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Transportation and Information

Trends in Technology and Policy

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To the memory of our fathers
Bhabesh Chandra Thakuriah
Donald Leslie Geers

Preface

In this book, we review recent developments at the intersection (no pun intended) of Information and Communications Technology (ICT) and surface transportation, and the technical, social and institutional challenges stimulated by these trends. Developments in pervasive sensing and widespread proliferation of vast numbers of mobile and static sensors promise to bring a sea-change in the way transportation information can be designed and used, particularly with Machine-to-Machine communications and by information generated by people-centric sensors. Methods to manage and analyze such data have led to novel mobility services which may have the potential to lead to sustainable and socially interesting travel. The use of such information stimulates numerous social, institutional, ethical, and legal challenges, some of which we have attempted to bring together in this book.

The book is aimed at researchers, graduate students, industry professionals, and decision-makers considering problems in surface transportation and approaches and limitations of ICT in understanding and addressing these problems. The use of the word transportation throughout the book refers to surface transportation, unless explicitly noted otherwise. Contributions from a number of academic disciplines have made these myriad developments possible. We take a broad-based view of policy and the underlying organizing theme is one of economic, environmental, and social sustainability. It is our hope that we have been able to bring together this broad spectrum of knowledge in this brief volume, albeit in a limited way. Our eventual goal is awareness-building about a wide range of problems in ICT and transportation, thereby stimulating research approaches that address multiple concerns and perspectives. The book is broad and non-technical in nature, with an emphasis on being a survey as opposed to an exhaustive treatment of a small set of topics. It may be read as part of an introduction to a graduate course on transportation and technology offered in transportation planning, transportation engineering, computer science, geography, or public administration.

The book begins, in Chap. 1, with an overview of the many facets of ICT in transportation, including Intelligent Transportation Systems (ITS), Location-Based Services (LBS), relevant aspects of smart and connected cities, dynamic resource management, mobile health, and assistive technologies. We also discuss environmental, economic, and social sustainability outcomes which an information-centered mobility environment can potentially address. In Chap. 2 we present an overview of the major existing and emerging sensor and communications technologies and describe the types of information they generate. Chapter 3 follows with a range of systems and services that utilize these sources of information. Chapter 4 addresses institutional, legal, and coordination issues as well as issues of behavioral effects and societal preparedness to handle the information-centered mobility environment. Conclusions and possible future directions are given in Chap. 5.

Whereas ITS and LBS have been very active research areas in transportation, the contributions of ICT have been greater than solutions and services developed under such banner. Examples include strategies for mobility-on-demand, mobility assistance for persons with disabilities, smart cities and ubiquitous information environment, community and urban informatics, resource management and asset condition monitoring. Although we try to devote space to many different types of ICT examples in transportation, we had to be selective, thereby making greater discussions of certain concepts than others and the book is far from an exhaustive survey of all that has been done on this vast topic. By a survey, we also mean that we do not go into detailed discussion of any one topic and attempt to merely provide an overview of what has been done in an area. Moreover, the emphasis is on the transportation system and service aspects and not on the details of the technology and methodological aspects.

The book was stimulated by our involvement in many research projects that are too numerous to list. However, virtually each of these projects gave us the ability to explore and appreciate the technical, social, and management challenges associated with the emerging information-centered mobility environment.

The book would not have been possible without the strong support of our spouses, Claude Hanhart and Nicole Geers, and Glenn's daughter, Céline. We would like to acknowledge the contribution of Dr. Caitlin Cottrill, University of Aberdeen, UK and John Laird, NICTA and University of New South Wales, who helped with reading through and editing the book. The book was written while the first author worked in Chicago and we would also like to thank ICT for making the 9,300-mile collaboration possible.

Glasgow and Sydney
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D. Glenn Geers

Contents

Chapter 1
Introduction

1.1 Trends in ICT-Based Surface Transportation

This book is concerned with the use of Information and Communications Technology (ICT) in the field of surface transportation. ICT is a major driver of both economic growth and improved quality of life in the new global economy. ICT has evolved over centuries and innovations in ICT have occurred throughout history. This book is concerned with digital ICT, which has its basis in computer software, hardware and communications systems, and the explosive development of which spans the last fifty or so years of human history.

Surface transportation has historically been a fundamental backbone of economies and societies, by contributing significantly to the Gross Domestic Product (GDP), employment and overall support of trade and commerce. Surface transportation is also a critical ingredient in the quality of life by enabling travel to jobs, educational, social and recreational activities. Surface transportation systems can also lead to poor economic and social outcomes because of traffic congestion, road fatalities, air pollution, Green House Gas (GHG) emissions and continued dependence on fossil fuels. Transportation technology, like ICT, has greatly evolved over time from primarily muscle (human or animal) powered systems to current-day motorized mobility for passengers and freight.

ICT has the potential to contribute to environmentally sustainable and safe travel and mobility management. Some examples of how such outcomes can result include:
Environmental Sustainability: On-board diagnostics of environmental pollution in cars, road traffic signals and motorway ramp meters which lead to shorter vehicle idling time, vehicle engines that turn off automatically when the vehicle is stationary and automatic eco-feedback to inform drivers about the environmental impacts of their driving behavior may enable eco-friendly travel;
Safety: Sensors which remotely telemonitor the health of a driver, anticipatory weather information to help drivers avoid hazardous driving conditions, cars that brake without driver intervention when sensing an obstruction ahead or warn drivers when they are overly fatigued or distracted may enable safer travel;

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Shared Mobility and Social Transportation Systems: Social media that allow people to find a real-time walking buddy from an unsafe train station in real-time, volunteer to be a driver for seniors in the neighborhood, or to share interesting location-based information to others nearby may lead to new models of co-production of shared transportation and mobility services;
Assistive Travel: Robotic assistive technologies for persons with disabilities, scooters that follow a senior person back home with the shopping load, and augmented real-world environments in which wayfinding and navigation are made easier may assist the mobility of those with special mobility needs;
Asset and Resource Management: Bridges that autonomously report their own structural health conditions to engineers and systems that monitor and adjust the charging load of electric vehicles in accord with location-specific load on the electricity grid may enable efficient ways of managing resources.

The above examples demonstrate that ICT may be used for transportation and mobility services in diverse ways and in different application areas. In the following chapters the focus is on growing ICT-based mobility strategies and a discussion of the technical, social, policy and user-related questions in the emerging information-centered mobility environment.

As in many other ICT-rich sectors such as health, energy, defense and finance, the use of ICT in transport enables knowledge discovery and service development that would otherwise not be possible. In each of the above examples, there are questions of coupling together sensors and communications systems; methods to extract, analyze and distribute information; and issues relating to user acceptance, legal implications and management. Yet, research, development and practice at the different stages of the technology lifecycle traditionally lie with professionals from different disciplines, and feedback and learning from experiences at each stage is not automatic (for example, professionals who are involved with the evaluation of the impact of such technologies on the behavior of travelers are often not involved at the design stage, or, technology designers may not be interested in the broader societal or economic impacts of a particular sensor, communication system or mobile application). In fact, it may be quite difficult to estimate what the broader impacts would be. By focusing on the "technology and policy" aspects of transportation and ICT together, we discuss the trends relating to these complex questions and directions towards which they are headed.

1.2 Overview of the State of Information-Based Mobility Environment

The convergence of several heterogeneous technologies has made the current state of information-centered mobility a possibility. The most relevant developments are in the fields of: (1) sensors; (2) location and positioning systems; (3) information extraction technologies; (4) sensor fusion technologies; (5) communication methods; (6) information and data management systems; (7) methods for information analysis; and (8) methods to understand user dynamics and impacts associated with the use of mobility information and services.

Sensor systems collect operational details on transportation conditions and provide real-time data on current conditions for immediate service delivery and informed decision-making. The transportation sector has a vast range of specialized infrastructure-based sensors for the detection and surveillance of mobility patterns and infrastructure conditions. In-vehicle sensors in the powertrain, chassis and the body of vehicles allow myriad automated tasks ranging from monitoring energy use to vehicle handling and safety as well as situational awareness regarding hazardous conditions on the road around the driver. People-centric sensors such as the microblogs, question-and-answer databases and mobile connected devices such as cell phones with location-aware technologies promise to allow large-scale, pervasive and distributed sensing system. Wearable biometric and other person-based sensors may have applications in mobile health and wellness informatics. In virtually all of the technologies discussed in this book the ability to more-or-less precisely locate a user or an asset, is a central ingredient. Satellite-based positioning systems such as the Global Positioning System (GPS) have been transformational in strengthening the role that mobile sensors can play.

Developments in spatial data management, geographic information retrieval, information extraction to retrieve intelligence from raw data (for example, data from digital images, text, audio data) and traffic and transportation engineering and planning have increased the overall utility of raw, sensor-based information. Mobility analytics generate knowledge for functions as diverse as automatic incident detection on roads (due to vehicle collisions or lane closures due to a hazardous material spill), prediction of bus arrival times at specific locations, future traffic conditions, location-based information-sharing among members of a social network, real-time management of vehicle fleets, or information on when people should travel. Such intelligence is necessary in order to support broader economic, environmental and societal outcomes as well as for high quality personal travel and freight movements.

Currently, different entities collect data on different aspects of the transportation system in a region. Mobility analytics based on such heterogeneous data sources will be critical components of intelligent cities of the future. We see future mobility intelligence giving rise to a *Digital Mobility Information Infrastructure* (DMII), which will comprise three tiers of information sources.

Primary Tier: The primary tier will consist of a myriad of infrastructure-based, vehicle-based, mobile, portable and wearable sensors, communications and information processing elements that are briefly discussed above, and which are the main subjects of this book. Some of these sensors may not be traditionally used in the transportation sector, e.g., weather sensors, but the information they offer may be critical for quality mobility information. This tier defines a continuum of information on transportation.

Secondary Tier: The second tier of information is comprised of information that is not directly generated by the primary tier but which may support its use in various ways. Examples include maps and Points of Interest (POI) databases which are critical for advanced and flexible mobility services, together with extant data sources pertaining to the overall state of the transportation network and the mobility environment. The latter sources include synthetic, model-derived information from regional transportation planning and travel forecasting models, which have historically served as the basis for making informed decisions about transportation infrastructure investments (for example, building highways or metro rail systems). Household travel survey programs and administrative data on transportation operations and performance management also support mobility intelligence and are rightfully part of this Tier.

Tertiary Tier: The third tier is comprised of "background data" from censuses, socioeconomic and demographic data programs, along with information sources on crime, health, safety, weather, emergencies, special events and related activities, to the extent that they can assist in mobility analytics.

Data from the three tiers of the DMII will support novel applications, services and planning activities that will be enabled through a range of technologies including, but not limited to, web services, standalone applications and peer-to-peer distributed applications, depending on end-user need. Although any specific end use may involve only a small part, perhaps even a tiny part, of the overall information infrastructure, the tiers of the DMII, taken together, can potentially stimulate discoveries about mobility intelligence to support various outcomes. Outcomes include safety, environmental and economic sustainability, social justice and cost-effectiveness. Additional moblity outcomes include personal satisfaction, interestingness and social-relevancy. These are outcomes which mobility intelligence can support, if designed adequately and inserted appropriately into society.

Several factors will jointly determine the extent to which these outcomes will result: the quality of the data and the communications aspects of the information infrastructure, the accuracy of mobility analytics which use the data to support mobility intelligence, and institutional and social factors in using that information. Data quality and accuracy and the way the data are used and connected to needs is critical; more data does not always mean better information. Mobility analytics consists of data management tools, systems and simulators that are able to extract mobility-specific intelligence from the large volumes of data in order to expose system behaviour and support services. Mobility analytics also consists of operations, management and planning tools to forecast demand, choices and preferences, manage resources, and to make impact and risk assessments. The reliability and accuracy of these tools is important to unleash the full power of such an information infrastructure and its eventual connection to outcomes of interest.

For the adoption and continued participation by users in sensing technology over time, many other factors are equally important to consider at the design stage. These include: (1) economic factors such as incentives and user benefits derived (for example, travel time saved, reductions in out-of-pocket travel expenses); (2) human-computer interaction factors such as user-centered and context-aware designs that are sensitive to ease of use and to attitudes and norms of users and expectations regarding privacy and information security; and (3) social factors such as value systems satisfied, social networking opportunities enabled and the psychological benefits derived from the interestingness of resulting mobility services.

The increasingly pervasive nature of location-aware sensing environments requires that various approaches should be in place to expedite the level of societal preparedness in terms of the institutional (governance, business management) and legal infrastructure. One important aspect is the extent of digital citizenship and citizen preparedness in terms of the level of awareness, and rights and responsibilities regarding the digital mobility environment. The development of an adequate evaluation framework and operational metrics for performance measurement of services and programs derived from the DMII would be important in developing technically robust and socially acceptable systems.

1.3 Key Trends Motivating ICT Use in Transportation

ICT use in transportation today is the result of both demand (market) pull and technology push factors and the co-evolution of technology and society. Market pull factors include the overall growth in population, urbanization, motorization and consequently, congestion; eco-considerations motivated by energy use, greenhouse gas emissions, and climate change; infrastructure needs relative to funding availability, capacity and age; safety, particularly crash avoidance and after-effect management; and changing demographics and special needs emerging from aging populations.

Technology push factors include developments in the areas described in Sect. 1.2: positioning, sensing, computing, communications, wireless networking technology, and methods relating to information extraction, analysis and simulation. The evolving nature of technical work in the transportation industry including the automotive industry, Original Equipment Manufacturers (OEM), the fleet management and logistics sector, and transportation asset management and traffic management sectors have also pushed innovations along certain pathways.

The major pull factors motivating the use of ICT in transportation is a complex combination of the need to reduce congestion levels and air pollution, concerns about energy use, and overall lack of accessibility and deteriorating levels of travel quality. In 2007, the total number of motor vehicles in use in the US (excluding motor-cycles) was 247.3 million, with a motorization rate of 820 per 1000 population [1]. During that same year, the Texas Transportation Institute [2] estimated delays in travel in the US to be 5.2 billion hours, with an estimated congestion cost of $126 billion (in 2009 dollars). While it is not possible to make rigorous international comparisons on these numbers, congestion is a world-wide phenomenon that is estimated to cost over $100 billion or about 0.69 % of the GDP in the US, based on estimates in [2] and about 1 % in the EU [3]. However, these costs can be much higher in certain economies, for example, in Asian regions, where congestion costs reached an estimated 4.4 % of GDP in South Korea and 6 % in the city of Bangkok [4].

According to data from the US Energy Information Administration, motor vehicle rates per 1000 people which are already very high in developed countries are expected to remain relatively steady during 2010–2020. However, the largest increases in motorization rates are expected to occur in less-developed countries. Motorization rates are widely different among less-developed countries, at an estimated 32 motor vehicles per 1,000 persons in 2007 in China, as compared with an estimated 338 vehicles per 1,000 persons in South Korea [5]. Increasing congestion and the concomitant time and fuel wasted in travel delays, especially in large urban areas, has led governments around the world to consider innovative solutions to managing traffic and congestion. Concurrent concerns regarding energy use and cost have only added to this motivation.

Reducing road fatalities has been a major incentive for seeking technological solutions. Although data from 31 countries showed that the average annual reduction in the number of deaths between 2000 and 2009 was higher than in the three preceding decades [6], the number of deaths remain high; examples are 33,808 in the US (or 11.1 per 100,000 population), 5,772 in Japan (4.5 per 100,000 population), 7,364 in Argentina (18.4 per 100,000 population) and 6,745 in Malaysia (23.8 per 100,000 population).

Different regions have very different needs regarding infrastructure management, including the need to build new transportation facilities to address demand or to maintain existing ones due to considerations of infrastructure aging and deterioration. The result has been to either seek information-based solutions when building new facilities, e.g., by instrumenting new highways with sensors or with electronic toll collection, or in the maintenance and repair stages, with workzone-based hazard warning and information systems for motorists.

The need to prepare for natural and man-made disasters and manage emergencies has revealed the need for enhanced emergency call services that upgrade current telephone-based capabilities to text, data, images and video messages. Changing demographics have been drivers in seeking technology-based mobility strategies, for example, in nations with high rates of aging population. Policy activities in the disability community are also leading to advancements in mobility solutions through universal design considerations.

The trends toward an information-based mobility environment have also been stimulated by technology push factors. Significant developments in sensor technology have led to smart commodities ranging from household appliances to smart buildings leading to cost-efficiencies and energy savings. It is not surprising that the automotive industry has been a strong participant in this overall trend, as have been transportation management agencies and the transportation industry overall.

The increasing proliferation of personal computers, the Internet, and wireless mobile devices have opened up possibilities for information management and sharing to a previously unknown degree. Strategies by which individuals learn about, receive and use such information have changed greatly over time, reflecting the ways in which the overall digital environment has evolved as broadband speeds have increased, with 133 million high-speed lines with more than 200 kB per second in at least one direction by the end of 2009 in the US, up from 2.8 million high-speed lines in December 1999 [7], and subscriptions to mobile, wireless phone services having grown to 302.8 million, up from 207.9 million in 2005 [8].

Worldwide, in high-income countries the number of mobile phone subscribers per 100 persons is 111.07, Internet users per 100 persons is 72.20 and broadband subscribers per 100 persons is 25.76 [9]. These numbers for middle income countries are 66.63, 20.73 and 4.03, and for low-income countries, 25.07, 2.57 and 0.04, respectively. Mobile phone subscription rates are higher in each type of country compared to other modes of communication. These trends open up the opportunity for a variety of new mobility services to be developed and used on a large scale.

1.4 Mobility Technology Areas

The types of mobility needs that people and society as a whole have are diverse and the range of functions and services that industries and government agencies provide to meet these needs are enormous. The efficient movement of persons and goods from point A to point B is a complex undertaking in any society; when factors such as quality, reliability, safety, equity and sustainability are thrown into the mix, the endeavor becomes even more complex.

A diverse range of industries, small entrepreneurs, government agencies and non-profits are involved in the mobility enterprise. Similarly, several academic disciplines are involved, including geography, engineering, economics, urban planning, management sciences, computer science, electrical engineering, public health and others.

It is not surprising, given the diversity and complexity of the mobility enterprise, that the motivations for the coupling of information technology and transportation have different roots. At the time of writing this book, several thematic ways of organizing ICT related to transportation exist, ranging from broad society/system-wide concepts to specific programs that reflect these roots to varying degrees. Some are established commercial or government program areas, whereas others are newer and more experimental. These thematic ways of organizing ICT for mobility form a collection of *meta-areas*.

As the reader will see, there are no clear-cut boundaries between the meta-areas since many of the technologies used are common to different areas. The differences stem from the overall purpose and different historical starting points behind the formation of a meta-area (for example, commercial need to remotely track assets in an industry versus the need for improved traffic management in cities). Additionally, there are differences in the community to which primary stakeholders within a meta-area identify themselves as belonging (for example, traffic engineering versus location-based services versus logistics).

The meta-areas have also been affected by specific strands within the intellectual body of work, methods of practice and legacy systems from which they have evolved. While all the areas make use of sensing, positioning, communications and information processing technologies in some way, the unique research, business and management practices that have resulted from the functionalities and stakeholders associated with each meta-area have led to varying levels of advancements regarding these technologies within each area.

Location-Based Services: Location-Based Services (LBS) are information services that capitalize on the knowledge of, and are relevant to, the context of a mobile user's current or projected location. While the military and emergency management services have always used positioning information for different activities, the motivation behind the bulk of LBS in recent years has been to use advancements in positioning and communication technologies for commercial purposes. Examples of LBS include services in response to spatial queries such as "Where am I?" or "What's around me?" Other examples are directory assistance and service location (for example, find the nearest gas station with cheap gas) or Points of Interest locations (for example, find the social services building).

Intelligent Transportation Systems: Perhaps most closely associated with transportation systems and technologies are Intelligent Transportation Systems (ITS). ITS programs use a vast range of sensor, positioning, communications and related technologies that are specifically geared to enhance the performance of the transportation system. The major policy motivations for the programs are improved traffic management and congestion reduction, traveler information, and safety. ITS components are currently deployed to varying degrees in many areas around the world, for functions as diverse as traffic management and adaptive traffic signal control, electronic toll collection, and management of city bus fleets. The instrumentation of highways, bridges, transit stations and toll facilities has led to mobility services which utilize real-time data streams generated from these (primarily government-funded) sensor systems.

ITS programs are currently substantially broader than in the initial years, and include a variety of functionalities such as road weather management systems, cooperative intersection collision avoidance systems, emergency management and vehicle-based safety systems. Many of these developments have leveraged innovations in automotive electronic and sensing technology. Recent areas of activity include connected vehicles and cooperative ITS (C-ITS) programs where the rationale is that by allowing vehicles to communicate with each other and with the infrastructure around them, it is possible to deliver safety, efficiency and sustainability outcomes beyond those achieved by the same vehicles acting alone.

Smart Cities and Ubiquitous Information Societies: Currently, there are several initiatives relating to smart cities, e-cities, u-cities and digital cities, where transportation is part of a mix of overall strategies to ICT-based intelligence in cities. These concepts regarding cities are a part of a continuum that emphasize different functionalities and integration strategies. The technologies and functionalities targeted by these concepts are common but the motivations and ultimate focus may be different to a certain degree. The term "smart city" is championed by commercial entities and the expectation is that such smart city integration approaches will enable cross-agency efficiencies in a range of functionalities in multiple administrative sectors (such as traffic management, utilities and law enforcement) and ultimately to a wide spectrum of services (utilities, garbage disposal, emergency services, aged care, etc) in urban areas. The u-city concept focuses on similar functionalities but with a long-term focus on making information available anytime, anywhere and about any place [10]. These ideas stem from ubiquitous information technologies and pervasive computing which could potentially transition society as a whole to a ubiquitous information environment, where intelligence is embedded into everyday objects (termed everyware, see [11, 12]), and where information is available anytime, anywhere and about any place.

Intelligent Infrastructure Technologies for Transportation Asset Management and Condition Monitoring: Monitoring the health of highways, transit systems, tunnels and bridges is a critical function needed to prioritize maintenance and repair before damage becomes extensive, and to avoid catastrophic failures. Failures can occur due to loading, age, or environmental conditions such as earthquakes, severe weather and freeze-thaw cycles. Increased vulnerability may occur in the future due to the potential impact of climate change. There are well-developed procedures in place to regularly inspect and test asset conditions. Structural Health Monitoring (SHM) allows continuous and autonomous monitoring of the structural integrity and physical condition of a structure using embedded or attached sensors and minimum manual intervention, using non-destructive techniques. Successful implementation of SHM can replace schedule-based inspection and maintenance of structures by condition-based maintenance, thereby reducing life cycle costs significantly, and improving safety. SHM systems involve a combination of data acquisition by sensors and computational models of the structure. A vast range of specialized sensors are used for these purposes.

Informatics for Citizen Engagement and Participatory Sensing: This meta-area focuses on methods to improve citizen engagement and community involvement in urban transportation planning, as well as to leverage users in the co-production of data. Traditional models of public participation such as public hearings, open meetings with officials, processes of reviewing and commenting on posted planning documents and other formal models have been problematic [13]. ICT has opened up the possibility of bringing communities closer to the planning process on a continuing basis, in contrast to project or plan-specific purposes; yet much remains to be done in this area. There are several synergistic viewpoints that support the idea of a sustained and involved citizen participation and engagement in community and urban decisions using ICT [14–16]. Social media technologies have the potential to move public engagement to a realm beyond planning and public policy issues into the role of direct co-production of services and information that historically rested with governments and commercial enterprises. For example, Web 2.0 and social media technologies have assisted citizens in real-time location-based participatory sensing of urban spaces. Static government or commercially-produced map databases may be augmented by Volunteered Geographic Information (VGI), where geographic content may be added collaboratively. Community members may self-organize for mobility to safety in crisis situations using ICT, by seeking and sharing peer-to-peer information to supplement information from emergency management personnel. These, and many other examples have resulted in several models of User-Generated Content (UGC), which can ultimately serve to inform mobility intelligence.

Mobile Health and Technologies for Special Mobility Needs: Recent policy has focused on evidence from the public health and medical literature that being physically active is an important contributor to health and well-being. Active transportation policies target obesity as a precursor to many diseases and support bike-friendly urban design, and built environments that facilitate physical activity as a part of people's everyday lives. ICT has generally been leveraged to play a supportive role in health in several ways. Mobile health technology (mHealth) which uses mobile technologies for health research and healthcare delivery has become an established area within health informatics. One area where ICT has played a significant role is with the mobility well-being of seniors and persons with disabilities. A report by the World Bank estimates that by 2050, the number persons with disabilities will be between 10 and 12 % of the global population [17]. The increase in the over-65 population, when the risk of disability is the greatest, is expected to more than double over the next 40 years, climbing from 7 % in 2010 to 16 % or nearly 1.5 billion people globally by 2050. Assistive technologies are another area; these range from robotic walkers to scooters that autonomously follow a senior person home from shopping. Augmented real-world environments, using ubiquitous sensing and display systems which place virtual objects into the real world, are being developed to assist persons with disabilities become more mobile both within the home and outside.

1.5 Mobility Policy Areas

We take a broad-based view of policy in this book and the underlying organizing theme is one of sustainability. Our framework is best represented by that given in the report *Sustainable Transport: Priorities for Reform* produced by the World Bank [18], which defines three components of sustainable transport:
The *economic and financial component,* which includes issues of adequacy of transportation infrastructure funding, organizations and scale;
The *environmental and ecological component*, which is concerned with how transportation investments and mode options influence travel and land use patterns and how these in turn influence energy consumption, emissions, air and water quality and habitats;
The *social component*, which emphasizes adequate access to transportation by all segments of society.

The economic, environmental and social aspects of sustainable transportation systems are overall mutually reinforcing in the sense that achieving sustainability in one aspect would likely result in favorable outcomes for the other two. In fact, the "interdependent and mutually reinforcing pillars" of sustainable development are noted to be "economic development, social development, and environmental protection" [19]. How ICT can be related to these broad goals us articulated by the World Summit for Information Society's (WSIS) Declarations and Principles [20]:

> … to build a people-centered, inclusive and development-oriented Information Society, where everyone can create, access, utilize and share information and knowledge, enabling individuals, communities and peoples to achieve their full potential in promoting their sustainable development and improving their quality of life.

Sustainable Mobility Policy Area 1: Economic and Financial Aspects: Policies that address the economic and financial components of transportation systems require that resources be used efficiently and that assets are maintained properly [18] (p. 5). ICT has the potential to address the efficiency and cost-effectiveness of mobility in many ways. For example, SHM technologies have the potential to bring about efficiencies in the monitoring of bridges, tunnels, highways and transit facilities for rapid maintenance and construction.

ICT-based capacity management strategies such as traffic management systems and electronic tolling for congestion pricing or Vehicle Miles Traveled (VMT) taxes whereby drivers could potentially be taxed, not through a fuel tax, but on the basis of actual distance travelled can lead to effective use of transportation networks. Incentives could be used to encourage participants of sensing systems to report incidents (e.g., road crashes or transit facility conditions) that have the possibility of affecting operational capacity of the transportation system and travel quality. Technologies supporting safety in transportation are particularly likely to support this aspect of sustainable transportation due to the large economic and social costs associated with traffic crashes.

ICT has significant potential for dynamic resource management of vehicles (truck or bus fleets), for shared transportation (ride-sharing, car-sharing or bicycle-sharing programs) and in mobility management (coordinating rides to work or for social purposes). If these strategies are effective, the result would be more efficient management of existing transportation resources.

Finally, ICT-based mobility strategies support several industries that contribute to economic development. A far from complete list includes automobile manufacturers, Original Equipment Manufacturers, telematics companies and hardware manufacturers such as cell phone and PDA manufacturers, electronics and infotainment manufacturers, transportation and traffic sensor manufacturers, and positioning system manufacturers. ICT is integral to the business of LBS such as routing and navigation and travel and tourism information, as well as industries that support them (for example, developers of map databases, web services and communications companies). Private and non-profit providers of mobility services (car-sharing companies, paratransit, assistive mobility companies, toll road operators, companies in the health and wellness realm) also depend on ICT-based strategies for their work,

Sustainable Mobility Policy Area 2: Environmental Aspects: ICT has both a direct and an indirect role in supporting positive environmental outcomes. Examples of direct support are design and control of clean vehicle engines, development of fuel alternatives and emissions monitoring and inspection strategies. Indirect strategies include supporting transportation demand management strategies for green travel. Examples of green travel strategies are travel information and service coordination for the use of public or shared transportation instead of single occupant vehicles, congestion and pollution charging and variety of other techniques.

Virtually all of the examples of capacity management in the previous section (on economic aspects of sustainability), in fact, can also potentially give rise to environmentally-friendly outcomes leading to the notion of mutual interdependence and reinforcement among the three aspects of sustainability. Eco-driving and