AUTOMOTIVE EDGE
COMPUTING CONSORTIUM

Operational Behavior of a High Definition Map Application White Paper

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Contents

Foreword

“Operational Behavior of a High Definition Map Application” was prepared by the Application Classification and Operational Behavior Special Interest Group of the AECC's Use-case Development Working Group.

The purpose of this document is to provide the AECC’s assumptions about vehicle application behaviors including data volume and frequency estimation as supplemental information to the AECC's "General Principles and Vision" White Paper. This document describes the estimated behavior of the High Definition Map service scenario included in that AECC White Paper. Other service scenarios, such as Intelligent Driving and V2Cloud Cruise Assist, will be described in future work.

The AECC is a not-for-profit association of industry members dedicated to promoting enterprise and systems management and interoperability in the connected car ecosystem. For information about the AECC and AECC publications, see http://www.aecc.org/.

1. Terms and Definitions

Term	Definition
High Definition Map (HD Map)	A topology representation with a high degree of precision and resolution. For example: a high-resolution map with static and dynamic information updates. Note that a High Definition Map is composed from a variety of sources, but is primarily intended for consumption by machine (hardware/software) systems rather than by human beings.
Static Map	A map that is not frequently updated; updates are controlled by a static map provider.
Dynamic Information	Information that changes with high frequency.
On-board Sensor	A sensor (camera, LiDAR, RADAR, etc.) located in a vehicle system.
Global Navigation Satellite System (GNSS)	A system that uses satellites to provide autonomous geo-spatial positioning. For example: GPS.
Inertial Measurement Unit (IMU)	An electronic device that measures and reports specific force, angular rate, and sometimes orientation. Note: an IMU can be used to complement GNSS functionality when satellite signals cannot reach a vehicle; for example, while driving in tunnels.

2. Overview

This paper proposes the operational behavior of an HD Map for use within the AECC System. The sources for information in this paper are external sources, including published literature.

What is an HD Map? The term generally means a map overlaid with various information such as traffic situations, access ways, street furniture within city streets and sub-surface ducts, with high precision at the centimeter level, which is updated frequently. In automotive use cases, the HD Map is a key to progress with Mobility as a Service, ADAS (Advanced Driver Assistance System) and autonomous driving. Many organizations are engaged in research and development around HD Maps. In the future, vehicle "big data" such as video data, 3D LiDAR data and vehicle motion data will be collected from many connected cars to contribute to HD Maps, in order to assist in automated and autonomous driving (Figure 1).

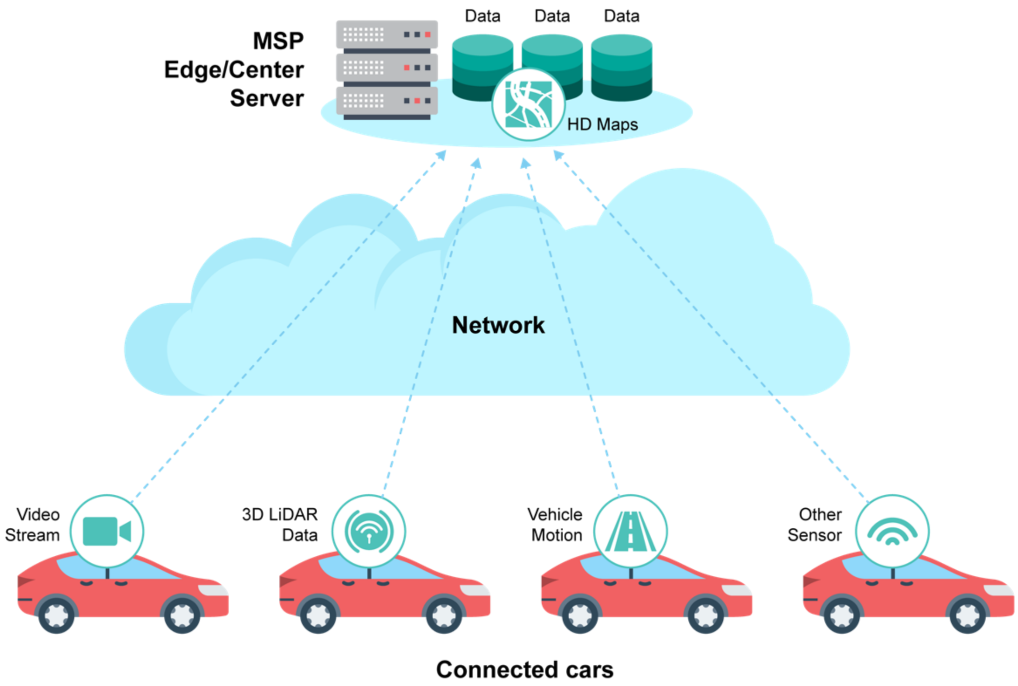

Figure 1. On-board Sensors' Data Collection from Connected Cars

Why are HD Maps needed? An HD Map is required for services such as autonomous vehicles on the highway (Society of Automotive Engineers Automation Levels 2 to 5 [1]), with resolution of 10-20 cm or better [2] [3]. Vehicles will need localization capabilities to place themselves into the mapped environment and to understand things beyond the line of sight, such as the topology of the upcoming roads.

In current maps, it is not a major concern if it takes a few days to correct gaps between actual circumstances and maps, because humans can drive the vehicles correctly. But with increasing levels of automation, this disparity becomes increasingly problematic. As more vehicles and their sensors come online, the challenge is how to handle the data and to extract the salient information from it.

For this purpose, there is a need to build infrastructures that can handle the huge volume of data collected by vehicles that can contribute to the creation and maintenance of HD Maps.

Unfortunately, definitions of HD Maps differ by organization, and the types of data and the data volumes that are used can also be different. Therefore, the AECC has created this paper to clarify the operational behavior of an HD Map and estimate the network traffic that occurs when vehicles contribute data to HD Maps. Our approach is to develop an assumption about the application's behaviors by introducing its composition and processing patterns, then describe possible implementation options based on the desired level of application functionality. Finally, we will summarize traffic patterns and data volumes based on the defined processing patterns and profiles, according to the AECC's expectations.

3. Assumptions about High Definition Map Application Behavior

3.1. Composition

Many organizations define an HD Map as a high-resolution static map overlaid with dynamic information, but the dynamic information content differs among organizations.

In the AECC model, dynamic information is classified into four layers according to the time intervals at which dynamic information changes (Figure 2). This is based on the concept of a Local Dynamic Map, which is standardized in Europe. It is created by on-board sensor data and Intelligent Transport System data [4] [5]. Note that other organizations may have differing numbers of layers.

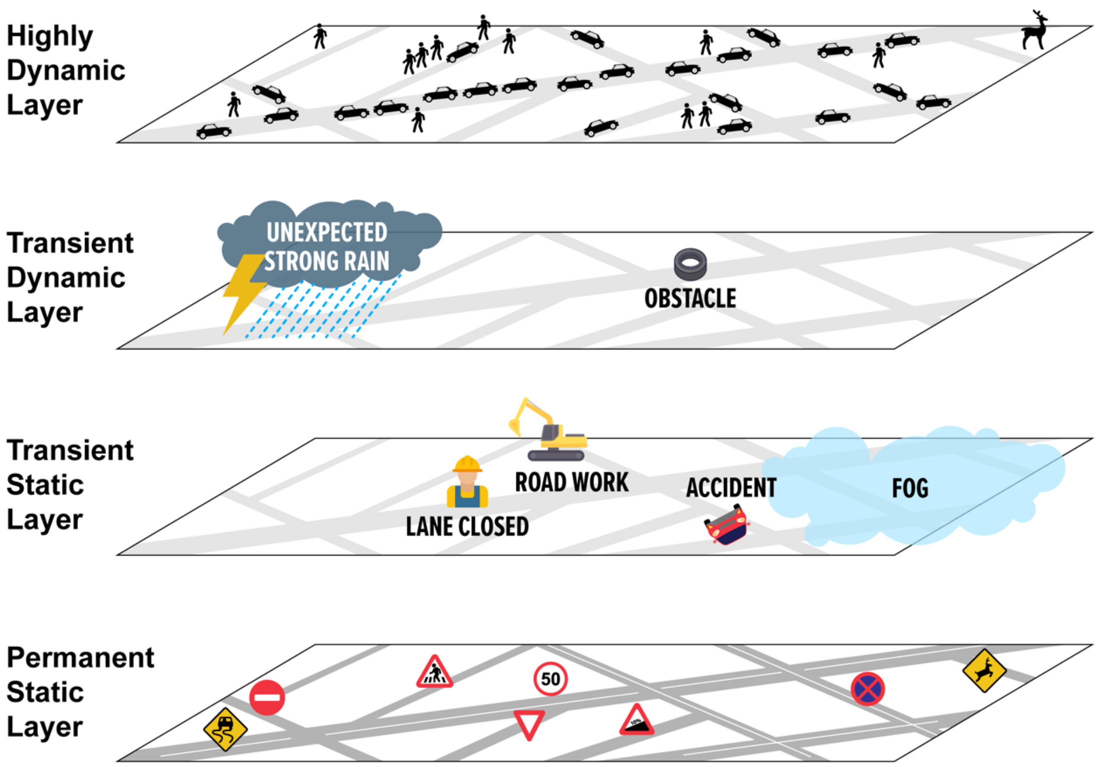

Figure 2. Layers of an HD Map

- The Permanent Static Layer comprises information that changes at intervals of one day or longer, such as lanes, traffic signals and the three-dimensional structure of the road. The Permanent Static Layer is what we call a static map.
- In the Transient Static Layer, changes occur at intervals of less than several hours. The Transient Static Layer includes the position and state information of road work, lane closures, broken-down vehicles, accidents and so on.

- In the Transient Dynamic Layer, changes occur at intervals of less than several minutes. The Transient Dynamic Layer includes the position and state information of obstacles such as fallen objects, illegally parked vehicles, trash, local weather such as unexpected heavy rain and tornados, and so on.
- In the Highly Dynamic Layer, changes occur at intervals of less than several seconds. The Highly Dynamic Layer includes the position and state information of pedestrians, vehicles, bicycles, motorbikes and so on. **The AECC does not focus on information that requires updates at time intervals of less than one second, which are used for automated driving control.**

Note that HERE, Volvo and the Toyota Research Institute-Advanced Development assume that HD Maps consist only of the Permanent Static Layer and the Transient Static Layer [6] [7] [8]. On the other hand, Japanese and European governments, TomTom and Waymo anticipate advanced HD Maps called Dynamic Maps, which will focus not only on the Permanent Static Layer and the Transient Static Layer but also on the Transient Dynamic Layer and the Highly Dynamic Layer [9] [4] [10] [11].

3.2. Other Initial Assumptions

Other initial assumptions are described below.

- HD Map application positioning – the HD Map application is a functional input that other applications, such as route navigation and ADAS, may leverage.
- Focusing on detecting information to update an HD Map – not only new dynamic information is detected but also changes in the dynamic information that is overlaid on the static map. A confirmed update (with high confidence) results in new dynamic information being overlaid on the static map.
- Static maps – static maps are created and updated by static map service providers, which are outside the scope of this paper. There are several methods for static map creation and updating. The details are described in Appendix A.

3.3. Actors

There are four actors: the vehicle system, the MSP edge server, the MSP center server and the network (access and core).

3.4. Expected Process Flow

The main function blocks include ***Sensor Data Acquisition***, ***Sensor Data Analysis*** and ***HD Map Update***. They are connected as shown below (Figure 3).

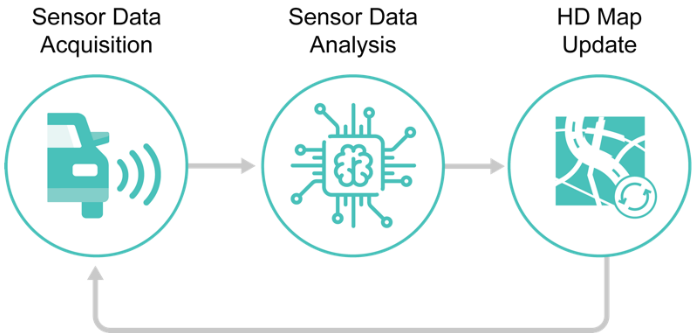

Figure 3. Expected Process Flow of an HD Map

Sensor Data Acquisition is the process of collecting sensor data at regular intervals from on-board sensors in the vehicle system.

Sensor Data Analysis is the detection of any new Transient Static/Transient Dynamic/Highly Dynamic information and of the change in Transient Static/Transient Dynamic/Highly Dynamic information using collected sensor data. The types of collected sensor data are various: for example, cameras and ECUs (electronic control units), LiDAR, radar and so on, according to the types of content in the Transient Static/Transient Dynamic/Highly Dynamic information or of the vehicle sensors. For example, video data and 3D data acquired from an on-board camera and LiDAR can be used when Transient Static information is lane closure location information and the vehicle is equipped with a camera and a LiDAR system. On the other hand, only video data can be used when the vehicle does not have LiDAR.

HD Map Update is the updating of the HD Map based on the Sensor Data Analysis.

This cycle from ***Sensor Data Acquisition*** to ***HD Map Update*** repeats. The frequency of the cycle will be defined in later sections, based on profiles.

3.5. Processing Patterns

Two processing patterns are defined below (Figure 4). ***Sensor Data Acquisition*** is on the vehicle system. The ***HD Map Update*** is run on both the vehicle system and the MSP edge/center server to keep the HD Map data up to date.

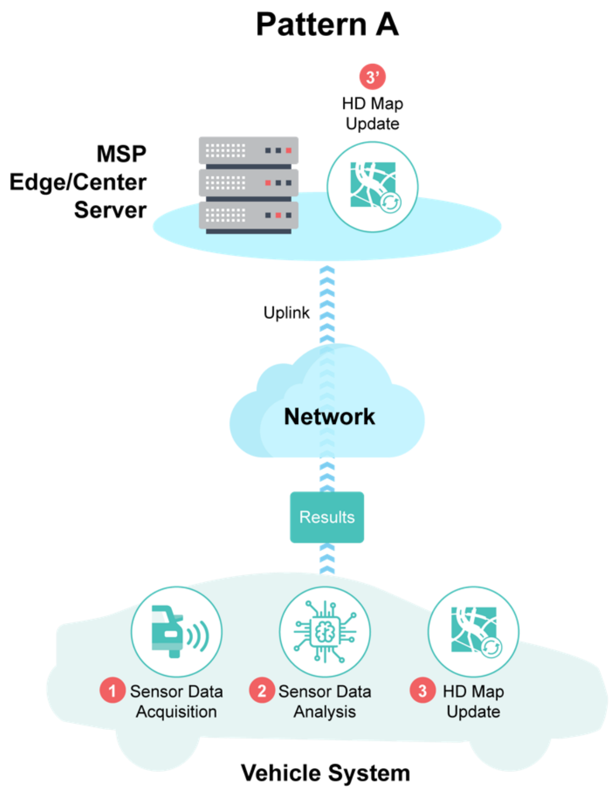

Figure 4. Processing Patterns

Pattern *A* shows a vehicle system with three function blocks (*1, 2, 3*), and the MSP edge/center server has one function block (*3'*). The vehicle system needs to receive confirmation information from the MSP edge/center server before an ***HD Map Update*** (*3*, *3'*). The confirmation information means that not one but dozens of vehicle systems detect Transient Static/Transient Dynamic/Highly Dynamic information. The results analyzed on the vehicle system are sent to the MSP server via networks, and the HD Map data on the MSP edge/center server is updated by the results. Network traffic volume between a vehicle system and an MSP server is not large because only the results are sent to the MSP server via networks.

In pattern *B*, a vehicle system has two function blocks (*1, 3'*) and the MSP edge/center server has two function blocks (*2, 3*). The vehicle system sends sensor data acquired from on-board sensors to the MSP server. On the MSP edge/center server, ***Sensor Data Analysis*** is run by using the sensor data, and the HD Map data is updated. The results are sent to the vehicle system, and the HD Map data on the vehicle system is updated by using the results. Network traffic volume is large compared with pattern *A* since all sensor data required for function block *2* is sent to the MSP server via networks.

Patterns *A* and *B* are the most basic patterns. There are alternative patterns, such as the following.

- In pattern *A*, the MSP server may aggregate results from multiple vehicles for HD map updates. In that case, the updated HD map could be different from the ones generated by each vehicle. There may also be a downlink path to send correct results to the vehicle.
- Both patterns *A* and *B* may coexist in a vehicle.
- There could be a pattern such that part of the ***Sensor Data Analysis*** is done on the vehicle system and the rest of the analysis is done on the MSP server.
- Evaluations of traffic volume, vehicle energy consumption, etc. should be taken into account in the future.

These may be included in the next version of this document.

4. Application Profiles

The AECC defines two application profiles for HD Map implementation (Figure 5).

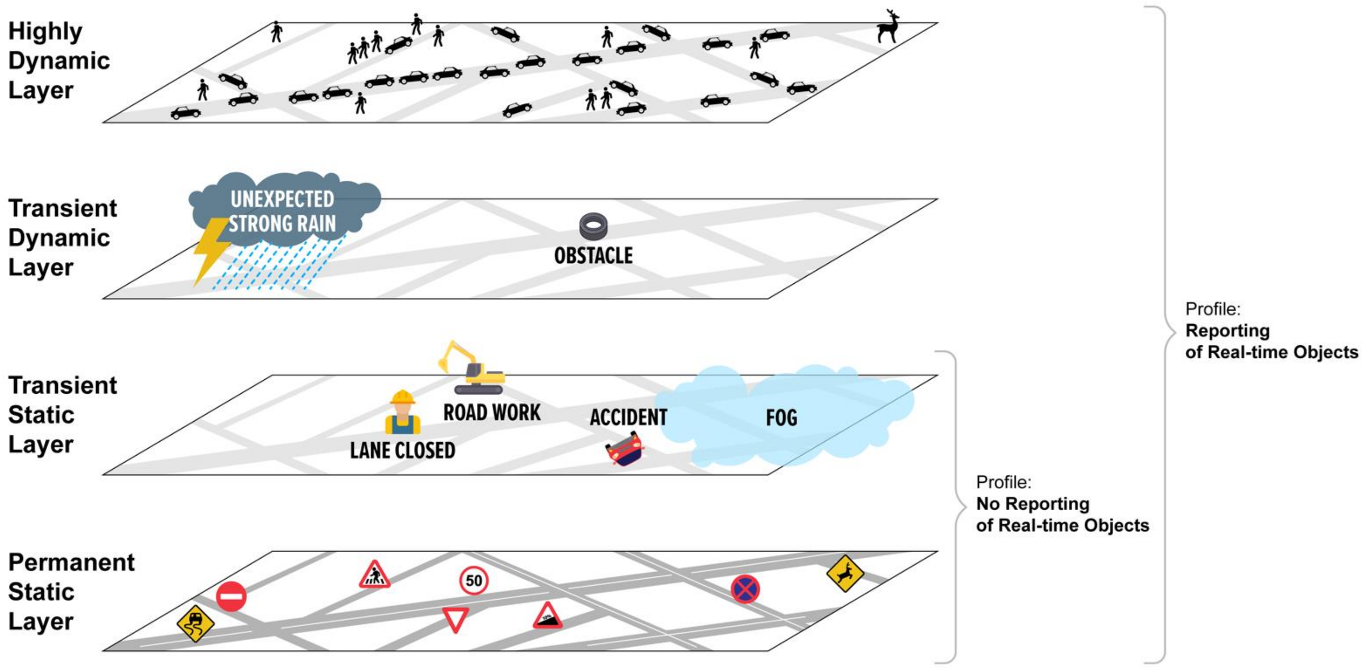

Figure 5. Image of an HD Map

◆ **No Reporting of Real-time Objects**

When there is no reporting of real-time objects, the Transient Static information is overlaid on the static map. Update frequency for the HD Map is not high because the interval at which Transient Static information updates is long. Therefore, the frequency of data collection from vehicles is not high and the network traffic volume is not large.

◆ **Reporting of Real-time Objects**

When there is ***Reporting of Real-time Objects,*** the Transient Static, Transient Dynamic and Highly Dynamic information are overlaid on the static map. This will require the HD Map to update at a high frequency because Transient Dynamic and Highly Dynamic information changes at short intervals. Hence, the frequency of data collection from vehicles is high and the network traffic volume is large. This profile is what is called the Dynamic Map [9].

4.1. No Reporting of Real-time Objects

4.1.1. Features

The vehicle system, the MSP edge server and the MSP center server have HD Map data for a designated area beforehand.

For example, a vehicle system has the HD Map data about its current location and traveling route, which includes data for an area smaller than several dozen square miles, while the MSP edge server has the HD Map data for one or more areas of a country. The MSP center server could have the HD Map data for the whole country (Figure 6).

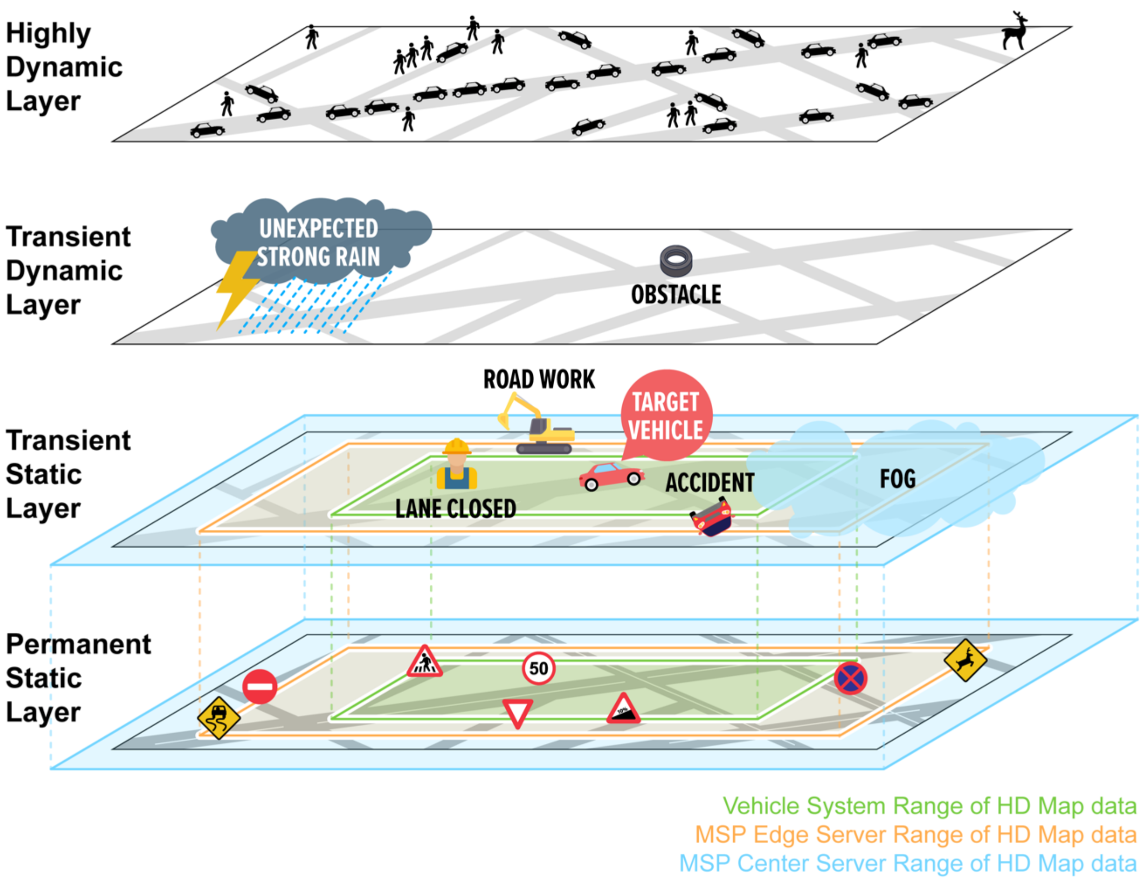

Figure 6. Example of Actors' HD Map Data Ranges (No Reporting of Real-time Objects)

4.1.2. Application Data Characteristics

The application data characteristics are as follows, and estimated values are summarized in Table 1.

◆ Data Upload/Download Frequency

We define frequency as the number of times per day that a vehicle detects Transient Static information and updates an HD Map. The frequency is indeterminate, but we have assumed that road work is a form of Transient Static information, and we calculated its average frequency per day based on data published on the internet [12].

◆ Upload/Download Data Volume (per vehicle system)

This refers to the total data volume per day between a vehicle system and an MSP edge/center server in processing patterns *A* and *B* as shown in Section 3.5.

◆ Upload/Download Data Volume (in total)

The number and type of connected cars' on-board sensors vary depending on vehicle age and OEM. In this paper, vehicle models are defined according to the number and type of on-board sensors. The "economy" model vehicle is close to the currently widespread vehicle model with some cameras and radar. (In *Upload/Download Data Volume (per vehicle system)*, the economy model is assumed.) The "mid-range" model vehicle has more on-board sensors than the economy model; for example, a LiDAR system. Details about the number and type of on-board sensors for each vehicle model are found in Table 3 in Appendix B.

We arbitrarily set the numbers of economy and mid-range model vehicles and calculated total data volume per day according to those: calculated by {*Data Volume (per vehicle system)*} * (the number of economy model vehicles) + {data volume of a mid-range vehicle *(per vehicle system)*} * (the number of 'mid-range' model vehicles).

Table 1. Application Data Characteristics (No Reporting of Real-time Objects)

Application Data Characteristics		Processing Pattern *A*	Processing Pattern *B*
Data Upload Frequency		2.3 times/day [1]	
Upload Data Volume per Vehicle System		14.2 MB/day [2]	49.4 MB/day [3]
Upload Data Volume in Total	2022 (5,000,000 Economy Model Cars, 0 Mid-range Model Cars)	70.9 TB/day [4]	246.9 TB/day [5]
	2027 (20,000,000 Economy Model Cars, 5,000,000 Mid-range Model Cars)	425.6 TB/day	2.1 PB/day
	2032 (40,000,000 Economy Model Cars, 10,000,000 Mid-range Model Cars)	851.2 TB/day	4.2 PB/day
Data Download Frequency		-	2.3 times/day [6]
Download Data Volume per Vehicle System		-	14.2 MB/day [7]
Download Data Volume in Total	2022 (5,000,000 Economy Model Cars, 0 Mid-range Model Cars)	-	70.9 TB/day [8]
	2027 (20,000,000 Economy Model Cars, 5,000,000 Mid-range Model Cars)	-	425.6 TB/day

	2032 (40,000,000 Economy Model Cars, 10,000,000 Mid-range Model Cars)	-	851.2 TB/day

[1][Preliminary assumption] We set the number of times a vehicle encounters road work while driving per day as the average frequency: {average number of instances of road work per 1km: 25 times/(year*1km) [12] / 365 days} * (average travel distance per day: 1000km/month [13] / 30days).

[2][Preliminary assumption] (data volume of results: 10MB/mile [from a European HD Map provider] / 1.6) * 2.3 times/day

[3][Preliminary assumption] {data volume of sensor data = camera data volume + vehicle motion, GNSS and IMU data volume: (1280×720) px * 3B * ¼ (Lossless JPEG) * 3(the number of on-board cameras) * 10 images + 500 kbps [14] / 8B/s /1000 * 10s} * 2.3 times/day

[4][Preliminary assumption] We assume that a mid-range model car's transmission data volume per time is twice that of an economy model because mid-range models have twice as many on-board sensors as economy models: 14.2MB/day * 5,000,000 + 14.2MB/day*2 * 0.

[5][Preliminary assumption] 49.4MB/day * 5,000,000 + {'mid-range model's data volume of sensor data = camera data volume + vehicle motion, GNSS and IMU data volume + LiDAR data volume: (1920*1080)px * 3 B * 1/4(Lossless JPEG) * 6(the number of on-board cameras) * 10images + 500kbps [14] / 8B/s / 1000 * 10s + 8.0 Mbps [15] / 8B/s * 10 s / 1000} * 2.3 times/day * 0

[6][Preliminary assumption] It is the same as the upload frequency.

[7][Preliminary assumption] It is the same as the uplink transmission data volume of processing pattern *A*.

[8][Preliminary assumption] We assume that a mid-range model's download transmission data volume per time is twice that of an economy model: 14.2MB/day * 5,000,000 + 14.2MB/day *2 * 0.

4.2. Reporting of Real-time Objects

4.2.1. Features

The vehicle system, the MSP edge server and the MSP center server have HD Map data of a designated area beforehand (the same as ***No Reporting of Real-time Objects***, but the HD Map data includes the Transient Dynamic and the Highly Dynamic information (Figure 7).

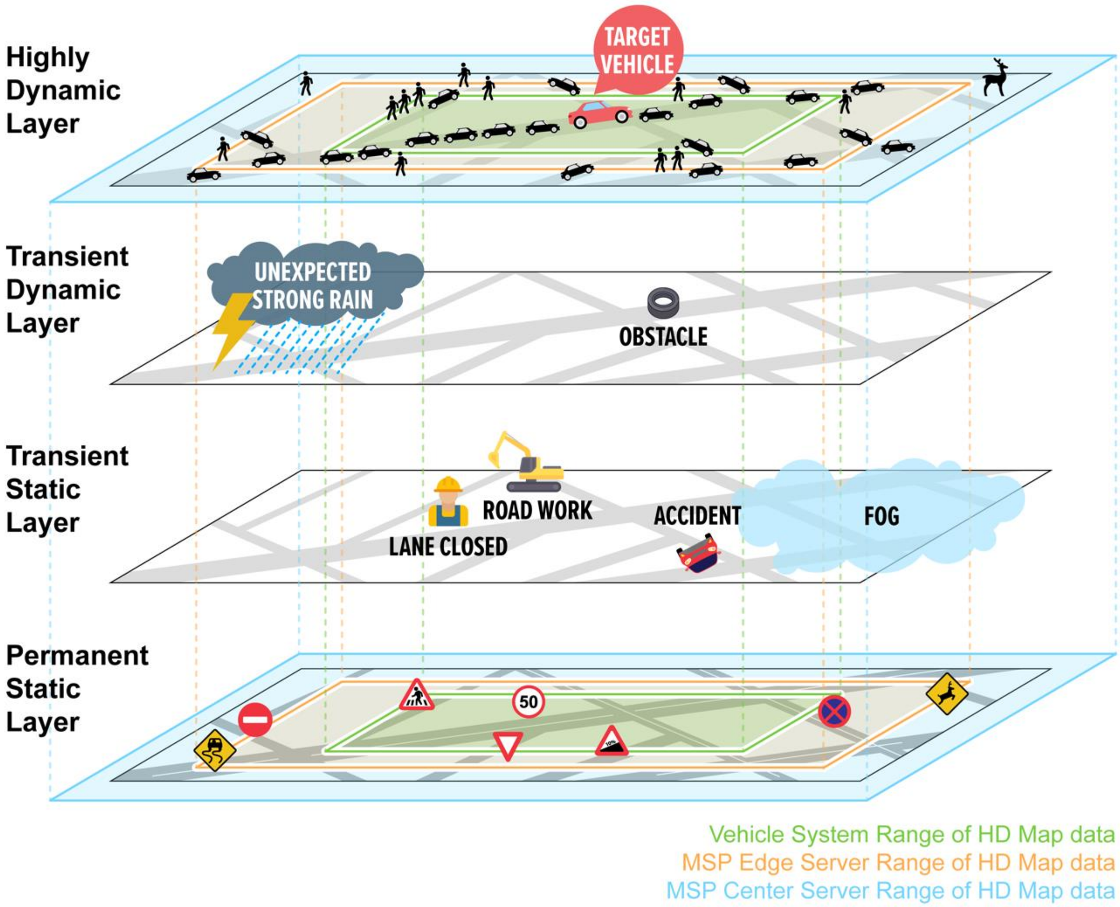

Figure 7. Example of Actors' HD Map Data Ranges (Reporting of Real-time Objects)

4.2.2. Application Data Characteristics and Latency

The application data characteristics are the same as for ***No Reporting of Real-time Objects***, with a few differences that are described below. The estimated values are summarized in Table 2.

- **Data Upload/Download Frequency**

We define frequency as the number of times per day that a vehicle detects Transient Dynamic information and updates an HD Map. The frequency is indeterminate, but we have assumed that illegally parked vehicles are a form of Transient Static information and calculated their average frequency per day based on the data published on the internet [16] [17].

- **Latency**

We define latency as the time from ***Sensor Data Acquisition*** to ***HD Map Update***.

Table 2. Application Data Characteristics and Latency (Reporting of Real-time Objects)

Application Data Characteristics		Processing Pattern *A*	Processing Pattern *B*
Data Upload Frequency		97.9 times/day [1]	
Upload Data Volume per Vehicle System		24.8 MB/day [2]	2.2 GB/day [3]
Upload Data Volume in Total	2022 (5,000,000 Economy Model Cars, 0 Mid-range Model Cars)	123.8 TB/day [4]	10.8 PB/day [5]
	2027 (20,000,000 Economy Model Cars, 5,000,000 Mid-range Model Cars)	743.1 TB/day	91.7 PB/day
	2032 (40,000,000 Economy Model Cars, 10,000,000 Mid-range Model Cars)	1.5 PB/day	183.4 PB/day
Data Download Frequency		-	97.9 times/day [6]
Download Data Volume per Vehicle System		-	24.8 MB/day[7]
Download Data Volume in Total	2022 (5,000,000 Economy Model Cars, 0 Mid-range Model Cars)	-	123.8 TB/day [8]
	2027 (20,000,000 Economy Model Cars, 5,000,000 Mid-range Model Cars)	-	743.1 TB/day
	2032 (40,000,000 Economy Model Cars, 10,000,000 Mid-range Model Cars)	-	1.5 PB/day
Latency		10 seconds	

[1][Preliminary assumption] (total number of illegally parked vehicles for one day in Tokyo: 71,902 vehicles/year [16] / 365days) / (total length of roads in Tokyo: 24,526km [17]) * (average travel distance per day: 1000km/month / 30days [13])

[2][Preliminary assumption] < {data volume of results: (1280×720)px * 3B * 1/4(Lossless JPEG) * 3(the number of on-board camera) * 10images + (500kbps [14] / 8B/s /1000 * 10s)} * 0.005 [18]> * 97.9 times/day + (data volume of ***No Reporting of Real-time Objects***: 14.2MB/day)

[3][Preliminary assumption] {data volume of sensor data = camera data volume + vehicle motion, GNSS and IMU data volume: (1280×720)px * 3B * 1/4(Lossless JPEG) * 3(the number of on-board cameras) * 10images + 500kbps [14] / 8B/s /1000 * 10s} * 97.9 times/day + (data volume of ***No Reporting of Real-time Objects***: 49.4MB/day)

[4][Preliminary assumption] We assume that a mid-range model car's transmission data volume per time is twice that of an economy model because the mid-range models have twice as many on-board sensors as economy models: 24.8MB/day * 5,000,000 + [<data volume of results: {(1280×720)px * 3B * 1/4(Lossless JPEG) * 3(the number of on-board cameras) * 10images + 500kbps [14] / 8B/s / 1000 * 10s} * 0.005 [18]> * 97.9 times/day * 2 + 28.4MB/day] * 0.

[5][Preliminary assumption] 2.2GB/day * 5,000,000 + <{mid-range model's data volume of sensor data = camera data volume + vehicle motion, GNSS and IMU data volume + LiDAR data volume: (1920*1080)px * 3 B * 1/4(Lossless JPEG) * 6(the number of on-board cameras) * 10images + 500kbps [14] / 8B/s / 1000 * 10s + 8.0 Mbps [15] / 8B/s * 10 s /1000} * 97.9 times/day + (data volume of ***No Reporting of Real-time Objects***: 221.1MB/day)> * 0

[6][Preliminary assumption] It is the same as the upload frequency.

[7][Preliminary assumption] It is the same as the upload transmission data volume of processing pattern *A*.

[8][Preliminary assumption] We assume that a mid-range model's download transmission data volume per time is twice that of an economy model: 24.8MB/day * 5,000,000 + {24.8MB/day * 2 + (data volume of ***No Reporting of Real-time Objects***: 14.2MB/day)} * 0.

5. Other Considerations

In this section, content supplementary to Sections 1 to 4 is discussed.

◆ **Data Format**

The data volume is greatly affected by data format. In the connected car over-the-air (OTA) era, many new data formats are being proposed and standardized to facilitate local area updates OTA. Examples are the NDS format [19] and OpenDRIVE format [20]. We will estimate data volume taking these data formats into consideration in the next version of this document.

The following is supplementary content, based on information obtained from a European HD Map provider.

◆ **Quality Index**

A Quality Index provides an indication of how reliable the map data is. This may be used as an input into Level 3/4 driving services [1] regarding their ability to rely on the mapping data for a particular location or region. It includes key meta-data:

- Existence accuracy -- who "saw" this last?
- Accuracy of location -- 5cm, 10cm, 1m, etc.
- Accuracy of object classification -- is it really a stop sign? Could it be a speed sign?

A key issue is that map data cannot be guaranteed at any point in time.

Path planning and object avoidance are up to the OEM and are not part of the map.

◆ **Edge Processing**

Edge processing (in the vehicle) will be required because not only do you need to obtain the data, you need to process it. 5G and increased bandwidth do not actually help with the problem -- they just shift where the processing takes place, but in so doing, they create a scalability challenge. The European HD Map provider does not want to obtain raw data streams unless it is really necessary. It is much more efficient to do the processing at the edge (or as close to it as possible) and then obtain the derived results. Transient data (such as parked vehicles, etc.) is not of interest to the HD Map but is relevant to the vehicle itself, so, again, local processing is required.

◆ **HD Healing**

HD Healing uses crowd-sourced data obtained by vehicles to build confidence that a change in the environment has been detected. Once consensus or sufficient confidence is reached, the confirmed changes are written into the appropriate layer. Changes to the static map require sensor sets to be installed on vehicles that are not mainstream today. In the future, mapping systems may include input from drones (not necessarily just aerial but ground-based, too), as well as "smart road" infrastructure (LiDAR sensors in roadside "furniture" such as traffic lights).

6. Next Step

This document intentionally does not provide a clear roadmap of an HD Map implementation and deployment scenario, as that is strongly related to the creation of a business ecosystem. Therefore, the current estimation in this document is calculated based on simple assumptions such as number of vehicles, volume of sensor data and frequency of upload/download, and still has several patterns and profiles that provide different estimated values.

However, providing a clearer view of a roadmap for application implementation is desired to support evaluations of technical solutions and deployment scenarios. The AECC will try to estimate a possible roadmap for HD Map implementation that is a combination of patterns and profiles described in this document with considerations of vehicle model/generation and country/region in the next phase of our work.

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https://www.flashmemorysummit.com/English/Collaterals/Proceedings/2017/20170808_FT12_Heinrich.pdf

Appendix A: Static Map Assumptions

There are two methods for static map creation and updating and how network traffic containing that data occurs. In the first method, static maps are created and updated by static map service providers. In the second method, that is done by on-board sensor data.

In this paper, we assume that static maps are created and updated by static map service providers and do not include the data volumes in the estimates in Sections 4.1.2 and 4.2.2. Data transmission from a static map service provider's server to connected cars via networks occurs a few times or more per month to update the car with the latest information. Thus the transmission frequency is low and the amount of data per vehicle is 6MB/km [2], so that there is little impact on current Communication Service Provider network designs, since the data volume is well within the typical profile of today's smartphones.

In the second method, static maps are created and updated by on-board sensor data that is collected from consumers' connected cars. In this case, the main composition is the same as in Section 3.1. Assuming that static information is traffic signs, in processing pattern *A*, *Upload Data Volume (per vehicle system)* is 10KB/time [from UK national mapping agency] * 0.15times/day = 1.5KB/day, which is about 9500 times smaller than ***No Reporting of Real-time Objects***. (Process pattern *A* does not have a downlink.) This is a small value that does not significantly affect current Communication Service Provider network designs. In processing pattern *B*, *Upload Data Volume (per vehicle system)* is 21.6MB/time * 0.15times/day = 3.24MB/day, which is about 15 times smaller than ***No Reporting of Real-time Objects***. (Process pattern *B* has a downlink with a small data volume, which is the same as the upload of processing pattern *A*.). This value has a larger impact on current Communication Service Provider network designs than processing pattern *A*.

Further, it is possible that HD Map update data may be sent in batches when the network is not congested, since static map creation and updating do not need real-time performance in milliseconds or seconds. In that case, the data is transmitted according to the specifications of the network, so that the current Communication Service Provider network designs are not affected.

Appendix B: Vehicle Model Assumptions

Our assumption about Vehicle Systems includes three types of vehicle models, based on their equipment [21]. The following table shows our assumptions about equipment quantities.

Table 3. Vehicle Model Assumptions[1]

Number of On-board Sensors per Vehicle System	Economy	Mid-range	Luxury [2]
Camera	3	6	12
Radar	2	4	6
LiDAR	0	1	5
Ultrasonic	2	8	16
Vehicle motion, GNSS, IMU	1	1	1

[1] These are merely assumptions made for the purpose of estimating data volume.

[2] In the future, we expect to see a luxury model, but we do not have enough data to estimate the data volume.