Smart Mobility

Exploring Foundational Technologies and Wider Impacts

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To my beautiful wife Nermein and my lovely children Renad and Kareem. You are the joy of my life.

Contents

About the Author

Dr. Alaa Khamis is AI and Smart Mobility Tehcnical Leader at General Motors, Canada. He is also a Smart Mobility Lecturer at the University of Toronto, Affiliate Member of the Centre for Pattern Analysis and Machine Intelligence (CPAMI) at the University of Waterloo, and Adjunct Professor at Nile University. He worked as Autonomous Vehicles Professor at Zewail City of Science and Technology; Head of AI at Sypron Solutions; AI Consultant at Menya Solutions; Senior Research Scientist at Vestec, Canada; Director of Engineering R&I—Canada at Marques Aviation Ltd.; Associate Professor and Head of the Engineering Science Department at Suez University; Associate Professor and Director of the Robotics and Autonomous Systems (RAS) Research Group at the German University in Cairo (GUC); Research Assistant Professor and AI Lecturer at the University of Waterloo, Canada; Visiting Professor at Universidad Carlos III de Madrid, Spain, and the Université de Sherbrooke, Canada; Visiting Researcher at the University of Reading, UK; and Distinguished Scholar at the University of Applied Sciences Ravensburg-Weingarten, Germany.

He is a senior IEEE member, recipient of the 2018 IEEE Member and Geographic Activities (MGA) Achievement Award, founder of the Minesweepers: Towards a Landmine-Free World international robotic competition, and member of the AI4SDGs Cooperation Network, IEEE SA P7007 Ontological Standard for Ethically Driven Robotics and Automation Systems Working Group, and P1872.2 Standard for Autonomous Robotics (AuR) Ontology Working Group.

His research interests include smart mobility, autonomous and connected vehicles, algorithmic robotics, humanitarian robotics, intelligent data processing and analysis, machine learning, and combinatorial optimization. He taught 37 different undergraduate and graduate courses at different universities in Canada, Spain, and Egypt. He published 4 books, 5 book chapters, 16 technical reports, and more than 130 scientific papers in refereed journals and international conferences. He also filed over 14 patent applications with the USPTO.

Preface

Nowadays, we are witnessing several paradigm shifts in mobility systems and services. Cities are decarbonizing the transportation sector and are moving from car-centric mobility to multimodal mobility, from restricted mobility in two-dimensional streets to 3D mobility, from rigid-schedule mobility to mobility on demand and on an as-needed basis, and from fragmented unconnected mobility to seamless integrated mobility. Mobility companies move from the manufacturing and trade economy to the service economy or servitization such as Mobility-as-a-Service (MaaS) as the neo-liberalization of people and freight transportation and from the unsustainable "number of cars sold"-based revenue model to "vehicle miles traveled (VMT)-based," infonomics-based data and customer experience monetization and passenger economy-based revenue models. Delivery service providers move from conventional slow, rigid, and nontransparent last-mile delivery to fast, elastic, and transparent last-mile delivery services. People move from ownership to usership and from passive mobility to active and zero-impact mobility. Different foundational technologies, technology enablers, and mobility disruptors are behind these paradigm shifts.

This book gives a holistic view of smart mobility systems and services and describes their foundational technologies, technology enablers, and disruptors. The market size of these technologies, their potential growth, and their eco-socioeconomic implications are highlighted in this book. Impacts of the COVID-19 pandemic on consumer behaviors and preferences and the expected short-term disruptions and longer-term structural changes in different aspects of mobility systems especially in micromobility, shared mobility, public transit, and contactless last-mile delivery services are also discussed.

The development of topics in this book follows a logical flow progressing from foundational technologies to technology enablers to smart mobility disruptors. The following is a concise chapter-by-chapter description of the contents of the book:

- Chapter 1 provides an overview of people-centric smart cities.
- Chapter 2 presents the smart mobility triad that comprises three complementary factors, namely, technology, governance, and city planning. These three components are not separate components as they impact each other.

- Chapter 3 introduces Position, Navigation, and Timing (PNT), Geographic Information System (GIS), wireless communication, mobile cloud computing (MCC), blockchain, Internet of Things (IoT), Artificial Intelligence (AI), robotics, and electrification as foundational technologies for smart mobility systems and services.
- Chapter 4 discusses several technology enablers for smart mobility such as intelligent infrastructure, connected mobility, automated mobility, e-mobility, micromobility, active/soft mobility, inclusive mobility, and Context Awareness Systems (CAS).
- Chapter 5 sheds light on potential smart mobility disruptors such as disruptive mobility platforms (autonomous ground vehicles, urban air mobility (UAM), river taxis, automated people movers (APMs), hyperloop, and urbanloop), shared mobility, Mobility-as-a-Service (MaaS), mobility on demand (MOD), seamless integrated mobility systems (SIMS), last-mile delivery, Vehicle-as-a-Service (VaaS), gig economy, and passenger economy.
- Finally, impacts of the COVID-19 pandemic on smart mobility systems and services are discussed in Chapter 6.

I do believe that the future mobility is people-centric, software-defined, connected, and electric. In spite of recent rapid development, smart mobility is still in its infancy. There is a growing need to use different mentioned foundational technologies, technology enablers, and disruptors to enhance the relationship between customers and mobility providers and to achieve affordable, inclusive, and seamless integration between different mobility services. The legal and regulatory environment around several smart mobility technologies needs to be well developed taking into consideration opinions and concerns of different stakeholders. Moreover, evolutionary and revolutionary changes in the city planning should be considered to accommodate the emerging services of smart mobility.

This book is intended for working professionals, training centers, and academic institutions. The book serves a wide range of audience including university students, researchers, mobility engineers, technologists, and city planners looking for a holistic vision and new ideas about future mobility technologies and services. The book gives the reader a comprehensive and easy-to-digest introduction to the current and emerging smart mobility systems focusing on foundational technologies, technology enablers, and disruptors that will shape the future of mobility.

While the book describes many future possibilities, some surprising achievements are already made and publicly used. We all enjoy and rely every day on shared mobility services, connected mobility, e-mobility, active mobility, micromobility, and same-day and instant last-mile delivery services. Moreover, in the not too distant future, we will enjoy safe and entertaining self-driving vehicles (SDVs) as a third living space with consumer-centric products and services; we will be able to use self-driving vehicles as a mobile motel, beauty salon, mobile store, and mobile clinic; we will have our online orders shipped to our doorstep by delivery droids; we will travel safely and conveniently in zero-emission hyperloops, autonomous air taxis, air metro, or autonomous boats; seamless integration between different mobility modes will be the norm; and finally affordable inclusive and sustainable mobility will be achieved. I hope you will enjoy this exciting journey into the future of people and goods mobility.

CHAPTER

1

Toward a People-Centric Smart City

Population shift from rural to urban areas driven by social and economic needs led to massive mobility challenges and several negative impacts in contemporary cities related to road safety, congestion, and emissions. Smart cities consider people and the environment as the central focus for a better quality of life, reasonable consumption of natural resources, and sustainable development and prosperity. In this chapter, implications of conventional car-centric cities and the need for people-centric smart cities are highlighted. Smart mobility is presented in this chapter as one of the main pillars of smart cities of the future.

1.1. World Urbanization Problems

According to the latest World Urbanization Prospects report published by the United Nations in 2018, the number of people living in cities will increase from 3.6 billion to 6.3 billion by 2050 (UN DESA, 2018). The global population will be two-thirds urban, and the world will be only one-third rural, roughly

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the reverse of the global rural-urban population distribution of the mid-twentieth century. According to a report from Navigant Research, currently there are about 1.2 billion vehicles on the road. The total number of cars worldwide could reach 2 billion by 2035, not including motorcycles. The negative implications of this conventional car-centric world include safety, congestion, and environmental impacts.

Road traffic accidents are enormously costly in terms of human suffering, economic loss, and wildlife and environmental impact. According to World Health Organization (WHO), the number of deaths on the world's roads remains unacceptably high with 1.35 million people dying each year or 3,698 deaths a day, making road traffic accidents the eighth leading cause of death for people of all ages and the first cause of death for children and young adults (World Health Organization, 2018). The number of traffic fatalities is expected to rise to 2.2 million by 2030. These traffic fatalities are the leading cause of death for 5–14-year-olds in high-income countries, representing 19% of all fatalities (Rothman et al., 2020).

Global economy loses $1 trillion worth of productivity annually sitting in traffic (McKinsey Global Institute, 2013). The study conducted by the traffic data company INRIX has ranked Bogota as the most congested city in the world with an average of 191 hours driving time spent in congestion. The same study ranked Toronto as the most congested city in Canada and the 19th most traffic-congested city across the globe in 2019 with an average of 135 hours driving time spent in congestion. According to INRIX, Canadians are spending an average of 27 hours a year stuck in traffic. American commuters spend about a week of their lives in traffic each year. Traffic Index provides real-time ranking and analytics about 416 cities around the world.

Conventional transport fuels are large emitters of pollutants, making transport a large contributor of global greenhouse gas (GHG) emissions. For example, according to the US Environmental Protection Agency (EPA), GHG emissions from transportation account for about 28% of the total US greenhouse gas emissions, making it the largest contributor of US GHG emissions. The current and expected growth in conventional transport fuel demand, particularly for diesel, will cause a tremendous public health burden and will accelerate global climate change (Hoornweg and Freire, 2013). Conventional vehicles with an internal combustion engine (ICE or ICEV) are one of the main causes of greenhouse gas. Figure 1-1 illustrates the carbon footprint and space required per mobility mode. Beside the high carbon footprint, conventional mobility modes take up way too much space in cities for paved roads and parking. Many downtowns devote 50–60% of their scarce real estate to vehicles (Plumer, 2016).

1.2. People-Centric Smart Cities

The aforementioned challenges cannot be solved by simply building more roads for the vehicles. Braess' paradox (Braess et al., 2005) shows the fact that adding one or more roads to a road network does not improve the traffic and sometimes worsens the traffic flow. Braess' paradox is not exactly a paradox and represents a counterintuitive result in which, like the prisoner's dilemma, collective good gets sacrificed because of self-interest. An interesting study conducted by the Transformative Urban Mobility Initiative (TUMI) concluded that a restructured multimodal mobility corridor can accommodate in total 74,000 people (2,000 in cars, 16,000 pedestrians, 44,000 in light rail, and 14,000 cyclists) compared to a traditional car-centric corridor that can carry only 24,000 people (8,000 in cars and 16,000 pedestrians).

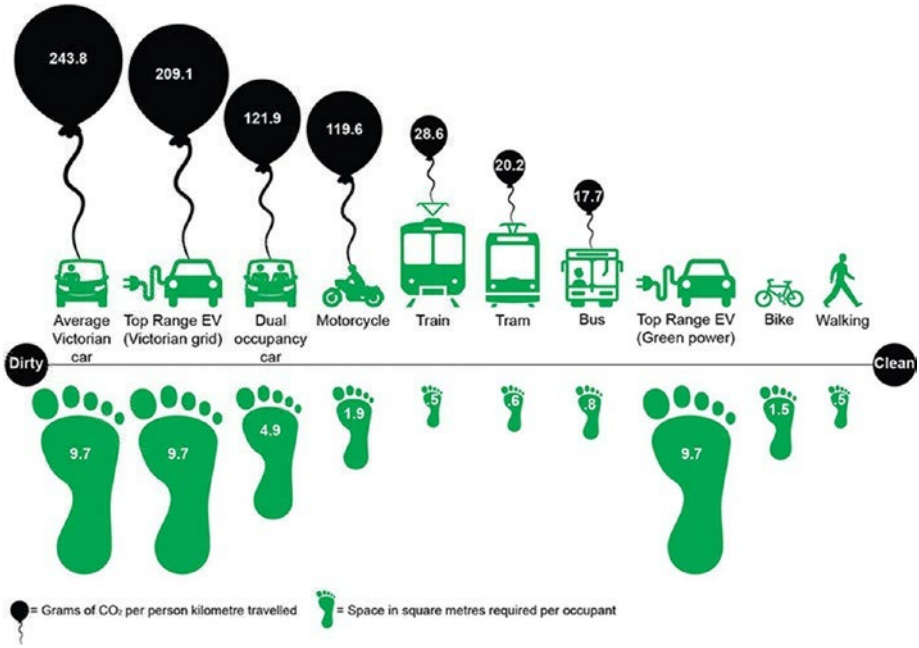

Figure 1-1. Carbon Footprint and Space Required per Occupant. Source: Courtesy of the Institute for Sensible Transport

■ **Note** A highway 20 lanes wide would be required to carry in automobiles the number of people now being served by Toronto's subway.

This arises the need to develop and deploy sustainable mobility systems able to change the current conventional car-centric cities to people-centric smart cities. Sustainability is meeting the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland et al., 1987). In recent years, the concept of "smart city" has received an increasing amount of attention from researchers, developers, and policy makers in academia, government laboratories, and industry.

Important According to market forecasters and analysts like Grand View Research, the global smart cities' market size is expected to reach $463.9 billion by 2027, registering a CAGR of 24.7% from 2020 to 2027.

There have been many definitions of a smart city given over the years. Smartness in the context of smart cities includes monitoring, control, and optimization to bring in efficiency and bottom-line benefits as well as environmental improvements. A city can be defined as "smart" when social capital and modern information and communication infrastructure fuel sustainable economic development and a high quality of life (Caragliu et al., 2011). In other words, a smart city uses digital technologies or information and communication technologies to enhance quality and performance of urban services, to reduce costs and resource consumption, and to engage more effectively and actively with its citizens. MIT defines a smart city as "systems of systems with digital nervous systems, intelligent responsiveness, and optimization at every level of system integration."

According to a report by the World Bank, smart cities adopt technical and information platforms to better manage the use of their resources, improve management, monitor developments, develop new business models, and help citizens to make informed decisions about the use of resources (Hoornweg and Freire, 2013).

Cities are very heterogeneous entities that integrate a wide variety of components with more similarities than differences. Digitization, automation, connectivity, and data analytics are key aspects to achieve seamless integration between these components. According to a survey conducted by PwC involving about 64 cities (Galal et al., 2011), after finance, the second most important barrier to smart city strategy implementation is prioritization. Cities must first address their very basic needs: security, health, and basic infrastructure such as clean water and sanitation. These infrastructures should be also optimized for the best use by the citizens. If these basic needs are already met, the focus shifts to safety and security needs, roads and transport infrastructure, and educational access, as the city moves from basic industrial production to becoming an informational society. In more developed cities, the focus will be on environmental needs, social integration, culture and

leisure, as well as information and communication technologies as an enabler for a knowledge-based society. At the next level are the smart cities, which are defined as a world leader able to maximize its performance across all capitals. Beyond that comes the level of self-actualization, when cities explore new paradigms and set new standards for the quality of life and are willing to share their experiences to help other cities advance (Galal et al., 2011).

Smart mobility, smart living, smart society, smart environment, smart economy, and smart governance are the main pillars of a smart city as illustrated in Figure 1-2. Digitalization, automation, connectivity, and analytics are four main enablers for monitoring, control, and optimization in each of these six pillars. Smart mobility addresses the availability of information and communication infrastructure and safety and the sustainability of mobility systems. Local and international accessibility of transport systems are also important aspects of smart mobility. More details about smart mobility are provided in the next section.

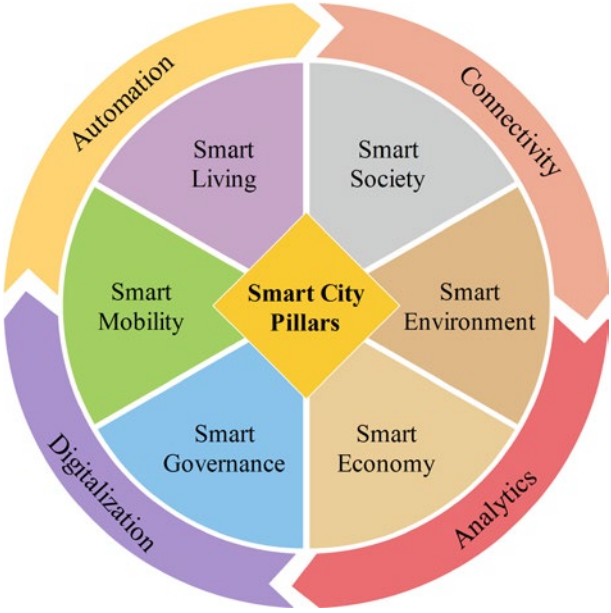

Figure 1-2. Smart City Pillars

Smart living comprises various aspects of quality of life such as culture, health, safety, housing, tourism, and so on. Agile civil society, level of qualification or education of the citizens, social inclusion, the quality of social interactions regarding integration and active participation in public life, and the openness toward the "outer" world are indicators for smart societies. Smart environment is described by attractive natural conditions (e.g., climate and green space),

pollution, resource management, and also efforts toward environmental protection. Smart economy includes factors all around economic competitiveness as innovation, entrepreneurship, trademarks, productivity and flexibility of the labor market, as well as the integration in the (inter) national market (Giffinger et al., 2007). Finally, smart governance comprises aspects of political participation, services for citizens, as well as the functioning of the administration.

There are several smart city projects and initiatives across the world. According to the latest Smart City Index report published in 2020 (IMD and SUTD, 2020), the top ten smart cities in the world are Singapore, Helsinki, Zurich, Auckland, Oslo, Copenhagen, Geneva, Taipei City, Amsterdam, and New York as shown in Table 1-1. This index ranks 109 cities based on economic and technological data, as well as by their citizens' perceptions of how "smart" their cities are.

Table 1-1. Top Ten Smart Cities in the World as per Smart City Index (IMD and SUTD, 2020)

City	Country	2020 Ranking	2019 Ranking	Change
Singapore	Singapore	1	1	0
Helsinki	Finland	2	8	+6
Zurich	Switzerland	3	2	-1
Auckland	New Zealand	4	6	+2
Oslo	Norway	5	3	-2
Copenhagen	Denmark	6	5	+1
Geneva	Switzerland	7	4	+3
Taipei	Taiwan	8	7	+1
Amsterdam	Netherlands	9	11	+2
New York	United States	10	38	+28

The Line was revealed in January 2021 as a fully sustainable smart city to be built as part of Neom, a planned cross-border city in the Tabuk province of northwestern Saudi Arabia. Neom was announced in 2017 and is part of Saudi Arabia's Vision 2030 drive to diversify its economy and become less reliant on oil. The Line is a linear 100-mile-long city with no cars or streets, with everything its inhabitants need accessible within a five-minute walk. The vision of this mega city is to be zero-energy walkable communities for a million people. The Line is inspired by Paolo Soleri's Lean Linear City concept (Soleri et al., 2012) where pedestrian-based communities are oriented around linear local and regional transportation systems.

1.3. Smart Mobility as a Key Enabler to Sustainable Development

In recent years, smart mobility systems and services have received an increasing amount of attention from major automakers, suppliers, academia, and governmental institutions due to their foreseen advantages in dealing with the negative implications of the conventional automotive technology in the current car-centric world such as safety problems, congestion problems, and environmental problems. General Motors (GM) is leading the way toward a future with zero crashes, zero emissions, and zero congestion (General Motors, 2018). The main objectives of this vision are summarized as follows:

- **Zero Crashes to Save Lives:** Advanced driver assistance systems (ADAS) and automated driving vehicles will reduce injuries and fatalities and improve access to mobility for those who currently cannot drive due to age, disability, or otherwise.
- **Zero Emissions to Leave Our Children a Healthier Planet:** Conventional internal combustion engine (ICE) vehicles release almost 2 billion tons of carbon dioxide into the atmosphere every year. Electric vehicles (EVs) will eliminate the emission contributing to a better environment. In early 2021, GM announced a plan to become carbon neutral in its global products and operations by 2040. As part of this plan, the company will offer 30 new electric vehicles globally by 2025.
- **Zero Congestion to Give the Customers Back Their Precious Time:** In the United States, commuters spend about a week of their lives in traffic each year. That's a week not spent with those we love, doing what we want to do, and being where we want to be. Shared mobility will create better use of time and space to reduce the congestion.

Aligned with 17 Sustainable Development Goals (SDGs) adopted by UN Member States, smart mobility can play an instrumental role in achieving many of these goals. The Sustainable Mobility for All (SuM4All[1]) initiative is a global partnership that aims to achieve sustainable mobility and help implement the SDGs. In order to transform the transport sector, SuM4All developed a Global Tracking Framework (GTF) for transport, complementing the targets and indicators in the SDGs. This global framework is featured in the Global

[1] www.sum4all.org/

Mobility Report (SuM4All, 2017), which provides the first-ever assessment of all modes of transport across the globe. GTF provides crucial information and tools to inform transport policy and investment decisions and provides a baseline for measuring progress toward sustainable mobility. According to the Global Mobility Report published by SuM4All, SDGs 3 and 11 are two main goals directly related to mobility. SDG 3 focuses on "Good Health and Well-Being" with target 3.6 about reducing global deaths and injuries from traffic accidents. This SDG target 3.6 identifies a quantitative target for road safety: by 2020, halve the number of global deaths and injuries from road traffic accidents. SDG 11 is about "Sustainable Cities and Communities" with target 11.2 that emphasizes on providing access to safe, affordable, accessible, and sustainable transport systems for all. The report illustrates how sustainable transport systems are necessary to provide food security (SDG 2: Zero Hunger), healthcare (SDG 3: Good Health and Well-Being), access to schools (SDG 4: Quality Education), and employment for women (SDG 5: Gender Equality).

Several indices are proposed to help city leaders in assessing and improving the quality of mobility systems. For example, the HERE Technologies Urban Mobility Index[2] is a comprehensive index that addresses how cities around the world are dealing with the challenges of mobility across four major themes, namely, sustainability, connectivity, affordability, and innovation. Sustainability reflects low-carbon mobility as a way to improve health and quality of life. Connectivity measures the availability of information and communication infrastructure such as intelligent transport systems to better manage the traffic and improve the public transport efficiency. Affordable mobility changes how a city moves, enabling the flow of people, boosting economic potential, and enhancing social well-being. Innovation reflects how cities respond to changing mobility demands with innovative solutions. The Deloitte City Mobility Index (DCMI)[3] is another index to gauge the health of the mobility system and the city readiness to embrace the future. Three major themes are assessed in this index, namely, performance and resilience (congestion, reliability, safety, integrated mobility, and modal diversity), vision and leadership (vision and strategy, investment, innovation, regulatory environment, environmental sustainability initiatives), and service and inclusion (public transport density, affordability, air quality, customer satisfaction, and accessibility). Similarly, the Urban Mobility Innovation Index (UMii)[4] provides insights into urban mobility and innovation in cities based on evaluating three main aspects: readiness (strategy, capability, and soundness), deployment (regulation, investment, and engagement), and

[2] https://urbanmobilityindex.here.com/
[3] https://bit.ly/3chv8YN
[4] http://umi-index.org/

livability (connectivity, well-being, and environment). Arthur D. Little's Urban Mobility Index 3.0 is another index that assesses the mobility maturity, innovativeness, and performance in different cities using 27 indicators (Van Audenhove et al., 2018).

1.4. Summary

Smart mobility is one of the main pillars that characterizes smart cities and maintains their sustainability as a way to deal with continuously growing world urbanization and its expected impacts on public health, congestion, and accelerated global climate change. Mobility is now being seen as an information service with physical transportation products, rather than a transportation product with additional services (Ho and Bright, 2018). This is manifested in different smart mobility services we are using nowadays such as shared mobility services, Mobility-as-a-Service (MaaS), mobility on demand, and last-mile delivery services to name just a few. However, the widespread deployment and the societal acceptance of smart mobility systems and their sustainability depend on the advances in not only the technology domain but also the availability of governing policies, regulations, and laws and the proper planning/replanning of the cities to match with the requirements of these emerging and continuously evolving mobility systems and services. More details about smart mobility are provided in the next chapters.