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**Abstract:** This TD is the output of draft Recommendation Y.dt-ITS “Requirements and capability framework of digital twin for intelligent transport system”, Q2/20 meeting, Arusha, 13-22 September 2023 - for determination.

This document is the proposed text of Y.dt-ITS “Requirements and capability framework of digital twin for intelligent transport system”, for determination at the SG20 meeting, Arusha, 13-22 September 2023. It is based on TD735, output of Q2/20 Rapporteur meeting, Beijing, 15-20 June 2023, and agreements on received contributions and other discussions at the Q2/20 meeting, Arusha, 13-22 September 2023.

The following table shows the agreements according to the discussion of the received contributions:

Contribution No.	Contribution title and proposals	Discussion and results
C267-R1	Y.dt-ITS “Requirements and capability framework of digital twin for intelligent transport system”: proposed text for determination	- It was agreed to change the location of Figure 1 (to put it below some introduction text)

		<ul style="list-style-type: none"><li>- Format changes of “NOTE” were agreed.</li><li>- It was agreed to make other updates according to Q2 meeting’s suggestions (clean up, alignment of 4G and 5G terminology to IMT-Advanced and IMT-2020 across the whole document)</li></ul>
C251	Proposed revision of TD735 of draft Recommendation ITU-T Y.dt-ITS “Requirements and capability framework of digital twin for intelligent transport system”	<ul style="list-style-type: none"><li>- The proposed editorial changes were agreed, including terminology alignment of 4G and 5G to IMT related terms.</li><li>- Instead of the new proposed appendix, it was agreed to make a minor update of figure 4 (adding another C-V2x vehicle, the arrow/radio signal symbol between two C-V2x vehicles, and changing 4G/5G terminology to IMT)</li><li>- It was also agreed to make a minor update of figure I.6 (changing 4G/5G terminology to IMT)</li></ul>

## **Draft new Recommendation ITU-T Y.dt-ITS**

### **Requirements and capability framework of digital twin for intelligent transport system**

#### **Summary**

Digital twin for intelligent transport system can provide digital representation of physical transportation world. With the meaningful and full-scale understanding of historical, real-time and statistical traffic related data in digital twin for intelligent transport system, the awareness of physical transportation is significantly enhanced, problems of transportation system can be discovered earlier, various traffic situations can be simulated, different long term, medium, short term strategies can be properly decided, and a lot of applications supported by intelligent transport system can be provided better and more intelligent.

This Recommendation specifies the requirements and capability framework of digital twin for intelligent transport system.

#### **Keywords**

Digital twin, intelligent transport system

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## Draft new Recommendation ITU-T Y.dt-ITS

### Requirements and capability framework of digital twin for intelligent transport system

#### 1 Scope

This Recommendation specifies requirements and capability framework of digital twin for intelligent transport system (ITS). The scope of this Recommendation includes:

- Introduction of digital twin for intelligent transport system
- Requirements of digital twin for intelligent transport system
- Capability framework of digital twin for intelligent transport system

Additionally, relevant use cases of digital twin for intelligent transport system are provided in Appendix.

#### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of Internet of things*.

[ITU-T Y.4105] Recommendation ITU-T Y.4105/Y.2221 (2010), *Requirements for support of ubiquitous sensor network (USN) applications and services in the NGN environment*.

[ITU-T Y.4407] Recommendation ITU-T Y.4407/Y.2281 (2011), *Framework of networked vehicle services and applications using NGN*.

[ITU-T Y.4600] Recommendation ITU-T Y.4600 (2022), *Requirements and capabilities of a digital twin system for smart cities*.

[ITU-T X.1752] Recommendation ITU-T X.1752 (2022), *Security guidelines for big data infrastructure and platform*.

#### 3 Definitions

##### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 **Device [ITU-T Y.4000]:** With regard to the Internet of things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage and data processing.

3.1.2 **Digital twin [ITU-T Y.4600]:** a digital representation of an object of interest.

NOTE – A digital twin may require different capabilities (e.g., synchronization, real-time support) according to the specific domain of application.

3.1.3 **Intelligent transport system (ITS) [ITU-T Y.4407]:** ITS is defined as systems utilizing the combination of computers, communications, positioning and automation technologies to improve the safety, management and efficiency of terrestrial transport systems.

3.1.4 **Internet of things (IoT) [ITU-T Y.4000]:** A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

3.1.5 **Sensor [ITU-T Y.4105]:** An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic.

## 3.2 Terms defined in this Recommendation

None.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ADAS	Advanced Driver-Assistance Systems
AI	Artificial Intelligence
C-V2X	Cellular V2X
DT	Digital Twin
DTA	Dynamic Traffic Assignment
DT-ITS	Digital Twin for Intelligent Transport System
eMBB	enhanced Mobile Broadband
GNSS	Global Navigation Satellite System
HIL	Hardware-in-the-loop
IoT	Internet of Things
ITS	Intelligent Transport System
LBS	Location-based Service
MIL	Model-in-the-loop
mMTC	massive Machine-type Communications
NB-IoT	Narrowband Internet of Things
OD	Origin-destination
QoS	Quality of Service
SIL	Software-in-the-loop
URLLC	Ultra Reliable Low Latency Communications
V2X	Vehicle-to-everything
VIL	Vehicle-in-the-loop

## 5 Conventions

The following conventions are used in this Recommendation:

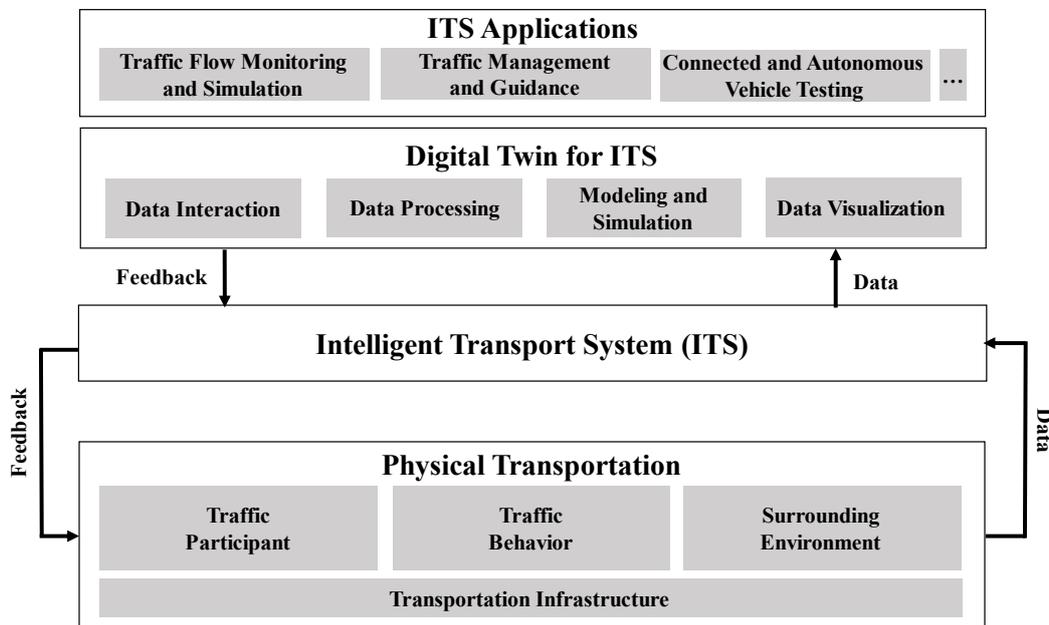
- The keywords “is required to” indicate a requirement which must be strictly followed and from which no deviation is permitted, if conformance to this Recommendation is to be claimed.
- The keywords “is recommended” indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

- The keywords “can optionally” and “may” indicate an optional requirement which is permissible, without implying any sense of being recommended. These terms are not intended to imply that the vendor’s implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

## 6 Introduction of digital twin for intelligent transport system

Intelligent transport system (ITS) utilizes a combination of advanced technologies to improve the safety, efficiency, management, usability of transport system.

Digital twin for intelligent transport system (DT-ITS) as shown in Figure 1 is the digital representation of transportation infrastructure (road, bridge, tunnel, traffic lights, etc.), traffic participant (vehicle, non-vehicle, pedestrian, etc.), traffic behaviour (departure, destination, path, etc.) and surrounding environment (urban functional area, buildings, river, forest, weather condition, etc.), which could be constructed by data interaction, data processing, modeling and simulation, and data visualization.



**Figure 1 – Concept of digital twin for intelligent transport system**

To achieve the digital representation of the physical transportation world accurately and timely, a variety of advanced ICT technologies, such as big data, artificial intelligence (AI), and 3D modeling, should be utilized in DT-ITS. Correspondingly, the Internet of Things (IoT), intelligent sensor, cellular V2X (C-V2X), and IMT-2020 may be integrated in intelligent transport systems to obtain accurate and real-time traffic data.

In DT-ITS, status of transportation entities is monitored, and tremendous traffic related data could be obtained. Based on processing of these historical, real-time and statistical traffic related data by data processing, the awareness of physical transportation is significantly enhanced, problems of transportation system could be discovered earlier, various traffic situations could be simulated, different long term, medium term and short term strategies could be decided, and various ITS applications could be provided by modeling and simulation as well as data visualization. For example, the following ITS applications could be enhanced by DT-ITS:

- Traffic flow monitoring and simulation: fine-grained and real-time traffic flow data could be monitored in DT-ITS. Based on this data, historic traffic flow analysis, traffic simulation on

various scenarios, and short-term traffic flow prediction could be done in a better way. A traffic flow monitoring and simulation use case of DT-ITS is provided in Appendix I.1.

- Connected and autonomous vehicle testing: intelligent vehicle which integrates connected vehicle technology and autonomous vehicle technology becomes increasingly complex and needs the most comprehensive testing. DT-ITS could produce such kinds of complex virtual scenarios for vehicle testing at low cost. A connected and autonomous vehicle testing use case of DT-ITS is provided in Appendix I.2.
- Traffic management and guidance: intelligent traffic management and guidance measures could be supported by DT-ITS by real-time collection, processing, simulation, and visualization of lane-level traffic flow, such as real-time and statistical analysis of traffic conditions, traffic optimization assessment, dynamic traffic control, dynamic route guidance, and dynamic traffic signal control. A traffic management and guidance use case of DT-ITS is provided in Appendix I.3.

## **7 Requirements of digital twin for intelligent transport system**

### **7.1 Requirements of data interaction of DT-ITS**

The following are the requirements of data interaction for DT-ITS:

- It is required to collect geographic data to build standard-definition map with meter-level precision.

NOTE 1 - Geographic data includes, but is not limited to:

- Road grade: highway, city express way, ordinary road
- Road length: starting point, end point
- Road geometry shape
- Speed limit: speed (such as miles/hour, km/h, unspecified)
- Road direction
- Number of lanes in the road
- Lane description: lane width, lane direction, lane attributes (such as bike, crosswalk, vehicle, parking, sidewalk).

NOTE 2 - Geographic data is widely used in ITS system [b-ISO-20524-1] [b-ISO-20524-2] and could be used for DT-ITS to support ITS applications including traffic flow monitoring and simulation, connected and autonomous vehicle testing, traffic management and guidance.

- It is recommended to collect geographic data to build high-definition map with centimeter-level precision [b-ISO-4804] [[b-HD-MAP].
- It is required to collect data on status of transportation infrastructure (road, bridge, tunnel, traffic lights, etc.).
- It is recommended to collect people's travel behaviour and activity pattern with user consent.
- It is required to collect data on traffic flow.
- It is recommended to collect data on traffic accident, traffic disaster and road construction.
- It is required to collect data on vehicle real-time status information (such as position, speed, heading, brake status).
- It is recommended to collect data on vehicle type, especially for special vehicles such as school bus, ambulance, fire engine, etc.

- It is required to collect historical data and real-time traffic data.
- It is required to guarantee QoS of data transmission.
- It is required to collect data from different sources.
- It is required to feedback traffic guidance or traffic warning information to the ITS.
- It is required to feedback traffic guidance to specific traffic guidance devices of the ITS, such as traffic guiding display devices.
- It is required to feedback traffic control strategy to traffic control devices of the ITS.

## **7.2 Requirements of data processing of DT-ITS**

The following are the requirements of data processing of DT-ITS:

- It is required to support processing of all the collected data from different sources.
- It is required to support high-volume data processing.
- It is required to support off-line data processing.
- It is required to support batch data processing.
- It is required to support online data processing.
- It is required to support data cleaning processing.
- It is required to support data classification.
- It is required to support data computing and analysis.
- It is required to support data query and data mining.
- It is required to support data exchange and sharing.
- It is required to support heterogeneous data fusion.
- It is required to support historical and real-time data fusion.
- It is required to support processing of ITS data related to space and/or time.
- It is required to support processing of data with different formats and different types.
- It is required to support processing of data on a uniform space-time coordinate system based on a uniform geographical map in order to provide a unified understanding of the whole traffic from different sources.

## **7.3 Requirements of modeling and simulation of DT-ITS**

The following are the requirements of modeling and simulation of DT-ITS:

- It is required to support modelling of transportation infrastructure (including traffic static objects, e.g., lane line, traffic signal, traffic sign, tunnel, bridge), traffic participant (e.g., motor/non-motor vehicle, pedestrian), traffic behaviour and surrounding environment of traffic scene (e.g., urban functional area, buildings).
- It is required to support simulation of different traffic scenarios.
- It is required to support simulation and evaluation of different traffic strategies.
- It is required to support long term, medium, short term strategy determination, and optimum strategies are recommended.
- It is required to support real-time decision.

## 7.4 Requirements of data visualization of DT-ITS

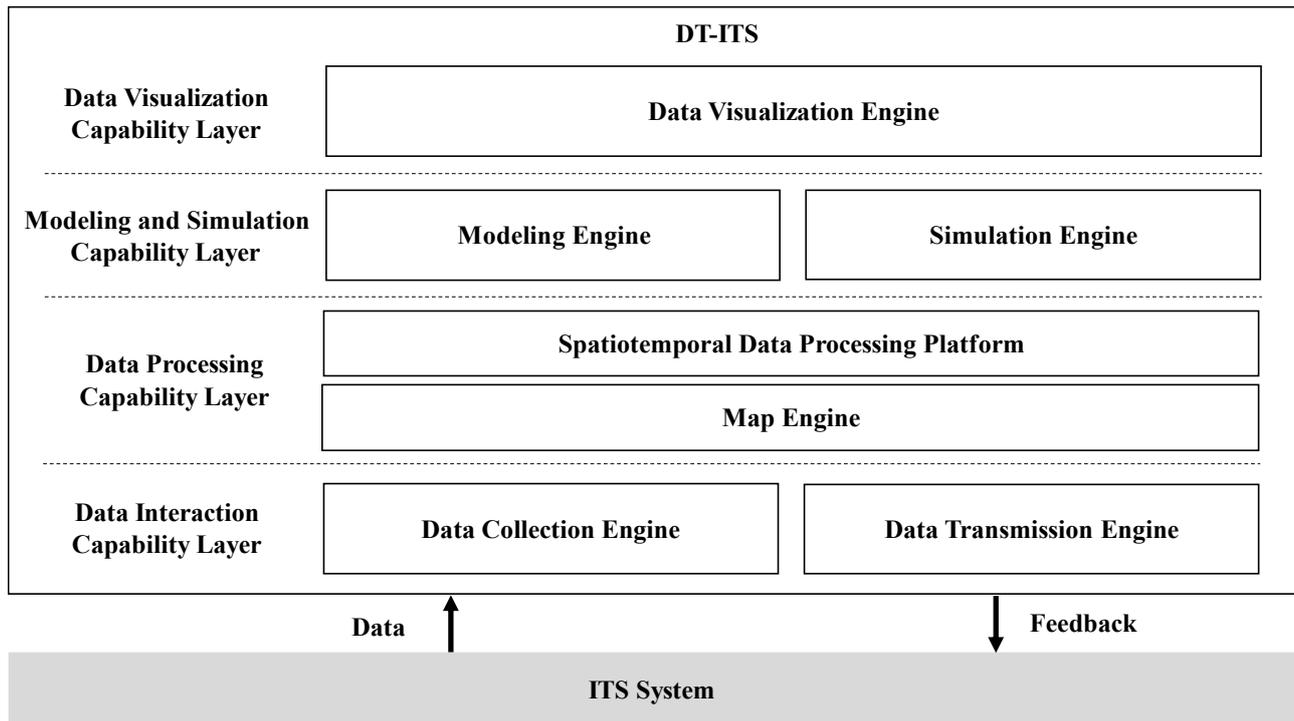
The following are the requirements of data visualization of DT-ITS:

- It is required to support data visualization processing.
- It is recommended to support visualization of different data types and data formats.

## 8 Capability framework of digital twin for intelligent transport system

### 8.1 Capability framework of DT-ITS

The capability framework of DT-ITS is composed of the capabilities shown in Figure 2 as identified by requirements in clause 7.



**Figure 2 Capability framework of DT-ITS**

It is composed of four capability layers: data interaction capability layer, data processing capability layer, modeling and simulation capability layer, and data visualization capability layer.

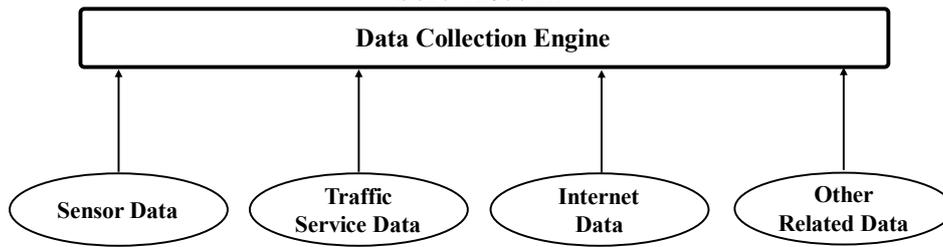
The data interaction capability layer consists of data collection engine and data transmission engine. The data processing capability layer consists of spatiotemporal data processing platform and map engine. The modeling and simulation capability layer consists of modeling engine and simulation engine. The data visualization capability layer consists of data visualization engine.

### 8.2 Capabilities of data interaction of DT-ITS

#### 8.2.1 Data collection engine

Multi-source heterogeneous data, including sensor data collected by various sensors, internet data related to traffic, traffic service data and other related data, should be collected to satisfy requirements of data collection of DT-ITS. Data may belong to different parties.

As shown in Figure 3, data collection engine provides the ability of collecting ITS data from different sources.



**Figure 3 Data collection engine for multi-source heterogeneous ITS data collection**

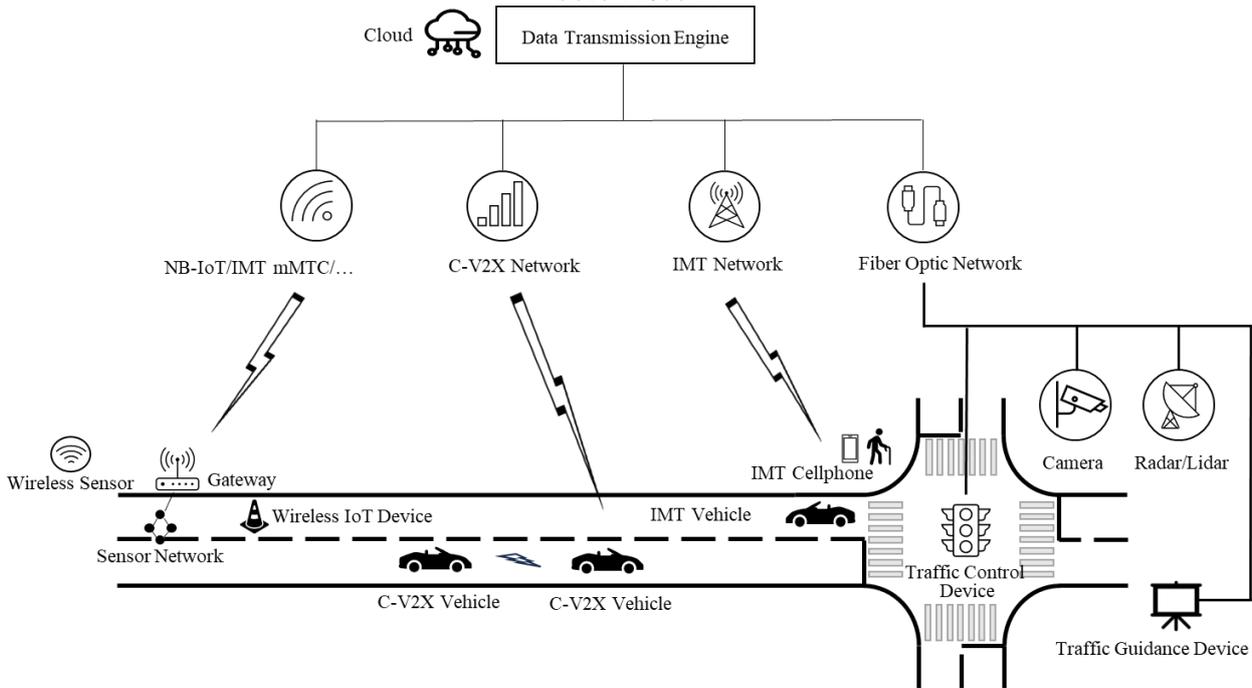
In particular, the following data is collected:

- **Sensor data**
  - Roadside sensors, including camera, radar, lidar, magnetic sensor, etc., monitor and provide data on objects and events on road, such as, traffic flow, traffic violation, traffic accident, vehicle identification and classification, vehicle tracking, obstacles on road, etc.
  - Thousands of different function sensors in vehicle, such as speed sensor, gyroscope, steering angle sensor, accelerometer, brake pressure sensor, etc., monitor vehicle driving status including position, speed, heading, brake status, etc. After processing in vehicle, the necessary vehicle status can be provided to DT-ITS by C-V2X or IMT-Advanced network or IMT-2020 network.
  - Sensors installed on transportation facilities, such as temperature sensor, humidity sensor, pressure sensor, smoke detector, etc., provide the operation status of important transportation facilities, such as bridge and tunnel.
- **Traffic service data**
  - Some dedicated data on traffic management is obtained from traffic dedicated systems, e.g., traffic signal status is obtained from traffic signal system, and traffic management information (such as parking information, speed limit information) is obtained from traffic management system.
  - Traffic data, such as, traffic flow data, origin-destination (OD) data, road accident blackspots, etc., is obtained from traffic service systems.
  - Geographic data is collected by dedicated hardware and software.
- **Internet data**
  - People’s traffic behaviour and travel preference are obtained from location-based service (LBS) after data desensitization.
- **Other related data**
  - Data on surrounding environment of transportation infrastructure is obtained from dedicated system, for example, weather data is obtained from meteorological observation networks.

This heterogeneous data includes historical data from historical database and real-time data from kinds of real-time transport systems.

### **8.2.2 Data transmission engine**

As shown in Figure 4, data transmission engine provides the ability of transmitting ITS data effectively across heterogeneous networks, including IMT-Advanced, IMT-2020, C-V2X [b-ITU-T Y.4471], Fiber, NB-IoT [b-ITU-R M.2440-0].



**Figure 4 –Data transmission engine for heterogeneous networks**

In particular, different networks provide different transmission capabilities:

- IMT-Advanced network provides low to high mobility applications (up to 350 km/h high speed vehicular) and a wide range of data rates (100 Mbit/s for high and 1 Gbit/s for low mobility) in accordance with user and service demands in multiple user environments [b-ITU-R M.2134].
- IMT-2020 network provides enhanced Mobile Broadband (eMBB) [b-ITU-R M.2410-0], Ultra Reliable Low Latency Communications (URLLC) [b-ITU-R M.2410-0], and massive Machine Type Communication (mMTC) [b-ITU-R M.2410-0], capabilities. The downlink and uplink peak data rate is respectively 20 Gbit/s and 10 Gbit/s for eMBB. The minimum user plane latency is 4 ms for eMBB and 1 ms for URLLC. The minimum connection density is 1 000 000 devices per km<sup>2</sup> for mMTC [b-ITU-R M.2410-0].
- C-V2X network provides vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P) data exchange via direct communication or IMT-Advanced network or IMT-2020 network, and vehicle-to-network data exchange via IMT-Advanced network or IMT-2020 network.
- Fiber optic network provides almost unlimited data transfer requirements over long distance whereas only fixed device is supported.
- NB-IoT network provides narrowband IoT applications with features such as large number of devices, low throughput, low power consumption, wide area and deep indoor coverage, low cost. [b-ITU-R M.2440-0]
- Sensor networks and gateways provide connectivity between sensors and infrastructure networks [ITU-T Y.4105].

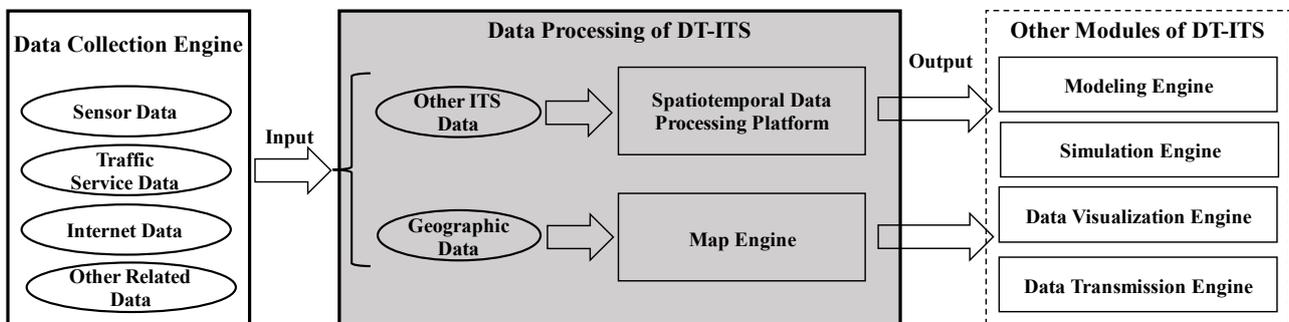
In particular, the following abilities of data transmission engine are provided:

- Appropriate data transmission mechanisms for effective transmission in each component network.
- Appropriate data transmission mechanisms for devices' data sending and receiving.
- Optional data transmission of camera or radar/lidar to DT-ITS via IMT-Advanced network or IMT-2020 network or fiber optic network.

- Optional data transmission of traffic flows to DT-ITS via IMT-Advanced network or IMT-2020 network or fiber optic network.
- Optional data collection on people’s travel behaviour and activity pattern by smart phone and data transmission to DT-ITS via IMT-Advanced network or IMT-2020 network (with user consent).
- Optional data feedback on traffic guidance or traffic warning information to IMT terminals of ITS via IMT-Advanced network or IMT-2020 network.
- Optional data transmission of low frequency, non-real-time sensor data (such as status of transportation infrastructure like roads, bridges and tunnels) to DT-ITS via NB-IoT and sensor network.
- Optional data transmission of vehicle real-time status information (such as position, speed, heading, brake status) to DT-ITS via C-V2X or IMT-Advanced network or IMT-2020 network.
- Optional data feedback on traffic guidance or traffic warning information to vehicles of ITS via C-V2X or IMT-Advanced network or IMT-2020 network.
- Optional data transmission of specific traffic guidance devices and traffic control devices to DT-ITS via fiber optic network or other wired networks.
- Optional data feedback on traffic guidance to specific traffic guidance devices via fiber optic network or other wired networks.
- Optional data feedback on traffic control strategy to traffic control devices via fiber optic network or other wired networks.

### 8.3 Capabilities of data processing of DT-ITS

Figure 5 illustrates data processing of DT-ITS. All data collected by data collection engine is processed.



**Figure 5 – Data processing of DT-ITS**

Data processing of DT-ITS, consisting of spatiotemporal data processing platform and map engine, provides the following capabilities:

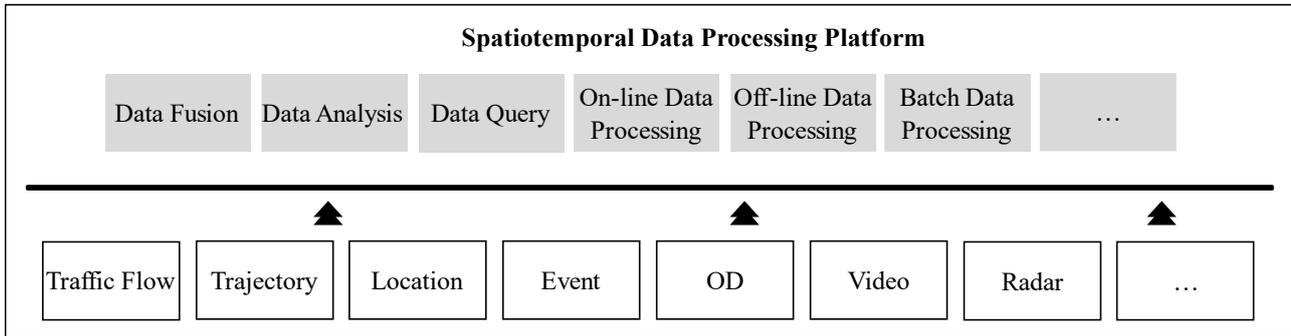
- processing of geographic data by map engine, for example, digital map update;
- processing of other ITS data by spatiotemporal data processing platform, for example, backward playing of traffic videos of DT-ITS at a specific time.

After processing, data is output to other modules of DT-ITS including modeling engine, simulation engine, data visualization engine and data transmission engine.

NOTE – A cloud infrastructure can provide computing resources, network resources and storage resources for data processing of DT-ITS.

### 8.3.1 Spatiotemporal data processing platform

As shown in Figure 6, spatiotemporal data processing platform provides basic data processing functions for ITS data, including on-line/off-line/batch data processing, data fusion, data analysis and data query, according to the requirements identified in clause 7.2.



**Figure 6 – Capability framework of spatiotemporal data processing platform**

In particular, the following abilities are provided:

- Processing of heterogeneous data from different sources.
- Processing high-volume traffic data with various formats.
- Processing on structured data, unstructured data, and semi-structured data.
- Fixing or removing incorrect, corrupted, duplicate, or incomplete traffic data.
- Data fusion on heterogeneous traffic data from different sources and/or on real-time traffic data and historical traffic data that provides a unified and comprehensive understanding of traffic data.
- Service data classification.

NOTE Service data may be classified according to different traffic information or different sensors or other rules.

- Data processing on non-geographic data.
- Data processing on data related to space and/or time.
- On-line data processing on real-time traffic data and historical traffic data.
- Off-line data processing on historical traffic data.
- Batch data processing on historical traffic data.
- Query on raw traffic data and processed traffic data.
- Query on historical traffic data and real-time traffic data.
- Data exchange and sharing between DT-ITS and other ITS.

### 8.3.2 Map engine

Map engine is a basic component of DT-ITS which provides digital representation of the physical transportation network and provides geographic data processing, according to the requirements identified in clause 7.2.

In particular, the following abilities are provided:

- Standard-definition map or high-definition map, according to the specific ITS applications supported. High-definition map which provides centimeter-level precision representation of

roads may support more intelligent transport applications, such as lane-level traffic flow monitoring and prediction, lane-level route guidance, cooperative autonomous driving.

- Display of different kinds of geographic datasets.
- A uniform map as a unified reference of the geographic data to be processed.
- A uniform space-time coordinate system as a unified reference to process data from different sources which may use different coordinate systems.
- Mapping of all data with geographic location to a uniform space-time coordinate system.
- Real time map update reflecting the latest changes of geographic data.
- Processing of geographic data.

## **8.4 Capabilities of modeling and simulation of DT-ITS**

### **8.4.1 Modeling engine**

Modeling engine is used for support of simulation engine.

In particular, the following abilities are provided:

- Modeling of traffic static objects, including from multi-source heterogenous data. Attributes of the model include position, size, shape, color, etc. 3D reconstruction technology is utilized to achieve maximum representation of physical static objects.
- Modeling of traffic dynamic objects (e.g., vehicle, non-vehicle, pedestrian), including from multi-source heterogenous data. Attributes of the model include position, speed, heading, size, shape, color, etc.
- Modeling of vehicle dynamics to represent the lateral, longitudinal, yaw motion of vehicle.
- 3D reconstruction to achieve maximum representation of surrounding environments.
- Modeling of traffic behavior to obtain regular pattern of traffic and predict traffic flow from macroscopic, mesoscopic, or microscopic perspectives:
  - Classic four-step travel models, including trip generation, trip distribution, mode choice and traffic assignment, to model traffic flow.
  - Models of flow, density and speed of the traffic stream of each road section, to generate traffic flow from macroscopic perspective, and macroscopic models, such as queue length model and route choice model.
  - Individual vehicle models to generate traffic flow from microscopic perspective, and driving dynamics of vehicles, such as car following model, lane-changing model, intersection model.
  - Models of traffic flow from mesoscopic perspective supported by dynamic traffic assignment (DTA). Traffic flow based on DTA may be calibrated by real-time traffic data.

### **8.4.2 Simulation engine**

Simulation engine is used to build simulation scenarios by implementing simulation methodology, and to evaluate optimization strategy, algorithm performance and system performance.

NOTE 1 - Typically, there are two kinds of simulation: traffic simulation and vehicle simulation. The traffic simulation mainly focuses on estimating and predicting current and future traffic flow and is used for transportation planning, traffic management, traffic optimization and so on. The vehicle simulation mainly focuses on the performance of individual vehicles and is used for autonomous driving and advanced driver-assistance systems (ADAS) testing.

In particular, the following abilities are provided for traffic simulation:

- Road level traffic estimation and prediction, and lane level traffic estimation and prediction.
- Macroscopic simulation, mesoscopic simulation, and microscopic simulation to simulate traffic on large scale network or specific road section or specific intersection.
- Combining different models in simulation depending on simulation scenario and methodology.
- Scenario library with kinds of simulation scenarios, such as those for highway, urban road, rural way.
- Evaluation index system for evaluating traffic estimation and prediction results, traffic optimization strategies, etc.

NOTE 2 - Optimum strategies are recommended according to evaluation results of traffic optimization strategies.

- Real-time online traffic simulation to provide online strategy suggestion and related information to support traffic management system, such as, traffic guidance, traffic signal control.
- Simulation of mixed traffic flow in which autonomous vehicles and human driven vehicles are present at the same time to cope with the gradual application of connected autonomous vehicles.

In particular, the following abilities are provided for vehicle simulation:

- Model-in-the-loop (MIL) simulation [b-MIL-SIL-HIL], software-in-the-loop (SIL) simulation [b-MIL-SIL-HIL], hardware-in-the-loop (HIL) simulation [b-MIL-SIL-HIL], and vehicle-in-the-loop (VIL) simulation [b-VIL].
- Combining different models in simulation depending on simulation scenario and methodology.
- Performance evaluation of ADAS, V2X, autonomous driving functions.
- Scenario library with different kinds of ADAS, V2X, and autonomous driving simulation scenarios. NOTE 3 - In some specific scenarios, sensor data, including from lidar, radar, camera, inertial measurement unit (IMU) and global navigation satellite system (GNSS), is provided.
- Evaluation index system for MIL, SIL, HIL, VIL simulation.

## **8.5 Capabilities of data visualization of DT-ITS**

Data visualization engine provides the ability of visual representation of information and data, and it is supported by both modeling engine and simulation engine.

In particular, the following abilities are provided:

- Visualization display of data according to the application requirements, e.g., via charts, tables, figures.
- Visualization display of models of traffic static objects, traffic dynamic objects and surrounding environment according to the application requirements.
- Visualization display of real traffic conditions.
- Visualization display of simulation scenarios.
- Optional visualization display of simulation process.
- Visualization display of simulation results.
- Real-time rendering of massive data.

- High-fidelity rendering of traffic objects and surrounding environment according to the application requirements, such as advanced dynamic lighting and texture detail on transportation infrastructure and surrounding buildings.
- High-fidelity rendering of simulation scenarios according to the application requirements, such as advanced dynamic lighting, different weather conditions including snow and rain, different times of day including midday, evening, and night.

## **9 Security considerations**

General requirements and capabilities of data security for DT-ITS align with the framework described in [ITU-T X.1752]. The security considerations for DT-ITS include considerations for data source security, data collection security, data processing security, application security and security management [ITU-T X.1752].

## **Use cases of digital twin for intelligent transport system**

(This appendix does not form an integral part of this Recommendation.)

### **I.1 Traffic flow monitoring and simulation**

As shown in Figure I.1 and I.2, DT-ITS of a district was constructed. In this DT-ITS, the traffic flow of the district could be monitored and simulated.



Figure I.1 Example of DT-ITS for traffic flow monitoring and simulation of a district



Figure I.2 Example of DT-ITS for traffic heatmap of a district

In particular, the DT-ITS for this district is constructed as follows:

- 3D reconstruction technology and high-definition map were used to recreate road traffic and city scenes to ensure the maximum representation of the physical world.
- Vehicles in the road could be detected in real-time via objection detection technology based on roadside cameras and merged in the 3D virtual environment by further object modelling. Thus, the real lane-level traffic status could be reflected in DT-ITS.
- Based on the large amount of lane-level traffic flow data, kinds of fine-grained traffic scenarios could be simulated, and various traffic optimization methods could be evaluated.
- Various weather conditions could be simulated in DT-ITS to assess the impact on traffic, and contingency plan could be made for extreme weather.

## I.2 Connected and autonomous vehicle testing

Digital twin may be used for vehicle-in-the-loop (VIL) testing. As shown in Figure I.3, in VIL testing, kinds of different virtual scenarios are produced and applied for real vehicle on the real proving ground. The real proving ground may be simple, while the virtual scenarios are generally complex. Thus, the evaluation of connected and autonomous vehicle can be implemented at low cost.



Figure I.3 VIL testing

Figure I.4 shows a digital twin for connected and autonomous VIL testing.

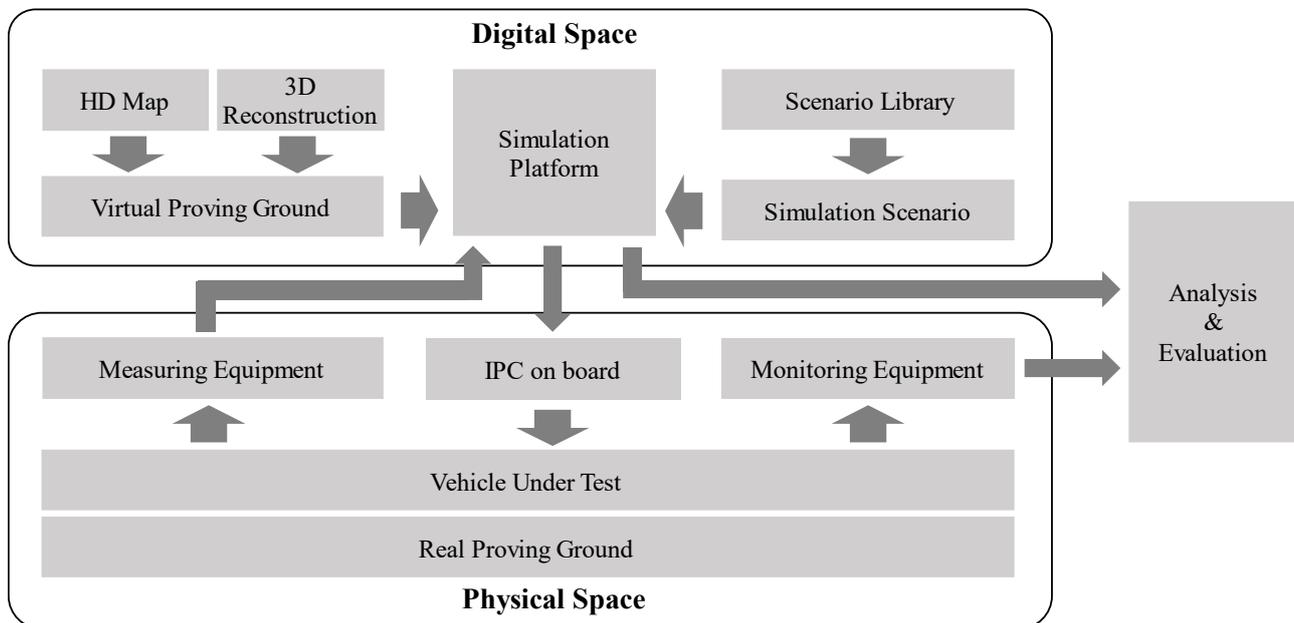


Figure I.4 Digital twin for connected and autonomous vehicle testing

In particular, the digital twin for connected and autonomous VIL testing is constructed as follows:

- Virtual proving ground is constructed by high-definition map and 3D models of physical proving grounds in digital space.
- Static elements of physical proving grounds, such as, roads, test tracks, and surrounding environments, are modelled by 3D reconstruction technology.
- The real vehicle under test is integrated into the virtual environment, and its status is reproduced in the simulation platform, including position, speed, size, heading, and so on.
- Depending on the definition of the simulation scenario, the simulation platform simulates dynamic elements around the vehicle under test, e.g., motor/non-motor vehicles, pedestrians. The status of simulated dynamic elements includes position, speed, size, type, heading, etc.
- Virtual dynamic elements are transmitted to the real vehicle under test in real-time by IPC on board. These elements may be seen as the sensing data of sensors in real vehicle.
- Measuring equipment on real vehicle under test is used to transmit its status and measuring data to the simulation platform.

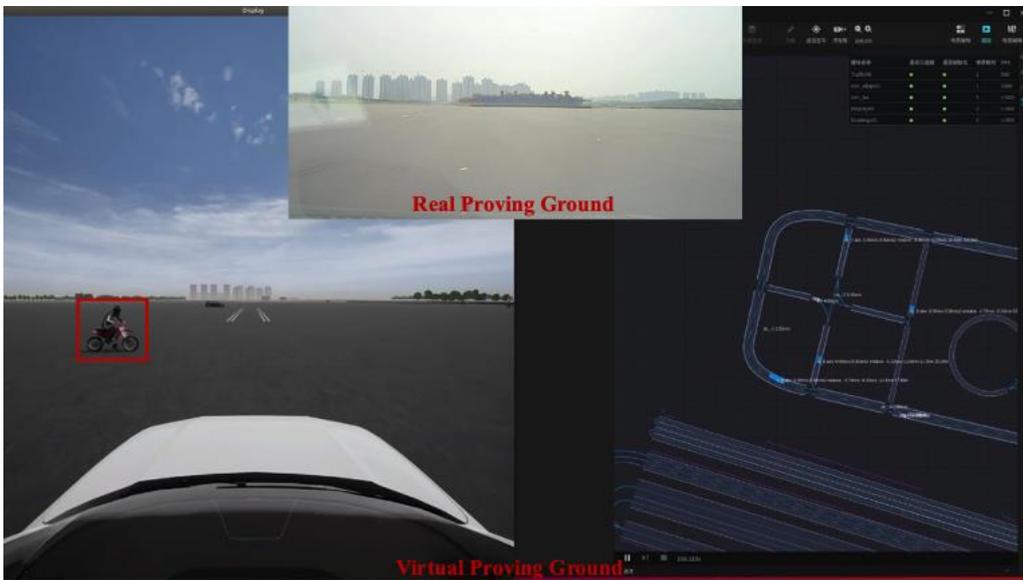
- By analyzing simulation data and responses of real vehicle under test, functions of vehicle can be evaluated.

In this VIL digital twin, different testing scenarios may be configured and a lot of L2/L3/L4/L5 autonomous driving [b-SAE J3016] and V2X functions can be tested.

Figures I.5 (a), I.5 (b) and I.5 (c) show the testing process of autonomous driving in VIL digital twin in which the real vehicle is driving on an open space.



(a) Pedestrians are simulated around real vehicle under test in the virtual environment



(b) Motorcycles are simulated around real vehicle under test in the virtual environment



(c) Vehicles are simulated around real vehicle under test in the virtual environment

Figure I.5 Testing Process of Autonomous Driving in VIL Digital Twin

### I.3 Traffic management and guidance

Figure I.6 illustrates an example of DT-ITS for traffic management and guidance at a highway.

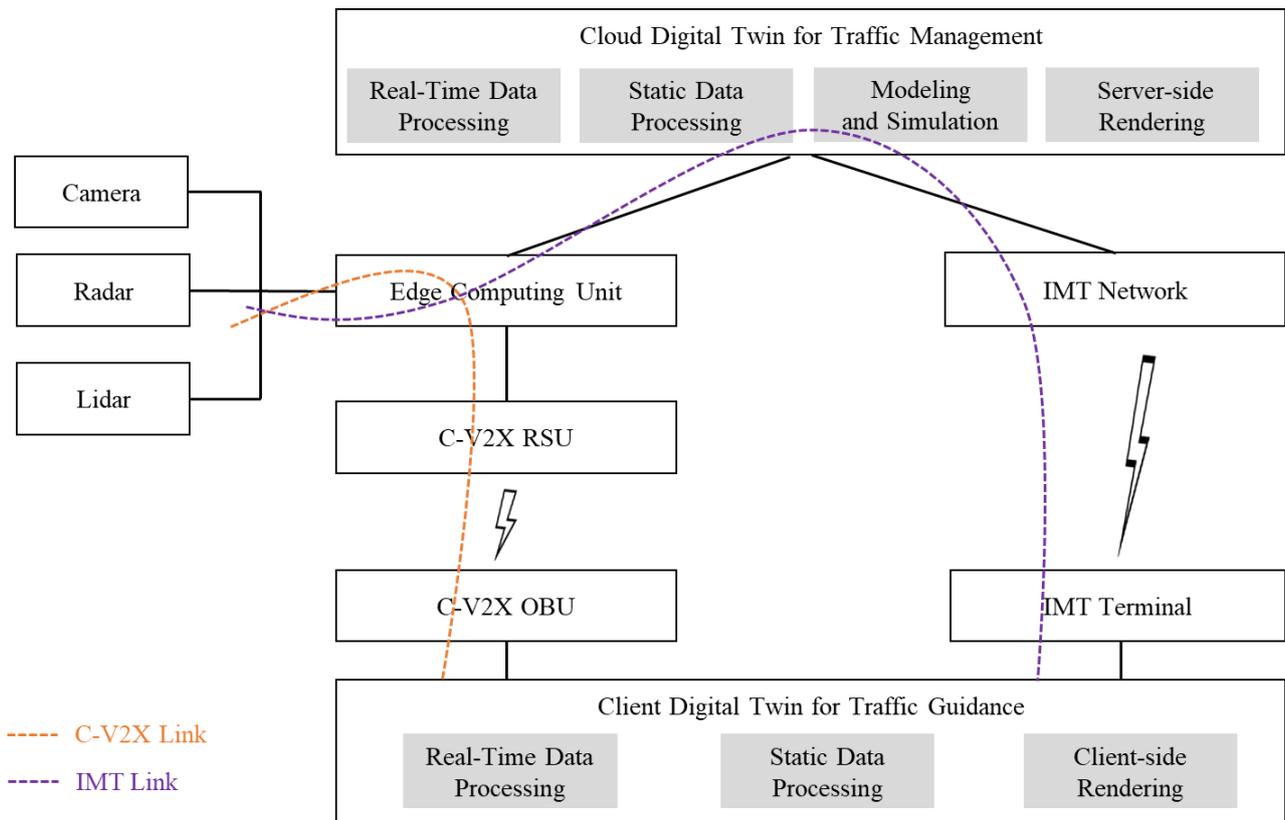


Figure I.6 Example of DT-ITS for traffic management and guidance at a highway

In particular, the DT-ITS includes two parts, cloud digital twin for traffic management and client digital twin for traffic guidance.

#### (1) Cloud Digital Twin for Traffic Management

- Sensors including camera, radar, lidar, were deployed at roadside to detect traffic participants and obstacles in highway.
- Edge computing unit was used to do sensor fusion and output the sensing results.
- Sensing data was further processed and smoothed by real-time data processing unit of cloud digital twin and converted to the appropriate data format for rendering engine, modeling engine and simulation engine.
- High-definition map and surrounding environment of highway were offline collected by mapping vehicles and processed by static data processing unit of cloud digital twin.
- Real-time traffic data was output to the modeling and simulation engine to do online simulation and provide online traffic management suggestion.
- The overall traffic status of highway was visualized after rendering of real-time data and static data.

## (2) Client Digital Twin for Traffic Guidance

- Sensors, including camera, radar, lidar, were deployed at roadside to detect traffic participants and obstacles in highway.
- Edge computing unit was used to do sensor fusion and output the sensing results.
- Sensing data was transmitted to terminal via C-V2X network or IMT-Advanced network or IMT-2020 network.
- Sensing data was further processed and smoothed by real-time data processing unit of client digital twin.
- High-definition map and surrounding environment of highway were offline collected by mapping vehicles and processed by static data processing unit of client digital twin.
- The overall traffic status of highway was visualized after rendering of real-time data and static data.
- Traffic guidance and safety warning information were timely given to people to assist driving based on the cloud computing or client computing of sensing data.

Figure I.7 shows the effect of cloud digital twin for highway traffic management at one moment of night, at which 78 vehicles were detected by radar and visualized.



Figure I.7 Cloud digital twin for highway traffic management

Figure I.8 shows the effect of cloud digital twin for highway traffic management and guidance. When detecting an accident, a short term strategy “closing second lane from the left” was decided after simulation according to the real-time traffic flow and traffic status. Then the decision was displayed to traffic guiding display system to guide people’s driving.



Figure I.8 Cloud digital twin for highway traffic management and guidance

Figure I.9 shows the effect of client digital twin for highway traffic guidance at one moment of night. Pad in the left shows the effect of digital twin in which sensing data was transmitted via C-V2X network, and smartphone in the right shows it in which sensing data was transmitted via IMT-Advanced network or IMT-2020 network.



Figure I.9 Client digital twin for highway traffic guidance

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