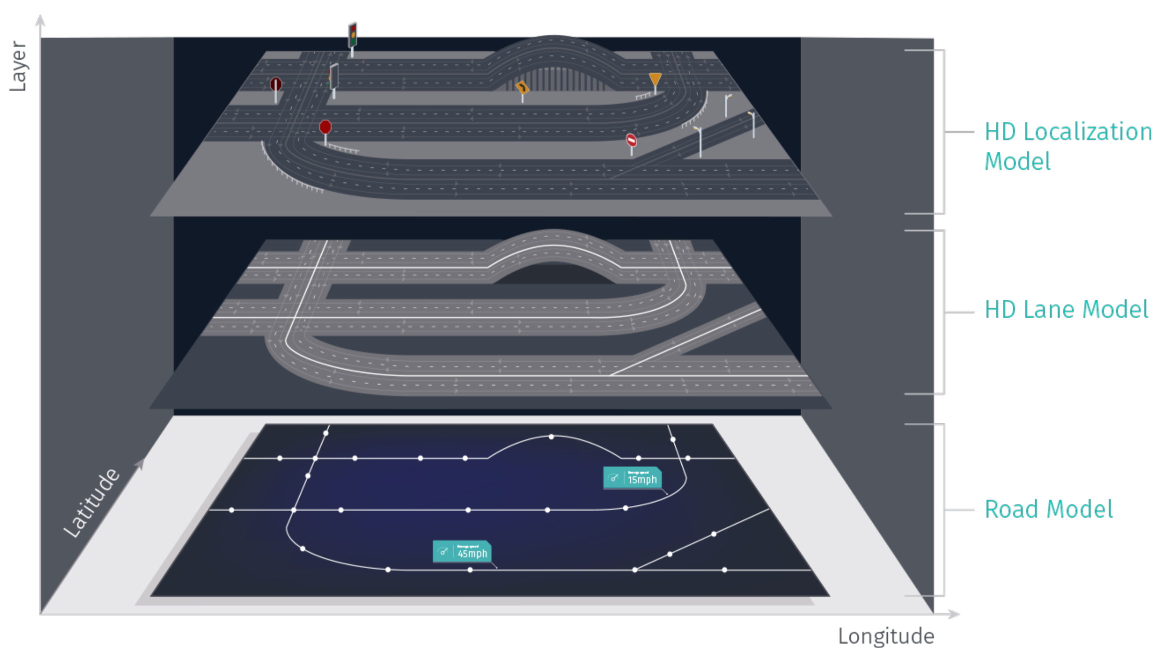
Figure 3: Open AutoDrive Forum *(Source: OADF)*



2.3 REQUIREMENTS

Requirements for advanced mapping include accuracy, quality, global and local coverage (including secondary roads, cycling lanes, indoor spaces), and detailed attributes (green spaces, pedestrian tracks and bridges, HD maps for driverless operation). These requirements can only be achieved by combining input from a wide range of complementary data sources.

Figure 4: Map Layers *(Source: HERE)*



Reliability and accuracy of HD maps used for mission-critical automotive safety applications and safety-critical components of AV platforms (maps-as-a-sensor) will be key requirements. Map providers will face the same liability challenges as all other involved suppliers in terms of who is responsible for damage and/or fatalities caused by erroneous map information. In this respect, high-quality production standards and strict testing procedures will be critical. Building maps through vehicle data crowdsourcing and the inherent redundancy that multiple, mutually independent sources provide contributes largely to the reliability of map-based positioning in AVs.

2.4 CHALLENGES

The mapping ecosystem currently experiences a range of changes, including:

- **Lack of Standards:** Despite ongoing standardization efforts, such as NDS, ADASIS, SENSORIS, TISA, *etc.*, maps are still essentially proprietary datasets lacking interoperability between mapping suppliers. The lack of standards is also resulting in a need for hosting, development, and consulting services.
- **Quality Control:** It continues to prove very difficult to produce error-free maps. This is due to the high complexity of the environment and its dynamic nature, as well as quality management complexities when combining and matching huge datasets from a large number of sources.
- **Cost:** The complexity, the need for manual verification, and new requirements for fresh maps and global coverage result in high production costs. Higher efficiencies and improved productivity in map making remains hard to achieve.
- **Business Models and Monetization:** With a large number of mostly cloud-based free maps and navigation solutions now available, it is increasingly challenging to monetize standalone map datasets.
- **Regulatory Limitations:** In many countries, map making is highly regulated, with foreign suppliers often banned from operating locally, resulting in the need for setting up local alliances or joint ventures.
- **Limitations of AI Tools:** Despite advances in AI, automating the generation of maps remains problematic with manual verification based on local expertise and specialist knowledge acquired over many years. This makes it hard for startups to enter the mapping ecosystem. New entrants, as well as large tech vendors like Apple, have attempted to explore shortcuts in the map production process in terms of only using limited datasets (vehicle sensor data, satellite imagery) and the level of automation (heavily or uniquely relying on AI to extract features from either sensor data or satellite imagery) to build commercial maps. The evidence strongly suggests this is not sufficient to build high accuracy, near-error-free maps. A maximum number of complementary and verification data sources need to be used, combined with sophisticated semi-automated and manual verification tools.
- **Size of Map Data Files:** The size of maps has increased exponentially with higher accuracy requirements, especially in relation to HD 3D maps for driverless vehicles. This complicates sending map updates Over-the-Air (OTA) in terms of time, bandwidth usage, and cost requirements. But it also increases onboard storage and processing requirements (both in terms of computation and power consumption). This results in a need for light(er)weight 3D maps based on simplified models of the environment.

2.5 THE MAPPING PRODUCTION PROCESS

Producing high-accuracy maps should be seen as a highly complex manufacturing process in terms of data collection, data cleaning and verification, layer creation, quality control, and publication.

2.5.1. MAP DATA SOURCES

The following data sources are typically used to generate maps:

- **Mapping Vehicles:** Highly specialized vehicles with high-quality Lidar, imaging sensors, and high-precision Global Navigation Satellite System (GNSS); critical for generating high-quality base maps.
- **Satellite Imagery:** Important additional data source for automated feature extraction.
- **Vehicle Sensor Data:** Critical data source for real-time, self-healing maps; this includes data captured from both embedded systems and community-based aftermarket solutions.
- **Government Data:** Data obtained from national, state, county, and city governments. This is important for base maps data and is a source of planned road modifications.
- **Community Feedback:** Input provided manually by mapping community members.
- **Other Data:** Data obtained from utilities.

Sources vary in terms of freshness (varying from real time for sensor data to several years old for satellite imagery), granularity and accuracy, geographical coverage, reliability, features and detail, and relevance. Combined, they allow map makers to build (and update) high-accuracy maps.

2.5.2. PRODUCTION PROCESS

The mapping production process involves a large number of sequential steps in what can be described as a highly specialized manufacturing workflow:

- **Data Capture:** Aggregation of content from a large number of sources.
- **Data Cleaning and Harmonization:** Matching/comparing/consolidating various datasets and global and local formats; harmonization of incoming data. Increasing number of automated database validations.
- **Map Layer Creation:** Various map layers supporting existing and new use cases like driverless vehicles.
- **Quality Assurance and Control:** Critical step, especially as it relates to functional safety requirements for mission-critical applications; in the future, new technologies like blockchain can be used to ensure origin, authenticity, and accuracy of map data sources and organized trusted data flow management.
- **Testing:** Navigable map testing programs.
- **Publication:** Maps need to be made available in file formats that can installed and/or downloaded OTA to vehicles or made available as cloud-based maps in real time.

2.5.3. CLOSED LOOP MAP UPDATE PROCESSES

With the emergence of real-time self-healing maps, the production and update processes increasingly overlap in what can be called a closed loop process of frequent incremental updates *via* OTA or continuous updates *via* cloud-based maps. This is turning map creation into a 24-hour ongoing process, requiring production and Information Technology (IT) infrastructure, not unlike advanced manufacturing plants.

3. HERE: STRATEGY AND APPROACH

This section takes a closer look at HERE's position and strategies in the fast-changing mapping ecosystem.

3.1 HERE PROFILE AND HISTORY

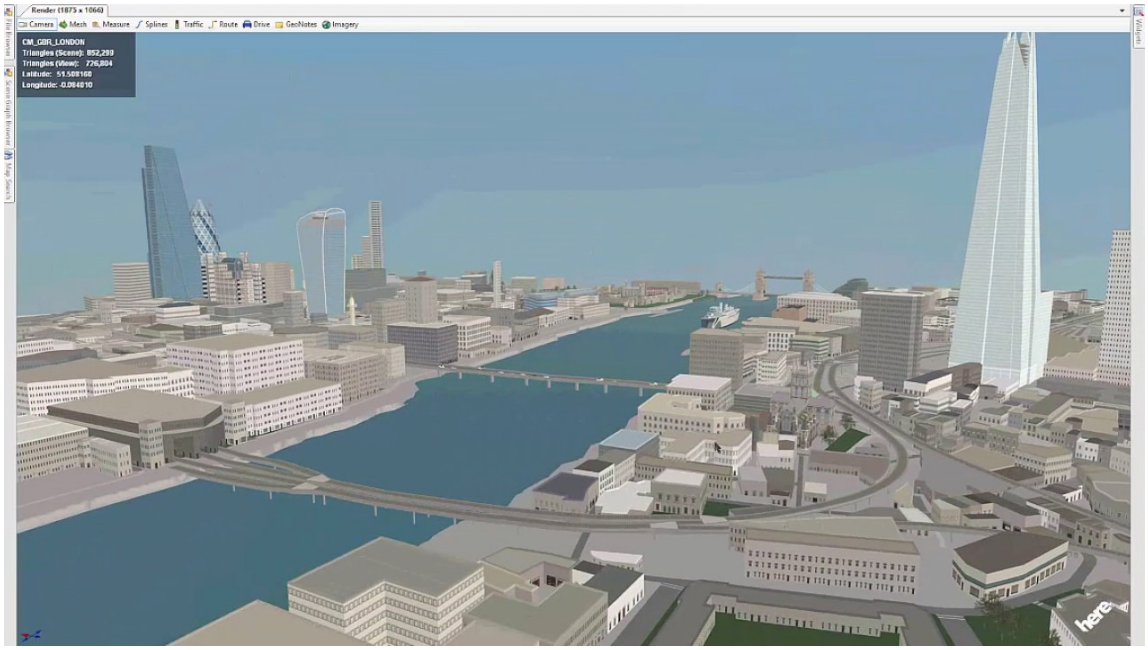
HERE's history stretches back to the pioneering days of map making (NAVTEQ was created in 1985), and subsequently being successively owned by Philips Electronics and Nokia. HERE is currently owned by a consortium consisting of founding members Audi, Daimler, and BMW, with Intel, Bosch, and Continental recently having joined as investors and taking stakes of 15%, 5%, and 5%, respectively. As the *de facto* mapping leader, HERE commands and controls large parts of the automotive, enterprise, and, to a lesser extent, consumer mapping environment.

3.2 HERE APPROACH AND STRATEGY

HERE's leadership is based on a combination of expertise acquired and tools developed over more than 30 years. It played a pioneering role in adopting and standardizing AI-based vehicle sensor data crowdsourcing for map generation, self-healing maps, real-time maps (HD Live Map), and maps-a- a-sensor for AV operation. Key strengths include:

- **Mapping Expertise:** HERE combines a wide range of assets, including map format conversion expertise, map making tools, local geographical knowledge, such as for street name coding, global training sets for feature recognition, *etc.*, into a streamlined, efficient map "factory" infrastructure and processes. It employs a large number of cartography analysts and a global production staff.
- **Access to Map Data Sources:** HERE has access to and uses more than 80,000 different validated sources of data. Data on more than 2 million kilometers of roads per year are captured with hundreds of HERE TRUE mapping vehicles.
- **Map Updates:** HERE applies millions of map updates on a daily basis. Map release frequency has increased to bi-weekly, and for parts of the HD Live Map service, updates are already published multiple times per day.
- **Map Layers:** HERE offers a wide range of map content types, with increasing coverage of indoor maps (venues) in more than 60 countries, 3D landmarks allowing humanized navigation through Natural Guidance, transit layers in cities, street-level imagery, and HD maps for driverless vehicle testing. More than 400 attributes are coded per road segment.

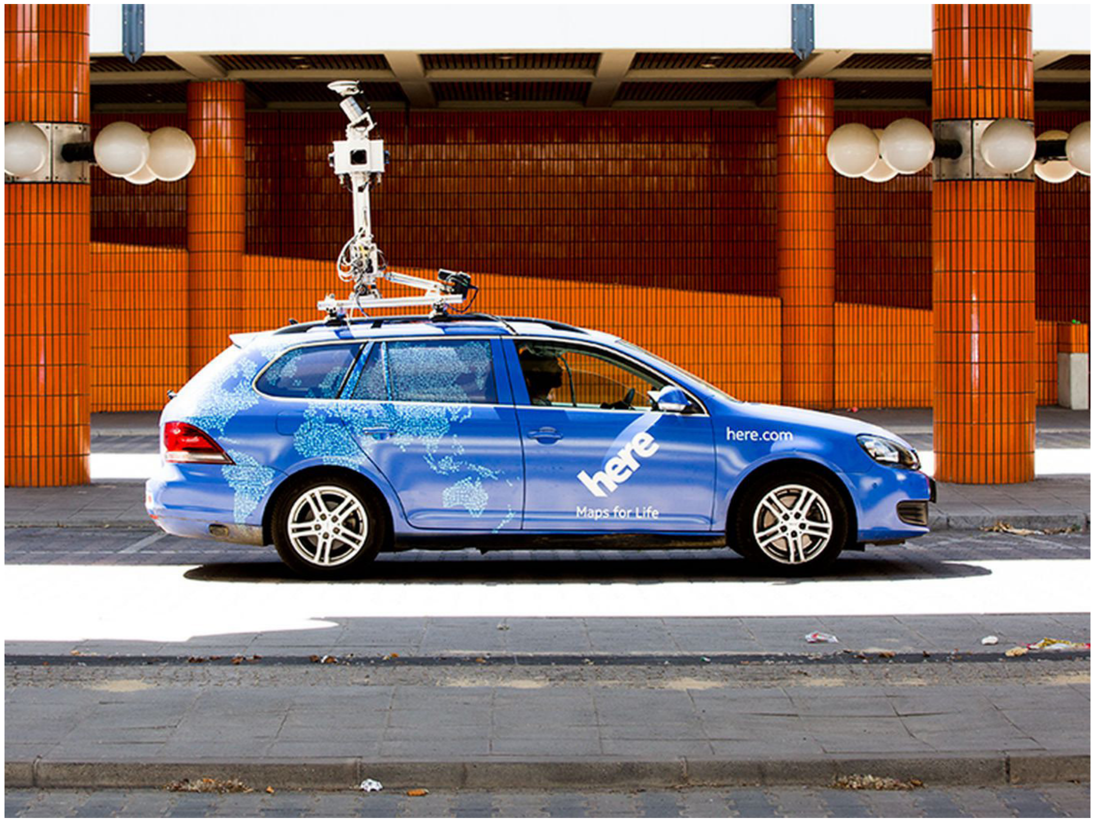
Figure 5: HERE 3D Maps *(Source: HERE)*



- **Scale:** HERE's operational capabilities allow building maps at scale on an industrial level. Map making far exceeds the narrow software engineering challenge, as is often uniquely focused on by new entrants. The really critical part is the "data maintenance factory" allowing the building maps at an industrial scale and at a consistent high quality.
- **Global Coverage:** Extensive coverage in terms of automotive-grade maps, in particular, achieved through decade-long efforts in traditional map making, community crowdsourcing, and partnerships. In this respect, the recently formed One Map Alliance with NavInfo of China, Increment P (IPC)/Pioneer of Japan, and SK Telecom of Korea is aiming for a single consistent HD map for driverless cars by 2020 for the Asian market. HERE's maps allow routing algorithms to work globally.
- **Vehicle Sensor Data:** HERE has privileged access to real-time vehicle sensor data from consortium members Audi, BMW, and Daimler, combined with probe data from OEM clients and partners, resulting in the number of probes exceeding 20 billion per month.
- **Partnerships:** Next to a growing number of partners within the consortium, HERE has set up technology and a commercial partnership with NVIDIA, NavInfo, and IPC, a mapping subsidiary of Pioneer Corporation to enable global mapping solutions for the autonomous driving era.
- **Open Location Platform (OLP):** This is a single environment for location-centric development, including storage of and access to built-in HERE map data.

As explained above, the fleet of HERE TRUE high-end industrial-capture vehicles remains critical in producing high-quality maps. These vehicles include state-of-the-art mapping technology, four 96-megapixel cameras, a 32-beam spinning Velodyne LiDAR camera, and an Inertial Measurement Unit (IMU) sensor unit. HERE TRUE vehicles collect 700,000 3D data points at a time, accumulating more than 140 gigabytes of location data per day.

Figure 6: HERE TRUE Mapping Vehicle *(Source: HERE)*



4. CONCLUSIONS

While the mapping ecosystem is undergoing huge disruptive changes in terms of map generation technologies, use cases, business models, and requirements, expertise in consolidating a large number of data sources, understanding of local mapping requirements, and toolsets developed over time to automate map making remain critical and cannot be just replaced with automated AI-based sensor data crowdsourcing attempted by many startups. More than ever, as maps become critical components in mission-critical automotive safety and driverless Level 4/5 systems requiring functional safety compliance, accuracy requirements and local expertise will be key differentiators in the new mapping landscape and ecosystem of the future. Clearly, HERE is in great position to take advantage of these new opportunities, combining first mover advantages in pioneering new map making technologies based on sensor crowdsourcing and AI, being part of an expanding consortium of technology players and car OEMs, and last but not least, expertise accumulated and finetuned over more 30 years of working with automotive OEMs and Tier Ones, enterprises, and consumer technology companies globally. It is this unique combination of legacy expertise, forward-looking technology adoption, creation and adoption of standards, and global partnerships that will allow HERE to maintain and expand its leadership position, which stretches back more than 30 years in an increasingly competitive mapping environment.

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