

Article

Defining Smart Mobility Service Levels via Text Mining

Jaehyun (Jason) So ¹, Hyunju An ² and Changju Lee ^{3,*}

¹ Department of Transportation Systems Engineering, Ajou University, Suwon 16499, Korea; jso@ajou.ac.kr

² Division for Smart City and Transport, The Korea Transport Institute, Sejong 30147, Korea; anhj0609@koti.re.kr

³ Civil and Environmental Engineering, University of Virginia, Charlottesville, VA 22904, USA

* Correspondence: cl8ax@virginia.edu

† Current affiliation: Transport Division, United Nations Economic and Social Commission for Asia and the Pacific, 10200, Bangkok, Thailand.

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Abstract: The concept of smart mobility depends on a country's or city's visions and surroundings, such as traffic issues and available transportation modes. This study, therefore, proposes a clear and consistent set of definitions for smart mobility, in the context of past, present, and future, based on investigations of smart mobility practices in South Korea and overseas. In addition, smart mobility definitions are collected from various written sources and analyzed via text mining to define levels of smart mobility beyond the present service level. This study therefore defines smart mobility in six stages: level 0, base infrastructure; level 1, individual digitization; level 2, partial integration; level 3, full integration; level 4, personalized integration; and level 5, mobility transformation. The definition of each stage includes the scope of transportation modes to be integrated, required technology level, mobility operations, and user convenience. This definition of smart mobility by stage will be beneficial for setting the targeted levels of smart mobility services in projects and for setting goals not only in the present context but also for the future of smart mobility, which will be utilized as a roadmap for the implementation of smart mobility in many countries and cities.

Keywords: smart mobility; integrated mobility; text mining; sharing; personalized user services

1. Introduction

With the expansion of urbanization in many countries and cities around the world, urbanization problems such as traffic congestion, traffic crashes, air pollution, and energy scarcity have been worsening [1]. In response to these urbanization problems, particularly in the transportation domain [2], smart mobility, often represented as transportation/mobility applications in the concept of smart cities, has recently been introduced to reform city transportation systems and enhance the quality of life of citizens. Many countries and cities have since initiated a variety of smart mobility projects, including intelligent transportation systems (ITS), traffic demand management, and the use of electric transportation modes. South Korea is one of the leading countries in the research and implementation of smart cities and smart mobility, and several smart mobility services, including integrated mobility, shared mobility, first- and last-mile mobility, and personal mobility services have recently been deployed in many of its cities [3,4]. The core of smart mobility is providing personalized (or user-centric) mobility services by integrating available transportation modes and their operational information based on information and communication technologies (ICTs), such as high-speed communications, big data, and artificial intelligence (AI) [5]. Smart mobility has been defined as a system that provides customized mobility services based on an understanding of user preferences and a city's vision by utilizing emerging

ICT infrastructures [6]. ICT-based personalized smart mobility services are expected to enhance user convenience by reducing social costs, including congestion, traffic crashes, and emissions. Additionally, smart mobility services integrated with emerging mobility technologies such as autonomous and electric vehicles are expected to drastically reform the mobility behaviors of people and ultimately resolve urbanization problems [7–9]. Studies have introduced the concept of mobility-as-a-service (MaaS) as an ultimate goal and form of smart mobility and suggested the following levels of MaaS: 0—no integration; 1—integration of information; 2—integration of booking and payment; 3—integration of service offers, including contracts and responsibilities; and 4—integration of societal goals [10,11].

However, no articulated definition of smart mobility exists at present, even though smart mobility projects have already been implemented in many cities around the world. Although it is known that smart mobility services are provided based on emerging ICTs, there is no definite agreement on the technology levels of smart mobility. Smart mobility has been implemented in different forms around the world, with each city or country deploying smart mobility services using a variety of emerging technologies. Smart mobility, therefore, must be characterized either based on multiple definitions or, sequentially, based on different technology levels, rather than on an assumption of a single form. On the other hand, in an analogous case, the Society of Automotive Engineers (SAE) defined automated driving based on six stages: level 0, no automation; level 1, driver assistance; level 2, partial automation; level 3, conditional automation; level 4, high automation; and level 5, full automation [12]. This six-stage definition of automated driving has contributed to governments and private companies setting appropriate project goals based on required technology levels and service goals.

Similarly, this study aims to define smart mobility in multiple stages based on required ICT levels and mobility service characteristics. To this end, this study reviews smart mobility cases from around the world and investigates the technologies deployed and the service characteristics of these smart mobility practices. Furthermore, for future developments of smart mobility, various definitions of future characteristics of smart mobility are collected and analyzed via text mining. Based on these investigations, this study provides definitions of smart mobility in stages, including the past, present, and possible future and identifies the characteristics (e.g., technology level and service characteristics) at each stage. The findings of this study will help stakeholders (e.g., governments, service operators, and service providers) in determining goals and developing detailed action plans for smart mobility projects based on their cities' visions and problems, technological resources, and users' needs.

2. Literature Review

For this research, previous studies on defining smart cities and mobility and on defining driving automation are reviewed. The National Highway Traffic Safety Administration (NHTSA) has categorized driving automation in five stages: level 0, no automation; level 1, function-specific automation; level 2, combined function automation; level 3, limited self-driving automation; and level 4, full self-driving automation [13]. However, a six-stage definition of driving automation (J3016) established by the SAE, outlined in Table 1, is being considered as the standard around the world. Most industries, governments, and organizations, including the U.S. Department of Transportation and the United Nations (UN) have adopted SAE's definition of driving automation and are setting their project goals and policies based on SAE's categorization.

Table 1. Six-stage definition of automated driving by the Society of Automotive Engineers (SAE) (J3016).

Level	Title	Definition
0	No driving automation	The full-time performance of the human driver on all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
1	Driver Assistance	The driving-mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
2	Partial Automation	The driving-mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
3	Conditional Automation	The driving-mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
4	High Automation	The driving-mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
5	Full Automation	The driving-mode-specific performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

Although there is no precedent case for defining smart cities and smart mobility based on either service or technology levels, several studies and reports have attempted to define smart cities and smart mobility in other ways. With regard to the conceptual modeling of smart cities, the concepts and goals of smart cities differ by location depending on their situations and problems. Smart city projects in developing countries focus more on social problems attributed to rapid urbanization, whereas developed countries undertake smart city projects in response to climate change, urban restoration, and new city development. For example, India is implementing smart cities mainly to provide water management and electrical supply facilities, whereas European countries define a smart city as an innovative city based on cutting-edge technology for securing citizens' safety and improving urban functions [14,15]. According to the International Telecommunication Union (ITU), a smart city can be defined differently depending on the environment and characteristics of each country, and at present, 116 definitions of a smart city exist. The ITU concluded that the definition of a smart city, based on collected definitions, is as follows [16]: "A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, and environmental aspects." In addition, the United Nations Conference on Trade and Development (UNCTAD) suggested a definition of smart cities from a comprehensive perspective, integrating social issues such as environment and governance into technical, physical, and spatial approaches [17]. The UN's definition of smart cities is divided into six areas: smart mobility, smart economy, smart living, smart governance, smart people, and smart environments. Meanwhile, the Korea Transport Institute (2016) defined a smart city as a transportation system that provides smart transportation services for users by integrating and connecting all the data generated by a smart city's integration platform in an organic manner and optimizes safety, mobility, convenience, and eco-friendliness [18]. In a scientific study, So et al. (2019) recently defined a smart city as "a system that utilizes cutting-edge ICT technologies to improve citizens' quality of life, has enough capacity and competitiveness that can vitalize urban economy, and

provides sustainable, user-focused comprehensive urban management services.” [6] Other definitions of smart cities are outlined in Table 2.

Table 2. Definitions of smart cities.

Source	Definitions	Keywords
Bakıcı et al. (2012) [19]	A smart city is a high-tech, intensive, and advanced city that connects people, information, and city elements using new technologies in order to create a more sustainable, greener city, competitive and innovative commerce, and an increased life quality.	high-tech, people, information, technologies, sustainable, innovative, life quality
Barrionuevo et al. (2012) [20]	Being a Smart City means using all available technology and resources in an intelligent and coordinated manner to develop urban centers that are at once integrated, habitable, and sustainable.	technology, intelligent, develop, integrated, sustainable
Caragliu et al. (2011) [21]	A city is smart when investments in human and social capital and traditional (transportation) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.	transportation, ICT, communication, infrastructure, sustainable, economic, growth, quality of life management, governance
Chen (2010) [22]	Smart cities will take advantage of communications and sensor capabilities sewn into the cities’ infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone.	communication, infrastructure, transportation, quality of life
Guan (2012) [23]	A Smart city, according to the International Council for Local Environmental Initiatives, is a city that is prepared to provide conditions for a healthy and happy community under the challenging conditions that global, environmental, economic, and social trends may bring.	healthy, happy, environmental, economic, social
Hall and Bowerman (2000) [24]	A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, and even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens.	integrates, infrastructures, communications, water, services
UK BIS (2013) [25]	The UK Department for Business, Innovation, and Skills considers Smart cities a process rather than a static outcome, in which increased citizen engagement, hard infrastructure, social capital, and digital technologies make cities more livable, resilient and better able to respond to challenges.	innovation, infrastructures, social, technologies, livable

Because smart mobility is often regarded as merely a mobility application of smart cities, few attempts have been made to define smart mobility as compared to those for smart cities. Although smart mobility is considered to be of the same or a more advanced level than ITS and ubiquitous cities, this is not enough to define smart mobility. Recently, So et al. (2019) described smart mobility as a new transportation system paradigm that supports safe and sustainable life and efficient mobility and promotes economic boosts and new mobility business industries [6]. Other definitions of smart mobility are listed in Table 3.

Table 3. Definitions of smart mobility.

Source	Definitions	Keywords
Siemens (2015) [26]	Smart mobility is a paradigm shift to a more flexible and multimodal transportation system or to a multimodal system with high flexibility and convenience	smart, mobility, flexible, multimodal, convenience
Benevolo et al. (2016) [27]	Smart mobility is largely permeated by ICTs, used in both backward and forward applications to not only support the optimization of traffic fluxes, but also to collect citizens' opinions about livability in cities or the quality of local public transportation services.	smart, ICT, citizens opinions, livability, quality
EU (2016) [28]	Smart mobility systems and services promise to contribute to the needed decarbonization of the transportation sector and might also help address persistent problems of congestion and accessibility.	smart, mobility, services, decarbonization, transportation, accessibility
Lyons (2017) [29]	Smart mobility can be defined as a way to move people and goods using new technology that is faster, cleaner, more accessible, and less expensive than traditional options. It is about striving toward frictionless, automated, and personalized travel on demand.	smart, mobility, technology, accessible, automated, personalized, on-demand
Ganter et al. (2017) [30]	Smart mobility has just started, and we define it as a combination of smartly powered trains (electrification), smart technology (autonomous driving), and smart use (car sharing/car hailing). Urbanization will be its main driver, with aging also a supportive factor. Sustainable investment aspects like safety, better fuel efficiency, and lower emissions play nicely into our theme.	smart, mobility, technology, autonomous, sharing, sustainable
Dia (2016) [31]	Smart mobility essentially includes systems that are used to provide seamless, efficient, and flexible travel across all modes of transportation.... Smart mobility includes instrumented smart infrastructure, intelligent transportation systems, and operational and strategic modelling. In addition, it also includes some of the emerging disruptive mobility solutions, including mobility as a service and the anticipated autonomously shared mobility-on-demand services.	smart, mobility, seamless, efficient, flexible, intelligent, transportation, mobility as a service, autonomous, mobility-on-demand services
Deloitte (2018) [32]	A transportation system designed around individual mobility would prominently feature four modes of alternative mobility (as well as more traditional modes, such as buses): ridesharing (i.e., carpooling), bicycle commuting, car sharing, and on-demand ride services.	ridesharing, bicycle commuting, vehicle sharing, on-demand ride

The literature review has revealed different definitions of smart cities and smart mobility applied to smart city and mobility projects; no clear and consistent definitions for smart cities and smart mobility currently exist. In particular, not as many definitions exist for smart mobility as compared to those for smart cities, and there have been no attempts to define smart mobility based on service and technology levels. Therefore, there is a need to define smart mobility in detail according to the hierarchical levels of mobility service characteristics and technologies required.

3. Methodology

Smart mobility cannot be described with a single definition; rather, it is an expandable concept in the temporal and spatial horizons. Smart mobility is interpreted in a variety of ways among different locations, and smart mobility projects are implemented differently in terms of their countermeasures in response to problems and their transportation modes and facilities. In addition, ITS is regarded, in a way, as an initial form of smart mobility, although many leading countries and cities are now exploring other horizons beyond ITS and working to provide advanced mobility services based on cutting-edge ICTs. A clear and consistent concept of smart mobility is still being deliberated upon by the research community. One way to define smart mobility is in stages, encompassing the past, present, and future. With this in mind, this study takes advantage of two approaches: reviewing the state of practice of smart mobility and investigating the wordings used to define smart mobility for the future. The former approach will be used to define smart mobility for the period spanning from the past to the present,

whereas the latter approach will be used to define smart mobility for the period spanning from the present to the future.

To review the practices used in smart mobility, data on past and ongoing smart mobility projects were collected, and implementation activities conducted through these projects were investigated. In particular, ITS practices in South Korea, which is one of the leading countries in the field of ITS and smart mobility services, were analyzed. The arterial traffic management system (ATMS), freeway traffic management system (FTMS), and bus information and management system (BIS/BMS) deployed in South Korea were first investigated. Furthermore, as the next level of ITS or the initial stage of smart mobility, MaaS cases in Europe were examined in terms of service scope, technologies deployed, and limitations. The concept of smart mobility was also structured based on wording elements that are frequently observed from numerous definitions collected from reports and scientific papers. To this end, various definition sentences about smart mobility (i.e., definition wordings) were analyzed via text mining, and frequent wordings were extracted, under the assumption that frequent wordings are representative of the concept of smart mobility. Text mining is a technique in big data analytics and has been used in many studies. Gao and Wu (2013) developed a verb-based text-mining method using a total of 945 crash records published by the Missouri State Highway Patrol [33]. Hong et al. (2017) studied a methodology for extracting information from social network services (SNS) using sentiment analysis to obtain the sentiments of road users [34]. Im et al. (2017) analyzed citizens' perceptions of autonomous vehicles (AVs) via text mining of online newspapers and their comments [35]. In an ITU report (2014), text mining of approximately 120 existing definitions of smart sustainable cities from various sources was utilized for a comprehensive definition of a smart sustainable city [16].

4. Analysis and Results

4.1. Approach 1—Reviewing the State of Practice of Smart Mobility

The initial stage of smart mobility is the ITS, whereas the basis of all transportation and mobility services should be physical infrastructure, such as roads, bus stops and transfer stations, and traffic controls. The representative systems and services of ITS are the ATMS/FTMS, automatic traffic enforcement system (ATES), BIS, and BMS. In the era of initial ITS, information on transportation operations was managed by separate digitized systems. For example, bus operation information and metro operation information were collected and managed by a BMS and a metro operation system, respectively. Table 4 lists a number of representative ITS services using the practices in South Korea.

Table 4. Representative examples of ITS services.

ITS Subsystem	Definition and Functions
ATMS/FTMS	Traffic volume, vehicle speeds, and any incidents are monitored and collected through sensor devices (e.g., loop detector and CCTV) installed on arterials and freeways. Collected data are processed in traffic management centers to produce traffic performance measures, such as delay, average speed, and incidents. Extracted traffic performance measures are provided to drivers through various mediums, such as electronic message signs, traffic broadcasting, navigation systems, and smartphones.
ATES	Speeding, traffic signal violations, and illegal parking are detected by sensors such as loop detectors and cameras. Enforcement information captured by enforcement sensors is transmitted to traffic management centers through high-speed communication networks (e.g., optical communications).

Table 4. Cont.

ITS Subsystem	Definition and Functions
BIS/BMS	BIS improve convenience of public transportation use by providing bus operation and management information through BMS, including bus arrivals and current locations of buses, through electronic bus information panels, internet/web, and smartphone applications. As of now, BIS has been deployed in 114 cities in South Korea.
Metro Information System	Metro operation information, including current location, destination, and estimated arrival, which are stored and managed by metro operation systems, are provided through electronic metro information panels, kiosks, internet/web, and smartphone applications.
Taxi Operation System	Taxi operation information, including speed, location, travel and service distances, fuel consumption, and revenue, are managed by taxi operation systems. In South Korea, the Korea Transportation Safety Authority has established and utilizes a taxi operation system to store taxi operation information and manage driving and service records.

Beyond this ITS, some cities managed public transportation modes by integrating operation information. The city of Seoul, the capital city of South Korea, has deployed an integrated mobility platform, with which buses and metros are serviced in integration through internet/web and smartphone applications. This system also leads to not only the integration of operation information, but also the integration of payment; thus, users in South Korea can use buses and metros by paying once using a smart card. In detail, the Seoul Metropolitan Government initiated the mobility integration project in 2004, and public transportation modes, such as buses and metros, were integrated in terms of operations and fares. Furthermore, to facilitate the operation of buses, bus median lanes were installed on major road sections in Seoul. The Transport Operation and Information Service in South Korea manages the buses and metros in Seoul and functions as a public transportation information and operation system [36].

Moreover, mobility integration has been implemented not only in the public sector but also by private mobility platform business companies. For example, Kakao mobility, Naver, and Daum, which are representative mobility platform businesses in South Korea, are also servicing real-time bus and metro operation information through their own smartphone applications. In addition, the Korea Smart Card offers an integrated fare collection system between buses and metros for Seoul's distance-based fare system and integrated transfer discount system. When a T-money card embedded with a smart chip has contact with a terminal, the terminal immediately receives the locational information from a satellite. Through radio frequency identification communications with the terminal information on board, the passenger's transfer is sent and received, and the payment of fares is completed [37]. These private mobility platform businesses are willing to expand their services into private transportation modes such as taxis and shared vehicles but this has not yet been fully realized in South Korea because of legal regulations and some other technical issues.

Overseas, many mobility platform businesses have attempted to integrate mobility services with the integration of public transportation. The first case is the Hannovermobil service introduced in Hanover, Germany [38]. In 2004, its first pilot study was conducted to collect ideas for the establishment of the world's first integrated mobility platform service [38]. After Hannovermobil was introduced, Whim, a mobility platform business in Finland, was launched in Helsinki, Finland [39]. The Whim service, which is operated by MaaS Global in the form of a consortium, established a mobility platform with which passengers can use buses, railroads, metros, trams, ferries, and rental cars [39]. Unfortunately, these transportation modes have not been fully serviced because of regulations and technical issues. On the other hand, GOLLA, which is an integrated mobility service operated by a private company, Xerox—in Los Angeles, the United States (U.S.)—provides a navigation service based on an integrated mobility platform that includes public transportation, taxis, bicycles, and motorcycles,

and carsharing services, including Uber, Lyft, and Zipcar [40]. Moovel, which is a mobility platform service operated by the Moovel Group, one of the subsidiaries of Daimler in Germany [41], provides integrated mobility services by integrating the operation information of trains, metros, buses, taxis, and car-sharing [41]. These mobility services pursue free-floating carsharing operations, for which, however, some studies reported possible limitations and challenges [42,43]. These studies revealed that a minimum public transportation network is necessary to achieve a minimum demand and to secure available parking spaces and that user tolerance for walking and waiting for a vehicle search is a key measure of a successful free-floating carsharing service [42,43].

4.2. Approach 2—Text-Mining of Descriptions for Smart Mobility

As a second approach to defining smart mobility, a C# programming-based text-mining technique was applied to descriptions of smart mobility to extract the wordings used in smart mobility descriptions and analyze the frequency of each word. For this purpose, a total of 41 studies and reports were collected and investigated, as stated in the Literature Review section. Representative descriptions are listed in Table 3. Text mining resulted in a total of 50 words captured, and their frequencies, outlined in Table 5, were analyzed.

Table 5. Frequencies of smart mobility definition keywords.

Rank	Word	Frequency	Rate	Rank	Word	Frequency	Rate
1	mobility	67	11.50%	26	create	9	1.50%
2	service	46	7.90%	27	data	8	1.40%
3	transport	41	7.00%	28	automated	7	1.20%
4	MaaS	31	5.30%	29	multiple	7	1.20%
5	Smart	25	4.30%	30	provide	7	1.20%
6	travel	19	3.30%	31	trip	7	1.20%
7	public	16	2.70%	32	provide	7	1.20%
8	transportation	15	2.60%	33	customer	6	1.00%
9	single	15	2.60%	34	future	6	1.00%
10	systems	14	2.40%	35	traffic	6	1.00%
11	integrated	14	2.40%	36	private	6	1.00%
12	payment	13	2.20%	37	different	6	1.00%
13	transformation	13	2.20%	38	including	6	1.00%
14	emerging	12	2.10%	39	way	6	1.00%
15	seamless	12	2.10%	40	travelers	6	1.00%
16	cities	11	1.90%	41	various	5	0.90%
17	options	11	1.90%	42	new	5	0.90%
18	sustainable	11	1.90%	43	demand	5	0.90%
19	modes	10	1.70%	44	concept	5	0.90%
20	apps	10	1.70%	45	platform	5	0.90%
21	solutions	10	1.70%	46	term	5	0.90%
22	providers	10	1.70%	47	sharing	4	0.70%
23	journeys	10	1.70%	48	flexible	4	0.70%
24	users	9	1.50%	49	across	4	0.70%
25	use	9	1.50%	50	better	4	0.70%

Among the 50 identified keywords, words that signify “smart mobility” itself, including “smart,” “service,” “mobility,” and “transport,” were excluded. Therefore, major keywords that were extracted are as follows: 31 instances of “Mobility-as-a-Service” (MaaS) (5.3%); 15 instances of “single” (2.6%); 14 instances of “integrated” (2.4%); and 8 instances of “seamless” (2.7%). In addition, the frequencies of elements of integration are as follows: 16 instances of “public” (2.7%); 12 instances of “car” (2.1%); 13 instances of “payment” (2.2%); 11 instances of “options” (1.9%); and 4 instances of “sharing” (0.7%). These data show elements of personal and public transportation modes and payment integration with sharing modes. Words that indicate personal transportation modes and customized transportation systems, such as “users” (9 times, 1.5%), “customer” (6 times, 1%), and “demand” (5 times 0.9%), were

also extracted, demonstrating that smart mobility integrates various available transportation systems and provides customized mobility services for users' convenience. Furthermore, smart mobility implies transformation of a mobility system beyond current mobility systems, based on "transformation" (13 times, 2.20%), "emerging" (12 times, 2.10%), "automated" (7 times, 1.20%), and "new" (5 times, 0.90%).

4.3. Six-level Definition of Smart Mobility

4.3.1. Level 0—Base Infrastructure (Supply of Base Infrastructure)

The first stage of smart mobility is infrastructure construction; base transportation infrastructure, including roads, transportation facilities, and transportation modes are constructed in this stage. This stage is a bottom line before smart mobility and is thus named level zero, and is the basis for the deployment of smart mobility services. Although many types of transportation facilities are required, the core facility for smart mobility is the transfer facility, where users transfer transportation modes.

4.3.2. Level 1—Individual Digitization (Digitization of Individual Transportation Modes)

The second stage of smart mobility is the digitization of individualized transportation modes. The operational information of each transportation mode is stored in a single separate system; thus, each transportation mode is operated separately without any connection or integration, and users will have to check every transportation operation system (e.g., website, kiosk, and smartphone application) in case they require intermodal transportation for their journey. This represents an initial form (first generation) of ITS in the 1990s and is practically the first phase of smart mobility beyond the base infrastructure.

4.3.3. Level 2—Partial Integration (Integration of Public Transportation Modes)

The third stage of smart mobility is the integrated operation of public transportation modes. This type of mobility integration is being operated in many countries, such as South Korea, Germany, and Finland. This is the middle course before full integration, because integrating public and private transportation may be challenged by a lack of an appropriate governance model agreed upon between the public and private bodies. For users, the utility of public transportation is maximized at this stage.

4.3.4. Level 3—Full Integration (Integration of Public and Private Transportation Modes)

The fourth stage of smart mobility is the integrated operation of public and private transportation modes. All available transportation modes, including not only public transportation modes such as buses and metro but also private mobility services, such as taxis and shared mobility modes are operated as a single integrated mobility service. This is the stage that is currently being pursued and targeted by many cities and mobility platform businesses. However, the implementation of this stage tends to be limited by a lack of appropriate governance between public and private mobility platforms. This stage should be achieved to maximize all available transportation modes, and some mobility platforms, such as Whim in Finland and SMILE in Austria, are currently expanding their service scope or the scope of transportation modes to be integrated. In particular, these mobility platforms are planning to achieve payment integration for public and private transportation modes, allowing users to search for and book optimum route options and to pay for all types of transportation modes with a single payment. Many smart mobility projects are heading toward this level.

4.3.5. Level 4—Personalized Integration (Personalized User Services Based on Users' Preferences and Experiences)

The fifth stage of smart mobility is an evolved form beyond full integration using big data and AI technologies. In this stage, smart mobility services will be tailored and personalized for users by analyzing user preferences and experiences with past mobility services. Although this level is identical to level 3 smart mobility service (full integration) in terms of the scope of integrated information, the

core of this smart mobility service level is user-centric, optimized, and personalized mobility services based on analyses of user preferences, including departure and destination, preferred modes and routes, and tolerance of price. Furthermore, available transportation modes would be operated in response to the real-time demand of users based on real-time user data collection and analysis using big data techniques and AI technologies. This is known as the final goal of MaaS considered at the current technology level. In this stage, the travel time and cost for all users are minimized from a social perspective, and user satisfaction is maximized because transportation modes are operated in response to real-time demand and preferences of users.

4.3.6. Level 5—Mobility Transformation (Evolution of Transportation and Mobility Services)

The sixth stage of smart mobility is the stage beyond information integration, wherein existing transportation modes will evolve into optimized forms or new mobility modes, or services will emerge based on user behaviors. Therefore, several types of innovative mobility services based on autonomous vehicles, electric vehicles, and shared vehicles will be introduced, and these will be serviced in optimized processes, which are evolved and tailored for users. This stage includes new types of vehicles (transportation modes) and new types of mobility services, which have not been introduced at present. From a social perspective, the operational efficiency, safety, and sustainability of all mobility services are maximized in this stage.

This six-stage smart mobility definition is summarized and described in Figure 1.

Category		Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
		Base infrastructure	Individual digitalization	Partial integration	Full integration	Personalized integration	Mobility integration
Definition		Supply of base infrastructure	Digitalization of individual transportation mode	Integration of public transportation modes	Integration of public and private transportation modes	Personalized user services based on users' preferences and experiences	Evolution of transportation and mobility services
Integration level of information and means		None	Individual mode	Public transportation modes	All(public and private) transportation modes	All(public and private) transportation modes	All(public and private) transportation modes
Core technologies required		None	Database	Big Data, system integration	Big Data, system integration	Big Data, A.I.	Big Data, A.I., autonomous driving
Mobility operation		Fixed	Fixed	Fixed	Fixed	Flexible (demand-responsive)	Flexible (demand-responsive)
User perspective	Whom to plan travel	User	User	User	User	System	System
	Tasks to do	Everything from departure to destination	Searching individual transportation mode	Searching and booking using partially integrated mobility information	Searching and booking using fully integrated mobility information	Searching fully integrated mobility information, and booking based on preferable modes and route	Searching fully integrated mobility information, and booking based on preferable modes and route
Expected impact		Basis to deploy smart mobility	Travel time and costs decrease	Maximized efficiency of public transport	Maximized efficiency of all(public and private) modes	Minimized travel time and costs, and maximized user satisfaction	Maximized social benefits including mobility operation efficiency, safety, and sustainability

Figure 1. Definitions of smart mobility.

5. Conclusions

This study defined smart mobility in six stages by investigating smart mobility practices around the world and analyzing the wordings of smart mobility definitions collected from several project reports and scientific papers. Currently, smart mobility is known to include new mobility services based on emerging ICTs, but no definite agreement exists on either the definition of smart mobility or its technology level. Furthermore, it is barely possible to describe smart mobility using a single definition because smart mobility has been implemented in different locations in a variety of forms based on their social issues, transportation/ICT infrastructure readiness, and visions. Therefore, this study defined smart mobility in stages based on service capabilities and required technologies. To this end, existing and already deployed smart mobility practices were used to define the smart mobility

service levels for the past and present, whereas wordings of the definitions of smart mobility were analyzed via text mining to define the next level of smart mobility beyond its present service level.

Based on this study of smart mobility practices and definitions, a six-stage smart mobility definition was developed as follows: level 0, base infrastructure; level 1, individual digitization; level 2, partial integration; level 3, full integration; level 4, personalized integration; and level 5, mobility transformation. The first stage (level 0—base infrastructure) of smart mobility is to establish base transportation infrastructure, such as roads, transportation facilities, and transportation modes. This stage is the bottom line before smart mobility and is the basis for deploying smart mobility services. The second stage (level 1—individual digitization) of smart mobility is the digitization of individualized transportation modes, wherein each mode of transportation is operated by a single separate system. This represents the initial form (first generation) of ITS in the 1990s. The third stage (level 2—partial integration) of smart mobility has been demonstrated in many countries (e.g., South Korea, Germany, and Finland). In this stage, the operational information of public transportation modes, such as buses and metros is managed in a single integrated system. This is the smart mobility level beyond existing ITS services. The fourth stage (level 3—full integration) of smart mobility is to provide mobility services by integrating the operational information of all available transportation modes, including not only public transportation modes such as buses and metros but also private mobility services, such as taxis and shared mobility modes. This is the stage that is pursued and targeted by many cities and mobility platform businesses. The fifth stage (level 4—personalized integration) of smart mobility is an evolved form of smart mobility beyond full integration using big data and AI technologies. In this stage, smart mobility services will be tailored and personalized for users by analyzing user preferences and experiences with past mobility services. This is known as the final goal of MaaS considered at the current technology level. Lastly, the sixth stage (level 5—mobility transformation) of smart mobility is the stage beyond information integration, wherein existing transportation modes will evolve into optimized forms, or new mobility modes or services will emerge based on user behaviors.

This six-stage definition of smart mobility is meaningful because its hierarchical definitions provide forms for smart mobility not only for the past and present but also for the future. Although the definitions of smart mobility extracted in this study require validation through reviews of more practices because smart mobility is being deployed in a variety of forms in many locations around the world, the cutting edge of smart mobility emerged as the pursuit of integrated and personalized mobility services based on emerging technologies (i.e., ICTs). This six-stage definition will be beneficial for setting the targeted level of smart mobility services when countries or cities undertake smart mobility projects. It will also be helpful in setting not only goals for the present but also the future of smart mobility, which will be utilized as a roadmap for the implementation of smart mobility in countries and cities.

Nevertheless, many researchers remain concerned with the future of smart mobility; thus, more studies about the implementation and business models of smart mobility are essential. As reported by Pangbourne et al. and Sochor et al. [10,11], sufficient subsidy and effective governance among the stakeholders of smart mobility services will be required for smart mobility to develop to better and more advanced levels. This is actually the main reason that smart mobility services are still unveiled with a perfect form, although the base technologies have already been revealed. Furthermore, it is expected that the COVID-19 pandemic will provide both opportunities and challenges for smart mobility because people in this era have come to prefer more individualized, spacious, and demand-responsive mobility services. Therefore, further studies on the future forms of smart mobility services and business models are necessary. If conducted, these research efforts will help boost the successful settlement of smart mobility services. In addition, beyond the methodology used in this study, applying various scientific methodologies to categorize and distinguish the smart mobility levels would enhance the credibility of the results obtained through this study.

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