AUTOMOTIVE EDGE COMPUTING CONSORTIUM

WHITE PAPER

Connected Infrastructure for the Realization of the Green Mobility Society

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October 2023 v1.0

Contents

1 Abstract

Today, it's essential for companies to address environmental issues including climate change, to avoid leaving a negative legacy for future generations. Freedom of movement is a fundamental human need, and while the pursuit of convenience will continue to be unavoidable, it is also a major problem, accounting for about one-quarter of the world's CO2 emissions[1]. Addressing current mobility/transportation problems would be a major step towards realizing an environmentally conscious society.

Solving mobility problems means finding new value in the mobility experience. This experience is multifaceted, including vehicle performance and services. What kind of connected infrastructure will be needed to maintain and improve the quality of this mobility experience while realizing a decarbonized, environmentally conscious society? We believe that answering this question will lead to the realization of a "green mobility society."

Along with the environmental and social context, there are also changes in technological conditions that we must adapt to, including the spread of generative AI which will inevitably affect new mobility experiences.

In this document, we're going to explore a family of related topics that will help us to better understand what it will mean to bring about a green mobility society, and the role that mobility services will play in it.

We will look at:

1. The concept and definition of a green mobility society.
2. Examples of what the experience will be like when a green mobility society is realized.
3. The challenges in bringing about a green mobility society and the characteristics of the connected infrastructure that will be needed.

We hope that this document will help to create a common understanding of the practical realities of creating a green mobility society. But we are also hoping to inspire you to help us solve these issues. If you find these ideas exciting, we invite you to join AECC and contribute to the proof-of-concept work that will make green mobility a reality.

1 Our World in Data (2023) "Which form of transport has the smallest carbon footprint?" (last accessed 9/12/2023, URL: https://ourworldindata.org/travel-carbon-footprint).

2 Objectives and Backgrounds

2.1 The Movement Toward Decarbonization

Countries around the world are investing in technology and implementing new regulations that will help to achieve a decarbonized society.

In particular, the EU announced its vision of "A clean planet for all" in November 2018, which aims to achieve a carbon-neutral economy by 2050. In its long-term strategy for the Paris Agreement, submitted to the United Nations in March 2020, the EU reaffirmed this commitment.

While the energy industry is a big focus for transition, the automotive industry is also seeing significant investments around the world, while regulations and penalties for noncompliance are increasing.

For example, some countries have adopted the Corporate Average Fuel Efficiency (CAFE) regulations, which calculate the average fuel efficiency (carbon dioxide emissions) of each automobile manufacturer. They also impose compensations on manufacturers that exceed these standards after taking into account their annual sales volume and other factors. In many cases, automobile manufacturers that fail to meet the fuel efficiency standards established by the CAFE regulations can purchase credits from other companies to make up for any shortfall.

2.2 The Popularization of AI for New Mobility Experiences

Mobility continues to evolve, and in-vehicle software has been driving this rapid evolution in recent years. The appeal of a vehicle lies not only in its hardware, but also in its ability to deliver new added value to the user through constantly updated software.

One of the greatest advantages of in-vehicle software lies in its ability to personalize added value for the user. The nature of software allows it to be customized to the preferences and needs of individual users, which allows users to have a more comfortable and convenient mobility experience.

To provide a personalized mobility experience for a large number of users, the use of AI is important. AI can analyze vast amounts of data and understand the preferences and behavioral patterns of individual users, enabling it to accurately capture their demands and predictions and provide an optimal mobility experience. AI is also an ever-evolving technology, and it would be expected to to continuously improve its algorithms in response to user feedback and circumstances.

The AI has been booming up three times: the first (around 1960) was limited to solving simple problems; the second (1980s) focused on R&D in specialized fields but had difficulty gathering information. Then, in the third boom (2000s onward), AI itself began to acquire knowledge with the advent of machine learning and deep learning (See Figure 1.).

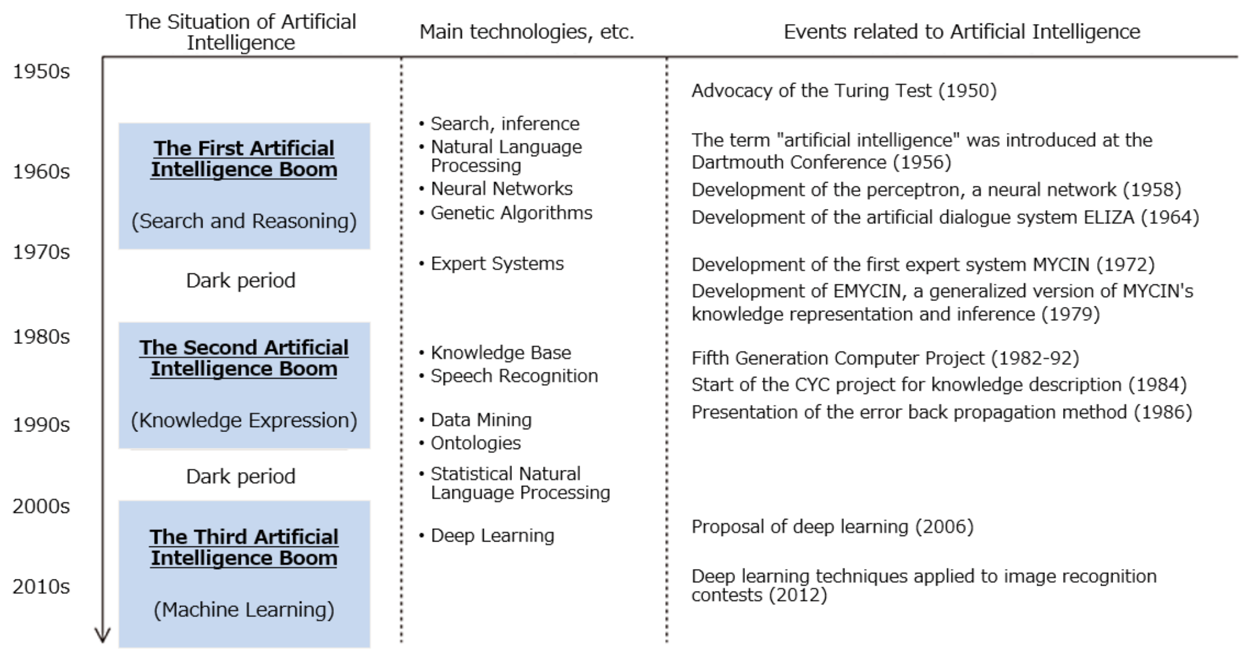

Figure 1. History of Population Intelligence (AI) [2]

Industry watchers are calling 2023 the beginning of a fourth AI boom. The leading reason for this is the rise in popularity of ChatGPT, an interactive AI model released by OpenAI at the end of November 2022. ChatGPT's greatest advantage is its ability to communicate using natural language, i.e., the way humans normally speak.

GPT stands for "generative pre-trained transformer," and this refers to the AI's ability to pre-learn large amounts of text data and generate natural sentences based on its understanding of context.

The use of ChatGPT is being considered for a variety of situations in various industries, such as customer service and marketing. Other AIs are capable of generating pictures and sentences like those created by humans, and this type of AI is called generative AI. This generative AI will bring a quantum leap in mobility in the near future.

AI could greatly assist in many use cases in connected vehicle services. The use cases in the original Green Mobility PoC document mainly refer to massive data communication loads from vehicle data collection and over the air (OTA). The generative AI is added for the use cases as a new one, since the generative AI requires both a huge amount of data and calculation for its learning, and since it causes huge energy consumption and heat generation.

The learning models for generative AI can be considered as regional models and as a global model. We would like to propose a distributed/centralized hybrid computing infrastructure for generative AI with well-balanced combination of the edge (regional learning model) and the cloud (global model), to resolve the challenges of energy consumption and heat generation by generative AI.

2 Ministry of Internal Affairs and Communications (2016), "Part 1: Special Feature: IoT, Big Data, and AI - New Value Created by Networks and Data" (last accessed: 2023/4/20, URL: https://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h28/(html/nc142120.html).

2.3 What Is a Green Mobility Society?

As mentioned above, in developing the automotive industry, it will be necessary to respond to changes in the external environment, such as the need for decarbonization and the spread of AI for new mobility experiences. We're defining this new way of motorization that takes these two points into account as a "green mobility society." The meanings of "green" and "mobility" here are as follows.

1. **Green as Social Value**
   The United Nations' 17 Sustainable Development Goals (SDGs) officially came into force on January 1, 2016. The diagram below shows the hierarchy of the SDGs, and natural capital is shown as the foundation of the other goals, with carbon neutrality being an indispensable theme for achieving the SDGs[3]. The term "green" here refers to social values that must be considered to avoid harming the global environment and preserve nature for the needs of future generations.

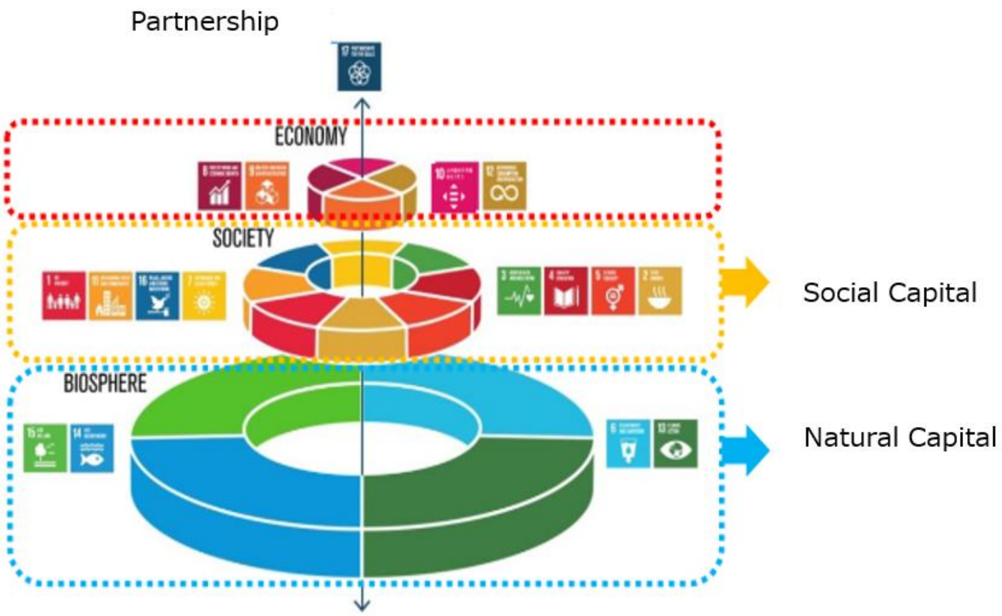

Figure 2. Layered image of the 17 goals of the SDGs

2. **Mobility as Customer Value**
   Freedom of movement is a fundamental human need, and people's demands evolve and increase every day. Mobility here refers to the demand for people to be able to use transportation products and services intuitively and without hassle, and to have their desired mobility experience. All providers of mobility-related products and services are expected to continue to meet these demands.

3. **Green Mobility Society: (Social Value) x (Customer Value)**
   A green mobility society refers to a society that creates new mobility experiences by pursuing mobility (a customer value) without compromise while achieving green practices (a social value).

3 Stockholm Resilience Centre (2016) "The SDGs wedding cake" (last viewed 9/12/2023, URL: https://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html).

A green mobility society aims to enhance both social value and customer value through AI and the IT infrastructure that supports it.

2.4 Purpose of This White Paper

To achieve green mobility, manufacturers such as OEMs and auto parts manufacturers and companies from various industries must join forces. These industries include:

- Telecommunication carriers that develop the communication environment for electric vehicles.
- Utility companies that supply the energy needed to run electric vehicles.
- Utility companies that manage power generation and transmission facilities for electric vehicles.
- Information and communication technology (ICT) service providers/vendors that provide digital technology for vehicles and road infrastructure.
- Software development companies that enhance the functionality and value of the vehicle itself.
- Companies that develop apps that run on smartphones and other devices carried by customers.
- Other companies from a variety of industries.

In particular, communication and calculation of enormous amounts of data are essential to enhance the value of the mobile experience, then the network and IT infrastructure (hereinafter referred to as "connected infrastructure") that supports this is extremely important.

In the pages that follow, we will consider the changes that will be brought about by decarbonizing transportation and the popularization of AI for new mobility experiences and present the challenges and solution hypotheses for the connected infrastructure that will be important in realizing a green mobility society.

3 Use Cases

3.1 Future New Mobility Experiences

With the evolution of AI, including the emergence of generative AI, we can expect that the automobile travel experience will change significantly. AI can be expected to be utilized from various perspectives, such as by task (moving, parking, charging, etc.) and by the source of input data (driver, vehicle, other external environmental factors, etc.).

1. **Concierge service:**
   The AI will engage in a conversation with the driver based on personalized information such as the driver's personality and tendency (e.g., who desires to recharge frequently, who drives until just before running out of power, etc) and plans for the day or trip. Combined with information on traffic congestion and road construction, AI suggests routes to destinations and appropriate recharging locations, and guides the driver through convenient functions of the in-vehicle software depending on the situation.
   The former type of technologies, the guidance on routes to destinations and recharging locations, is expected to be evolved further with Google Built-in[4].

2. **Accident Prevention Support (Road Repair and Collision Avoidance):**
   AI identifies the loss of painted lanes based on image data from drive recorders, etc., and automatically notifies the appropriate organization with the necessary information for repainting (location information and images showing the loss) to encourage repairs. Also, based on map information and vehicle location information, AI can identify vehicles hiding in blind spots at intersections and notify drivers in a safety-conscious manner. If AI can be utilized in this way, it has the potential to reduce traffic accidents.

3. **Providing a New Entertainment Space:**
   Equipped with large displays, vehicles are being used as “new living rooms” for enjoying movies and other entertainment[5]. Further in the future, new in-vehicle entertainment can be offered in a metaverse space that combines real-time vehicle data with virtual content for rear-seat passengers. For example:

   - AI could replace the video data read by in-vehicle cameras with a game space, allowing users to play adventure/shooting games while taking any physical shaking of the vehicle into account.
   - Rear seat passengers could sing songs or have conversations with virtual passengers (AI) while driving or listen to conversations between virtual passengers like background music.

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4 Google (N.D.) " Cars with Google built-in | A more connected, personal, and helpful drive." (last viewed 9/12/2023, URL: https://built-in.google/cars/).

5 BMW.com (2022) "Experience technology of the future: Entertainment" (last viewed 9/15/2023, URL: https://www.bmw.com/en/magazine/innovation/experience-the-technology-of-the-future-today-entertainment.html).

- Provide a space that makes users feel as if they are riding in a car even when they are not driving (e.g. they can see the scenery through the car window, hear the engine and other environmental sounds, and feel comfortable riding without getting carsick, even if they are prone to it).

3.2 Examples of New Customer Value as a Result of Changes in the Mobile Experience

This section takes the above use case of Concierge service (#1, directly above) as an example, and explains its value to customers, highlighting the kind of data and continuous learning that would be necessary.

The following requests may be received from drivers if the system attempts to deal with "electric shortages" without an AI:

- I would like to charge the battery when it is below 50% remaining with plenty of time to spare due to my personality.
- I tend to run out of battery earlier than the time remaining before I run out of power (because I drive roughly, which consumes electricity easily), so I would be happy if the system made predictions that match my driving style.
- The route to the charging location is congested, and I would appreciate it if the system navigates me to the charging location taking traffic congestion information into account.
- It is good that AI kindly tells me how to charge if the charging place and the charging device are not familiar to me.

By using AI to predict power shortages and find charging locations, drivers will have a more comfortable travel experience. Here are some specific examples.

- AI notifies the user of "power loss" at the optimal timing for the user, taking into account the user's driving tendencies (preference for remaining charge, when the user wants to take a break, etc.), cell temperature and degradation status, route to the destination, location of charging stations along the route, information on full capacity and availability, and facilities attached to the charging stations, etc.
- The AI could suggest multiple charging locations that are as convenient and affordable as possible. The AI would then advise the driver about charging times, proximity, prices, and other characteristics of each charging location.
- The AI should provide a route to the recharging location in an easy-to-understand manner.

3.3 Data and Learning Procedures Required for AI Applications

AIs will require the following data to achieve their full potential to assist drivers and infrastructure systems.

- **Information on the Vehicle**
  - Contents: GPS data of each vehicle, charging status, battery charge status, and outside temperature.
  - Sources: Vehicles, smartphone apps linked to vehicles, etc.
- **Information on Recharging Stations**
  - Contents: Location of charging stations, charger type, charging speed, current congestions levels, and past usage and failure information.
  - Sources: APIs from companies that provide information on charging stations and local governments that provide open data.
- **Information on Traffic Congestion**
  - Contents: Real-time traffic information, accidents, construction locations, etc.
  - Sources: Vehicles, APIs provided by traffic information providers, public transportation, and police.
- **Information on Weather**
  - Contents: Real-time weather information near the driving site, future forecasts, etc.
  - Sources: Public meteorological agencies, private weather information providers, etc.
- **Information on the Driver's Habits**
  - Contents: Driving trends (average speed, frequency of brake and accelerator use, etc.)
  - Sources: Vehicles.
- **Information on the Driver's Charging Practices**
  - Contents: Charging cycles (e.g., whether users tend to charge when half depleted).
  - Sources: Vehicles, smartphone apps linked to vehicles, etc.

Using the input data above, the AI model will become more sophisticated when it learns using the following steps. By repeating the learning process, it will be able to provide more accurate forecasts.

1. **Constant Collection of Real-time Data**
   To accurately predict battery charge loss, real-time vehicle data should be collected at all times.
   - Data to be collected: remaining battery level, cell degradation status, temperature, current trip distance, speed, vehicle position, etc.
2. **Data Pre-processing**
   This is the cleaning of the collected data and extraction of relevant information.
   - Main attributes: time of day, region, traffic congestion, weather information, user behavior trends, etc.

3. **Construction of Learning Models**
   Using the collected data, the AI will need to select an appropriate machine learning algorithm and build a learning model.

   - Types of learning models to be constructed:

     1. Battery charge loss prediction model.

     2. Optimal recharging location and recharging time suggestion model.

     3. User preference model, etc.

4. **Model Evaluation**
   The AI must appropriately evaluate the constructed learning models and identify areas for performance improvement.

   - Possible evaluation indicators: accuracy of recharging locations, user convenience, etc.

5. **Model Update**
   The AI will need to improve the learning model based on the evaluation results. It will also need to update the learning model using new data to achieve better accuracy.

6. **System Implementation**
   From there, the AI must be able to implement a system that suggests recharging locations using the constructed learning model. The system will also need to collect data in real-time and update the model.

This process, properly conducted, would result in the following outputs.

- **Recommended Charging Locations**
  The optimal charging location will be recommended based on the vehicle's location, battery level, type and distance of charging spots, traffic information, and weather information.

- **Recommended Charging Times**
  The AI will recommend the time needed for the vehicle to reach the required charge level, taking into account the battery level and the speed of the charging station.

- **Recommended Routes**
  Recommending the best route will need to factor in the vehicle's current location, the location of the charging station, traffic information, weather information, etc.

- **Congestion Level at Charging Stations**
  Based on past usage and real-time information, the system will predict the degree of congestion at nearby charging stations and suggest routes that avoid stations that are expected to be crowded.

To predict a drained battery and suggest recharging spots in a more user-friendly manner, the AI will analyze detailed information about the driver, the vehicle, and the external environment (roads, weather, etc.), and provide results that are useful to the driver.

4 Challenges and Solution Hypothesis

4.1 Challenges and Solution Hypotheses for the Popularization of AI

If the use cases discussed in the previous chapter are to be realized on the scale of hundreds of thousands or millions of vehicles, and if the scope of data utilization is to be expanded, what should the connected infrastructure look like?

There are various challenges to be considered, but it will be necessary to focus on addressing the following two primary challenges:

1. Optimization of load on network and computer resources.

2. Acquisition and management of personal data.

When designing infrastructure to overcome the first challenge, we'll need to remember that connected vehicles will be communicating the following types of data[6]:

- **Data from LiDAR** will utilize countless point cloud data to accurately measure distances to distant locations.
- **Data from cameras** (real-time video data) will be utilized to detect obstacles, pedestrians, etc.
- **Drive recorder data** (video data with no real-time requirement) will provide records of traffic events to clarify responsibility in the event of an accident and to provide data about driving to the cloud for software improvement.
- **Data on location information** will utilize GNSS, etc. to acquire highly accurate positional information and integrate dynamic spatial changes with digital twins.
- **Data on users** will utilize occupant schedules and preferences to provide comfortable driving/transportation services.
- **Security functions** will be utilized to save lives from malicious hacking.
- **Data from vehicle-to-anything (V2X):** (data linkage between vehicle-to-vehicle/road-to-vehicle). Obstacle information will be utilized to communicate hazard information, etc. on the road to the surrounding area to prevent accidents.
- **Data about the vehicle:** Monitoring/event information obtained from the onboard computer (ECU).
- **Data on AI:** Obtained from the cloud to update in-vehicle AI models so that they become more accurate.

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6 Automated Driving LAB (2019) "Data Generation for Automated Driving Cars '767 TB/day' Theory: Why? (Deep Dive! Automated Driving x Data Part 1)" (last visited Nov 07, 2022, URL: https://jidounten-lab.com/u_1-767tb-autonomous).

With such a large variety of connected car communications, the amount of data transmitted is expected to increase enormously.

With the proliferation of these connected cars, the amount of data being communicated is expected to increase enormously. For example, some users have confirmed that approximately 4 GB of data has been uploaded from a Tesla car after driving to the Tesla's autonomous driving program for analysis of its driving data[7].

McKinsey predicts that there will be 1.8 billion connected vehicles in 2030[6] with each car generating 1 to 2 terabytes of raw data each day.

This means that there will potentially be 3.6 zettabytes of data to receive, process, and store every single day. To make the scale easier to understand, that's over three trillion gigabytes (the average laptop shipped today has 256 gigabytes of storage space on the hard drive).

In addition, as the provision of a variety of services for connected cars progresses, the requirements for communication are expected to diversify. For example, there are differences in requirements such as data that requires real-time performance and data that does not. In terms of the nine types of data listed above, camera data and V2X data require high real-time performance, while other data do not require so much real-time performance.

A possible service that uses data that does not require real-time performance is one that uses a digital twin. For example, Tesla is using a camera mounted on the vehicle to acquire and transmit driving data from a Tesla vehicle in the real world, and having Dojo, a supercomputer, analyze the vast amount of driving data to improve self-driving programming.

In this way, the use of fully automated driving is expected to accelerate as AI analyzes vast amounts of driving data in the real world and software for improved for safe driving continues to be reflected in the vehicle. This kind of data, which does not require real-time operation, is expected to be transmitted (received) while the car is parked and, in an environment, where large-volume data transmission is possible, and will account for the majority of the data volume that will grow as connected cars become more widespread.

There is a concern that the network will be flat with the current facilities if all such large and diverse data is to be accommodated by the cellular network.

For that reason, the combined use of cellular communications and Wi-Fi will be useful to manage all of the data. The other useful tactic will be prioritization of data that is important for the operation of the vehicle over services that do not emphasize real-time or immediate response, such as vehicle data collection and software or content distribution.

However, even if the necessary communication environment for Wi-Fi can be established, it does not necessarily mean that the communication problems will be solved. For example, the network may become bottlenecked and cause delays. There may also be processing delays or system/service downtime caused by data load increases in the cloud infrastructure (computer resources).

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7 Electrek (2020) " Tesla is collecting insane amount of data from its Full Self-Driving test fleet", (last visited 9/12/2023, URL: https://electrek.co/2020/10/24/tesla-collecting-insane-amount-data-full-self-driving-test-fleet/).

In other words, from both the network and computer resource perspectives, the current mainstream method of consolidating and processing in data centers (cloud computing) will no longer be able to handle the situation.

Concerning the challenge presented by the acquisition and management of personal data (#2 above), it is necessary to comply with each country's regulations for the handling of personal data.

One of the most well-known of these regulations is the General Data Protection Regulation (GDPR), the European law for the protection of intra-regional personal data, enacted in 2018. The GDPR allows data transfer from within the EU to another country only if the European Commission recognizes that the other country ensures an adequate level of protection. If outside countries do not provide adequate protection, the GDPR prohibits the transfer of personal data.

To advance AI models, it is useful to learn by incorporating data used in various countries and regions as needed, but it is not possible to easily transfer data from a regulated country to another country. If regulations are violated, compensation for damages may be sought.

Considering this, the following measures may solve both challenges we mentioned above:

1. Instead of transmitting raw data directly from the vehicle to the cloud, a computer acting as an intermediary should perform the necessary data processing, so that the cloud side only needs to perform minimal processing.

2. Instead of transmitting all data directly from the vehicle to the cloud, personal data should be filtered out and transmitted to the cloud side in a privacy-preserving manner.

Both options above result in essentially the same measures. As shown in the figure below, a server for pre-processing (hereinafter referred to as an edge server) should be installed between the vehicle and the data center (cloud). Intervening edge servers would distribute the processing of large amounts of data and would be able to successfully create more accurate models while holding AI models in each of the vehicle, edge server, and cloud.

At the same time, the edge servers will perform fine-tuning of local learning models to establish “locally-produced and locally-consumed” AI models that match regional characteristics. A virtuous cycle can be expected to be created, in which the local learning model is integrated into the overall model in the cloud by separating the parts that can be used for general purposes. The advanced, general-purpose learning model is then returned to the local learning model.

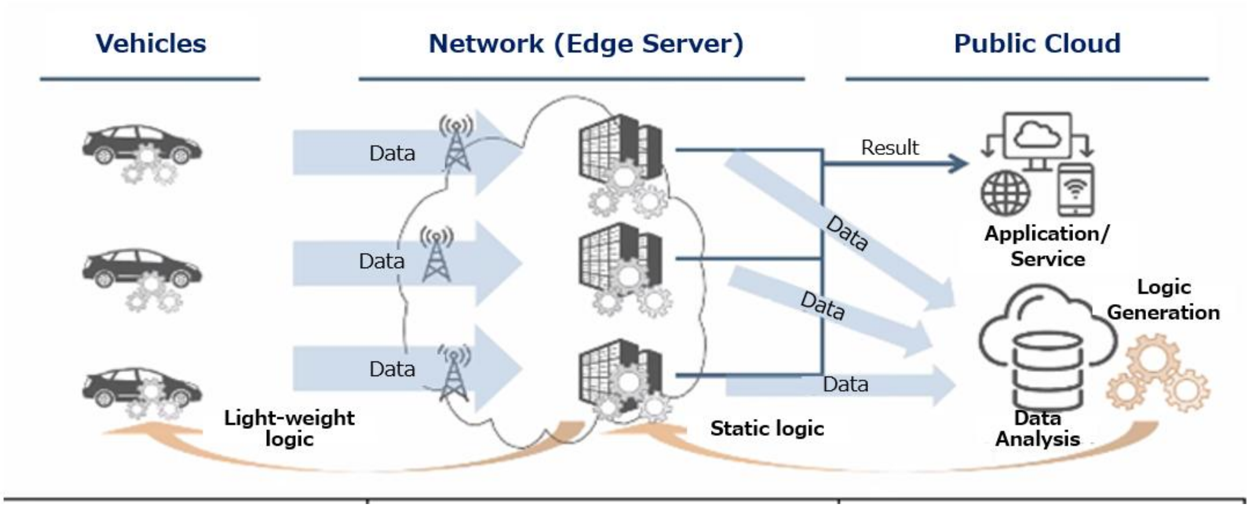

Figure 3. The three-tier model of vehicle, edge server, and cloud

4.2 Affinity with the Challenges of Decarbonization

The three-tier model of vehicles, edge servers, and cloud presented above is also linked to the decarbonization efforts outlined at the beginning of this paper.

As we have seen, the more AI is used to improve people's convenience, the greater the amount of data communicated and the greater the computation required by computers. In other words, the amount of energy required by society as a whole to make use of AI will continue to increase.

On the other hand, one of the current issues related to energy is the reality that there is a surplus of locally generated renewable energy that is being disposed of. If inter-regional power grids (interconnection lines) are not sufficiently developed, it is difficult to transfer surplus power to areas suffering from power shortages, and if power consumption is concentrated in large data centers (cloud computing), it is difficult to use the surplus power generated in the region. As a result, the issue of power shortages and rising electricity costs in metropolitan areas has become a hot topic, while renewable energy is being discarded in rural areas.

Edge servers are an effective solution to this challenge. By placing edge servers in each region to process data, operating them using local surplus energy, and utilizing them to coordinate raised DR, renewable energy can be used instead of going to waste.

In addition if one compares the cost of transporting electricity to run the data center to the communication cost of transporting data processed at the data center, it is more economical to transport processed data at a location with electricity than to transport electricity to a data center location, from an energy efficiency perspective[8].

It is said to be more economical and energy-efficient than transporting power to the data center location.

8 Ministry of Economy, Trade and Industry and Ministry of Internal Affairs and Communications (2023) " Tesla is collecting insane amount of data from its Full Self-Driving test fleet", (last visited 9/12/2023, URL: https://www.meti.go.jp/policy/mono_info_service/joho/conference/digital_infrastructure/0006/torimatome2_01.pdf).

This hypothesis also leads to the effectiveness of installing machines for data processing near where energy is generated, i.e., installing edge servers in rural areas where renewable energy is generated.

Of course, large vendors that lease cloud infrastructure to their customers have multiple data centers globally and are working hard to withstand the load concentrations on their cloud infrastructure that we have seen in 4.1. In fact, Microsoft monitors the performance of computing resources at multiple locations running ChatGPT so that it can load-balance according to resource utilization. From the standpoint of energy efficiency, however, the large amount of electricity required for computer calculations and the heat generated by such calculations make centralized management approaches in data centers much difficult. The more connected cars become, the more desirable it is to use them in combination with edge servers.

In fact, there are estimates that carbon emissions can be reduced to 1/30 to 1/40 compared to the use of fossil fuel-derived electricity by locating systems that require large amounts of data processing in places where renewable energy is abundant and processing during times when renewable energy is readily available[9]. Thus, the decentralized deployment of edge servers and local production for local consumption of electricity can be effective toward decarbonization.

In the future, it may be important to use power coloring mechanisms to enable users to trace whether their power comes from renewable energy sources, as consumers themselves may choose how decarbonized their power supply sources are.

4.3 Mechanism of Federated Learning

A method of learning AI models called "federated learning" is compatible with the three-tier model described above.

Coalitional learning is one of the generic learning methods for machine learning models in environments with distributed training data sets. It is also an approach that makes use of large amounts of data at a reduced cost.

9 GIZMODE (2023) "Is Generative AI Bad for the Environment?", (last visited 9/12/2023, URL: https://gizmodo.com/chatgpt-app-ai-is-generative-ai-bad-for-the-environment-1850481190).

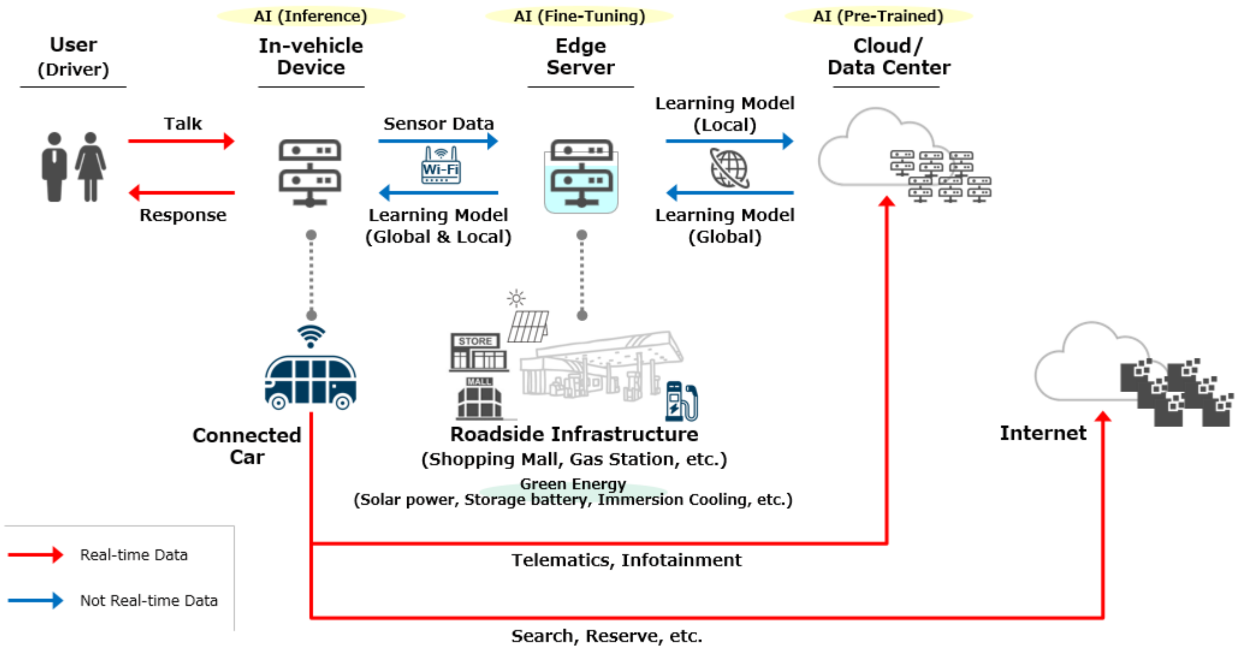

Figure 4. Image of future connected infrastructure

Conventional machine learning assumes that training data sets are aggregated in advance. In contrast, federated learning (also known as collaborative learning) trains an algorithm with many client computers, each with its own dataset. They're all connected to a central server on a network.

In this type of learning, the central server first distributes a model (called a global model) that it wants to provide to the clients. The clients learn the distributed model using their datasets and send it back to the server. The central server then updates the global model by integrating all the models sent by the clients and distributes the updated version to all the clients. By repeating these steps many times, the central server can eventually obtain a high-performance global model that looks as if it has been trained by aggregating data from many clients.

In this federated learning framework, the central server does not need to be the repository of a large amount of data. The data collection problem can be solved by asking many clients to collect and learn the data. In addition, federated learning does not require that the clients provide the central server with the collected data, which is a promising approach in terms of communication, central server-side storage, privacy, and security.[10]

10 Ryu Yoneya (2021), "Introduction to Coalition Learning" (last accessed 04/19/2023, URL: https://www.omron.com/jp/ja/technology/omrontechnics/2021/OMT_Vol53_No2_006JP.pdf)

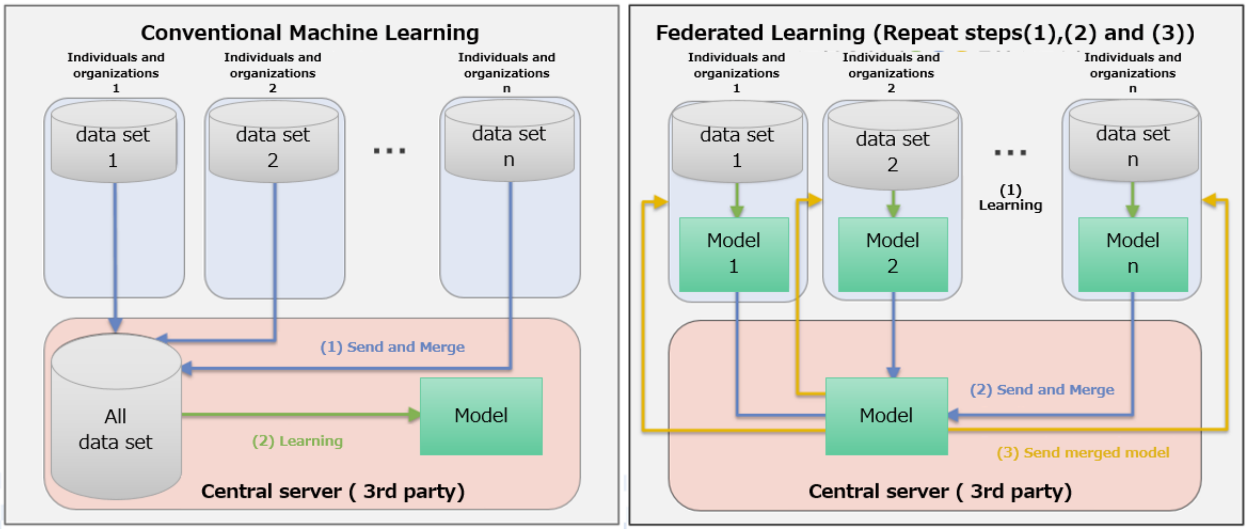

Figure 5. Conventional Machine Learning and Federated/Coalitional Learning[11]

4.4 Use Case: Applying Federated Learning

Let's apply federated learning to the use case for power shortage prediction and charging station location guidance introduced in the previous chapter. If it were executed using the cloud as the central server and the vehicle and edge server as clients, the following specific issues could be considered to be solved.

- **Challenges and Solutions Related to Real-Time High-Capacity Data**

  Predicting battery power shortages and suggesting charging locations involves handling large volumes of real-time data, including location information and battery/cell data from vehicles, data on charger specifications and full/empty status from charging stations, traffic, and weather information from government ministries, etc.

  - **The Challenge with Conventional Machine Learning**

    In conventional machine learning, it is critical to aggregate all the necessary data in the cloud beforehand. From a communication perspective, this puts pressure on bandwidth and makes communication delays more likely. Also, from a processing perspective, aggregation to the cloud places an excessive load on the computing resources in the cloud.

  - **The Solution with Federated Learning**

    In federated learning, each client (vehicle, edge server) uses the dataset it maintains to learn and sends the results to the cloud. Since a large amount of data is transferred in a processed form, the amount of communication is reduced, preventing bandwidth pressure. The load on the cloud could also be reduced by distributing the processing.

11 Murata, Tomoya (2022), "What is Federated Learning?" (Last accessed 04/19, 2023, URL: https://www.msiism.jp/article/federated-learning.html)

In addition, research is currently being conducted on algorithms that would further reduce the number of communications. If each client learns from its dataset while referring to the model update information of other clients, it could pseudo-imitate the situation when learning by aggregating the data sets of all clients. The number of communications required would thereby be reduced.

- **Challenges and Solutions for Personalization**

  When predicting battery power shortages and providing charging locations, it is necessary to suggest the appropriate charging location for each user at the appropriate time.

  - **The Challenge with Conventional Machine Learning**

    Conventional machine learning involves uniformly applying a model created from all data collected from various locations. Since it is difficult to tune models for each region, it would be difficult to make highly personalized suggestions.

  - **The Solution with Federated Learning**

    In federated learning, since data is accumulated and learned at each client computer, a separate model would be learned for each region where vehicles and edge servers are located. Therefore, it would be possible to provide highly accurate personalized suggestions tailored to regional characteristics.

- **Data Privacy Challenges and Solutions**

  When proposing charging locations, their capacity and availability would be determined from image and other data. Any personal information, such as license plates and images of passengers, would need to be filtered or masked to protect privacy.

  - **The Challenge with Traditional Machine Learning**

    Since all datasets are transferred directly to the cloud, the masking process for all received data would need to be performed there. This would increase the data processing load and possibly the processing time. In addition, it would be difficult to handle data across international borders, because the degree and type of data masking processing can be unique from country to country.

  - **The Solution with Federated Learning**

    The data could be transferred to the cloud with any masking processing applied, thereby reducing the data processing load in the cloud. Since the data masking process could be performed with different privacy settings for each region, the data processing could be performed according to the privacy laws of each country when deployed globally.

In the future, we aim to further specify the ideal connected infrastructure (see Figure 5) and verify its feasibility. The connected infrastructure can be broken down in terms of data as shown in the table below, but this project will focus on data that does not require much real-time performance and will lead to effective measures for green mobility.

Table 1. Themes for validation for connected infrastructure design (example)

#	Real-time Response	Role in the Connected Infrastructure	Verification Theme (Example)
1	Not Required	Data collection from sensors	Can camera data, etc., captured while the vehicle is in motion, be uploaded to the cloud via an edge server? (Distributed from the vehicle via Wi-Fi offload, etc. when parked.)
2		Generate training models for in-vehicle AI	Can decarbonization-conscious energy enable locally appropriate fine tuning on edge servers?
3		Delivery of advanced training models to vehicles	Is it possible to download large amounts of data in the vehicle? (Distributed to the vehicle via Wi-Fi offloading, etc. when parked.)
4	Required	Inference in learning models for in-vehicle AI	-
5		Data collection from the Internet	-
6		Utilization for telematics services	-

5 Conclusion and Perspective

A green mobility society is a concept that should be shared by stakeholders in various industries in order to balance environmental considerations with the evolution of mobility, i.e., vehicle performance and services. The key to achieving this society is decarbonization and AI, and it turns out that the two are not trade-offs by any means but have a good affinity in building a decentralized society that is environmentally conscious. We have also hypothesized that a distributed architecture that utilizes edge servers and the like is effective as a connected infrastructure to support this.

In the future, we aim to verify the feasibility of the issues presented in Chapter 4 by co-creating them with a wide range of stakeholders. To this end, it is essential to gain a deep understanding and agreement on the value of a green mobility society from all stakeholders and society, and we hope that this document will play a role in this process.

On the other hand, electric vehicles, which are one means of realizing a green mobility society, are still in the process of evolution, and at this point, it is important to enhance the value of various means of transportation to broaden user choices. Therefore, this document itself is a work in progress, and in parallel with the verification work, it is necessary to pay attention to and continuously update cutting-edge research, inventions, and new application cases in Japan and abroad.

We hope that this publication will raise the interest of all concerned in the green mobility society, and we would also like to seek advice and new recommendations from a wide range of people to further deepen the discussion and make it more meaningful.

About the AECC

The Automotive Edge Computing Consortium (AECC) is an association of global leaders from across industries working to explore the rapidly evolving and critical data and communications needs of the billions of vehicles in the world. AECC members are leaders in automotive, high-speed mobile networking, edge computing, wireless technologies, distributed computing, artificial intelligence, distributed computing, and artificial intelligence markets.

To learn more, visit AECC.org or contact the AECC here.

References

1. Business + IT (2022) "What is the Greenhouse Gas (GHG) Protocol? Scope 1-3 in plain language" (last accessed 11/14/2022, URL: https://www.sbbit.jp/article/cont1/78027).

2. Ministry of Internal Affairs and Communications (2016), "Part 1: Special Feature: IoT, Big Data, and AI - New Value Created by Networks and Data" (last accessed: 2023/4/20, URL: https://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h28/ (html/nc142120.html).

3. Ministry of Agriculture, Forestry and Fisheries (2019) "Agriculture, Forestry and Fisheries x Environment and Technology x SDGs" (last viewed 2023/01/20, URL: https://www.maff.go.jp/j/kanbo/kankyo/seisaku/kankyogijyutuSDGs/attach/pdf/index (-7.pdf).

4. Ryu Yoneya (2021), "Introduction to Federated Learning" (last accessed 04/19/2023, URL: https://www.omron.com/jp/ja/technology/omrontechnics/2021/OMT_Vol53_No2_006JP.pdf)

5. Murata, Tomoya (2022), "What is Federated Learning?" (last accessed 04/19, 2023, URL:)

6. Cisco Blogs (2019) "Connected Car - All That Data - Cost and Impact on the Network" (last viewed 11/07/2022, URL: https://blogs.cisco.com/sp/connected-car-all-) (that-data-cost-and-impact-on-the-network).

7. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/unlocking-the-full-life-cycle-value-from-connected-car-data

8. https://transformainsights.com/blog/connected-cars-cellular-iot-5g