Cyber-Physical System Use Case Release-1

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[CPS Use Case]

Legal

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Preface

The IOWN Global Forum is committed to the principles of data privacy and confidentiality. As an organization, we will work to ensure any potential use cases developed will respect individual privacy and not abuse access to confidential information. Individual service providers and other entities leveraging these use cases are responsible for protecting user data and keeping information private.

1. Introduction

The world today has experienced growth faster than ever thanks to advancements in communication and computing technologies.

At the same time, these same technological advancements have, in some cases, served as the source of political, societal, and moral debates. This is due to the sheer magnitude of change these advancements bring to people's daily lives around the world. In particular, there is a perceived lack of power by the average person over critical decisions on developing and using technologies that affect the general population. Recognizing the need to manage the social disruptions brought about by technology, the World Economic Forum, for one, has launched the Center for the Fourth Industrial Revolution to promote multi-stakeholder discussions on the governance of new technologies.

In the near future, another quantum leap in computing and communication capabilities is expected to propel the world toward a new era of sustainable growth. The growing trend of sustainability, including the United Nations' Sustainable Development Goals (SDGs) for the global business community and the broader society, coupled with the expansion of the ESG (Environmental, Social and Governance) investing that integrates social and environmental impacts of business, provides an outstanding opportunity to imbue technology with social purpose. This new focus has the potential to open up new, untapped market opportunities while safeguarding both society and businesses from the unintended risks associated with the use of new technologies.

The mission of the IOWN Global Forum is to develop fundamental technologies on communication, computing, data, and energy efficiency that will bring a quantum leap performance improvement to enable a much smarter world with advanced applications.

The primary purpose of this document is to provide prominent future-looking use cases and identify application-specific service requirements benefiting users from different vertical industries. The collection of data will be used to build the technical requirements necessary for a feasibility study on these advanced use cases.

Use cases are categorized into human-centric applications that assist and enhance the means for communication (AI Integrated Communications: AIC), and smart city applications that aim for autonomy that goes beyond human capability (Cyber-Physical Systems: CPS). Two documents are created to capture each category's different objectives and define a distinct set of requirements [IOWN Global Forum, 2020].

2. Scope

The document intends to provide a key feature set and requirements for use cases categorized into Cyber-Physical Systems.

The initial focus will be put into the following categories:

- Area Management
- Mobility Management
- Industry Management
- Network Infrastructure Management
- Healthcare Management
- Smart Grid Management
- Society Management

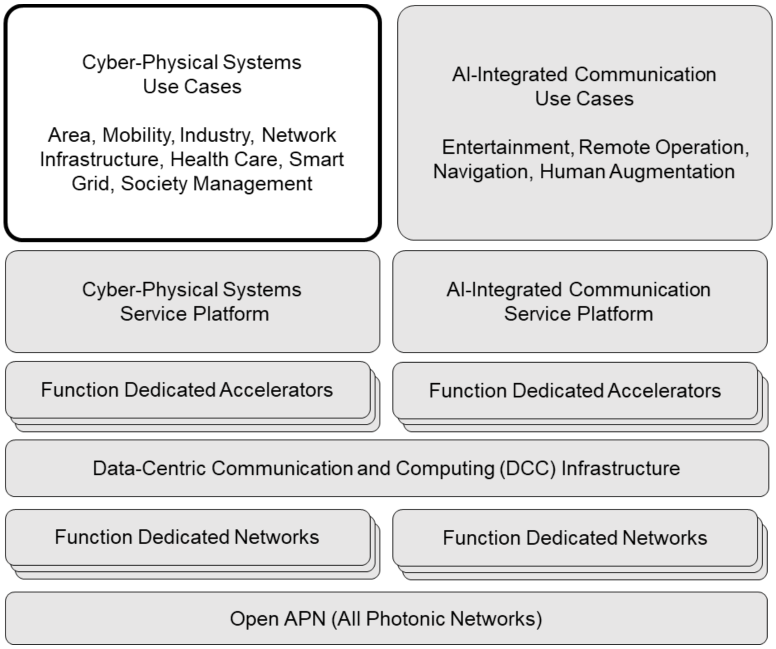


Figure 1 IOWN GLOBAL FORUM-Work Item Structure

3. Use Case Details

3.1. Area Management

As many cities have launched the concept of a “smart city,” advanced area management is one of the key investment areas for many nations, cities, and any person or business related to real estate development. Fostering this evolution are advanced sensing technologies.

Sensor devices capturing information beyond the capabilities of human beings are already a reality. Image sensor performance exceeding 1,000-fps is one of the examples already seen in the market today. Together with neuromorphic or AI integrated sensors, event-driven and adaptive-data type sensors requiring different levels of QoS will soon be available to handle applications of various types.

Advanced sensing is not limited to image capturing. LiDAR will capture the precise position of objects. Fiber sensing will capture the condition of a wide geographic area in which fiber is installed.

We can build live 4D maps by collecting various sensing data and matching the four-dimensional "latitude, longitude, altitude, and time" information. The 4D maps will facilitate the development of various valuable applications. Some may detect incidents and automatically initiate the incident response operation. In contrast, others, which are referred to as digital twin applications, may make short-term predictions and generate some proactive actions.

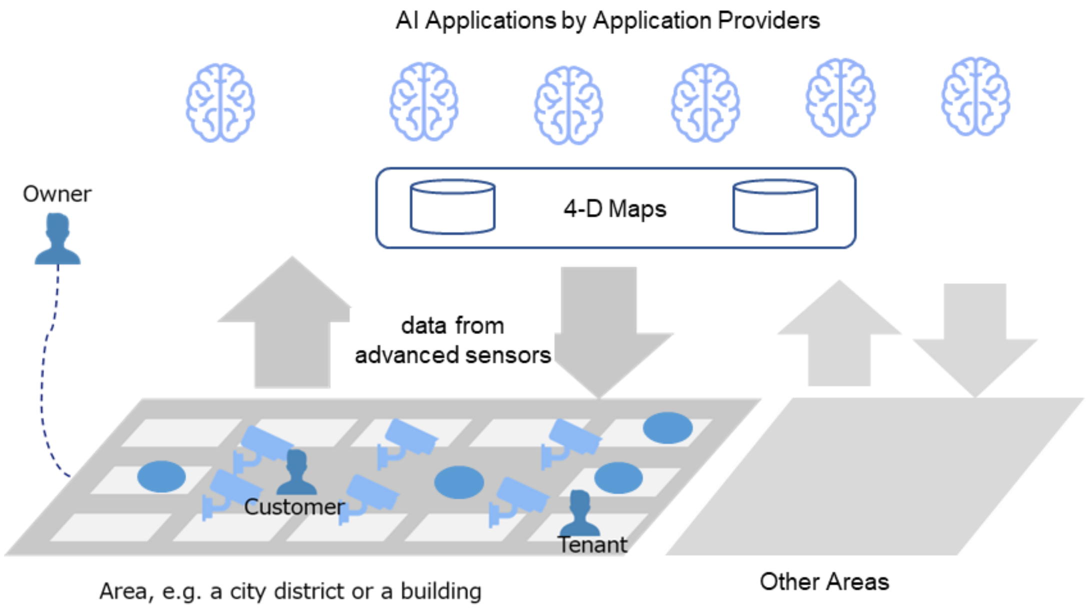


Figure 2 Area Management with Advanced Sensors and 4D Map

The remainder of section 3.1 describes promising use cases with the common personas defined below:

- Area Owner: A person who owns the area, e.g., a building or a city district, or is responsible for the area operation.
- Area Tenant: The owner of a tenant, e.g., store or office, in the area.
- Area Citizen: A person who works in or lives in the impacted area.
- Area Visitor: A person who visits the area.
- Area Customer: Area Citizen or Area Visitor

3.1.1. Security

3.1.1.1. Description

This use case addresses an area owner's desire to prevent incidents/crimes while reducing the security-related cost. AI-based incident detection will automate the process of initiating incident responses. In addition, making short-term predictions about the incident/crime rate will help them optimize the deployment of security agents.

In addition to the common personas defined in section 3.1, the following persona appears in this use case.

Security Information Provider: An entity that collects data from area owners, generates security insights, and feeds them to area owners

3.1.1.2. Key Feature Set

3.1.1.2.1. Persona #1: Area Owner

As an Area Owner, I want to:

- automate the process of
    1. detecting an incident
    2. calling the police and/or security agents
    3. saving the incident image for records and generating an incident report
    4. suggesting responses, e.g., actions to avoid secondary damage
    5. sending alerts to area customers

so that I can reduce the labor cost for area security.

- In accordance with local regulations, identify persons demonstrating suspicious behavior via AI-driven technologies and take proactive actions to prevent crimes and reduce the crime-related cost
- make a short-term prediction about the incident rate to optimize the deployment of a security agent
- get real-time information about the surrounding areas from the security information provider to improve the accuracy of the incident rate prediction.
- track people with suspicious behaviors with AI so that proactive or responsive actions can be taken
- detecting features of suspect persons (such as those on a no-fly list) via facial features and body/attire identification (if available), and take proactive actions

3.1.1.2.2. Persona #2: Area Tenant

As an Area Tenant, I want to:

- be notified of the incident so that I can avoid being negatively impacted

3.1.1.2.3. Persona #3: Area Customer

As an Area Customer, I want to:

- be notified of the incident so that I can avoid being negatively impacted

3.1.1.2.4. Persona #4: Security Information Provider

As a Security Information Provider, I want to:

- collect data from Area Owners, including live maps of people in their areas and incident/crime report to and develop an algorithm for short-term prediction about the incident/crime rate in the area and use this information to provide an incident/crime rate prediction service
- collect from the Area Owners the body/attire features of persons on a potential security list and redistribute them so that the Area Owners can track these individuals in accordance with local regulations

3.1.1.3. Service Gap/Requirements

Network Bandwidth Issue

In today's typical deployment, a frame rate of around 5 fps is chosen for security surveillance. Assuming full HD image resolution and the motion JPEG compression, the data rate from one camera would be about 12 to 20 Mbps.

A typical medium-size building with about 100 -150 tenants deploys 600 - 800 cameras. This means that, without an event-driven approach, the total image traffic would be approximately 7 - 16 Gbps. Sustaining such a high bandwidth for each building with today's network would be challenging or at least very costly. Some means for interaction/incorporation of local and network processing would be necessary.

More importantly, for this intelligent management system to continuously evolve with new applications, we should connect multiple geographic areas and multiple AI application providers with a single, unified infrastructure. By doing so, new application developers can provide their outstanding services to many regions without the need to "re-invent the wheel." In other words, this is a critically important element that's needed for this market to scale. Considering that each area generates data at about 10-15 Gbps, supporting such a significant data flow would be challenging to analyze without that underlying common platform.

Energy Consumption Issue

An AI-based image cognition task for small 400x400 images at 15-30 fps consumes around 10 watts. Assuming 600-800 cameras are operated at 5 fps, the above medium-size building generates image cognition tasks at 3000-4000 fps in total. This means energy consumption is around 1kW. This may sound acceptable, but this holds true only when each camera is enabled with one simple AI application. As more applications are deployed, more cameras will be enabled with more than one AI application, and some applications may require higher image resolution and higher frame rate.

3.1.2. Disaster Notification

3.1.2.1. Description

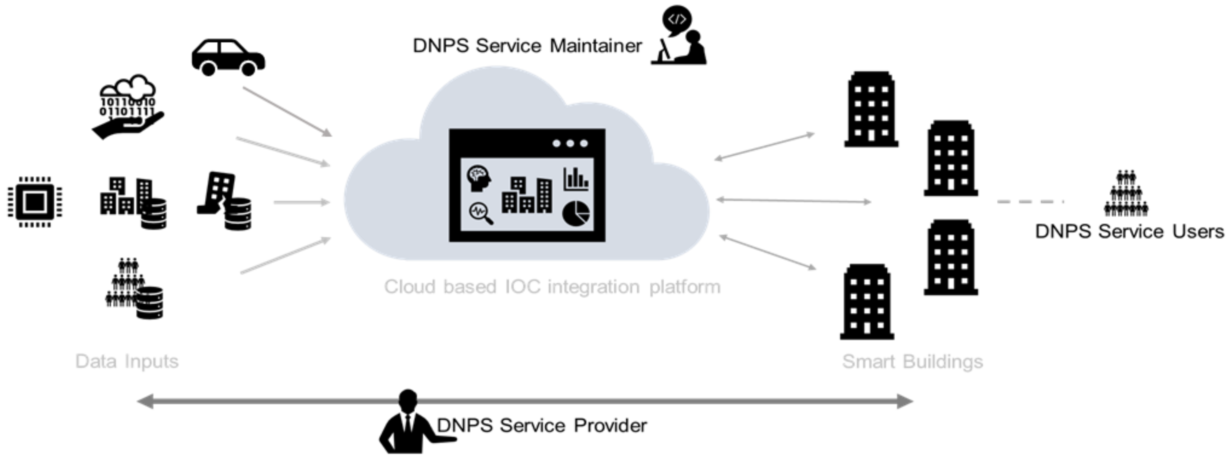


Figure 3 Overview of Disaster Notification and Prevention System

A typical Disaster Notification and Prevention System (DNPS) is composed of IOC (Intelligence Operating Center) and smart buildings, which automatically perform emergency tasks such as issuing an evacuation order from a building upon the occurrence of an earthquake. DNPS integrates many different data sources from buildings in-vehicle sensors and wide-area fiber sensing and has the capability of AI analysis and prediction. By utilizing non-stationary in-vehicle sensors, the digital twin can create a more holistic view of the surrounding environment.

DNPS can alert people in time and control the safety equipment dynamically when a disaster occurs. DNPS also provides a full visualization interface for relevant authorities to intervene quickly. The goals of the DNPS are as follows; (1) fast disaster detection, (2) deliver a quick response, (3) mitigate any damages, and (4) achieve a rapid recovery

For this goal to be fulfilled, IOWN technologies need to be developed to handle multiple chores. These include the massive ingestion of data in various formats from many geographically dispersed locations, the applications of AI models to detect disasters, the ability to issue alerts to populations in the affected region, and the ability to send control signals to disaster prevention equipment. All of these functions need to be performed with very low latency. In addition, to ensure high reliability, this system needs to be built in a distributed, less centralized, and consensus-driven manner.

In addition to the common personas defined in section 3.1, the following personas appear in this use case:

- DNPS Service Provider: Person or group providing the DNPS service, e.g., government
- DNPS Maintainer: Person or system operating the DNPS system
- Data Provider: Dynamic data such as IoT devices, IoT systems, and in-vehicle sensors, as well as static data such as building design data (e.g., BIM)

3.1.2.2. Key Feature Set

3.1.2.2.1. Persona #1: Area Owner

As an Area Owner, I want to:

- receive the alert from a DNPS service provider with very low latency when a disaster happens
- automatically generate the response actions

so that I can save area tenants and customers and minimize the damage.

As an Area Owner, I want to:

- build a live map that shows people requiring assistance in disaster evacuation
- automate the process of sending rescue staff or robots

so that I can assure their safety in disaster evacuation.

As an Area Owner, I want to:

- build a live map that shows people in my area
- when a disaster happens, automatically suggest to area customers optimal evacuation paths based on the above live map and information from the DNPS Service Provider

so that area customers can smoothly evacuate without coming across congestion.

3.1.2.2.2. Persona #3: Area Customer

As an area customer, I want to:

- receive the alert through SMS, smart devices, etc., in very low- latency when a disaster happens
- receive the suggested evacuation path from the area owner
- to escape safely from the disaster area using dynamically controlled equipment
- automatically alert relevant authorities when the disaster happens
- get disaster information with a simple and clear user interface

so that I can live a safe life.

3.1.2.2.3. Persona #2: DNPS Service Provider

As a DNPS Service Provider, I want to:

- collect massive data sources from open data, sensors, citizen data, disaster warnings, etc.
- integrate all buildings in the service area and have the authorization to collect and control equipment.
- not only analyze the data very fast but also get insightful data very precisely.
- send alerts and evacuation routes immediately so that residents can safely evacuate from disaster events
- transmit the data securely and prevent fake alerts from people with malicious intentions
- visualize the real-time status, e.g., dashboard, BIM/CIM, AR/VR/XR

so I can provide a high-quality safety service.

3.1.2.2.4. Persona #3: DNPS Maintainer

As a DNPS Maintainer, I want to:

- build a system that can scale quickly to handle various environments
- build highly automatic systems to reduce manual operation and avoid human error

so I can efficiently maintain the system.

3.1.2.2.5. Persona #4: Data Provider

As a Data Provider, I want to;

- make data available that is focused on opening or distributing data sources
- abstract data sources that involve publishing metadata or data catalog

3.1.2.3. Service Gap/Requirements

Latency and Security Issue

For disaster-related applications, it is crucial to minimize the end-to-end latency in the process flow and increase the speed of computing and analysis. One technical challenge is achieving fast messaging with enough security. Traditional secure communication mechanisms, such as TLS and DTLS, require a few round trips for the mutual authentication and key exchange, which lead to latency of tens of milliseconds. Establishing TLS/DTLS sessions for all sensors would incur immediate messaging upon disaster. However, this would be very costly given that there will be millions of sensors.

Network Bandwidth and Energy Consumption Issues

When cameras are used, the network bandwidth and energy consumption will become the bottleneck. Building a live map that shows people requiring assistance would require many surveillance cameras if blind spots were to be eliminated.

Other Considerations

- DPNS needs a standard interface that can quickly integrate every subsystem (e.g., smart buildings, data sources, etc.). In addition, this standard interface design must be compatible with CAP (Common Alerting Protocol)
- each alert signal sent from any subsystem needs to be mapped to a holistic geographical picture. AI models should be executed against this picture while avoiding an essential increase in end-to-end latency. This is essential to remove measurement errors and increase accuracy

3.1.3. Energy Management

3.1.3.1. Description

Smart City solutions are capable of managing energy consumption by collecting data from sensors and cameras and analyzing the data with AI technologies. With the development of AI algorithms, it is possible to accurately estimate how much electricity should be consumed and allocated in each area.

The following are the possible solutions delivered by advanced energy management.

- air conditioners inside a building will be automatically optimized by AI analysis based on variables such as the number of people present, their attributes such as the people flow rate, their attributes such as gender, age, and attire, the temperature and the humidity of an area
- the brightness of each streetlight would be optimized depending on the weather, car traffic congestion, the presence of pedestrians, and so forth. Energy from various harvesting solutions such as solar and vibration are appropriately distributed to each area

This energy management should be implemented not only in each building but also throughout entire cities by local government. For a city to establish the total energy management required, it is necessary to build an immense data management platform.

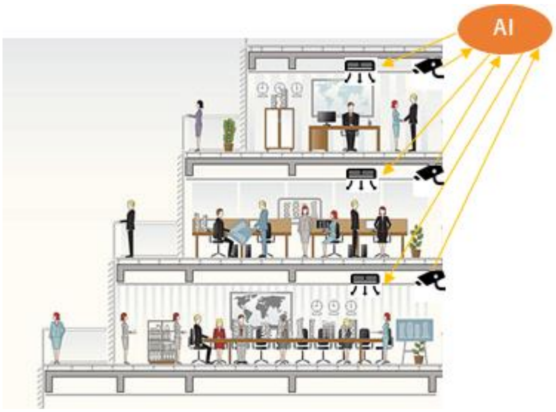


Figure 4 Image of Energy Management

3.1.3.2. Key Features

3.1.3.2.1. Persona#1: Area Owner

As an Area Owner, I want to:

- build a live map that shows the area-wise crowd density and temperature

so that I can reduce energy consumption, make short-term predictions about the temperature, and adjust air conditioning power dynamically.

3.1.3.3. Service Gap/Requirements

Network Bandwidth and Energy Consumption Issues

When cameras are used, we will struggle with the network bandwidth and energy consumption issues as previously described. Building a live map showing the crowd density would require surveillance cameras operated at a frame rate higher than 10 fps, e.g., 15 fps. In addition, as many persons appear in the image, AI inference workload increases, leading to increased energy consumption.

3.1.4. Staffing/Inventory/Price Optimizations

3.1.4.1. Description

This use case contributes to daily business operation of retailers and shopping malls by providing them with detailed information on the potential customers visiting their physical storefronts. Three scenarios apply to a big supermarket with dozens of staff, retail stores strategically controlling inventory for selling "today's" goods, and convenience stores dealing with fresh foods and lunch boxes with one-day consumption limit.

Cameras on the street or inside a shopping mall capture the crowd image, count the number of people in the image, classify them into customer personas such as a parent interested in children's goods, an elderly interested in a hobby, and so on, predict their near-future traffic patterns, and identify potential customers visiting each individual shop. Based on the area-specific potential customers, the retailers can optimize their operations: increasing, decreasing, or reallocating selling staff, adjusting the selling goods or restaurant menus, and discounting products to avoid being wasted. A 4-D map that shows the area-wise distribution of people with their demographic attributes, e.g., sex and age, will facilitate short-term predictions about potential customers and their product/service demands.


Figure 5 Heat Map Inside Supermarket

3.1.4.2. Key Features

3.1.4.2.1. Persona#1: Area Owner

As an Area Owner (e.g., a shopping mall owner), I want to:

- provide information directly related to the area tenants' (e.g., individual retail stores in the shopping mall) business, based on the AI analysis for Staffing, Inventory, and Price Optimizations

so I can support them to raise their sales and reduce their operation costs

3.1.4.2.2. Persona#1: Area Tenant

As an Area Tenant, I want to:

- get a live map that displays people with their demographic attributes, e.g., sex and age
  - ➢ so I can optimize the number of clerks on each timeframe based on a prediction of how many customers will visit my store. For example, there are more than twenty staff working in a large supermarket, which is near the train station and the main street. The number of incoming customers has a strong relationship with

the number of the passengers to/from the trains and the number of people on the road. Based on the real-time, area-specific volume of people and their near-future prediction, I can have more staff standby for extra work or allow some staff to take a few hours off. [Staffing]

- so I can precisely estimate the required quantity of each ingredient. For example, I own a restaurant in a large-scale building, and customers visit there from other facilities. Some popular menus of lunch packs will be sold out. However, it depends on the business day. Therefore, one can precisely predict the characteristic of the target customers and procure the items so that I want to avoid the shortage. [Inventory]
- so that I can dynamically make accurate decisions about pricing. For example, at lunchtime, the majority of customers are housewives who raise children. In the evening, the majority are office workers going home. When some special events occur nearby, such as a school event for children and parents or a big party at the office, the regular trend will change dramatically. I want to know the coming customers as precisely as possible and adjust my target customer segments based on more specific demographical analysis. [Price Optimization]

3.1.4.2.3. Area Customer

As an Area Customer, I want to:

- get an item at a retail store without the stock shortage
- avoid waiting in a long queue at the cashier corner
- buy my favorite food menu items of the lunch pack at a restaurant without the stock shortage
- buy an item at a better price at a retail store

so I can shop smoothly.

3.1.4.3. Service Gap/Requirements

Network Bandwidth and Energy Consumption Issues

When cameras are used to count and classify people in the crowd, we struggle with network bandwidth and the energy consumption issues described in Section 3.1. Creating live maps that classify and count people with different attributes, such as gender and age, requires higher image resolutions and frame rates in excess of 10 fps. e.g., 4k resolution, 15fps frame rate. In addition, a more detailed classification of customer attributes requires multiple kinds of AI processes, which further increases computing workload and energy consumption.

3.2. Mobility Management

The IOWN Global Forum aims to play a key role in the rapidly advancing mobility technology. The Forum, with its communication bandwidth and computational power, will enable the prompt collection and processing of vast sensor data from numerous vehicles and roadside sensors, enabling a safe, robust navigation service for autonomous and manned vehicles. In addition, the collected data will be integrated within IOWN to create a Traffic Flow Digital-Twin, which will forecast energy-optimal routing for each individual vehicle. Furthermore, this digital twin will interact with the Smart-Grid Digital-Twin, which will enable the batteries within the vehicles to act as means to effectively transfer power, to help create a carbon neutral society.

Soon, the technologies cultivated by the IOWN Global Forum are expected to be installed within each vehicle, creating an energy-efficient and highly intelligent next-generation mobility system.

3.2.1. Safety Maneuver

3.2.1.1. Description

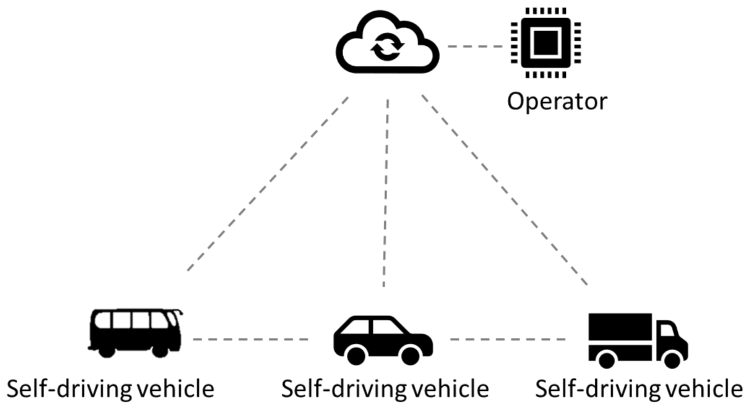


Figure 6 Overview of Safety Maneuver System

With the IOWN Global Forum's proposed solution, vehicles will be remotely controlled by CPS, complementing standalone sensing and maneuvering technology, enabling a safe, assured mobility system. In-vehicle and roadside sensor data will be processed within CPS to promptly create optimal maneuvering instructions for each vehicle. To avoid collision with other vehicles and any obstacles on the road (including pedestrians), maneuvering instructions must be fed back to the vehicle within a specific response time from when an object is first detected.

The established infrastructure will be further utilized for safety applications ranging from automated overtake, pre-crash warning system, see-through safety to automated unmanned vehicles [1], [2].

The description of each sub-use-case can be summarized as in Table 1.

Table 1 Summary Description of Safety Maneuver Sub Use Case

Sub Use Case	Description
Automated Overtake	Automated overtake requires cooperation among vehicles traveling in multiple lanes to create the necessary gap to allow the overtaking vehicle to quickly merge into the lane corresponding to its direction of travel in time to avoid collision with an oncoming vehicle.
See-Through Safety	For roadside safety, camera images and other sensor data are shared between vehicles to compensate for views blocked by surrounding vehicles and obstacles.

Pre-Crash Warning	Pre-crash sensing application provides warning to vehicles in the event of an imminent and unavoidable collision by exchanging the vehicle's attributes when a crash is anticipated.
Automated Unmanned Vehicle	Automation of unmanned vehicles such as delivery trucks or security bots is expected to proliferate in the near future. Although the safety requirements are expected to be relaxed compared to manned vehicles, the same in-vehicle and roadside sensor data will be needed to realize the use case.
Security	By collecting and analyzing high-definition image data and location information of vehicles in real-time, we will grasp the trends of vehicles and people to be searched and aim for crime prevention services and accident prevention by AI analysis.

The following Personas appear in this use case;

- Drivers and Passengers: Drivers and passengers in autonomous vehicles
- Operator: Person or group to monitor safe mobility in the city
- Resident: Residents/Citizen

3.2.1.2. Key Feature Set

3.2.1.2.1. Persona #1: Drivers and Passengers

As Drivers and Passengers in self-driving vehicles, we want to:

- safely arrive at the destination without encountering accidents

3.2.1.2.2. Persona #2: Operator:

As an Operator monitoring traffic flow in the city who may directly work for or is associated with local government or city, I want to:

- provide a safe and secure mobility system with no traffic accidents

3.2.1.2.3. Persona #3: Residents/Citizen

As Residents/Citizens, we want to:

- live in a safe city where there are no accidents

3.2.1.3. Service Gap/Requirements

- due to network and computational limitations, current technology cannot determine the physical positions of objects or collect the environmental information of millions of moving vehicles and fixed equipment required to predict the future positions within the desired latency

Service requirements can be summarized as follows;

- predict the current and near-future positions of hundreds to tens of millions of moving devices and estimate the surrounding environment at super-high speed
- according to the purpose and situation, it is necessary to have super-high-speed control of hundreds to tens of millions of moving devices. It may also be required to synchronize multiple devices and equipment according to the purpose and situation.
- the speed controlled by the operator is of no value unless it is faster than the speed controlled by human judgment
- moving devices and fixed equipment must always be connected to the network

3.2.2. Energy Optimal Routing

3.2.2.1. Description

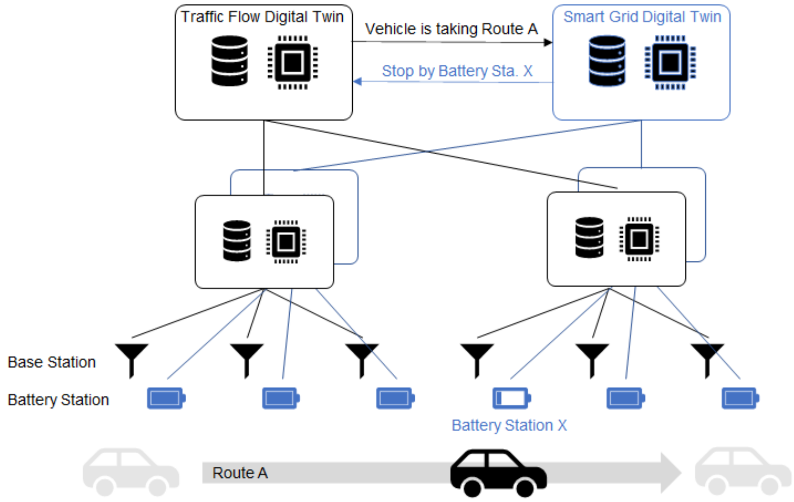


Figure 7 Overview of Energy Optimal Routing System

By 2030, most mobility in the decarbonized society will use electricity as the energy source. Optimization of operation routes according to the characteristics of electric motors and their surrounding environment will be essential to contribute to carbon neutrality. The IOWN Global Forum will enable processing of the vast sensed data from vehicles and roadside sensors to create a Traffic Flow Digital-Twin and provide energy optimal route information to each electric vehicle.

Furthermore, batteries within the vehicle will be recognized as one power unit in society and can be factored into optimal power generation and utilization plans for society as a whole. The Traffic-Flow Digital-Twin interacting with the Smart-

Grid Digital-Twin, which manages the societal energy flow, including usage of renewable energy, will enable the batteries within the vehicles to act as means to effectively transfer power and further help create a carbon neutral society.

3.2.2.2. Key Feature Set

3.2.2.2.1. Persona #1: Drivers and Passengers

As Drivers and Passengers, we want to:

- achieve environmentally-friendly mobility with energy optimal route selection, including linkage to external information such as weather and road conditions
- efficiently generate, charge, and store power for operation of the mobility
- contribute to the realization of a carbon-neutral society through the utilization of in-vehicle battery units and efficient usage of renewable energy
- promptly check the deterioration status of the in-vehicle battery and receive equipment maintenance services at the appropriate time

3.2.2.2.2. Persona #1: Energy Distributor

As an Energy Distributor, I want to:

- collect information such as location, power utilization, and storage amount to manage in-vehicle power units as a power storage facility
- predict future power demand with high accuracy and formulate a power plan that includes power from in-vehicle batteries
- achieve quick power transfer between infrastructure and mobility
- systematically implement charges for buying and selling electricity based on secure personal information

3.2.2.3. Service Gap/Requirements

- secure linkage of personal information such as mobility and financial accounts
- management of individual deterioration information of power units and advanced battery life detection
- reduction of charging time and improvement of power supply efficiency
- breaking through the limit of power saving of mobility itself
- route search service specializing in electric-powered mobility
- increasing the capacity of in-vehicle batteries to serve as terminals for social power infrastructure
- promotion of infrastructure construction such as stations that can supply power to mobility at high speed

Large-scale power management that takes into account the movement of many power supply units

3.3. Industry Management

The IOWN Global Forum revolutionizes operation in various vertical industries. In this section, we will describe an example use case of smart plant/factory management.

3.3.1. Factory Remote Operation

3.3.1.1. Description

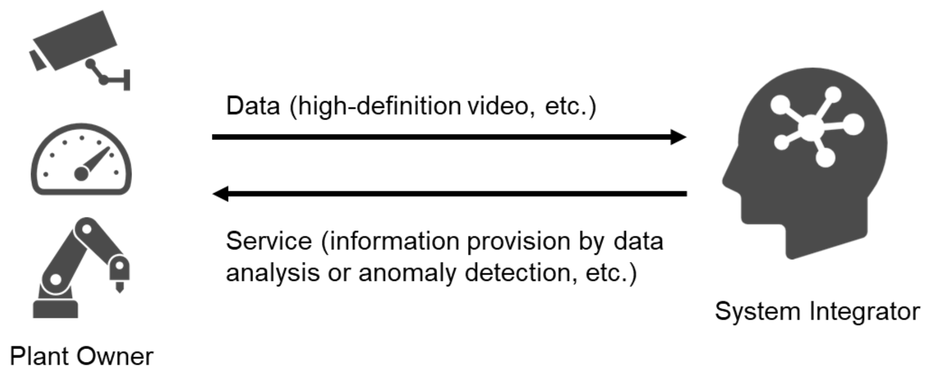


Figure 8 Overview of Factory Remote Operation

Given the combined trends of the Fourth Industrial Revolution (or Industry 4.0) and the recent spread of the COVID-19 virus, there is a growing need for remote and real-time monitoring of people, goods, machinery, equipment operation, etc., throughout the modern factory. The objectives of such monitoring include early detection of abnormal situations and rapid implementation of required measures (dynamic adjustment of machine parameters, emergency stop on the production line, evacuations, etc.) because these contribute to improve yield ratio and keep workers safe.

For example, suppose an anomaly is detected at a chemical plant. In that case, there is increasing demand to let experienced engineers check real-time on-site conditions through video captured with high-definition (4K/8K) cameras to accurately grasp the situation and quickly analyze the anomaly's cause. In this way, these experienced personnel would be able to issue instructions on how to adjust the current operating state before a major production failure or accident occurs and how to return the production status to normal at an early stage.

At present, however, no service can reliably transmit such large volumes of data whenever and wherever needed in real-time at a reasonable cost. The current situation is that the cause of a detected anomaly is inferred based on limited and incomplete information and assigned engineers' experience and intuition, resulting in the longer time, larger labor, and higher cost in handling the problem on-site.

As a result, many companies faced with stagnant productivity, labor shortages, and increased accidents look forward to a solution that can transmit large volumes of data as in high-definition live video inexpensively and safely.

Even today, high-speed, large-capacity communication services exist, but bandwidth-guaranteed network services are expensive, and their use as necessary insurance against abnormal times is not worth the cost.

In addition, services for managing and automatically optimizing communications traffic loads directly through from a high-definition camera to LAN, gateway, edge computer, access circuit, communications building, relay circuit, Internet, and global cloud, for example, are insufficient.

Furthermore, high-definition video from the field often includes sensitive information involving personal privacy and corporate secrets. Still, it is not unusual for the work of on-site management, remote monitoring, and implementing measures to minimize damage, restore operations, etc., to be handled by different companies. As a result, appropriately protecting such confidential information based on inter-company contracts requires complicated security management operations that tend to drive up business costs. This problem, in turn, makes remote maintenance operations of factories, plants, buildings, and urban spaces difficult. As a result, it has been necessary to deploy personnel in the field to visually inspect on-site facilities and manage safety by human wave tactics (i.e., by sheer force of numbers). This is considered one reason why productivity has not risen in industrial sectors such as manufacturing, distribution, and transportation.

In cooperation with domestic and overseas communications operators, hardware vendors, software vendors, users, universities, research institutions, the national government and municipalities, community groups, etc., we seek to achieve a secure and high-efficiency data distribution service that can appropriately protect, transmit, and share large volumes of data such as high-definition live video used for safety monitoring of manufacturing sites, urban spaces, etc. based on laws, regulations, and ethics.

This use case also includes the following situations: Factory managers watch high-definition video data from cameras in factories and plants from a remote headquarters office of the same company while on a business trip or working from home. Factory managers connect the manager's office and the machine manufacturer's office and share the same video data to both offices simultaneously while consulting with the maintenance staff of the machine used in the factory to recover from the trouble. In such cases, there is a problem 5G cannot solve yet in interconnecting multiple private networks and public networks operated by each location or company to minimize latency and synchronize the transmission of high-definition video data.

To address this issue and accelerate the Fourth Industrial Revolution initiative, the development of new technology which can transmit a large volume of data continuously, reliably, and inexpensively is desired.

This use case assumes the following scale:

- Region: Country-wide
- Factory and plants: 10,000 sites
- Cameras: 100 per a site

The following Personas appear in this use case:

- Factory Owner: A person who is responsible for operating a factory or a plant
- System Integrator: A person who provides factory owners with engineering services such as machine troubleshooting and machine condition monitoring

3.3.1.2. Key Feature Set

3.3.1.2.1. Persona #1: Factory Owner

As a Factory Owner, I want to:

- have my factory monitored and controlled with AI to improve operational efficiency, reduce downtime, and optimize the operation with more insights
- have my factory monitored remotely by the system integrator so that I can prevent major accidents causing a huge revenue loss and increase the productivity
- allow a system integrator to remotely access my factory while keeping my confidential information from being exposed to the system integrator
- share detailed operational data, including high-definition video data, with my engineers and system integrators quickly and at a low cost so that they can resolve problems more quickly
- share my factory data with system integrators while enforcing the necessary policy and an audit process so that I can protect my confidential data

3.3.1.2.2. Persona #2: System Integrator

As a System Integrator, I want to:

- remotely access detailed operational data, including high-definition video and sensor data, so that I can find the cause of the anomaly
- utilize an AI system that receives the telemetry data from factories and makes short-term predictions about the current failure/anomaly occurrence rate so that I can avoid overlooking problems
- analyze customer's factory operational data with my AI software without exposing it to the customers. (Note that, conversely, a factory owner wants to avoid exposing the factory operational data)
- collaborate and discuss with other engineers, including those who work in a different place, so that I can precisely and effectively analyze the problem
- utilize a method of handling customer's data under the agreed policy so that my customers can share their factory operational data

3.3.1.3. Service Gap/Requirements

Latency and Security Issue

Monitoring and controlling factory machines require a high-speed feedback loop. That's why today's OT (Operation Technology) infrastructure uses industrial LANs, which are not TCP/IP-based. Adding AI capabilities to such latency-sensitive systems is a technical challenge. Deploying AI computers to factories is a possible approach. However, this approach will lead to significant CAPEX for factory owners, as AI computers get outdated very quickly. Alternatively, more sustained hardware and software update capabilities are required to maintain state-of-the-art AI capabilities in the factory. Connecting factory controllers, located in factories with cloud-based AI applications will be a promising approach. However, achieving this requires an ultra-reliable, high-bandwidth, and low-latency communication link. Furthermore, as detailed below, there should be some mechanism whereby factory owners can avoid exposing confidential operational data to others. Monitoring and controlling factory mechanisms and data management systems require appropriate security features to ensure confidentiality, integrity, and availability.

Data Management Issue

Most existing confidential data protection concepts control data access on a network-by-network basis, but to realize the above scenario flexibly (i.e., to change the accessibility of real-time data flow of large volumes of data or high-definition video streams within a minute), a novel mechanism for data-centric access control is needed.

We consider that a system combining the following functions will control and ensure a communications bandwidth in an on-demand and flexible manner according to each user's usage scenario and type of request. Such a system will securely and reliably transmit required information (large volumes of data) at minimum cost whenever needed to the target place or person at the speed and security level required.

1) Automatic monitoring and automatic optimization of communications traffic

This function will monitor communications traffic in an integrated manner from a device (high-definition camera, etc.) connected to a terminal on the IoT network to a LAN, gateway, edge computer, access circuit, communications building, relay circuit, Internet, and the global cloud. After observing load conditions on the device, communications node, network, server, etc., it will optimize that traffic.

2) End-to-end authentication and access control

This function will appropriately control access to the hardware of each device and access to the data provided by each device in accordance with the contract concluded between the data provider and data user and applicable laws and regulations. It will also prevent that data from flowing to corporate entities or individuals having no contract with the data provider or to unauthorized servers depending on the data-providing device. When distributing data among many data providers and data users, it may be necessary to have an efficient distribution method of credential information for end-end encryption. Data sharing between Data Owner(s) and Data User(s) ensures their confidentiality, integrity, availability, and privacy and authenticity.

3) Social sharing and use of data

In abnormal times (including major catastrophes and national states of emergencies), this function will transfer and share on-site surveillance data to and with related operators and municipal entities (such as fire departments, police departments, cyber police, health authorities, and Self-Defense Forces) based on laws and regulations and national-assembly/government decision-making. It will use that digital data to prevent damage and bodily harm and achieve early restoration in cooperation with concerned parties.

4) Democratic management of confidential information

Access Control and data sharing are to be taken based on consensus between Data Provider(s) and Data User(s) regarding the content data use (e.g., the quality of the data or how the data will be processed). Also, the consensus can be enforced and audited. Data Provider(s) and/or Data User(s) or authorized entities (e.g., authorized external organizations) can check the data usage history (including create, read, update and delete) at any time.

This function will manage access control and data-sharing authority described above in a fair manner from diverse viewpoints such as international treaties, trade rules, the constitution, laws, human rights, ethics, and Sustainable Development Goals (SDGs). It will enable a third party to appropriately (democratically) monitor and manage those operation rules so that the use of confidential information is not monopolized or abused by certain companies or groups, government entities, or law enforcement agencies.

5) Cost allotment (charging, billing, settlement)

This function will appropriately allot the construction and operating costs of the system described above among related players, including data providers, data users, the national government and municipalities, communications operators, and cloud operators, and will charge, bill, and settle accordingly.

The additional requirement of the data management platform is the interoperability between international data-sharing platforms or architectures considered by other communities. Considering that some technologies in compliance with international data management rules have yet to be firmly established, we recognize the need for assembling specialists in various fields from countries around the world to discuss the form of a next-generation data management platform and for implementing it in society in a stepwise manner such as through demonstrations and other activities. Some international communities/projects considering data management architectures include GAIA-X, International Data Spaces Association (IDSA) in Europe, and the Robot Revolution & Industrial IoT Initiative (RRI) in Japan.

3.3.2. Process Plant Automation

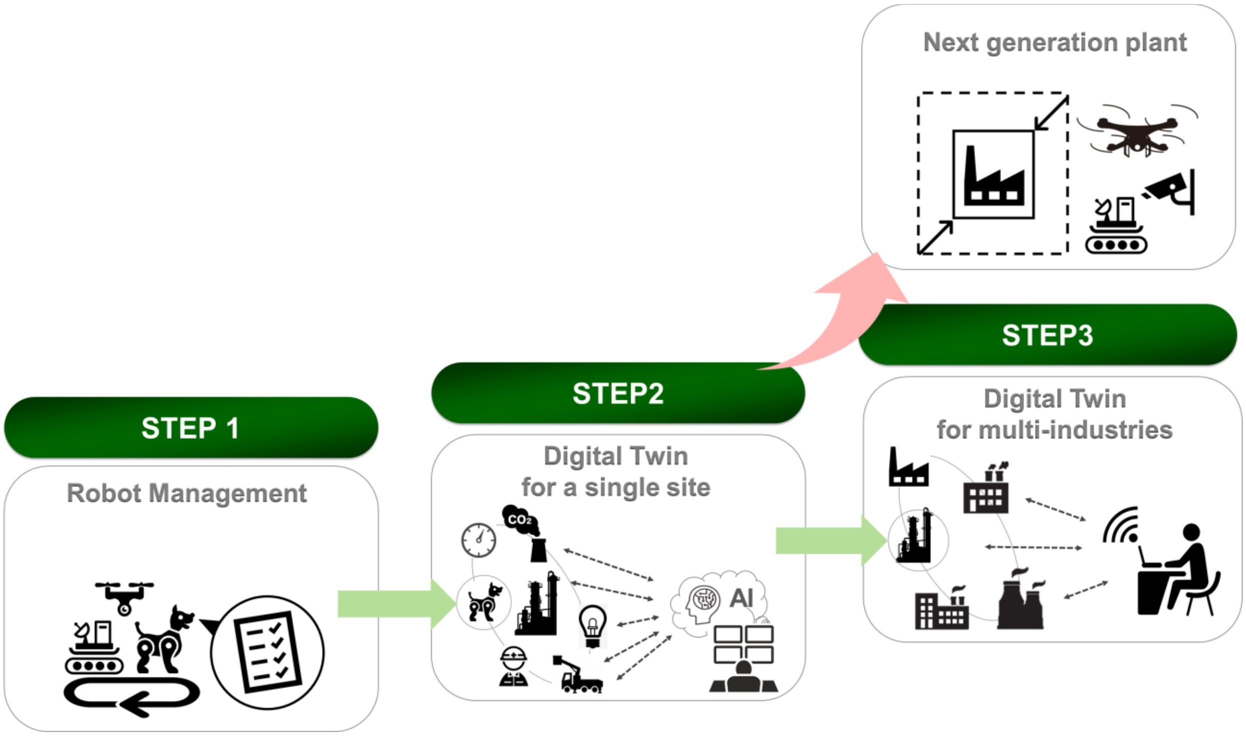


Figure 9 Overview of Process Plant Automation

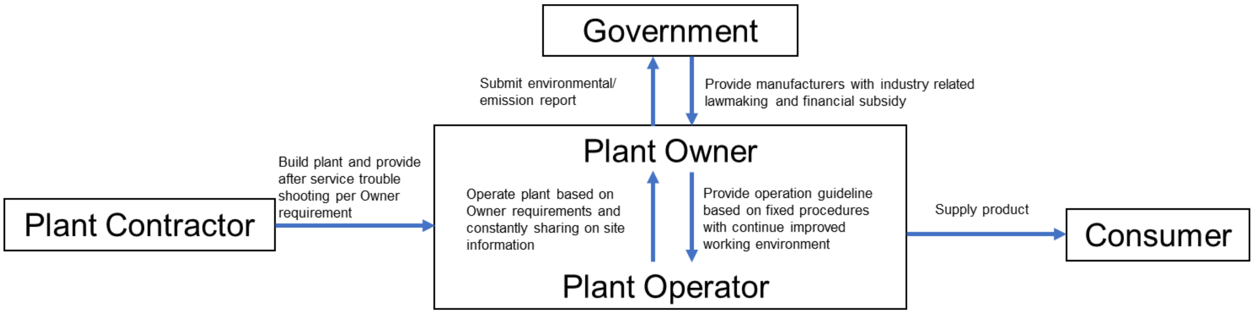


Figure 10 Persona Correlation

3.3.2.1. Description

Towards 2030 and beyond, process plant owners face various issues, such as aging plants, increasing maintenance costs, ensuring worker safety, lack of human resources, and controlling CO2 emission to meet local/global regulation. Process plants produce chemicals, oil, gas, etc., which usually are liquid or vapor that need to be contained and consist of variously shaped and sized equipment, such as tall columns/ chimneys, large tanks, heat exchangers with tube bundles, rotating machines, complex piping, and cables. Several different types of equipment and connecting piping are installed in a congested block called a unit. Multiple units constitute a process plant on a vast site, as seen in Figure 10.

Figure 10 Image of a Process Plant

There are a huge number of items to inspect within a process plant, including wall cracks, corrosion, and water leaks. There are also many locations where it is difficult for human operators to enter or inspect, such as narrow areas, hazardous areas, and high places.

Currently, any inspections, maintenance, and operations are still borne by human operators because of the complexity of these facilities. Furthermore, production efficiency changes according to the external environment, such as temperature, humidity, and particulate content of the atmosphere.

By controlling massive numbers of sensors and operating robots/drones in real-time, plant owners can easily check all kinds of data remotely and enable remote maintenance by XR with haptics communication. In addition to allowing the inspection and maintenance of all previously difficult areas for humans to access, plant owners can achieve safer, long-term operation and early detection of abnormalities beyond human capabilities. (Step1: Robot Management)

In addition, all information such as visual data, operation data, human flow data, atmospheric data, and greenhouse gas emissions will be converted into real-time data and integrated into the system. AI will analyze this data to improve more efficient operation and autonomous control. Furthermore, AI will simulate by changing operating parameters, e.g., raw material, reaction, atmospheric condition, or switching production. (Step2: Digital Twin for a single site)

In the future, by interconnecting multiple plants related to the supply chain, we will realize much higher efficient data management for the entire plant industry. (Step3: Digital Twin for multi-industries)

Furthermore, achieving and introducing the concepts in Step1 and Step2 into the new future plant, the next generation plant can be constructed that enables:

- Area optimization
  - no need for access areas, stairs, or scaffolding for human operators
  - minimizing equipment capacity and high-efficiency operation
- Power usage optimization
  - no need for lighting for human workers.
  - lowering required pump driving power by shorter fluid flow path (pipe route)
- Electric power optimization

  - ideal mix of power generation sources, i.e., maximize the percentage of renewable energy, under the balance of energy consumption among multiple interconnected plants
- Multiple and various productions
  - highly flexible switching operation depending on market demand and regardless of the season and time of the day

3.3.2.2. Key Feature Set

3.3.2.2.1. Persona #1: Plant Owner

As a Plant Owner, I want to <Step1, Step2>:

- avoid regular large-scale shutdowns (usually from 2 to 4-year cycle to a more extended cycle period) for plant maintenance to improve plant operation availability and its running cost
- remotely inspect places where it is difficult for human operators to that people cannot access, such as hazardous areas, narrow areas, and high places, and detect potential corrosion and cracks by AI that even skilled workers cannot find or hide under thermal/ cold insulation and the junction point of components so that people cannot access, such as high places and narrow areas, so that we can avoid overlooking the abnormalities and realize longer-term and safer operations
- monitor the site situation at the site in real-time in the event of an accident or disaster and execute safety measures by remote haptics robotic management to keep workers safe and respond quickly to dangerous situations
- accurately calculate the amount of CO_2 and the other greenhouse gas emissions required for each product and supply chain so that we can meet the strict requirements of manufacturers regarding CO_2 emissions for manufactured products (Including energy consumption converted into CO_2 emissions)
- carry out inspections /heavy work remotely, such as at home, to respect the diversity of employees involved in plant operations, such as the family environment and work-life balance
- adopt a system of robots and sensor-based monitoring to reduce workers' physical and mental stress and eliminate industrial accidents

Table 2 Example Operation Requiring Reduction of Human Worker Burden

Location	Activities by Human Operators	Burden on / Risk to Human Operators
Indoor	Visual checks in the manufacturing process near the rotor.	Entanglement in rotating parts
Indoor	Instrument readings at high temperature and high humidity	Heatstroke
Indoor(construction)	Safety confirmation work after construction (Checking the fire source)	Limited human resources
Indoor (Material storage room)	Feeding flexible containers	Dust particles

Indoor (Material storage room)	Feeding raw materials	Loading work of heavy objects
Outdoor	Receiving pallets of raw materials	Limited skilled operators
Outdoor	Checking of piping leakage (e.g. of gas or liquids), corrosion] *24h	Massive surface area
Outdoor	Outdoor instrument reading *24h	Wide area
Outdoor	Night-time security patrols	Wide area
Explosion-proof area	Any activities	Wearing a gas mask / gas concentration measurement and Instrument readings
Inside the tank	Any activities	Wearing a gas mask / Gas concentration measurement
Cleanroom (e.g., in a semiconductor manufacturing plant)	Visual checks in the manufacturing process	Cleanroom suits

<Step3>

- construct a facility that can operate completely remotely by utilizing robots and sensing technologies so that we can locate new plants in remote areas, operate safer, and lead to higher operation availability by operating around the clock
- construct a space-saving plant on condition that people will not pass through inside the plant so that we can reduce the cost of construction and operation, including power usage, and provide a more suitable product
- optimize the ideal mix of power generation sources for plant operation so that we can maximize the percentage of renewable energy considering the total energy cost and balance among other users
- introduce an automated production control system by utilizing enormous operating data, simulation, and digital twin to change the type and amount of products according to market demand, time, and season
- improve the accuracy of anomaly detection to prevent accidents
- quantify the operation status and consolidate and share it across business sites to achieve higher productivity through the use of AI
- centrally manage information related to maintenance and inspection across multiple sites to take proactive prevention measures for each site
- reduce the workload of workers so that we can ensure the safety and security of workers
- compare and verify the construction of new plants and improve existing ones for capacity to make investment decisions

3.3.2.2.2. Persona #2: Plant Operator

As a Plant Operator, I want to: <Step1, Step2>

- place the sensors and cameras in the right places so that we can leave the efficient patrol to robots
  - Self-control robots: regularly patrol activity
  - Remote control robots: temporary patrol/ maintenance activity/ emergency operation (real-time interaction for severe remote operation)
- leave a lot of activities at the site to robots so that we can reduce the number of complicated operations and continue safe operations
- display necessary procedures and reminders according to the inspection points to the on-site operator with XR hologram and AI so that we can eliminate mistakes and secure proper maintenance, e.g., how much to tighten the valve and at what speed to push the lever, etc.
- check precise location of robots/ drones/ human operators and status of operation and maintenance in real-time by using digital twin holograms that show the entire plant operation so that we can:
  - find visualization of abnormal signs from fixed sensors, operation data, or patrolling robots/drones.
  - check the location and situation with abnormal signs immediately and remotely by live video with visual appearance, actual sound, and/or odor data.
  - safely guide human operators at the site to the most appropriate evacuation route in a disaster.
  - easily guide maintenance robots to the target location remotely.

3.3.2.2.3. Persona #3: Plant Contractor

As a Plant Contractor, I want to: <Step1, Step2>

- conduct an on-site survey remotely from outside of the site to plan and design for the revamping of the plant.
- understand an on-site detailed trouble situation in real-time so that I can offer the best solution from our office.

<Step3>

- modularize unit facility (including equipment) fabrication using the latest construction technologies such as large-scale 3D printing so that we can minimize human resources for construction work in hazardous or remote areas.
- accurately calculate CO2 emissions for each facility during construction so that we can report it to a plant owner required for each product and supply chain (We also would like to calculate the amount of CO2 emissions during equipment manufacturing by each supplier).
- optimize project execution, including project budget, schedule, and quality control by simulation based on digitalizing client's requirements and specifications so that we can provide an attractive proposal

3.3.2.2.4. Persona #4: Consumer

As a Consumer, I want to:

- understand information about the LCA (life cycle assessment) of products manufactured in the factory, including the amount/ history of carbon dioxide emissions, to select environmentally responsible products
- confirm the amount of CO2 emissions in the manufacture of each product to purchase environmentally friendly products

3.3.2.2.5. Persona #5: Government

As Government, I want to:

- accurately calculating total CO_2 emissions and CO_2 reductions in the plant industry to confirm the degree of achievement of targets under the Paris Agreement and promote CO_2 emissions trading to achieve these targets
- reduce power consumption in the entire plant industry so that we can improve the consumption ratio of renewable energy

3.3.2.3. Service Gap/Requirements

- Sensor systems
  - high-resolution sensing that can discover abnormal signs beyond human capability and AI-based analysis system for a large amount of sensed data
  - wide range of measurement devices to cover all environments and conditions, and their widespread use to reduce installation costs
- Robot/ drone systems
  - Various types and a great number of robots working autonomously or with remote control at the same time depending on the work purpose, such as described in Table 3 and Table 4
  - a system that can remotely control the following actions in real-time with high accuracy and without accidents
    - self-control patrolling robots
    - remote control robots for inspection and heavy work
    - remote haptics robotic management
  - robot-friendly designed plant
  - Ultra-low latency for haptic response (10msec or lower)
- AI/computing systems
  - detection of potential corrosion and cracks beyond human capability
  - eliminate human error in tasks that require complex and flexible responses
  - a lot of high-resolution sensors in a complex plant, coordinated monitoring by many robots, coordinated operation system
  - efficient, low-power computing resources
- XR hologram systems
  - showing instruction to on-site operators with the following technology
    - real-time synchronization
    - correspondence to complicated spatial shapes in the field
- establishing a digital twin hologram that represents the operation and maintenance status of the entire plant in real-time
  - human flow data, robots/ drones positioning are also displayed
  - piping temperature, Reactor temperature/ pressure
  - when operators touch a place on the hologram, the monitoring robot rushes to the site to provide real-time video.
- continuous connection reliability
  - seamless network switching when the drone operates aerial images on the plant site (2 million m^2)

  - self-control to predict and avoid locations where communication will be cut off, such as the backside of complex piping and small areas.

- the high data rate for high-quality video transfer including;
  - data on transportation and construction equipment
  - utility data under construction
  - real-time video data (8K level)
  - 3D spatial data (real-time hologram generation)
  - monitoring of dust, etc.
  - atmospheric gas concentration data (early leak detection)
  - production/operation data (materials used/operating conditions/construction method)
  - human flow data in the plant
- CO2 emission monitoring system
  - installation of a large number of sensors to measure physical CO2 emissions
  - real-time calculation of total CO2 emissions, including the amount of power consumed in production and the collection of large amounts of information such as sensors.
  - formulation of global LCA(Life Cycle Assessment) definitions and calculation rules for CO2 emissions

Table 3 Types of Devices and Key Functions

Device Type	**Purpose**	**Function**	**Autonomy**	**Haptics Control**	**Number (per Plant)**
Air Drone 1 	Monitor	• High-resolution(8K) video collection on site • Up to 100 meters above the sky • Including the interior of complex equipment • Continuous connection reliability • Autonomous movement to the inspection site • Avoiding dead areas of the network • Avoiding obstacles	x		100
Air Drone 2 	Deliver	• Logistics delivery and collection of fallen objects • Up to 50 meters above the sky • Lifting objects up to 10 kg • In special environments such as high temperatures • Autonomous movement to the inspection site • Avoiding dead areas of the network • Avoiding obstacles	x		10

Ground Drone

	Monitor
	
	Deliver
		• Logistics delivery and collection of fallen objects
		• Lifting objects up to 20 kg
		• In special environments such as high temperatures
		• Autonomous movement to the inspection site
		  ○ Avoiding dead areas of the network
		  ○ Avoiding obstacles
			x		100

Mobile Robot I

	Monitor
	
	Inspect
		• Remote inspection in an emergency
		• Autonomous movement to the inspection site
		  ○ Avoiding dead areas of the network
		  ○ Avoiding obstacles
		  ○ Ascending and descending stairs
		• In special environments such as high temperatures
		• Read analog gauges measuring pressure, flow, temperature, and more.
		• Collection of the following information
		• High resolution(8K) video
		• Temperature
		• Humidity
		• Gas concentration
		• Leakage (water/ gas)
		• Laser scanning
			x		200

Mobile Robot II

	Monitor
	
	Inspect
	
	Maintain
		• Remote maintenance in an emergency
		  ○ Autonomous movement to the maintenance site
		  ○ Haptics control by human workers to do the following
		    ▪ Closing valves
		    ▪ Replacement of parts
		    ▪ Operation of electronic devices
			x	x	100

Table 4 Roles between Robot/Drone and Human

Work Item	Robot/Drone	Human

• Regular Inspection
  ○ Visual: Water leak, Wall deterioration, Piping corrosion
  ○ Audio: Abnormal noise
  ○ Scent: Gas concentration
• Data Collection
  ○ Operation data
  ○ Inspection data
	Self Control	

○ location data (Human workers/ robots/ drones/ cars)		
● Temporary Inspection ○ Re-investigation when an anomaly is detected under regular inspection ○ Emergency inspection/maintenance ● Replacement of parts ○ Collection of falling objects	Action	Control

3.4. Network Infrastructure Management

The IOWN Global Forum will enable full autonomy of IT/NW infrastructure operation. In this section, some use cases on how this can be made possible are described.

3.4.1. Network Device Failure Prediction

3.4.1.1. Description

Unexpected network component failures cause service disruption and result in a higher cost of running a network. McKinsey has estimated that if failures could be predicted and repaired ahead of time, this could amount to savings of as much as 2% of sales [Chui, Michael, et. al., McKinsey & Co, 2018]. Therefore, creating a failure system capable of predicting service disruptions would save significant costs to operators.

The IOWN Global Forum's proposed solution goes beyond traditional network management systems because it is able to gather information outside of the network to use in this predictive analysis – for example, component temperature readings which can be combined with traffic load rates to determine wear due to heat. A large number of metrics can be combined and can be applied to AI models so that detailed failure modes can be specified and possible future failures can be computed.

As network functions become virtualized, similar algorithms can be applied to software (with slightly different input metrics). For example, long-running software that has not failed, but performing slowly, can be rebooted to avoid future failure.

3.4.1.2. Key Feature Set

3.4.1.2.1. Persona #1: Infrastructure Provider

As an Infrastructure Provider, I want to:

- predict and repair hardware failures before they cause problems
- predict and reboot software functions that are likely to cause future problems

so I can provide reliable infrastructure.

3.4.1.3. Service Gap/Requirements

It is expected that the transmission and integration of real-time telemetry information from multiple distinct systems within the network will require a scalable, standards-based application messaging platform with minimal infrastructure overhead.

In addition, each telemetry data collected should be linked together in a meaningful way to apply AI models. For instance, a single room temperature measurement may be applied to multiple network devices placed in the room. Thus such a relationship between telemetry data should be represented before applying AI models. To update and utilize such extensive relationship data in a distributed and near real-time manner would be challenging, and a suitable technology may need to be developed.

A logical structure of such a real-time monitoring system will look like Figure 11.

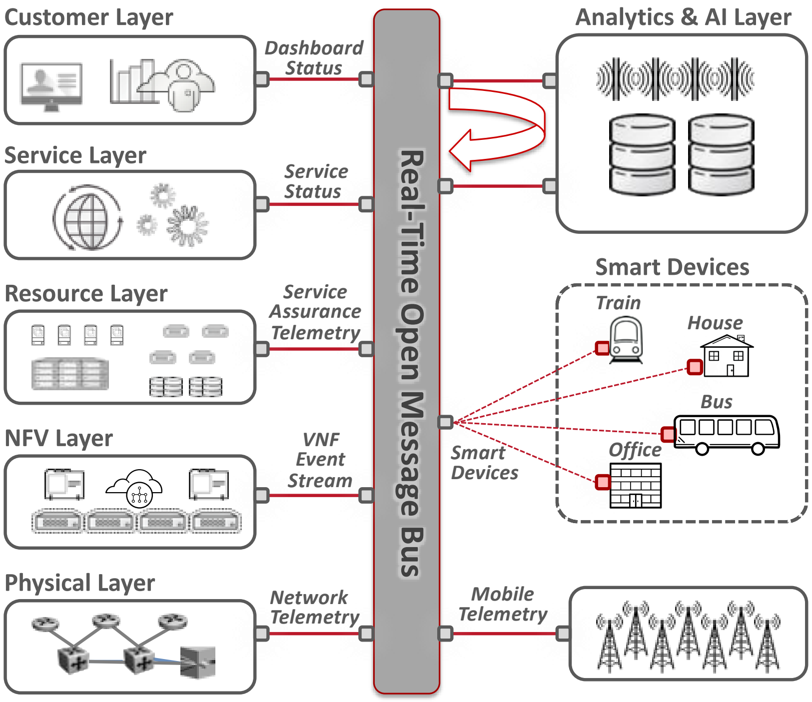


Figure 11 Collecting Real-time Telemetry for Intelligent Predictive Failure

3.4.2. Telegraph Pole Collapse Detection

3.4.2.1. Description

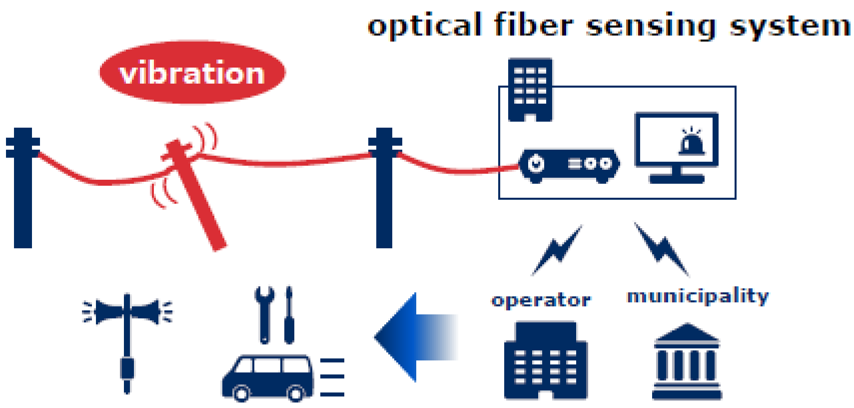


Figure 12 Overview of Telegraph Pole Collapse Detection

If a telegraph pole collapses in the event of a hurricane, typhoon, or earthquake, the damage can disrupt our daily life. Suppose we could detect the collapse of telegraph poles by optical fiber sensing. In that case, it could be possible to remotely locate the point of collapse and then perform related works more quickly and efficiently. Optical fiber sensing devices capturing vibration information are already in reality. The IOWN Global Forum will oversee the massive deployment of these sensors in a new type of sensor network, dynamically adapting to the data pattern of each sensor, maximizing data utilization, minimizing data loss and unnecessary data flow.

The following Personas appear in this use case:

- Operator: Person or group maintaining telegraph poles
- Municipality: Person or group preventing someone from accidents

3.4.2.2. Key Feature Set

3.4.2.2.1. Persona #1: Operator

As an Operator, I want to:

- identify the location of a collapsed telegraph pole quickly and precisely

so I can fix the telegraph pole quickly

3.4.2.2.2. Persona #2: Municipality

As a Municipality, I want to:

- have immediate information about any failures of my infrastructure that can impact or endanger daily life

so I can protect the citizen from accidents.

3.4.2.3. Service Gap/Requirements

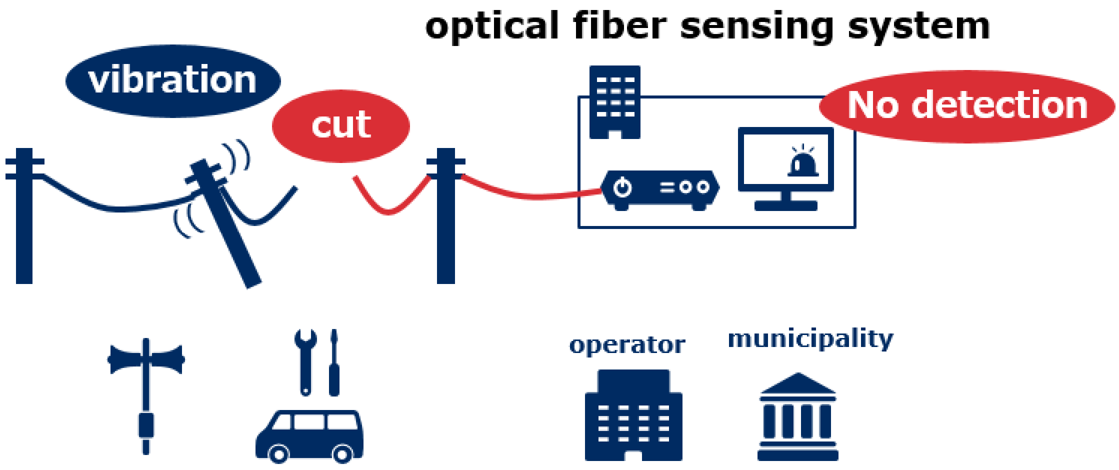


Figure 13 Overview of Current Telegraph Pole Collapse Detection

This service should be continuous and stable. However, if a fiber that itself is used as sensor is cut off, a collapse of the telegraph pole cannot be detected. If we want to detect the damage of telegraph poles even fiber is cut off, we need redundant design and deployment of fibers.

3.4.3. Underground Optical Cable Protection

3.4.3.1. Description

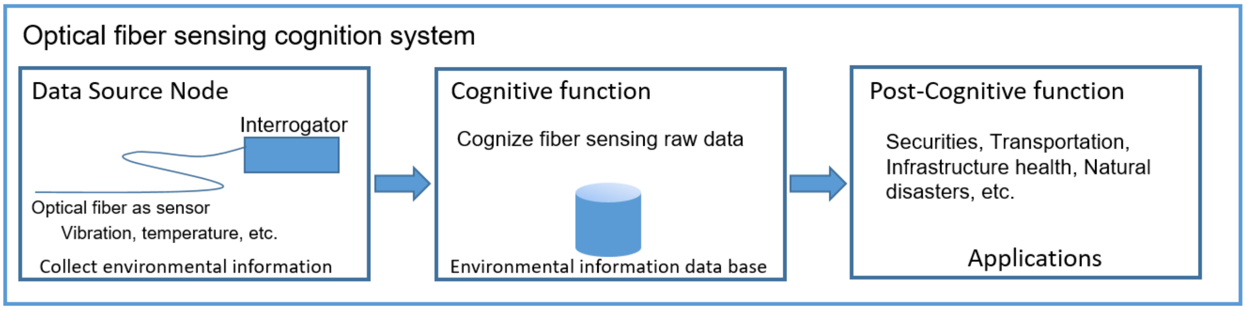


Figure 14 Reference Architecture for Disaster Information Base

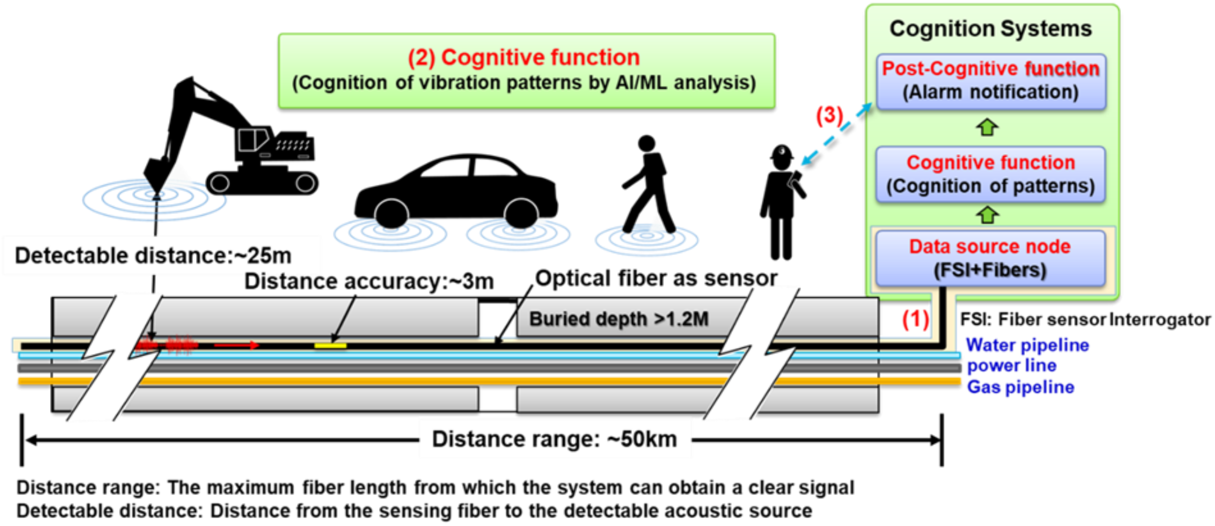


Figure 15 Use Case for Underground Optical Cable Protection System

For all photonic networks, highly dense networks of optical fibers will need to be deployed. These optical fibers will provide suitable sensors for cognitive systems to collect environmental information, such as vibration, temperature, etc., to build valuable databases for various applications.

Optical fiber sensing cognition systems can be used in conjunction with other cognition systems to jointly establish smart city management (such as securities, transportation, and infrastructure health monitoring) and avoid or mitigate natural disasters. Due to the ubiquitous optical fibers and the ability to collect continuous information along each point of the fiber, fiber optic sensing can be used to fill the blind areas of other types of sensor networks, such as underground facilities and road sections without cameras.

In order to accelerate the application of fiber optic sensing in the field, it would be most efficient to select specific use cases that can produce material benefits in the short term. Fiber optic cable damage caused by road excavation is a common pain point for telecom carriers, which prompted them to develop fiber optic sensing technology. Since this process requires similar technologies for other applications (such as traffic monitoring), established technologies and experiences can be expanded to various smart city applications faster.

3.4.3.2. Key Feature Set

3.4.3.2.1. Persona #1: Communication Carrier/Infrastructure Provider

As a communication carrier/Infrastructure Provider, we want to:

- use the existing optical fibers as sensors to solve the problem of road excavation damage to the optical cables
- detect vibration signals effectively within the required distance range that we can more efficiently protect the optical cables
- detect threatening excavation vehicles in the distance required to take measures to prevent damage to optical cables
- precisely locate the threatening excavation vehicle to reach the correct location to stop the excavation quickly.

- analyze vibration patterns to identify threatening excavation vehicles to send the right message and avoid false alarms

3.4.3.3. Service Gap/Requirements

- Distance range: It's necessary to detect vibration signals effectively within the required distance range. The required value is about 50 km
- Detectable distance: The vibration source will not directly hit the optical cable, and the detectable distance largely depends on the road surface, soil composition, and duct structure. The required value is about 25 m
- Distance accuracy: We need to determine the precise location of the vibration source to take measures to prevent damage. The required value is about 3 m
- Vibration pattern analysis: The characteristics of the vibration source must be determined to avoid false alarms. It must be ensured that the vehicle approaching the fiber optic cable is a digging vehicle, not just a car or a pedestrian

The promising solution is phase-sensitive optical time domain reflector (φOTDR) techniques.

ϕOTDR has been using in various commercialized specific applications, such as oil and gas downhole monitoring, pipeline leak detection, and intrusion detection, but these applications use dedicated optical fibers in a well-controlled environment. However, the deployment environment of the existing communication optical fibers is very complicated, which will affect the performance of the optical fiber sensing system. Therefore, it requires more advanced fiber sensing detecting and AI analysis techniques than are currently possible.

3.5. Healthcare Management

The IOWN Global Forum will create technology that will aid all people to live a healthy life. This section describes use cases on how a disease outbreak can be predicted and potentially prevented.

3.5.1. Disease Outbreak Prediction

3.5.1.1. Description

Covid-19 caught the world off guard. To ensure such pandemics never surprise us again, innovative technologies that utilize enormous sensor data, communication, and computing power shall help us predict disease outbreaks and give the public an early warning. The advancement of sensor technologies and improved ML/AI capabilities will extend human sensibilities and detectability of environmental change.

In this use case, data is collected from multiple sources. With enriched big data, an advanced ML algorithm is able to detect abnormal patterns, which assists health experts and authorities in determining if a pandemic is imminent.

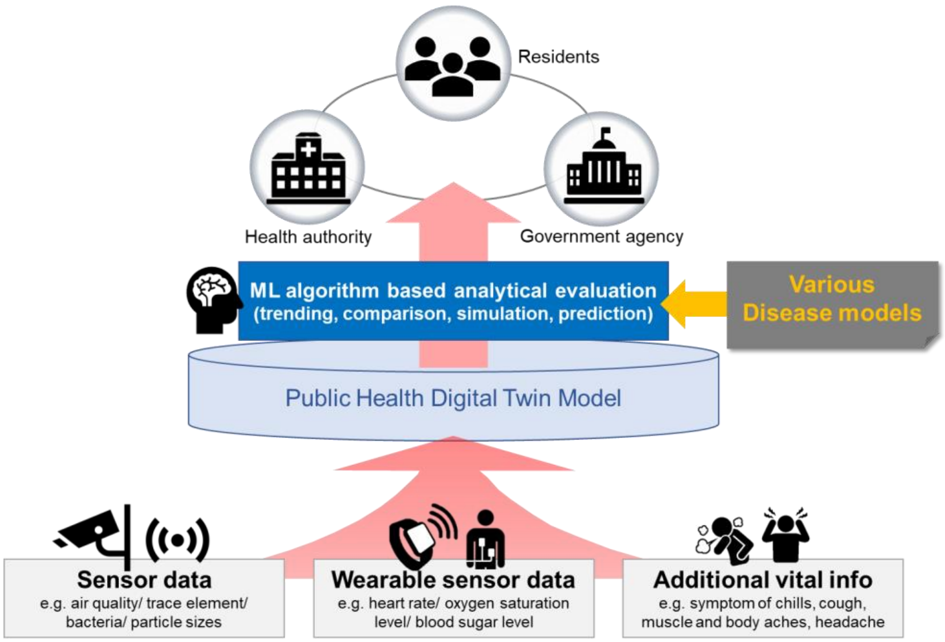


Figure 16 Disease Outbreak Prediction Workflow

3.5.1.2. Key Feature Set

3.5.1.2.1. Persona #1: Government/Public Health Organization Officer

As a Government/Public Health Organization Officer, I want to:

- build a system that can detect and display environmental conditions and basic mass health information in public locations
    - deploy smart sensors capable of measuring trace elements, bacteria, and other components in air and water
    - deploy smart sensors capable of measuring airborne particle sizes, odorant, wind level, pollen count
    - deploy scanners capable of measuring the temperature of the human body and ambient temperature
- collect and consolidate the above data with no individual identity revealed and transmit them back to a server via either wireless or wired networks securely and reliably
- display environmental conditions such as air quality with precise locations in near real-time
- automatically alert people in the area if hazardous environmental conditions are identified

3.5.1.2.2. Persona #2: Public Health Researcher

As a Public Health Researcher, I want to:

- establish a health digital model aggregated anonymous biometric and health information from crowd-based data collection with the following data
    - symptom of
        - chills, cough, shortness of breath. difficulty breathing, fatigue, muscle or body aches, headache, new loss of taste or smell, sore throat, congestion or runny nose, nausea or vomiting, diarrhea
    - body temperature, blood pressure, heart rate, sleep time, movement (step) via wearable devices

  - oxygen saturation level, blood sugar level, cough-detecting, metabolism, breath analysis via sensors/devices
  - biometric data: age, sex, and others
  - broad location at zip code or district level
- sensors/devices are paired with mobile phone/application
- a database with digital health models of known diseases
- an ML/AI platform continuously training, revising, and interfering ML model

3.5.1.2.3. Persona #3: Resident

As a Resident, I want to:

- reduce my risk of infection in places and actions
- know my own infection risk in real-time
- decrease the risk of infection to my family and acquaintances

3.5.1.3. Service Gap/Requirements

Presently, wearable sensors cannot detect the presence of Covid-19 directly because they cannot detect virus-specific RNA [Wearable fitness devices deliver early warning of possible COVID-19 infection, 2020]). However, it may be possible to detect flu-like illness via wearable sensors.

For instance, compounds in sweat can offer indications about a person's health. A smart sweat sensor can detect pH, sodium ions, glucose, and alcohol content. Additional compound contents may also be added as more research and development are carried out. Sweat rate may also be used as an indicator of temperature change, which helps detect ailments including Covid-19. Smart contact lenses with chemical sensing capability may reveal compounds released from the body in tears. Implementation of these smart sensors is yet to be completed and validated.

A digital health model can be established with data detected from smart sensors and other information. Any deviation from a normal digital health model indicates abnormal health conditions.

Existing small and portable sensors have limited capability to measure and analyze trace elements, bacteria in airborne particles. The sensing capabilities and accuracy of sensors/devices need further improvement. Wireless network capability, battery life of device/sensor often limit deployment location and duration. Lack of on-device intelligence cannot eliminate false information in captured data.

The deployment and maintenance of a vast number of sensors/devices, potentially more than mobile network subscribers, poses a daunting network management challenge. Sensors and devices are likely to be administrated and maintained by different organizations and entities, further complicating data sharing. There is no established protocol or standard to integrate different types of data into a centralized and standard data format. This is potentially a huge barrier, as plug-and-play, device authentication, highly reliable network operation, maintenance, and the ability to consolidate all data into a central repository are critical to ensuring the network supporting a Smart City is effective.

Another major challenge is how to extract reliable health and environmental information from the widely deployed sensor networks. There will inevitably be false and corrupted data from various data sources. The inability to recognize problematic data reduces the credibility of the Smart City system.

Following is a summary of capability requirements for sensors and devices.

- smart sensors capable of measuring trace elements, bacteria, and other components in air and water
- smart sensors capable of measuring airborne particle sizes, odorant, wind level, pollen count

   - ➢ currently, sensors have the capability to measure many airborne or in water elements as listed above, including airborne particle size, gases (17+), and other components [Sensor networks to monitor air pollution in cities, 2010]
   - ➢ however, these sensors need to be improved with new functions or enhanced for better usability, as listed below:
      - ✧ in-device wireless module to support the latest wireless standards
      - ✧ longer battery life
      - ✧ small form factor
      - ✧ consolidated module rather than separated modules for each different element
      - ✧ security feature to ensure data captured are not compromised
      - ✧ In-device intelligence to filter out false data and reduce the amount of data to be transmitted
- smart sensors/devices measuring oxygen saturation level, blood sugar level, cough-detecting, breath analysis
- scanner capable of measuring the temperature of the human body and ambient temperature
- wearable devices measuring blood pressure, heart rate, sleep time, movement (step)
- all above sensors are physically and digitally secured, with any privacy and security breach immediately detected and reported to a network administrator
- all above sensors should have an in-device wireless module that can transmit data over a wireless network and also can connect to a wired network
- ML/AI platform including data collection, synchronization, model training, and model inference
- device battery life > one year
- wireless reliability of 99.999%

3.6. Smart Grid Management

3.6.1. Renewable Energy Flow Optimization

3.6.1.1. Description

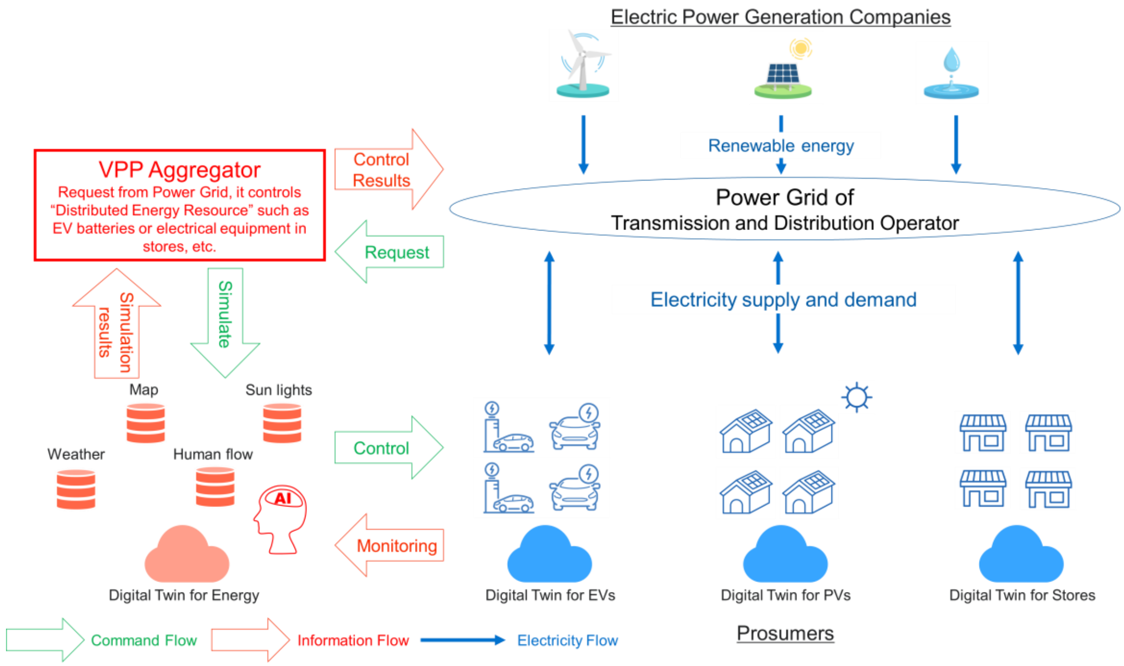


Figure 17 Overview of Renewable Energy Flow Optimization

The IOWN Global Forum will contribute to realizing a carbon-neutral society by accurately predicting and controlling the rapid and dynamic changes in energy supply and demand associated with the introduction of renewable energy. It will achieve this goal through its enormous computing capacity and ultra-high-speed networks and by realizing low-cost and stable power generation and transmission facilities. Because electricity is hard to store in large volumes efficiently, it is critically important to match the supply to the dynamically changing demand, which is currently carefully controlled by transmission and distribution operators. If there is a significant discrepancy between the actual demand and supply, it will seriously impact blackouts.

However, there might be problems with supply reliability and social costs in the near future. As for supply reliability, the difficulty in adjusting supply and demand will be increased due to instability associated with the shift to renewable energy. Although there are several technologies for power balancing, such as the inertia force of thermal power generation and the pumped-storage hydroelectricity, they are not sufficient for resolving the expected instability when renewable energy dominates the majority of power generation. In that model, the range of power fluctuations becomes unpredictable and very large.

Today, on the supply side, thermal power plants, which have a built-in physical frequency adjustment mechanism, are mainly used. However, if it remains a core component of the grid system in the era of renewable energy, then, from the viewpoint of social cost, we have the following issues:

- need to maintain thermal power generation facilities even though its usage ratio is low to meet peak demand
- need to continuously operate the thermal power generation facilities, at a certain ratio to renewable energy
- need to apply restrictions to the demand-side economic activities, including Commercial and Industrial, when there is a gap between supply and demand that exceeds the acceptance of the Grid System

Thus, such a traditional framework of centralized grid management is approaching its limits due to increased social costs and burdens on both commerce and industry. We should advance to a new type of grid operation that integrates demand-side resources such as distributed power sources. Another problem for the future is the response speed when the frequency deviates rapidly from a stable frequency like 50 Hz due to a failure. Current technology involves direct control of a massive battery but with extra costs. When controlling a large number of small batteries through a third-party service provider, the service provider takes a long time to calibrate and cannot respond within the required response time.

The overview of this use case is shown in Figure *17*. There are many prosumers as resources, such as EVs (Electric Vehicles), PVs (Photovoltaics), and drug stores. When the power grid gets in trouble and decreases the frequency, the VPP (Virtual Power Plant) aggregator requests adjusting the electricity supply and demand. The VPP aggregator then immediately simulates which resources can be used and how much based on various data from the digital twin for energy and consumer data from each digital twin. Based on the result, the VPP aggregator controls electricity supply and demand using prosumers equipment such as EV batteries in EV stations, PVs, and air conditioners/refrigerators in the drug stores. Thus, the cycle can make the power grid stable even if renewable energy will increase.

As mentioned earlier, we have to solve social challenges with IOWN technology such as high accuracy forecasting of power generation and demand by digital twin computing and real-time procurement of supply and adjustment power from many demand-side resources (EVs and consumer devices) using large-scale, high-speed communications.

For example, when the VPP aggregator wants to know how much energy it can gather from EVs, it has to determine which EV battery can be taken, based on the simulation from various data such as route information of each EV, the status of the battery, map, weather, etc. Also, the required time to respond to the adjustment request from the power generation company should be for example, within 250ms in ERCOT, Texas. When the aggregator responds, it should continue to provide stable power for 10 minutes. In this case, private PVs and EVs aren't used, but commerce and industry batteries are used usually because of the response time.

3.6.1.2. Key Feature Set

3.6.1.2.1. Persona #1: Transmission and Distribution Operator

As a Transmission and Distribution Operator, I want to:

- make use of existing distributed power resources to stabilize the grid instead of holding and maintaining much expensive power reserves
- minimize the possibility of a power outage by stabilizing the grid with VPPs even if renewable power is widely spread

3.6.1.2.2. Persona #2: VPP Aggregator

As a VPP Aggregator, I want to:

- aggregate distributed power resources and supply adjustment power to stabilize the grid
- make a profit by selling VPP power to supply and demand adjustment market, electric power generation company

3.6.1.2.3. Persona #3: Electric Power Generation Company

As an Electric Power Generation Company, I want to:

- reduce imbalance cost by utilizing VPP resources

3.6.1.2.4. Persona #4: Prosumer

As a Prosumer, I want to:

- provide as much coordination as possible to generate as much income as possible
- operate my resources in a stable manner

3.6.1.3. Service Gap/Requirements

Latency Issue

Response requirements for power conditioning due to generator or transmission system failure vary from country to country but are most stringent in the range of 0.5 to 1 second. Currently, only large batteries that large enterprises can directly manage can meet the strict response requirements. In particular, the communication delay between the VPP aggregator and the prosumer and the data processing in the VPP aggregator become barriers. The EV or PV managed by the VPP aggregator cannot be used for adjustment. As the use of renewable energy will increase in the future, the amount of electricity to be adjusted will increase, so the use of small batteries in EVs and PVs is essential.

Data Volume Issue

When the prosumer's market increases or the area of control expands, the amount of data we should handle for simulation will increase. Of course, the amount of data and the types of data will also increase in the case of a more detailed simulation. For example, when the EVs increase to 920 thousand in Tokyo Prefecture in 2030 as the MaaS market increases, the total data becomes 128Pbps. Therefore, the network and the computing infrastructure which can endure this data quantity are required.

Data Processing, Privacy and Confidentiality Issue

VPP aggregators want to collect various observations (the amount of sunlight, the number of people) on a regional from external data sources and a second-by-second basis for AI analysis to predict power generation and consumption accurately. Real-time AI analysis needs huge compute resources and cross-sectoral data. However, most data owners create silos of data individually because of privacy issues. It takes a very long time to cleanse individual data silos with a normal batch process, share them, and copy them to a shared database. In addition, due to the latency as mentioned above issues, it is necessary to gather information in a very short time and execute a very fast feedback loop. But in practice, this is impossible because it requires a centralized, high-speed database that ignores privacy and confidentiality and is shared by multiple data owners and operators.

3.7. Society Management

One of the key goals of the IOWN Global Forum is to help to create a sustainable society. This section describes use cases on how this can be made possible.

3.7.1. Sustainable Society

3.7.1.1. Description

Increasingly complex social structures have made it difficult for individuals to comprehend the impacts and benefits of sustainability efforts. As a result, it's challenging to develop effective policies around sustainability, as well as to convince the broader population of the benefits of potentially restrictive environmental policies, such as those involving the climate crisis and increase of natural disasters, including heavy rain, hurricane, and flooding. The IOWN Global Forum will focus development on the creation of an "explorer engine" that will enable individuals, governments, and other organizations to simulate societies of the future and showcase the results of the actions and behaviors that will achieve the best possible outcomes for long-term initiatives like disaster prevention and response, de-carbonization, and other sustainability efforts. This is critically important, as it gives us a valuable tool to determine the appropriate course of action to achieve the best possible outcomes for society as a whole. It will also enable individuals to better understand the impact of their behaviors and thus help educating the broader society on why specific behaviors (such as not littering, choosing an electric vehicle, or raising awareness towards disaster response) are essential to the well-being of the community.

The IOWN Global Forum's "exploring engine for the future society" uses large–scale computation that will integrate various elements, such as individual behaviors, group activities, livelihoods, economic activities, and the natural environment. By doing so, we hope to predict what these potential future societies will look like based on multiple variables so that we can understand the impact of the choices we make on our own lives, both now and in the future. This will aid municipal planning, educate populations on the benefits of specific policies, and guide policy decisions based on solid predictions intended to create the best outcomes.

E.g.1) Foreseeing how to mitigate disaster damage by means of knowing and sharing the state of disaster-effected areas and resident behavior characteristics, and showing the effectiveness of active communication among the residents, rescue, and local government

E.g.2) Increase in migration to suburbs with more people working from home, economic revitalization of local towns, reconstruction of central urban structures, changes in child-rearing environments.

E.g.3) Reduction in CO2 emissions, reduction in gas stations, and increase in electricity consumption through the use of electric vehicles

This explorer engine will visualize the impacts of individual actions and efforts on society and the natural environment and encourage many individuals to voluntarily act and cooperate to achieve the societies they want while thinking proactively.

Figure 18 illustrates the concept of an Explorer Engine. Here, "crowd" means a group that happened to be there, while "society" means a group of individuals involved in some kinds of social interaction. "Unchosen world" implies an output of simulation but not realized, while "Future world" means an output of simulation and realized accordingly. P1-P6 stands for a probability of social transformation over time, respectively. AA, AB, BA, BB stands for output of various simulation conditions, respectively.

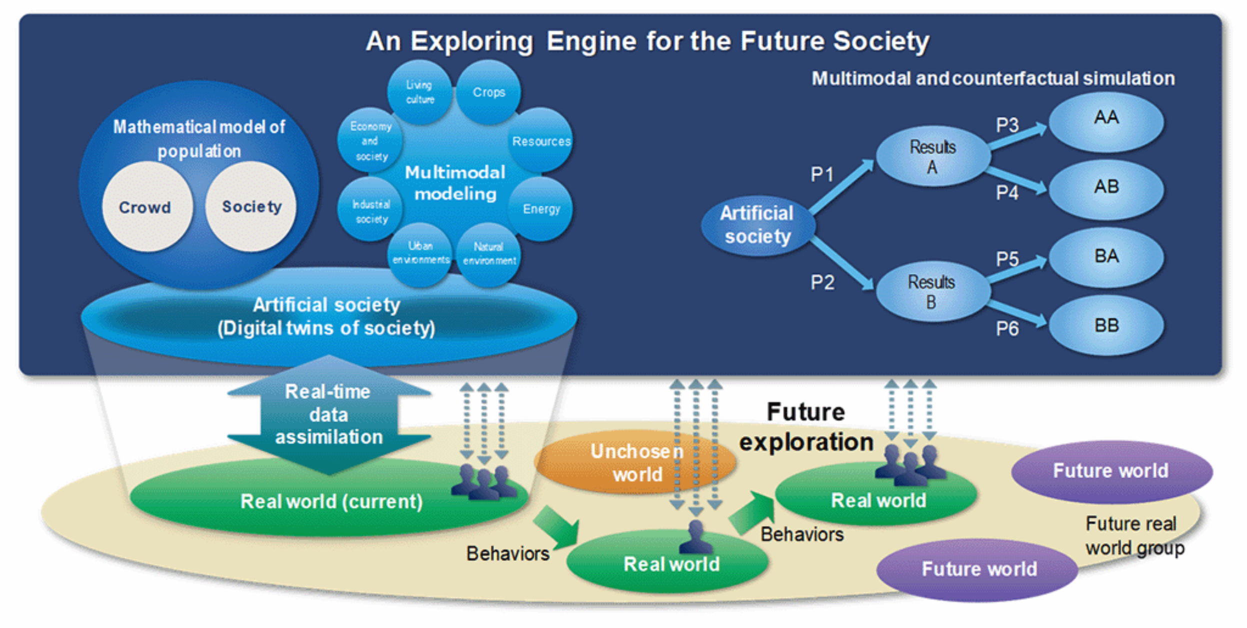


Figure 18 Exploring Engine for the Future Society

3.7.1.2. Key Feature Set

3.7.1.2.1. Persona #1: Corporation / Local Government

As a Corporation/Local Government, I want to:

- put several scenarios of business plans/city policies into the exploring engine and observe the progress
- decide actual business plan/city policy on those viewpoints such as ESG(Environmental, Social, Governance)/SDGs, regional revitalization, economic revitalization, energy efficiency, disaster prevention/mitigation, and so on.

3.7.1.2.2. Persona #2: Exploring Engine Provider

As an Exploring Engine Provider, I want to:

- collect all kinds of data in cities such as buildings, roads, demographic data, traveling routes of residents, energy supply and demand, CO2 emissions, landslides/building collapse risk in a disaster
- build digital virtual world consisting of several digital twins of physical structures, individual behaviors, group activities, livelihoods, economic activities, and the natural environment, including weather
- interact those digital twins in the digital virtual world, and provide corporation/local government with the output, that is, future appearance

3.7.1.2.3. Persona #3: Person

As a Person, I want to

- decide my lifestyle (e.g., city/town to live in, corporate to work at, and so on) based on referencing several future predictions on aspects such as living environment (e.g., good parenting/education, household stability, preventing congestion, and so on.)

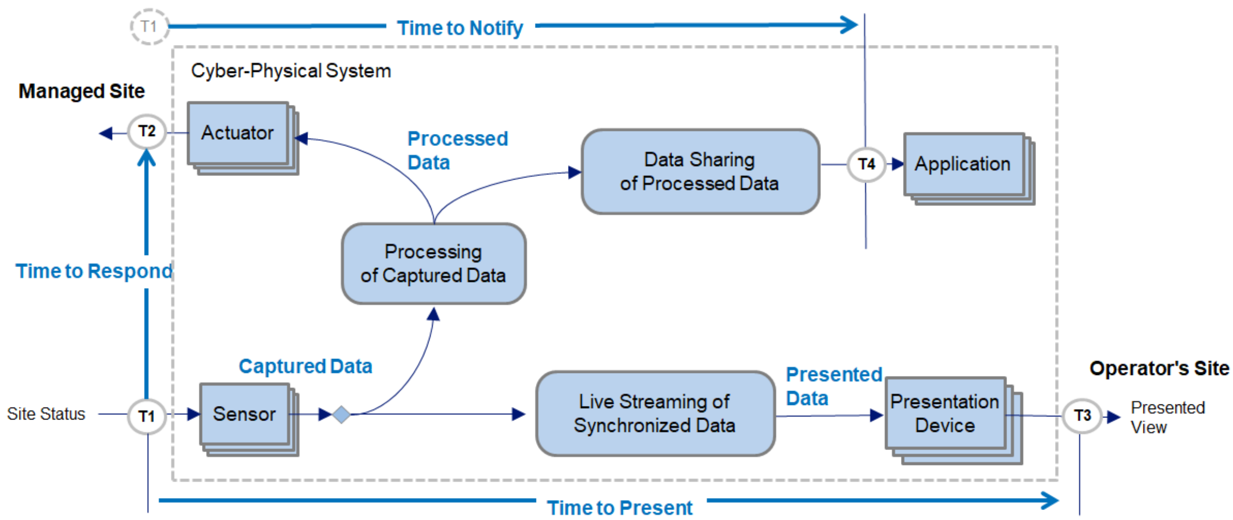
3.7.1.3. Service Gap/Requirements

- it is difficult to predict future appearance using current statistical and machine learning methods when uncertain/unexpected events (e.g., the COVID-19, car accidents) happen, as those events are not considered in existing statistical and machine learning models
- so, the technologies needed are, for example, in a traffic-flow simulation, reproduce interactions of respective vehicles precisely then predict traffic phenomenon as a whole
- in existing technologies, the problem is that minor errors accumulate and become significant errors. To overcome this issue, the following approaches are considered to be effective
    - Correcting vehicle behavior in simulation according to the behavior of the vehicle in the real world (e.g., data assimilation)
    - Refinement of mathematical models such as car-following models to improve the accuracy of reproduction of each vehicle behavior
- for example, in a traffic-flow simulation, we need to collect data such as position coordinate, which is generalized from large numbers of vehicles and needs to access the spatio-temporal database in a real-time basis
- it is necessary to define concepts and technologies that can be used as a reference for building digital twins for individual behaviors, group activities, livelihoods, economic activities, and the natural environment. In other words, the reference model of dealing with interactions among digital twins of individual behaviors, group activities, livelihoods, economic activities, and the natural environment in a synthesized/unified manner is needed

4. Requirements

As described in the previous section, CPS Use Cases involve recognizing the physical world through the utilization of various sensors and the recreation of this physical world in cyberspace by manipulating the collected data. The most critical requirement that arises from the set of use cases is the ability to process the enormous amount of data and promptly feedback the processed data to the physical world. This requirement is further described as the Data Volume aspect below. The full set of key requirements can be depicted as follows.

Common workflows for the CPS Use Cases are shown in Figure 19.



Note 1: This diagram shows a common workflow of the CPS use cases and can be rationally customized, e.g., adding additional boxes and making some of the existing boxes null depending on the use case.
Note2: Outputs from the applications can be utilized for many purposes (e.g., visualization for operators, feedback to the CPS, interaction with external systems, etc.).

Figure 19 Common Workflows and Key Requirements for CPS Use Cases

Key requirements can be expressed along the following workflows;

- **Quick feedback (T1 to T2):** “Sensors” capture a physical space, the “Captured Data” is processed at “Processing of Captured Data,” and “Actuators” act upon the physical space according to the “Processed Data.” The end-to-end delay for this flow is named “Time to Respond (TTR)”
- **Remote Live Monitoring (T1 to T3):** “Captured Data” (e.g., images, voice, and haptic data) are transferred to “Presentation Devices” in remote sites for remote live monitoring via “Live Streaming of Synchronized Data, which are used for the creation of enriched contents from multiple steams of “Captured Data.” The end-to-end delay for this flow is named “Time to Present (TTP)”
- **Data Sharing (T1 to T4):** “Processed Data” are made available to many “Applications” through “Data Sharing of Processed Data.” The end-to-end delay for this flow is named “Time to Notify (TTN)”

Given the above workflows, the following aspects will be critical requirements of the use cases:

- **Data Volume:** CPS Use Cases require enhanced broadband support in their communication and computing infrastructure. To support the use cases, various classes of data with different requirements need to be efficiently and flexibly accommodated to meet various customers' demands. For example, Area Management requires 48 Gbps per site, Mobility Management requires 1 Gbps per vehicle, and Industry Management requires 10 Gbps per plant of “Captured Data“to effectively grasp the physical environment.

- **Data Velocity:** CPS Use Cases impose various types of end-to-end latency requirements for their communication and computing infrastructure. Mobility Management Use Case requires TTR at 10-500 ms to effectively feedback maneuvering information in order to avoid collisions. Area Management Use Cases have a relatively relaxed requirement of 100 ms TTR and require computationally intensive AI tasks, making it extremely difficult to satisfy this requirement. Industry Management Use Cases, although local, have an extremely strict requirement of 1-2 ms on TTR.

- **Scalability and Elasticity:** CPS Use Cases require high scalability and elasticity in their communication and computing infrastructure. For example, Mobility Management use cases assume processing of 120 Gbps input data per service area, but the amount of processing data will dynamically change depending on the vehicle traffic flow at the time, so elasticity of computational power is required. Area Management use cases require enormous bandwidth, low latency, and low energy consumption. It is suggested to use an event-driven approach, which is expected to improve the energy efficiency by identifying meaningful video frames at the camera and sending only these to the subsequent network and cloud. This event-driven approach requires elasticity for sporadic workload fluctuation and coordination between relevant functions.

- **Energy Efficiency**: Widely installed sensors with higher sensitivity will allow more precise capturing of the physical world and more sophisticated AI applications. However, it also increases the energy consumption in the operation of massive sensors, data transfer of high volumes of captured data, and AI computing. Therefore, it is critically important that IOWN Global Forum establishes an energy-efficient computing and networking architecture that can make the world smarter with less energy consumption.

- **Other Aspects:** For ease of installation of ubiquitous sensors and actuators, wireless connectivity will be a crucial requirement in many scenarios. The utilization of installed fibers to sense the environment will add further to this ubiquity. Furthermore, the ability to monitor the network conditions in real-time would play a key role in maintaining a stable network.

The details on the key requirements for each use case are described in the following subsections.

4.1. Area Management

4.1.1. Key Requirements

- Data Volume:
    - Captured Data
        - from cameras: 48 Gbps per building
        - from sensors: 100,000 sensors per square km, each of which is updated every 1-to-10 seconds
- Data Velocity:
    - TTR: less than 100 msec

  - TTN: less than 1 minute, e.g., for short-term predictions
- **Scalability and Energy Efficiency**:
  - processing of Captured Data:
    - around 200 TFLOPS per application per building
- **Energy Consumption:**
  - less than 1 KW to cover one building and multiple applications
- **Other Aspects:**
  - Data Management in non-real-time data sharing

4.1.2. Assumptions

The above Key Requirements are derived under the following

- Captured Data
  - from cameras: The Area Management use case category needs to support remote video surveillance by a massive number of cameras. Some of its use cases (e.g., the camera-based people-counting use for Energy Management) require a frame rate of 15 fps or over. Assuming full-HD image resolution and Motion JPEG compression, the data rate from one camera would be about 45-60 Mbps. A typical medium-size building with about 100 -150 tenants would require 600 - 800 cameras. This means that the total image traffic would be in the region of 27-48 Gbps.
  - from sensors: The Area Management use case category, especially the Disaster Notification use case, covers broad areas and needs wide coverage. There would be 100,000 sensors per square km, each of which would generate 0.1-1 MB data every 1 to 10 seconds. The information update frequency could reach 100,000 updates per sec.
- TTR
  - Time-To-Respond refers to the end-to-end latency from an event occurrence in a physical space to the start of some action in response to the event. Immediate action and interaction with relevant devices and people are required for this use case category. For accident prevention, the time-to-respond should be below 100 msec.
- Scalability and Energy Efficiency
  - processing of Captured Data
    - typically, with current technology, a single AI function using video images with relatively low resolution and low frame rate needs 200 TFLOPS of processing power.
    - energy-efficient communication and computing for a sustainable society is an essential requirement for IOWN. Typically, with current technology, a single AI function consumes 1kW per site (600-800 cameras). The Area Management use cases are expected to support multiple AI functions with relatively high image resolution and frame rate. Even with these higher specifications, it should be possible to keep power consumption at the same level, i.e., 1kW.

4.2. Mobility Management

4.2.1. Safety Maneuver

In order to realize the envisioned safety service, it is crucial that the system provide instant feedback to any obstacles sensed by the vehicle itself, surrounding vehicles, or roadside sensors. It is expected that the IOWN Global Forum will provide vast computational power to quickly process the gathered data, and an ultra-low latency network to promptly deliver the maneuvering information to each vehicle.

4.2.1.1. Key Requirements

Key Requirements for the Smart Transportation use case can be summarized as follows:

- **Data Volume:**
  - Captured Data
    - up to 1 Gbps per vehicle, up to 12 Gbps per cell, from sensors
- **Data Velocity:**
  - TTR
    - see Table 5
- **Scalability:**
  - processing of Captured Data
    - up to 1200 Gbps input data per service area needs to be processed
- **Other Aspects:**
  - high speed wireless connectivity is necessary. Also, rapid handover will occur due to its mobile nature.
  - synchronization between multiple devices and roadside equipment may be necessary (e.g., up to 100Hz frequency [M. Li, Y. Wang. (2019)]).

Table 5 Time to Respond Requirements in Smart Transportation Use Case

Use Cases	Requirements
Automated Overtake [K. Lee, 2017]	10 ms
Pre-Crash Warning [K. Lee, 2017]	20 ms
See-Through Safety [K. Lee, 2017]	50 ms
Automated Unmanned Vehicle [A. Fellan, 2018]	40-500 ms

4.2.1.2. Assumptions

The above Key Requirements are derived under the following assumptions

- Vehicle Speed: 60 km/h = approx. 16.7 m/s
- Vehicle Traffic: 100,000 vehicles /12h = approx. 2 vehicles /s [3]
- Vehicle Density
  - 1200 vehicles / 10 km Service Area (10000m / 16.7m x 2 vehicles), 12 vehicles / cell (cell size = 100m), assuming 1-dimention cell
- Data Volume

  - up to 1Gbps (LiDAR = 70MBps, Camera = 40MBps, RADAR = 100KBps, GPS = 50KBps [Winter, 2017])
- the above value is the maximum possible value, not all sensed data will be required in most conditions

4.2.2. Energy Optimal Routing

The envisioned system will provide route information, taking into account not only the real-time traffic situation but also the utility of various energy sources to charge the in-vehicle batteries en route. The IOWN Global Forum is expected help realize this use case by providing vast computational power for processing sensed data gathered from each vehicle, and means for the Traffic Flow Digital Twin, which process the sensed data, to efficiently communicate with the Smart Grid Digital Twin, which controls the electricity flow to each charging station.

4.2.2.1. Key Requirements

- Data Volume:
  - Captured Data
    - up to 1 Gbps per vehicle, up to 12 Gbps per cell, from in-vehicle sensors
- Data Velocity:
  - TTR
    - up to 10ms
- Scalability:
  - processing of Captured Data
    - up to 1200 Gbps input data per service area needs to be processed
- Other Aspects:
  - high speed wireless connectivity is necessary. Also, this means it is necessary for digital twin traffic (process or groups of processes that create optimal energy routing) and micro-grid digital twin (process or groups of processes that predict and manages the power demand and supply) to interact in real-time
  - means to integrate IOWN with in-vehicle network necessary

4.2.2.2. Assumptions

The above Key Requirements are derived under the following assumptions

- Vehicle Speed: 60 km/h = approx. 16.7 m/s
- Vehicle Traffic: 100,000 vehicles /12h = approx. 2 vehicles /s
- Vehicle Density
  - 1200 vehicles / 10 km Service Area (10000m / 16.7m x 2 vehicles), 12 vehicles / cell (cell size = 100m), assuming 1-dimention cell
- Data Volume
  - up to 1Gbps (LiDAR = 70MBps, Camera = 40MBps, RADAR = 100KBps, GPS = 50KBps)

the above value is the maximum possible value, not all sensed data will be required in most conditions

4.3. Industry Management

4.3.1. Factory Remote Operation

In this use case, there are two data flows that require different characteristics. One is the video data flow for remote plant monitoring, the other is the sensor data flow OT/IT integration.

4.3.1.1. Key Requirements

- **Data Volume:**
  - Video data flow
    - Captured Data: 10 Gbps per plant/factory
    - Presented Data: 100 Mbps per view (maximum of 1 Tbps per remote monitoring site)
- **Data Velocity:**
  - Sensor data flow
    - TTR: less than 2 ms [3GPP TR 22.804, 2020]
- **Other Aspects:**
  - change of data flow and access permissions: less than a minute
    - a CPS should support the rapid change of accessibility to real-time data (large volumes of data or high-definition video streams) within a minute. It will require a data-centric access control mechanism rather than the existing per-network data access control. It is necessary to add ad hoc permissions for users from different organizations to access a specific set of data owned by one organization (defined, for example, by a name that identifies the data or by the type of data).
  - usage control / secure computing
    - a CPS should allow data users to combine and use (i.e., mashup) each other's data without revealing their confidential property of data

4.3.1.2. Assumptions

These key requirements are derived under the following assumption:

- Captured Data / Presented Data:
  - using a conventional video frame-based approach, that is, 60 FPS of 8K video encoded by H.265, each stream will need up to 100 Mbps
  - each plant or factory will send 100 video streams (Captured Data), and each remote monitoring site may need to receive a maximum of 10,000 streams (Presented Data), while with the ability to switch between streams selectively, the remote monitoring site does not have to receive all the data

4.3.2. Process Plant Automation

There are three main types of key requirements.

A: Requirements for Monitoring by Robots/Drones that require accurate positioning and processing of massive volume data by high-resolution video transmitted from multiple robots/ drones, which are self-driving/self-monitoring.

B: Requirements for Controlling Robots that require high-speed data velocity for haptic feedback to synchronize human movement with robots and correspond to the function of interactive holographic/AR/VR applications for inspection/ maintenance in real-time.

C: Requirements for Digital Twin that require high-efficiency computing resources / low power consumption with low latency for simulation and AI-based controlling.

4.3.2.1. Key Requirements

A: Requirements for Monitoring by Robots/Drones (Air Drone and Ground Drone/ Mobile Robot I described in section 3.3.2.3)

- Data Volume aspect
  - Captured Data: 8K in Visual Field: 2.35 Gbps per drone or robot
  - Presented Data: 300 Gbps per remote monitoring site
    - using a conventional video frame-based approach, 60 FPS of 8K video encoded by H.265
      - each plant will send 100 video streams (Captured Data) and each remote monitoring site
- Data Velocity aspect
  - Time to Respond: sub-seconds to a second *Among robots/ drones and Central Control Room(CCR)
  - Time to Present: sub-seconds to a second
- Other aspects
  - the function of positioning: accurate positioning with a difference of less than 5 cm(Vertical, Horizontal, Height)
  - seamless inter-cell and inter-edge handover
  - usage control / secure computing
  - wireless power supply

B. Requirements for Controlling Robots (Mobile Robot II described in section 3.3.2.3)

- Data Volume aspect
  - Captured Data / Presented Data:
    - 8K*8K in Visual Field: 2.35 Gbps per equipment; Hologram: 100 Gbps to 4.32 Tbps per equipment
    - Hologram: 100 Gbps to 4.32 Tbps per equipment
- Data Velocity aspect
  - Time to Control + Time to Present: 10 msec (for haptic feedback).
    - among robot and Central Control Room (CCR)
- Other aspects
  - Network Jitter / Reliability: 1 msec jitter, 99.9999% reliability
    - Synchronized audio, video, and haptic response rendering
  - function of positioning: accurate positioning with a difference of less than 5 cm(Vertical, Horizontal, Height)

- ➢ seamless switching between multiple networks (200 million m^2)
- ➢ usage control / secure computing.
- ➢ wireless power supply

<u>C. Requirements for Digital Twin</u>

- Data Volume aspect
  - ➢ Captured Data: 300 Gbps per plant based on the sum of required data in Table 6 Equipment Type Requiring Data Collection
  - ➢ Presented Data: 500bps per remote monitoring site. *Up to 1-5Tbps when interconnecting multiple plants
- Data Velocity aspect
  - ➢ Time to Respond: sub-seconds to a second
  - ➢ Time to Present: sub-seconds to a second
- Other aspects
  - ➢ secure computing
  - ➢ visualizing Green Gas emission, including power consumption for each product/ each plant/each supply chain.

4.3.2.2. Assumptions

These key requirements are derived under the following assumption:

- Plant type: Chemical plant
- Site size: 2.0million m^2
- Total power consumption: 132MW
- Total greenhouse gas emission: 8.1Mt @2019
- Expected years of operation: 50 years
- Year of construction: 1990

Table 6 Equipment Type Requiring Data Collection

Equipment Type	Data Type	Note
Chimney	● Greenhouse gas emissions (CO_2, NOx, SOx) ● Atmospheric particles ➢ High-precision sensor NDIR (non-dispersive infrared absorption method) ➢ Measurement precision ✧ ±80ppm（0~2000ppm） ➢ Particle size ✧ 0.3 (fixed)/0.5/1.0/2.0/5.0/10.0μm	● 57.84 million tons/ CO_2 emission at chemical industry ● 8.1 million tons/ Greenhouse gas emission at 2.0 million m^2 chemical plant ● Particle Counter (Optional choice of 3 particle size)

Sensor ● Pressure sensor ● Leak sensor ● Temperature sensors ● Gas sensors ● Acceleration Sensors	● Measure pressure leaks(50m/pc) ● Measure liquid leaks(400m/pc) ● Measure object temperature ● Measure gas leaks(100m/pc) ● Measure the movement speed of an object	● Pressure range -100Kpa to +40Mpa ● Leakage detection response time (800 msec or less during operation)
Mobility Robots/Drones	● High-resolution video ● Atmospheric information such as temperature, humidity, and gas concentration ● Haptics transmission information	See section 3.3.2.3

4.4. Network Infrastructure Management

Network infrastructure management includes the ability to gather information regarding the data around individual network ports (traffic transmitted/received, rate, etc.) as well as corresponding environmental effects from sensors that could affect them (such as temperature). This information needs to be aggregated and sent for analytics purposes in a scalable fashion.

It should also be possible to signal this infrastructure to enable/disable network objects, such as ports, if it is determined they are malfunctioning.

4.4.1. Network Device Failure Prediction

One of the benefits of sending the information for analytics is that it is possible to identify patterns that indicate possible future failure of the network element. Should such a situation be detected, it can be replaced before the failure actually occurs.

4.4.1.1. Key Requirements

- **Data Volume:**
  - Captured Data: 80 Gbps for 10,000 edge systems
- **Data Velocity:**
  - TTN: less than 10 sec
- **Scalability and Elasticity:**
  - Processing of Captured Data: 100,000 messages / sec for 10,000 edge systems

It is important that the information be sent in real-time and not take up unnecessary resources. As such, it is not necessary to write this data to storage at every stage of the process. In fact, storage may only be needed at the central analytics stage. During the data streaming phase, data can be kept entirely in memory, reducing latency significantly. Details from this work will come from Data-Centric Infrastructure (DCI) work items, as described in the IOWN Global Forum System and Technology Outlook [IOWN GF, 2021]

4.4.1.2. Assumptions

- there are 10,000 edge systems
- each edge system reports 100 different metrics (average 100 bytes each) every 10 seconds

4.4.2. Telegraph Pole Collapse Detection and Underground Optical Cable Protection

"Telegraph Pole Collapse Detection" and "Underground Optical Cable Protection " use cases employ an optical fiber sensing technology that uses existing optical fiber cables as sensors.

4.4.2.1. Key Requirements

- **Data Volume:**
  - Captured Data: up to 32 Gbps per fiber sensing interrogator
- **Data Velocity:**
  - TTR: 1 s to 10 s
  - TTP: 1 s to 10 s
  - TTN: 1 s to 10 s
- **Scalability**:
  - Processing of Captured Data: Up to 32 Gbps per fiber sensing interrogator needs to be processed
- **Other Aspects:**
  - in most cases, it is required that the captured raw data of the fiber sensing interrogator can be shared with other applications through different data processing algorithms and AI technology

4.4.2.2. Assumptions

The above Key Requirements are derived under the following

- Captured Data
  - Measurement distance: 20 km
  - Spatial sampling resolution: 0.1 m
  - Number of measurement channels: 2
- Data Velocity
  - TTR: for communication carrier/Infrastructure provider
    - it is required for outside plant facility maintaining staffs to take measures for collapsed telegraph pole and threatening road excavation.
  - TTP: for municipal departments

    - ✧ provide Municipal Disaster Prevention Unit immediate information about any infrastructure failures that can impact or endanger daily life so it can take measures to protect the citizen from accidents.
    - ✧ provide Municipal transportation Unit with immediate traffic information to monitor and manage the traffic.
  - TTN: for companies with underground facilities
    - ✧ provide information on threatening road excavation and abnormal conditions, such as natural gas/water leakage and discharge to tap water, natural gas and power companies, to prevent underground facility damage and disasters.

4.5. Healthcare Management

4.5.1. Disease Outbreak Prediction

4.5.1.1. Key Requirements

- **Data Volume:**
  - Aggregated data (to cover 25 km^2 cell area) 1 Gbps
- **Data Velocity:**
  - TTR: Minutes to hours (Time to take from receiving data from sensors to AI inference, decision making, and authority action)
  - TTP: Seconds to minutes (Time to take from sensor measurement to results display, e.g., air quality in a public site)
  - TTN: Minutes to hours (Time to take from receiving data from sensors to AI inference, decision making, and authority notifying people in the affected area)
- **Scalability:**
  - outdoor sensors: self-sustain power (e.g., solar) with battery backup up
- **Other aspects:**
  - build-in ML/AI capability in the sensor for false data filtering
  - security/Privacy: physically and digitally secured, with any privacy and security breach (e.g., location change, hardware break) immediately detectable and reported to a network administrator
  - a common protocol or standard to integrate different types of data into a centralized and standard data format
  - for this use case, key requirements are not in data volume and data velocity. Instead, key requirements are (1) assurance of privacy and security of user data; (2) Development of a common protocol or standard to integrate different types of data into a centralized and standard data format; (3) Accuracy of Machine Learning model and capability of inferences, data visualization, and data exposure; (4) Capability to run data model and data management of nationwide aggregated data

4.5.1.2. Assumptions

- number of sensors: 2,000 / km^2

4.6. Smart Grid Management

4.6.1. Renewable Energy Flow Optimization

In order to achieve a precise balance between power supply and demand, in addition to predicting power consumption, it is necessary to predict precisely where and how much power can be supplied in a short period. The IOWN Global Forum is expected to contribute to the realization of this use case by utilizing platforms and ultra-low latency networks that can utilize a wide variety of large-scale data, such as EV and PV data, and weather and human flow data that affect simulation results, and by simulating supply and demand forecasts and actuating prosumers equipment as needed.

4.6.1.1. Key Requirements

- Data Volume:
    - command data: 24Gbps (80 KB * 100,000 prosumers)
    - sensor data from prosumers: 24Tbps (80 MB * 100,000 prosumers)
    - data from other data sources: 3.2Gbps + 128Pbps
- Data Velocity:
    - TTR: less than 200 msec
    - TTP: less than 50 msec
- Other aspects:
    - area size to manage: 2,500 km^2
    - data from other data sources are updated in a second continuously

4.6.1.2. Assumptions

These key requirements are derived under the following assumptions:

Data Volume:

- Command data
    - suppose that the command data size of an electricity control protocol, which is often used for power control, is 10 KB, and data is exchanged 4 round trips per second between 100,000 processors and the VPP aggregator
- Sensor data from prosumers:
    - suppose that the command data size of an electricity control protocol, which is often used for power control, is 200 KB, and data is exchanged 20 round trips per second between 100,000 processors and the VPP aggregator
- Data from other sources:
    - we envision the use of EVs, solar homes, and drugstore power conditioning. When we predict the possibility of use for power conditioning, we have to use the following data:
        1. Weather data: 10 Gbps
            - The data of the sunlight, rain, and cloud in the target area is assumed. The height of the target area is 50 km, and the amount of data per cubic km is 10 MB.
        2. Traffic data: 128 Pbps
            - Assuming that resource prediction data volume for 1 Maas EV is 136 Gbps and 920,000 cars in the target area are available in 2030
        3. Human flow data: 2 Mbps
            - Assume that one record is 100 bytes and that there are records of human flow data per square km in the target area

TTR:

- TTR is the response time from the arrival of the Electric Power Generation Company's request to adjust the supply and demand to respond from the VPP aggregator.
- Several countries require from 0.25 msec to 1 sec as response time.

TTP:

- TTP is the response time from the request of the VPP aggregator to the actuation of the prosumer's equipment, such as a battery
- considering the processing time in AI, the time until the start of control for the prosumer selected by the VPP aggregator should be about 1/4 of the TTR

Area size:

- Tokyo in Japan is approximately 2,200 km^2, and for the sake of clarity, one side is set at 50 km

4.7. Society Management

4.7.1. Sustainable Society

4.7.1.1. Key Requirements

- **Data Volume:**
  - 10 PB as storage capacity and 2-3 PB as memory capacity. 10-20 PFLOS as computational power
- **Data Velocity:**
  - TTN: the order of hour/day

4.7.1.2. Assumptions

The simulation result shall be acquired within an hour in the scale of the city area (i.e., 2,194 km^2 Tokyo) with an adequate spatial resolution (i.e., mesh size of space is 5m^3. Data size is estimated at up to 30 MB per mesh.

This data size breakdown is following.

- 1 MB per minute (including temperature, humidity, amount of solar radiation and rainfall, wind direction.) We assume 30 minutes accumulation for the predictive computation
- data retention period is one week in the data volume aspect
- data assimilation (every minute) and data pre-processing / post-processing are involved in the computational power aspect

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History

Revision	Release Date	Summary of Changes
1.0	October 21, 2021	Initial Release

