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Past and Future of ICT Utilization in Mobility-Related Fields

Ryo Ariyoshi*

Institute of Urban Innovation, Yokohama National University, Yokohama-shi, 240-8501 Japan

***Corresponding author:** Ryo Ariyoshi, ariyoshi-ryo-gd@ynu.ac.jp

Abstract

In the field of mobility, information and communication technology (ICT) was initially positioned as a technology to support road traffic safety and smoothness. However, with the emergence of new mobility services such as ride-sharing based on the Internet and smartphones, the acceleration of research and development in autonomous driving, and the widespread adoption of concepts like "CASE" and "MaaS," ICT has become a fundamental pillar of the new era of mobility services. Furthermore, ICT's role is expanding not only from a technological perspective but also in the policy-making process aimed at addressing transportation-related challenges. In the utilization of ICT-related data in transportation planning, challenges arise from the mismatch between data users and data owners, as well as differences in their objectives. It is crucial for data users, often policy and research entities, to engage with data owners, typically private sector operators, to deepen their understanding of how data is used in the transportation planning process. This collaborative effort is essential for effective data utilization in the field of transportation planning.

Keywords

Mobility
Transportation planning
ITS
MaaS
Big data

1. Introduction

This paper discusses the utilization and prospects of information and communication technology (ICT) in the field of mobility in Japan. An overview of the historical background of ICT utilization in the mobility sector is provided in section 2. The use of ICT in the planning process of mobility-related policies is discussed in section 3, providing examples from services and research studies. An outlook on the future collaboration between mobility and ICT is presented in section 4.

Before proceeding with the discussion, let's define the term "mobility" as used in this paper. The word "mobility" means "the ability to move," and in this paper, it represents the concept of "ease of movement." It is worth noting that the term "mobility" is sometimes used to refer to the physical vehicles themselves (referred to as “means of transportation” in transportation planning). However, this paper does not strictly limit the interpretation to this context.

2. The use of ICT in the field of mobility: a historical overview

2.1. The early period of ICT utilization (1970s–1980s)

The development of technology for ICT utilization in the field of mobility in Japan began in the 1970s (**Figure 1**). Pioneering this effort was the Comprehensive Automobile Control Systems (CACS) initiated by the Ministry of International Trade and Industry (MITI) in 1973. CACS aimed to merge information collected by sensors on both the road and vehicles, estimate and predict traffic conditions, and develop a system that provides dynamic real-time route information based on the results. Subsequent to this, in the 1980s, the Ministry of Construction embarked on the Road/Automobile Communication System (RACS) project, while the National Police Agency began to work on Advanced Mobile Traffic Information and Communication Systems (AMTICS). These initiatives, in collaboration with the Ministry of Posts and Telecommunications (which regulated radio licenses), evolved into the Vehicle Information and Communication System (VICS). VICS now plays a central role in providing traffic information systems on major roads.

2.2. Towards ITS focused on road traffic (until the late 1990s)

From the late 1980s through the 1990s, various government agencies in Japan pursued technological developments aimed at enhancing road infrastructure and vehicles using ICT. These initiatives sought to evaluate the overall quality of road transportation through the integration of roadways and vehicles. Notable projects included the Ministry of Construction’s Advanced Road Transportation Systems (ARTS) project aimed at

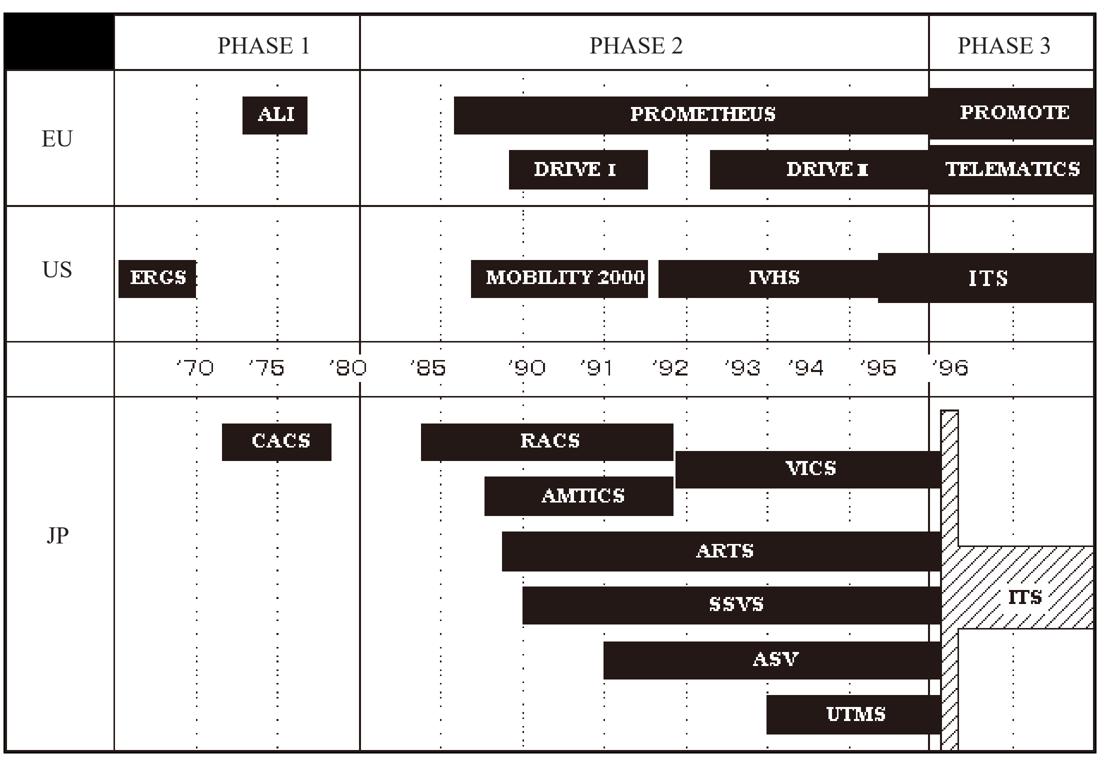


Figure 1. The early period of ICT utilization in the mobility field [1]. Abbreviation: EU, Europe; US, United States; JP, Japan.

achieving integration for advanced road transportation systems, the Ministry of Transportation's Advanced Safety Vehicle (ASV) project focused on advancing vehicle safety technology, the Ministry of International Trade and Industry's Super Smart Vehicle System (SSVS) aimed at increasing the intelligence of automobile transportation systems, and the National Police Agency's Universal Traffic Management Systems (UTMS) aimed at comprehensive traffic control including traffic demand management.

During the same period, in the United States, the development of Intelligent Vehicle-Highway Systems (IVHS) began, which later became known as Intelligent Transport Systems (ITS) after the enactment of the Inter-Modal Surface Transportation Efficiency Act (ISTEA) in 1991. Nakamura suggested that the expansion of ITS from vehicle and road-centric applications to encompassing the broader and diverse field of transportation was a significant shift in understanding the term [2].

Subsequently, the first ITS World Congress was held in 1994, and the term ITS became universally recognized. In Japan, ITS is often translated as "Intelligent Transport System" or "Intelligent Transportation System," with the "T" referring to "transport," although it is commonly interpreted as "road traffic."

In 1996, Japan established the "Overall Concept for ITS Promotion," consolidating the efforts of relevant government agencies. This concept outlined nine development areas and 21 user services. As a result of extensive technological advancements, the Electronic Toll Collection System (ETC) with a usage rate exceeding 90%, standard-equipped car navigation systems, VICS providing real-time road and parking information through car navigation systems, and bus location systems for real-time bus position information retrieval and provision became widely adopted among various road transportation-related services.

2.3. Expansion of the ITS Scope (until the early 2010s)

Since the 11th ITS World Congress was held in Nagoya in 2004, ITS has been positioned as entering its second stage (see **Figure 2**). To translate the results of previous individual technological developments into concrete

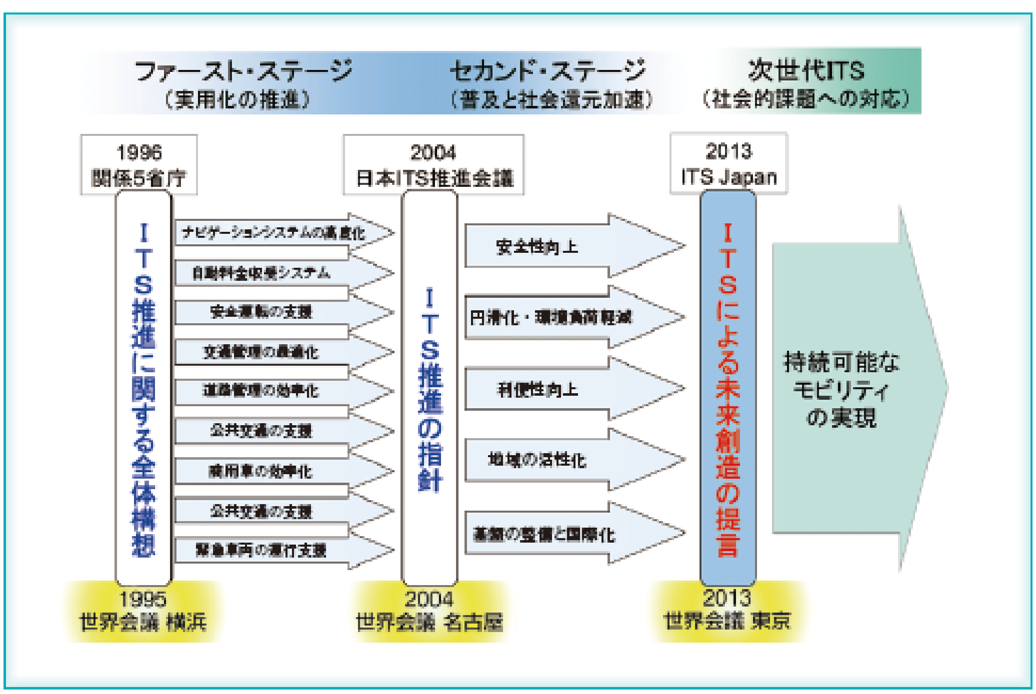


Figure 2. Society aiming for development through ITS [3]

solutions for societal challenges, the “ITS Promotion Guidelines” were introduced. These guidelines established “Safety and Security, Environment and Efficacy, Comfort and Convenience” as the fundamental principles.

While ITS has previously focused on automobile safety and smooth road traffic, during this period, it expanded its application to individuals and regions, establishing connections with various policy areas, including public transportation and welfare. The late 2000s to the following decade marked a period when ITS, which had been driven by seed-oriented initiatives from its inception, transitioned towards purpose-driven and user-centric efforts.

Several factors contributed to this transformation. Japan experienced a peak in both its total population and automobile traffic volume in 2008, accompanied by economic stagnation. These changes altered the premise for promoting ITS as a solution to road traffic issues. Simultaneously, there was a growing global interest in environmental concerns after the Kyoto Protocol, as well as advancements in aging populations, urban depopulation in regional cities, and various challenges related to mobility. These factors made mobility-related issues and challenges more diverse and complex.

2.4. Rapid convergence of mobility and ICT (late 2010s)

In the late 2010s, the widespread adoption of concepts like CASE (Connected, Autonomous, Shared, Electrification) and MaaS (Mobility as a Service) brought about a significant convergence between the mobility section and ICT. Unlike the government-led societal implementations seen in the promotion of ITS, this convergence took the form of privately driven new mobility services (such as car-sharing, bike-sharing, ride-sharing, on-demand buses, etc.) based on Internet-related technologies, which began appearing in our everyday lives one after another.

Here, CASE is a term that summarizes the new trends in the automotive industry, representing Internetization (Connected), automation (Autonomous), sharing (Shared), and electrification. However, Electrification and Autonomous primarily pertain to the vehicles themselves, while Connected and Shared are more related to how vehicles are used and the services they offer. In this sense, CASE can be seen as a symbol of the convergence and integration of ICT and mobility services. In section 3, the new mobility services closely related to CASE, such as Sharing and Autonomous driving, and MaaS, are discussed, providing an overview of their trends.

3. Trends in new mobility services

3.1. Entry of ICT-related companies into mobility services

Among the CASE elements, a typical example of a new mobility service that embodies both Connected (C) and Shared (S) is represented by individual-to-individual ride-sharing services such as Uber, Lyft, DiDi, and others. These services utilize the Internet for demand and supply matching, allowing individuals to provide paid transportation services to those in need. It is often referred to as ‘ride-hailing,’ as it involves easily summoning a ‘ride’ via the Internet. In Japan, providing such services with a personal vehicle is considered illegal, referred to as “Hakutaku,” but in countries without such regulations, these services have gained many users due to their lower cost, shorter waiting times compared to traditional taxis, the assurance provided by driver ratings, and the fact that the destination is pre-communicated to the driver, reducing language-related issues.

Rapid smartphone adaptation and improvements in server-side information processing technology have greatly reduced the marginal costs associated with matching individuals for transportation services. This led ICT companies, which were previously less involved in the mobility sector, to enter the mobility market with on-demand ride-sharing services facilitated

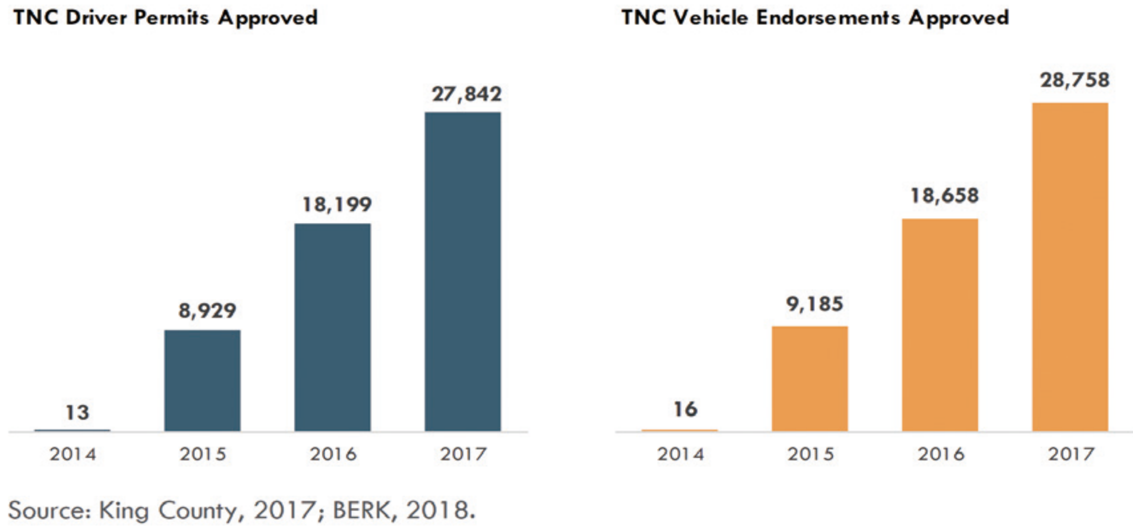


Figure 3. The transition of registered drivers and vehicle numbers in TNCs [4]

through the Internet. Over time, they came to be known as Transportation Network Companies (TNCs), and their role within urban transportation systems began to be discussed and debated (**Figure 3**).

3.2. Development of autonomous driving technologies

During this period, there was significant progress in the development of autonomous driving technologies. In 2014, the government formulated the "Government-Industry ITS Vision and Roadmap," which aimed at the early realization of autonomous driving through collaborative efforts of the government and the private sector, focusing on improving vehicle safety, ensuring mobility for the elderly, and enhancing the efficiency of passenger and cargo transportation to address driver shortages. With support from relevant government agencies, initiatives were carried out across various regions, including the market introduction of level 3 autonomous vehicles in March 2020, as well as pilot projects for level 4 equivalent unmanned autonomous mobility services in restricted areas (**Figure 4**).

During this period, core technologies for autonomous driving such as high-precision three-dimensional (3D) maps, dynamic maps, and artificial intelligence (AI) made remarkable advancements. However, the societal landscape surrounding automobiles underwent significant changes, including efforts to address global warming. In addition, the outbreak of the COVID-19 pandemic in the late 2010s led to shifts in people's mobility patterns and values. Some have pointed out that the approach to problem-solving solely through autonomous driving technology may no longer be sufficient [6].

In summary, there is still room for essential discussions about who autonomous driving is for and for what purpose. Nevertheless, it remains an undeniable fact that ICT is indispensable for autonomous driving. ICT in the automotive sector has evolved from technologies that assist driver operations and decision-making through information provision to a fundamental prerequisite for level 3 or higher autonomous driving, where real-time remote monitoring is necessary. In this sense, the 2010s, which can be considered the developmental phase of autonomous driving technology, saw a significant transformation of ICT from a supportive role in road transportation mobility services to a position central to the system's core.

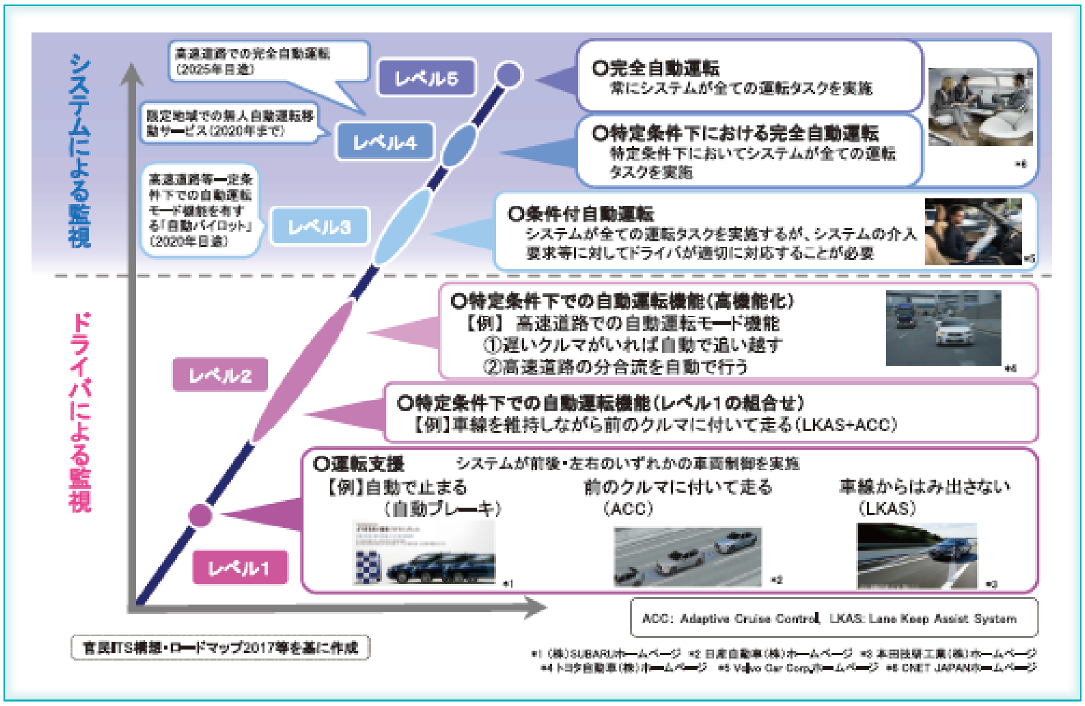


Figure 4. Classification of autonomous driving levels [5]

3.3. The global expansion of MaaS

Another concept that became widespread globally during this period, in terms of its relationship with ICT, is Mobility as a Service (MaaS). MaaS refers to the idea of providing one-stop access to multiple modes of transportation, allowing users to search for travel routes that combine various transportation modes, reserve tickets, and complete payment procedures, all for the available transportation options in a given region. While this concept had been around for some time, it gained significant momentum in 2016 when Finland's MaaS Global successfully materialized it into a smartphone application. This sparked the proliferation of MaaS initiatives worldwide (**Figure 5** shows a Japanese version of such an application).

It is important to note that MaaS itself does not introduce new modes of transportation. Instead, it represents the concept of bundling existing modes of transportation into a single service to make them more user-friendly. Therefore it is not accurate to say that MaaS has created new modes of transportation. Rather, the ease of connecting transportation users and providers through the Internet has made it easier for MaaS operations to be technically and commercially viable.

4. The utilization of ICT in the planning process of mobility-related policies

In section 3, the evolution of the relationship between mobility and ICT over time was reviewed, focusing on individual technological developments and services. This chapter discusses the use of ICT in the general planning process of mobility-related policies from a transportation policy perspective, accompanied by examples.

4.1. Assessment of the current mobility system

In the planning process of the mobility system, the current situation assessment involves capturing actual traffic phenomena of roads and identifying specific phenomena (often undesirable ones such as traffic

Figure 5. MaaS Global's app, Whim (Japanese version) [7]

congestion) and their causes.

In this process, ICT is used to accurately grasp real-world traffic phenomena. A typical example of ICT utilization is the monitoring of road congestion based on data transmitted from in-vehicle devices. The analysis of road traffic conditions using "ETC2.0 probe information" promoted by the Ministry of Land, Infrastructure, Transport, and Tourism is one such example. Here, the term "probe" implies the exploration of a road section's required time by vehicles equipped with sensors, typically a small sample of vehicles.

Specifically, as shown in **Figure 6**, GPS location information sent from individual vehicles' ETC2.0 onboard devices or car navigation systems is aggregated on the server side. Analysis is then performed to identify the locations and severity of road congestion, as well as the timing of congestion occurrences. These insights are used to devise measures such as improvements to traffic facilities and congestion leveling through route guidance (**Figure 7**).

In recent years, ETC2.0 has made vehicle ID-tagged probe information available, including data on not only travel time but also the start and end points of the vehicle's movement and the route taken. Utilizing such data allows for the identification of specific locations with concentrated vehicle access. It not only aids in understanding the current state, i.e. where the congestion is occurring, but also deepens the diagnostic understanding of why congestion is happening.

On the other hand, the environment for using probe data provided by private sector entities is also becoming more robust. For instance, ESRI Japan, in collaboration with Toyota Motor Corporation, started selling the "Road Traffic History Statistics" service in 2021. This service uses GPS location information collected by Toyota vehicles equipped with connected car navigation systems to calculate statistics on total traffic volume and average travel speed for different road sections matched to maps, all on a three-month basis. It is offered as a subscription-based spatial data service. One of its distinctive features is its coverage of all roads traveled by the target vehicles, including residential streets not covered by the VICS information system. It is suitable for gaining a comprehensive understanding of traffic conditions and trends in specific areas, including analyses by day of the week and time of the day (**Figure 8**).

Figure 6. The collection of probe information through ETC2.0 onboard devices [8]

Figure 7. Analysis of road congestion based on probe information [8]

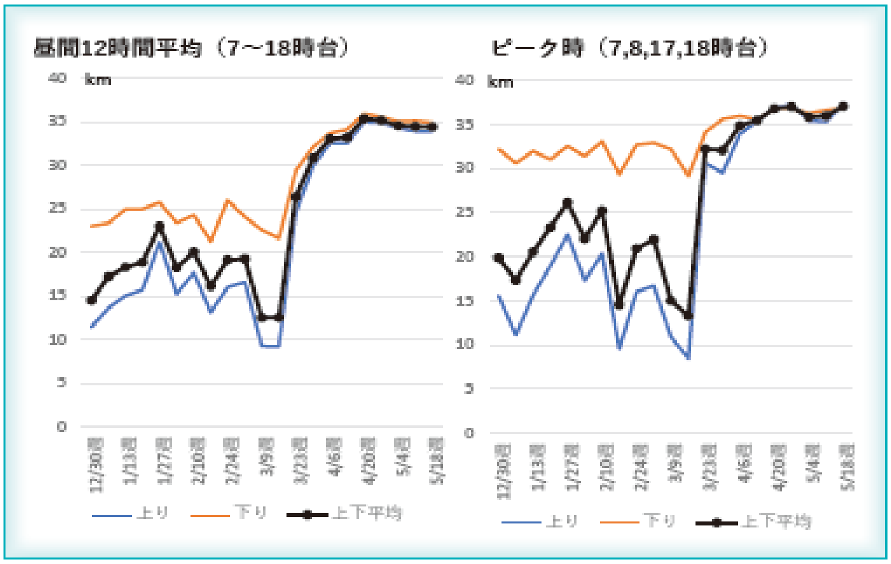
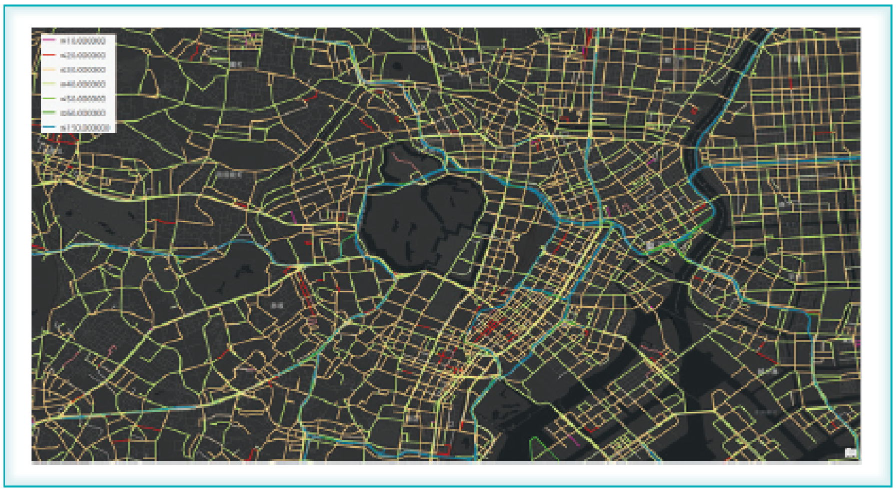


Figure 8. Road traffic history statistics based on probe information [9]



4.2. Setting and evaluating policy alternatives

4.2.1 Setting policy objectives and key performance indicators (KPIs)

Following the current situation assessment in section 4.1, the policy alternatives to solve the identified problems and challenges are examined. In this process, policy objectives to be achieved are first established, and corresponding key performance indicators (KPIs) for alternative policy evaluation are established. For example, if the policy objective is to alleviate road congestion in tourist areas, policy alternatives may include time and spatial smoothing of automobile demand through real-time traffic congestion information provision and reducing automobile demand (mode shift) through improved convenience and fare discounts for public transportation.

The former KPIs include the average travel speed on target road segments or total travel time for the entire surrounding road network including those segments that can be considered, while the latter KPIs include changes in the mode share of access transportation modes to the tourist destination. It is desirable that both sets of KPIs can be quantified based on objective data, making the availability of data collected through ICT, such as the aforementioned probe information, of great importance.

4.2.2. Prior evaluation of policy alternatives

When multiple policy alternatives have been established for addressing transportation problems or challenges, transportation demand is estimated under the conditions of these alternative policies, and the merits and drawbacks of each alternative are compared based on KPIs determined for this demand. While there are numerous research studies on transportation demand estimation in theory and practice, this article does not aim to provide an exhaustive explanation. Instead, the example of the widely applied four-step estimation method in transportation planning is used to discuss the data requirements and the relationship with ICT in each estimation process.

The four-step estimation method is a set of methods used to estimate the transportation load on road networks and other transportation networks resulting from people's movement. It was developed in the 1950s in the United States, first introduced in the Hiroshima metropolitan area in Japan in 1967, and has since become an established forecasting method for comprehensive urban transportation planning. The four-step estimation method divides the total generated transportation volume for an entire metropolitan area, as estimated from the total population, into four sequential processes: (1) trip generation (by zone), (2) trip distribution (by origin-destination pairs), (3) modal split (by transportation mode), and (4) travel assignment (by travel route) (**Figure 9**). While there are theoretical criticisms, such as the limited representation of causal relationships in estimation models and discrepancies between estimated blues for the same indicators across different processes, the practical value of the four-step estimation method remains significant.

(1) Step 1: Trip generation and attraction

In this process, the number of trips, defined as individual movements from a departure point to a final destination point occurring within a certain geographical zone during a specific period, was estimated. Traditionally, this has been achieved through questionnaire surveys, such as metropolitan person-trip surveys, which sample a small percentage of the resident population to determine the actual number of trips per person per day. However, in recent years, the availability of dig data from GPS location information collected and stored through smartphone applications has enabled capturing trip generation and attraction data for specific areas or facilities. This advancement offers the potential for increased reliability and spatial resolution in trip estimates. Major mobile telecommunication service providers in Japan have also commercialized services

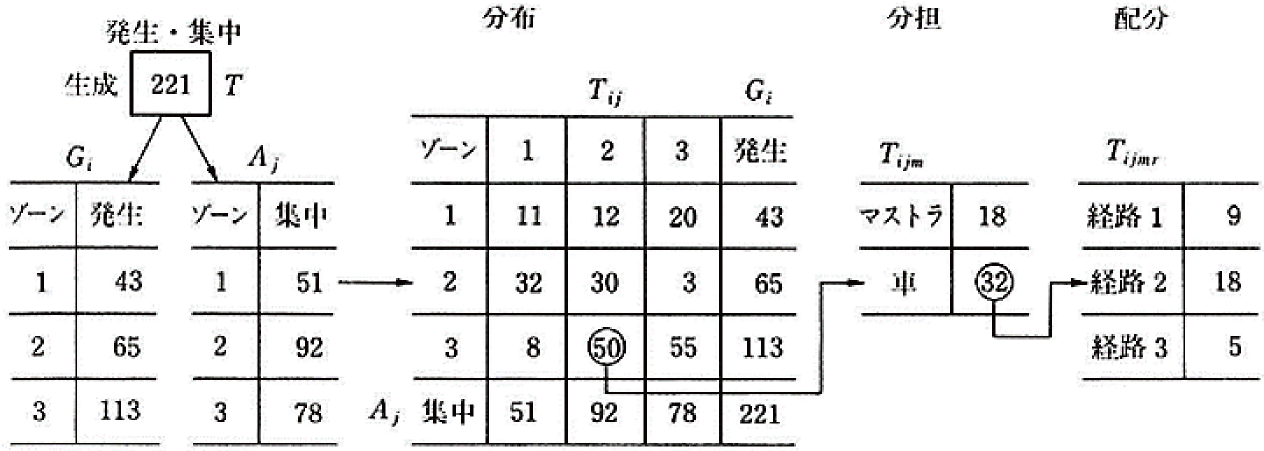


Figure 9. The traffic volume forecasting process in the four-step estimation method [10]

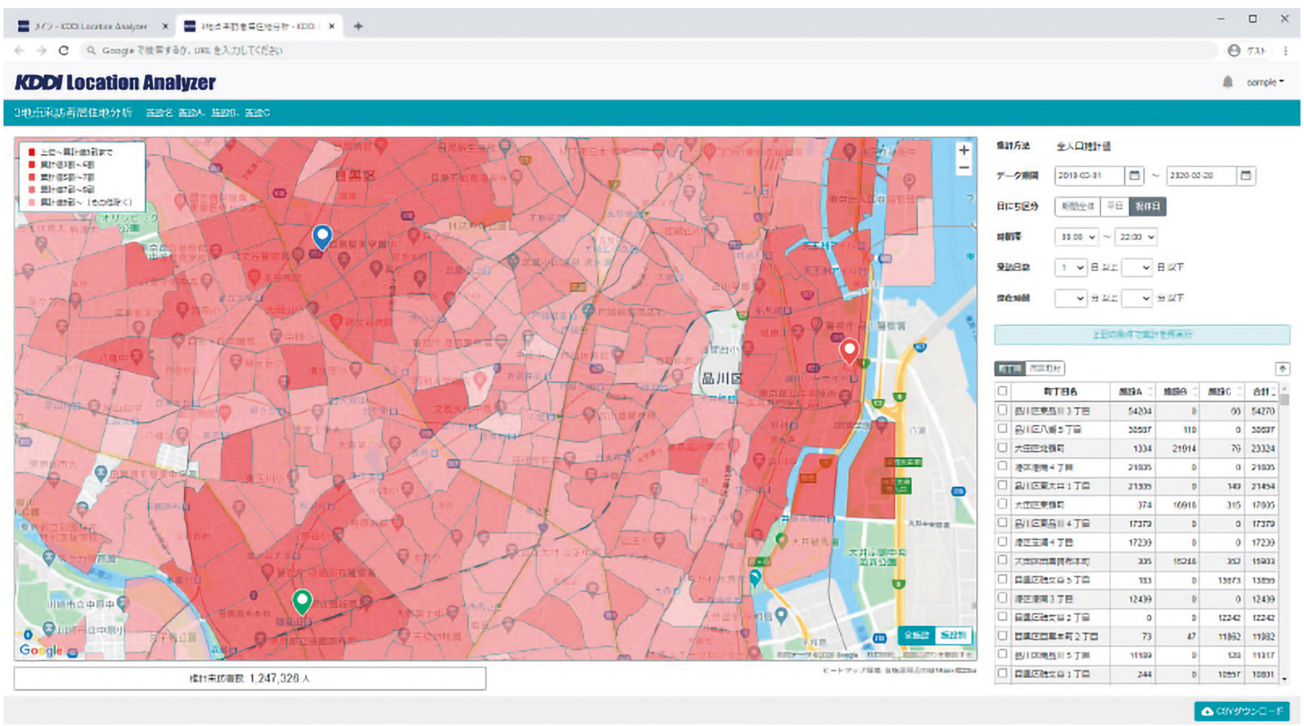


Figure 10. Analysis services for mobile phone location data [11]

for analyzing human mobility using mobile phone location data, expanding the range of applications (**Figure 10**).

(2) Step 2: Estimation of trip distribution (OD matrix)

The estimation of trip distribution is a process of estimating to which zones trips departing from a particular zone will arrive. Specifically, this process involves estimating the values in the cells of an Origin-Destination matrix (OD matrix), where each cell represents the number of trips moving between an origin zone and a destination zone. The estimation is typically done using models like the gravity model. The gravity model, analogous to the law of universal gravitation in physics, suggests that trips originating from a zone tend to be attracted to zones with a higher total trip generation (mass) and shorter distances from the origin zone. This concept is mathematically expressed by the following formula [10]:

$$T_{ij} = k \times G_i^{\alpha} \times A_j^{\beta} \times f(D_{ij})$$

where k, α, and β are parameters, $f(Dij)$ is a distance function representing the spatial gap between zone ij, where Dij represents the travel time or other measures of distance between zones.

In this process, similar to the estimation of trip generation and attraction in step 1, the use of big data from mobile phone location information can be valuable for creating the current OD matrix, which forms the foundation for model estimation.

Furthermore, for understanding trip patterns involving rail or bus travel between station-to-station or bus stop-to-bus stop, big data derived from transit smart cards, which record boarding and alighting histories, can be leveraged. There is also a study of such data that has been used to identify similar patterns between stations [12].

(3) Step 3: Estimation of modal split for transportation volumes

This process estimates how trips, previously calculated for each OD pair in step 2, are distributed among different transportation modes. This involves determining which modes of transportation will be used and to what extent. Typically, aggregate logit models are applied to estimate transportation modes between zones, using explanatory factors such as travel time, cost, individual attributes (like driver's license ownership, age, and employment status), population density, and distance from the city center. When there are two transportation modes to consider, an aggregate logit model is expressed as shown in the following equation [10]:

$$P_1 = \frac{1}{1+\exp(-G(x))}, P_2 = 1 - P_1 = \frac{\exp(-G(x))}{1+\exp(-G(x))}$$

$$G(x) = \alpha + \sum_k b_k (X_{1k} - X_{2k})$$

where P_1 and P_2 are the proportion of travelers using transportation modes 1 and 2, respectively, X_{1k} and X_{2k} are the factors related to transportation modes 1 and 2, such as travel time and cost, α and b_k are parameters, and $G(x)$ is a composite variable representing the overall difference between transportation modes 1 and 2.

Mobile phone location data is also valuable in this process. By analyzing the time-series latitude and longitude information, it becomes possible to determine the mode of transportation used in a trip, providing detailed trip data that includes the actual travel route. For travel on roads, there are methods for automatically identifying the mode of transportation from GPS log data. These methods involve using features like travel speed and angular velocity to score the likelihood of a match [13], or factors like maximum speed and acceleration to determine the mode using decision trees [14]. Whilst there may be still room for improvement in the accuracy of mode identification depending on the combination of transportation modes, it is entirely feasible to estimate usage rates based on categories of major transportation modes, as shown in **Figure 11**.

(4) Step 4: Traffic volume distribution (traffic assignment)

In this step, the traffic volumes for various transportation modes such as trains, buses, and cars, estimated in step 3 for each OD pair, are assigned to a predefined transportation network under optimization conditions such as minimizing total travel time. A frequently used method in recent practical applications is known as user equilibrium assignment. This method assumes that in a situation where multiple routes exist between OD pairs, the travel times on all routes are equal, and no route has a shorter travel time than any other (known as Wardrop's first principle or the 'principle of minimum travel time'). Traffic volumes are then distributed to individual road segments as a solution to a mathematical optimization problem [16].

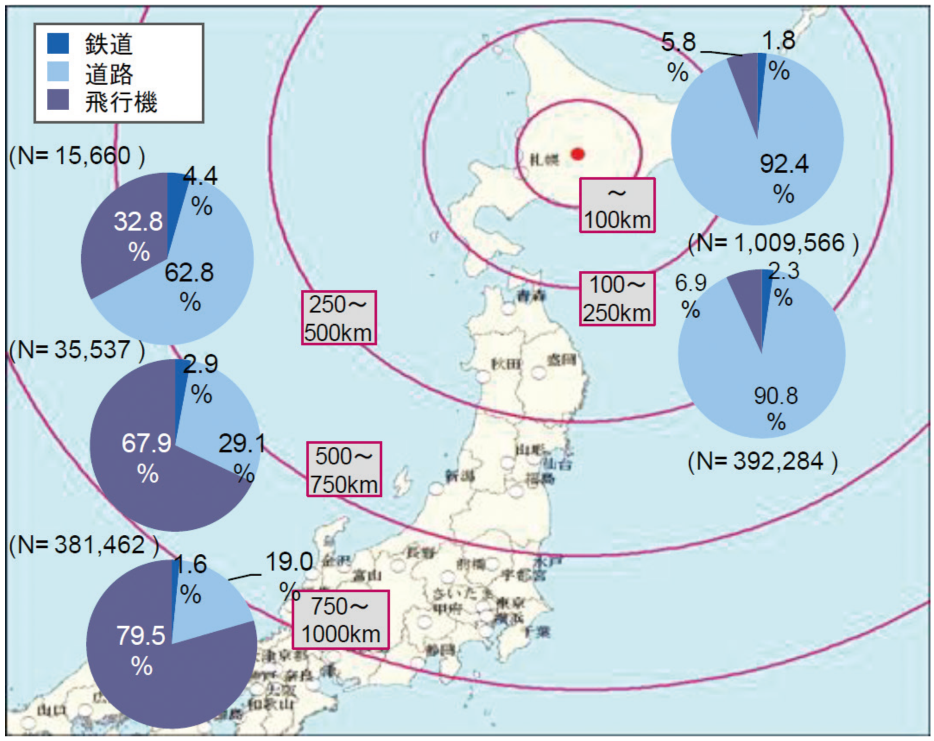


Figure 11. Transportation modes by distance bands from the origin place [15]

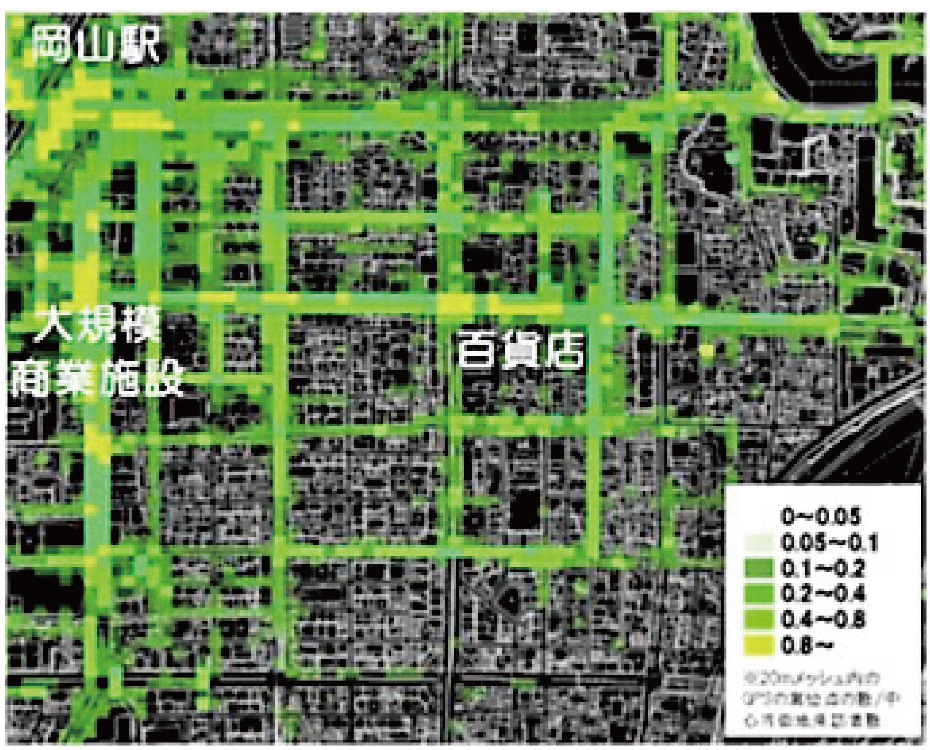


Figure 12. The movement patterns of visitors on urban streets (Okayama City) [17]

As mentioned earlier, the use of mobile phone location data is technically valuable in this process because it allows the identification of the actual travel routes for each mobile device. However, it is important to consider privacy concerns when applying this technology. Mobile phone location history data is one of the few datasets that can accurately capture pedestrian movement routes. **Figure 12** depicts the movement patterns of visitors on the urban road network acquired using a survey app for smartphones in a social experiment conducted to assess the effects of enhancing urban mobility in Okayama City in 2015.

Furthermore, the use of vehicle ID-linked probe data mentioned in section 4.1 allows for the accurate tracking of automobile travel routes. In this way, big data related to human movement, as a byproduct of ICT services, significantly contributes to the understanding and modeling of route selection behavior for both people and vehicles.

5. The prospect for ICT utilization in the mobility sector

This paper reviews the historical context of the relationship between the mobility sector and ICT and examines how ICT or ICT-related data can be utilized in planning mobility-related policies, aligning with the traditional 4-step estimation method. As described in section 2, ICT was initially positioned for the smooth and safe operation of road traffic, supporting road infrastructure and drivers. However, the landscape has changed significantly with the proliferation of the Internet and smartphones. ICT has become a cornerstone for new-era mobility services such as autonomous driving and ride-sharing.

Furthermore, ICT plays a crucial role not only in the technical aspects of mobility service operations but also in the policymaking processes related to mobility. The traditional transportation behavior survey system, which relied on large-scale cross-sectional surveys conducted once every decade, is undergoing a fundamental transformation thanks to ICT-related human mobility big data. Indeed, innovative approaches based on various big data sources, such as mobile phone location information and road congestion data, are being applied, including machine learning-based traffic congestion prediction and the development of novel tourism flow estimation systems that fuse heterogeneous data [18,19]. These advancements are being driven by a variety of public and private entities and are poised to revolutionize planning and analysis methodology.

Thus, the relationship between mobility and ICT has rapidly strengthened over the past decade, and this trend is expected to continue in the future. However, there are several challenges due to the rapid convergences of these two domains. One of the challenges is the misalignment between the consumers and owners of mobility-related big data, as well as differences in their objectives. As mentioned frequently in this paper, mobile phone location information data is primarily owned by mobile communication service providers and Internet companies, rather than institutions responsible for transportation planning and research, such as universities and government agencies.

Naturally, the objectives of these companies do not revolve around transportation planning or evaluation, so the data may not be collected with such usage in mind. On the other hand, urban transportation issues and challenges, such as support for the elderly’s outdoor activities and the creation of walkable environments, have become more diverse. There is a growing demand for detailed analyses of transportation behaviors at a small scale, such as residential areas around suburban railway stations, and the development of transportation plans based on these analyses. To meet these needs, policymakers require transportation behavior data with high temporal, spatial, and attribute resolution, but universities and government agencies often do not have the freedom to access such data. Therefore, they must either purchase it from private companies or collect data through their independent surveys.

Recently, even private entities have started to recognize such needs and have begun selling pedestrian flow data as a business. However, it is not uncommon to find cases where the data being sold may not necessarily align with the specifications desired by policymakers. If both private entities and policymakers wish for the circulation and utilization of data, private entities need to understand how the data is being used within the transportation planning process. Similarly, policymakers also need to adequately communicate how they are using the data and how they intend to use it in the future. While this paper has provided limited insights into the relationship between ICT and mobility policy, it is hoped that it can serve as a starting point for fostering better communication and collaboration between private entities and policymakers.

Disclosure statement

The author declares no conflict of interest.

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