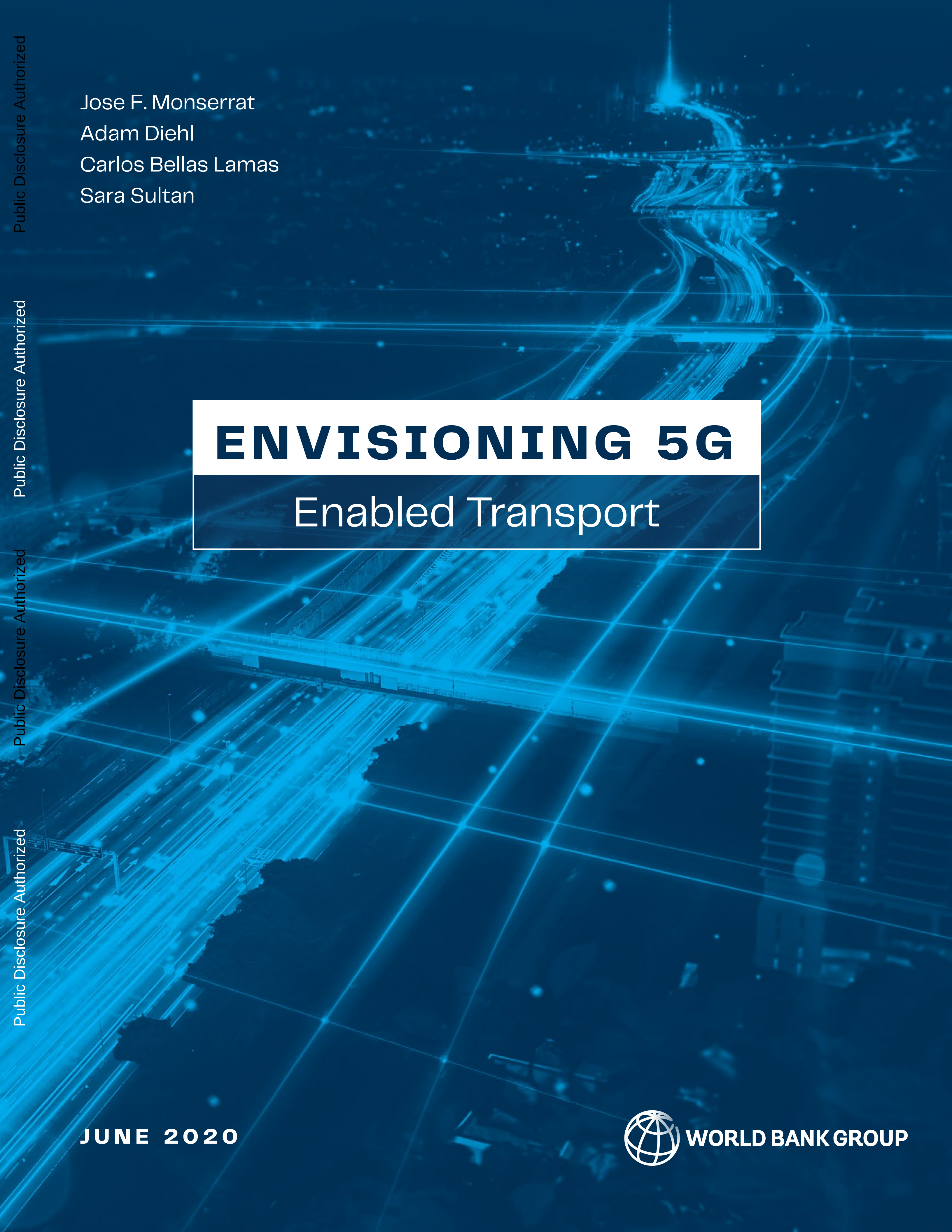


Jose F. Monserrat
Adam Diehl
Carlos Bellas Lamas
Sara Sultan

ENVISIONING 5G

Enabled Transport

JUNE 2020

WORLD BANK GROUP

1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

Editor: Kara Watkins

Cover photo: Adobe Stock / © jamesteohart
Cover and editorial design: Sergio Andres Moreno

Jose F. Monserrat
Adam Diehl
Carlos Bellas Lamas
Sara Sultan

ENVISIONING 5G

Enabled Transport

JUNE 2020

WORLD BANK GROUP

Contents

ACKNOWLEDGMENTS / 04

ACRONYMS / 05

EXECUTIVE SUMMARY / 06

01 INTRODUCTION / 12

02 RELEVANT FEATURES OF 5G FOR TRANSPORT / 16

03 TRANSLATING 5G INTO THE TRANSPORT SECTOR / 22

Vehicle-to-everything Communications / **24**

Smart Connectivity / **30**

Real-time monitoring of passengers and freight/ **31**

04 THE 5G-ENABLED TRANSPORT SECTOR / 34

The Trend Towards Connected and Autonomous Vehicles / **37**

Smart and Efficient Logistics / **39**

Evolving Urban Mobility and Public Transport / **42**

05 5G ADOPTION, STANDARDIZATION, AND TIMELINES / 48

06 IMPACTS OF 5G-ENABLED TRANSPORT / 52

Economic Growth and Poverty / **53**

Road Safety / **54**

Energy Use / **55**

Employment / **59**

07 COSTS AND POTENTIAL REVENUE FOR 5G-ENABLED TRANSPORT / 64

08 CHALLENGES AND LESSONS LEARNED / 72

Challenges / **73**

Lessons Learned / **76**

09 POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES / 78

Applicability to the Sustainable Development Goals / **82**

Policy Implications / **83**

Figures, Tables and Boxes

FIGURE E.1. Key Impact Linkages between 5G and the Transport Sector 7
FIGURE E.2. Impact of CAVs on Energy Use: Optimistic and Pessimistic Estimations 9
FIGURE 2.1. Relevance of 5G Features for Transport 17
FIGURE 2.2. Example of Network Slicing to Support Various Industries 19
FIGURE 3.1. Linkages between 5G Features, Transforming Opportunities and New Transport Applications 24
FIGURE 3.2. 5G Features Applicable to V2X 25
FIGURE 3.3. Day 1 V2X Services 26
FIGURE 3.4. Day 2 V2X Services 27
FIGURE 3.5. Day 3 V2X Services in the 5G Era 28
FIGURE 3.6. SAE Levels of Driving Automation 29
FIGURE 3.7. 5G Features Applicable to Smart Connectivity 30
FIGURE 3.8. 5G Features Applicable to Real-Time Monitoring of Passengers and Freight 31
FIGURE 4.1. The Four Technological Innovations in the CAV Paradigm 37
FIGURE 4.2. European 5G Cross-Border Corridors 38
FIGURE 5.1. Spectrum Allocation to Date 50
FIGURE 6.1. Connected Automated Vehicles and Improved Road Safety 55
FIGURE 6.2. Spectrum of Electric Vehicle Technologies 57
FIGURE 6.3. Projection of Vehicle Sales Volume 57
FIGURE 6.4. Energy Consumption Reduction Expected in the Most Optimistic and Most Conservative Estimation, Relative to 2020 59
FIGURE 7.1. Segment Selected for the Deployment Analysis 68
FIGURE 7.2. Examples of RSUs Deployed in the United States 68
FIGURE 7.3. Accumulated Costs and Revenues without Cellular Support for Day 1 to Day 3 Services 69
FIGURE 7.4. Accumulated Costs and Revenues with 50 percent of Cellular Support for Day 1 to Day 3 Services 69
FIGURE 7.5. Accumulated Costs and Revenues with 50 Percent of Cellular Support and 50 Percent Cost Sharing for Day 1 to Day 3 Services 69

TABLE 3.1. V2X Subcategories 22
TABLE 4.1. Selected 5G-Enabled Transport Pilots 36
TABLE 6.1. New Skills Demand and New Jobs Opportunities Created Because of Automation in the Transport Sector 60
TABLE 6.2. Declining Skills and Jobs That Will Become Redundant Due to Automation in the Transport Sector 61
TABLE 7.1. Data Rate Requirement for Each C-ITS Deployment Phase 66
TABLE 7.2. Radio Channel Propagation Modeling for Each Type of Road Considered 66
TABLE 7.3. Additional Assumptions for RSU and OBU 67
TABLE 7.4. Maximum Inter-RSU Distance for Each Type of Road and ITS Deployment Phase 67
TABLE 7.5. Number of Vehicles per Day in the Machakos Turnoff-JKIA Stretch 67
TABLE 7.6. Number of RSU as a Function of Service Type 67

BOX 4.1. Benefits of Incorporating 3PL Players into Transport Logistics 36
BOX 4.2. Japan Puts Truck Platooning to the Test 40
BOX 6.1. 5G and the Potential Energy Savings of Platooning and Vehicle Sharing 56
BOX 9.1. How 5G Applies to the SDGs 82
BOX 9.2. The First Obstacle: Spectrum Allocation 85
BOX 9.3. 5G and Public–Private Collaboration in Developing Countries 86

Acknowledgments

This report has been prepared by a World Bank Group team, led by Adam Diehl, urban transport specialist, consisting of Sara Sultan, senior knowledge management officer, and Carlos Bellas Lamas, young professional. A team at Universitat Politècnica de València, led by Professor Jose F. Monserrat, provided major contributions with research, analysis, and writing contributions from David García, David Martín-Sacristán, Saúl Inca, and Faîza Bouchmal.

This paper was prepared as a sectoral input into a wider World Bank flagship report on the impacts of 5G. The team acknowledges the excellent guidance and support received from the flagship lead, Je Myung Ryu, and the team, including Maria Claudia Pachon, and Hyea Won Lee, along with many others.

The team would also like to thank the World Bank peer reviewers, Tatiana Peralta, Rebekka Bellman, Winnie Wang, and Raman Krishnan, for their very valuable insights. In addition, the paper received invaluable guidance from external reviewers, including Andreas Kwoczek (Volkswagen AG), Frank Hofmann (Advanced Engineering Connected Mobility Systems, Robert Bosch GmbH), Roberto Fantini (Telecom Italia), and Alessandra Balletti (INWIT).

The report team gratefully acknowledges the excellent guidance and support received from World Bank colleagues, including: Makhtar Diop, Guangzhe Chen, Franz Drees-Gross, Vivien Foster, Cecilia Briceno-Garmendia, Martha Lawrence, Antoine Kunth, Victor Aragones, Helena Goetsch, Luis Blancas, Georges Darido, Arturo Ardila Gomez, Karla Domínguez González, Nicolas de Leon de Maria, Desta Wolde Woldeargey, Emiye Deneke, and Tatiana Daza among many others.

Acronyms

3GPP	Third Generation Partnership Project
3PL	third-party logistics
5G	fifth-generation mobile standard
5GAA	5G Automotive Association
5G-PPP	5G Public-Private Partnership
ACC	adaptive cruise control
ADAS	advanced driver assistance systems
AI	artificial intelligence
AR	augmented reality
AV	autonomous vehicle
BAHV	battery-assisted hybrid vehicle
BEV	battery electric vehicle
CACC	cooperative adaptive cruise control
CAD	connected and automated driving
CAV	connected and autonomous vehicle
C-V2X	cellular-based vehicle-to-everything communications
C-ITS	cooperative intelligent transport systems
CNG	compressed natural gas
DSRC	dedicated short-range communications
eMBB	enhanced mobile broadband
EU	European Union
EV	electric vehicle
FCEV	fuel-cell electric vehicle
GDP	gross domestic product
GLOSA	green light optimal speed advisory
GPRS	general packet radio service
HEV	hybrid electric vehicle
ICE	internal combustion engine
ICT	information and communications technology
IDB	Inter-American Development Bank
IEA	International Energy Agency
IoT	Internet of Things
ITS	intelligent transport systems
LNG	liquefied natural gas
LTE	long-term evolution
MaaS	Mobility as a Service
mMTC	massive machine-type communications
NR	5G new radio
NRA	National Regulatory Agency
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
PPP	public-private partnership
PTC	positive train control
RSU	roadside unit
SAE	Society of Automobile Engineers International
SDG	Sustainable Development Goal
TaaS	Transport as a Service
uRLLC	ultra-reliable low-latency communications
V2D	vehicle-to-device communications
V2I	vehicle-to-infrastructure communications
V2N	vehicle-to-network communications
V2P	vehicle-to-pedestrian communications
V2V	vehicle-to-vehicle communications
V2X	vehicle-to-everything communications
VRU	vulnerable road user
WAVE	wireless access in vehicular environments

Executive Summary

The transport industry has entered a period of rapid advancement, and the pace of change is only increasing. The proliferation of electric vehicles, rapid advances in autonomous vehicles, the advent of the sharing economy and digital platforms, advances in big data and machine learning, and rapidly evolving business models, such as eCommerce and Mobility as a Service (MaaS), are causing profound changes throughout the sector. The development and rollout of fifth-generation (5G) mobile broadband has the potential to not only support, but accelerate these revolutionary changes as today's digital transport solutions evolve and entirely new opportunities become viable.

5G presents a variety of benefits over previous generations of wireless connectivity, including greater bandwidth, lower latency, capacity to dedicate resources for critical functions, potential for greatly expanded numbers of devices, and easy sharing of data. In some cases, we see dramatic and exponential gains from previous technologies. Each of these 5G features will have an impact in the transport sector, contributing to transport-specific applications. Of these, three key opportunities present themselves: (1) revolutionary advancements in the potential connectivity of vehicles, (2) an increase in the number and ubiquity of connected devices, and (3) improved data availability for transport operations and management.

When applying these new technologies to transport, changes can be expected across the sector, with—to some extent—no corner left untouched. While impossible to foresee all potential applications, the study predicts three likely and significant changes: (1) the rise of connected and autonomous vehicles, (2) increasingly smart and efficient logistics, and (3) improved urban transportation with the implementation of MaaS platforms. Figure E.1 highlights some of these key impact linkages between 5G and the transport sector.

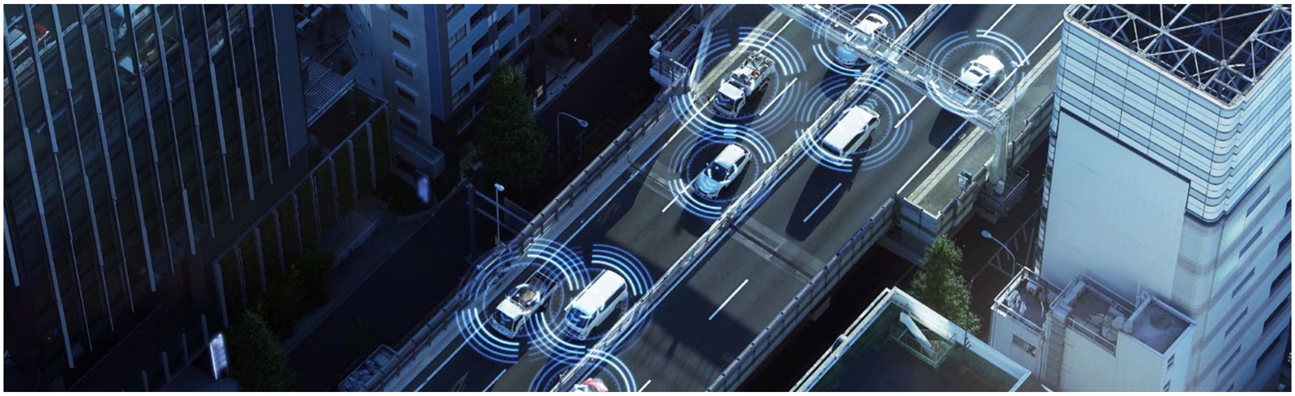
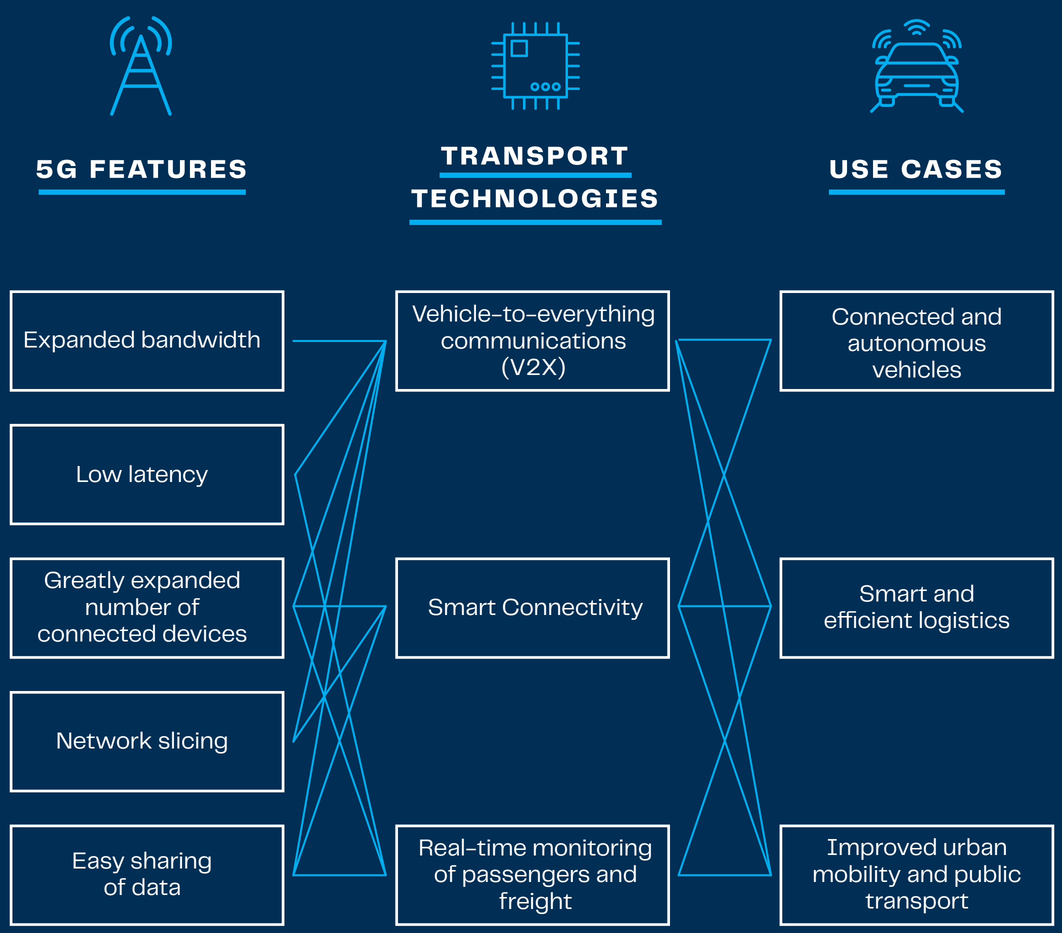


FIGURE E.1. Key Impact Linkages between 5G and the Transport Sector



Envisioning 5G-enabled transport

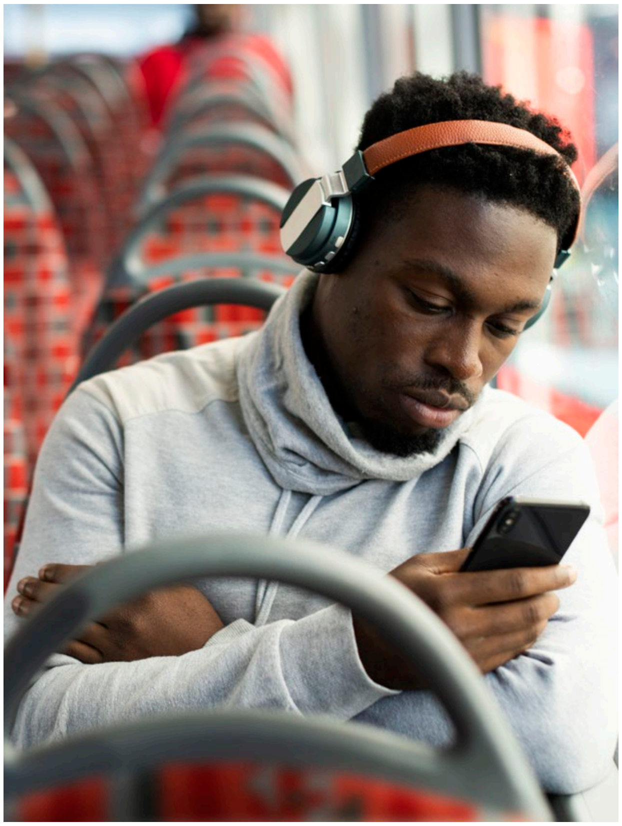
5G-enabled vehicles will differ from those in use today, with business models in the transport sector expected to differ significantly from the current paradigm. Connected and autonomous vehicles (CAVs) will bring together a series of changes impacting the sector, including connectivity, electrification, autonomy, and new business models such as MaaS. While the connectivity provided by 5G represents only one enabling facet of this equation, it fundamentally changes the overall potential scope and viability of the model.

In the logistics sector, 5G technology opens up three fundamental dimensions for increasing efficiency: (1) enabling the operation of autonomous vehicles, by land, by sea, or by air; (2) simplifying many communications and signaling processes, and dramatically reducing the cost of connected devices; and (3) increasing battery life, potentially up to 10 years. Taken together, these impacts massively increase the potential for connected freight, and thus the ability to track goods throughout the logistics chain and streamline logistics planning. They will empower increasingly autonomous shipping—initially through truck platooning—but eventually in all transport modes. And finally, they will facilitate the management of the logistics sector, improving port operations, facilitating third-party logistics (3PL) players, improving rail safety, enhancing the monitoring of infrastructure, and boosting overall efficiency.

In cities, the availability of 5G poses a revolutionary opportunity for urban mobility, allowing cities to modernize and make their transport systems more efficient. With access to 5G, cities will have an increased ability to improve public transport operations and planning, even introducing dynamic transport planning, and potentially reduce traffic congestion or reallocate space for cyclists and pedestrians. They also may generate more revenues by increasing public transport ridership or through a best use of developing business models such a MaaS. In turn, this could potentially help reduce tariffs and increase affordability for low-income users, who would benefit from improved monitoring and control systems for smart cards through reduced fraud and the ability of public transport agencies to better target the subsidies for public transport users in vulnerable situations. Better smart-card monitoring and control systems could also facilitate better transport planning through an enhanced understanding of the mobility patterns of various population groups.

5G can improve the efficiency of urban public transport operations. Technology-based real time monitoring of public transport vehicles and real-time user demand management would allow better matching between supply and demand, creating near real-time Origin–Destination (OD) matrix proxies to make transport operators more efficient by avoiding the operation of either empty or overloaded vehicles, which would enhance the quality of service for users. Moreover, increased multimodal connectivity among transport modes integrating all mobility options into single MaaS platforms, will allow users to choose among dozens of trip options. Additionally, users will enjoy better onboard entertainment and information display, as well as an enhanced feeling of onboard safety thanks to improved onboard video connectivity to the control center and police, which reduces response time in case of violent assault or sexual harassment within the public transport network.

Regarding active transport, 5G-enabled smart connectivity and vehicle-to-everything (V2X) communications will improve cyclist and pedestrian safety, who will also benefit from the safer automobiles. City and national governments might promote infrastructure sharing for providing telecom services and other services for mobility, such as using traffic lights or streetlights for deploying the 5G ultra-dense networks and create intelligent transportation system (ITS)-related services, thus boosting jobs in the digital economy. 5G could empower well-regulated systems that give preference to active modes and public transport over private cars. In total, if connected and autonomous cars can streamline traffic, and transport demand management is paired with improved public transport, 5G has the potential to open significant areas of urban space for people instead of cars.



Impacts of 5G

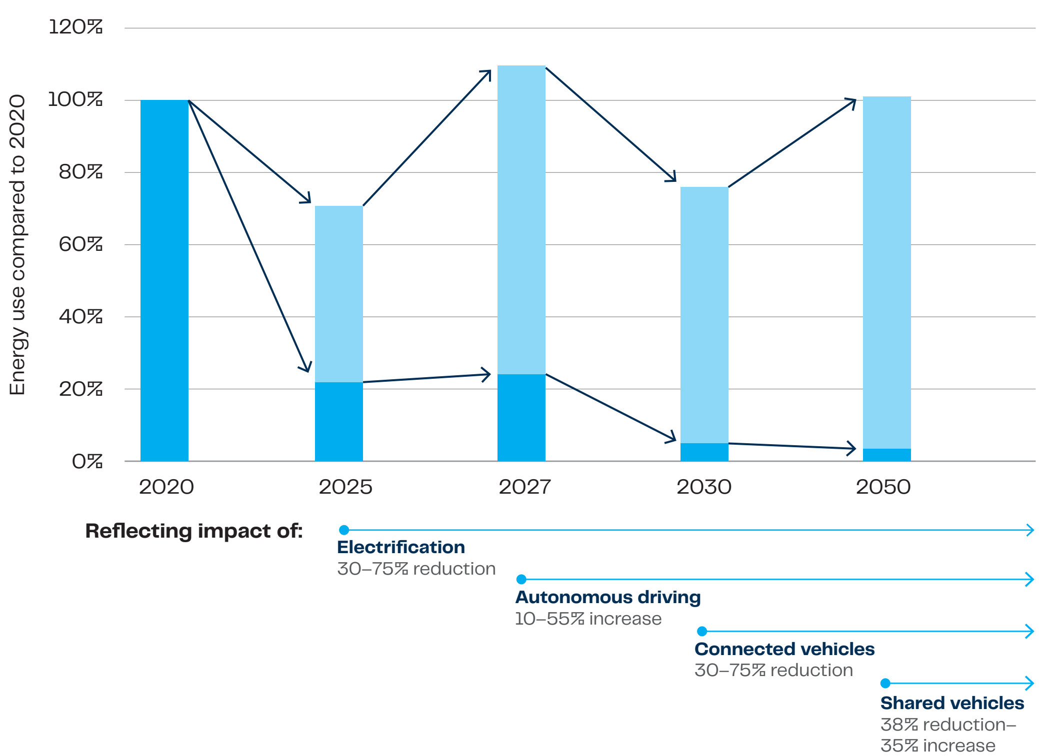
As 5G rolls out more widely, all evidence indicates it will have a dramatic impact on the global economy, with an estimated contribution to global gross domestic product (GDP) of US$700 billion by 2030, with nearly one-third coming from transport sector impacts. And these impacts within the sector will likely go far beyond simply boosting economic growth, offering additional potential benefits in terms of safety, energy use, climate change mitigation, and employment.

Every year the lives of approximately 1.35 million people are cut short as a result of a road traffic collisions, with an additional 20 to 50 million suffering non-fatal injuries. As the vast majority of these crashes (up to 94 percent) can be at least partially attributed to human error, the potential for connected and autonomous vehicles to save lives is immense. However, in order to truly make the world's roads safe for all users, more work is needed. Several high-profile collisions involving the current generation of autonomous vehicles shines a light on the continuing problem. The introduction of 5G-enabled communications will help address these challenges, allowing tomorrow's vehicles to see beyond their own field of view, make cooperative driving decisions, and process information from an increasingly rich set of sources.

Reducing the energy demand of the transport sector will be fundamental in moving to a sustainable and carbon-neutral economy. 5G-enabled connectivity is expected to drive energy use down in a number of ways. The ability to synchronize speeds and shift to truck platooning will reduce air resistance, potentially reducing fuel use by 7 to 16 percent. Smart infrastructure and 5G connectivity have the potential to improve the operation of dynamically controlled intersections, thus streamlining the flow of traffic and reducing delays—potentially reducing the energy demand by 13 to 44 percent. By empowering smoother acceleration, coordinated breaking, and other optimized driving patterns, 5G connectivity could reduce energy demand by 10 to 20 percent. Finally, eliminating the need to search for parking spaces could drop energy use by an additional 5 percent. All told, full connectivity could reduce energy demand by between 30 and 70 percent.

The study recognizes, however, that increased connectivity will not represent the only difference between the cars of today and those we will be driving in 20 or 30 years. The impacts of electrification, automation, and new sharing business models will either reinforce the gains from increased connectivity, or erode them entirely, depending on how the policy environment and demand for transport evolve. Figure E.2 shows the optimistic and pessimistic estimations for the possible impact of CAVs on energy use.

FIGURE E.2. Impact of CAVs on Energy Use: Optimistic and Pessimistic Estimations



In other sectors, increased connectivity and automation place many jobs at risk, while at the same time creating others. In the transport sector this will be no different. Many of today's jobs in the sector will face elimination, as vehicles increasingly drive themselves, warehouses become more efficient and automated, and simplified mechanical designs reduce the need for mechanics. That said, it is likely that at least as many new jobs will be created, such as data analysis, software developers, process automation specialists, eCommerce specialists, and customer service specialists. How and where these new jobs are created—and whether those impacted are ready to move into new roles—will be an important challenge to address. This will be particularly true in developing countries, where the heavy reliance on informal labor puts many workers at risk, specifically women, who represent the majority in the informal economy. Because fewer women than men participate in careers related to science, technology, engineering, and mathematics (STEM), they might not immediately benefit from the potential opportunities offered by jobs created as a result of required increased connectivity.

Importantly, the benefits between 5G and the transport sector will not flow in one direction only, as mobility driven connectivity demand will provide an important revenue stream for expanded 5G coverage, potentially driving down the cost of connectivity for other purposes and providing economic and financial return on otherwise marginal investments. An initial study indicates the potential revenue generated by connected vehicles along a major corridor could pay back the cost of 5G deployment in as little as three to four years. Ongoing work will analyze the potential use of telecom infrastructure deployment by city governments or transport agencies, such as metros, to provide high speed data connections within the city and improve commuting.

While the rollout of new technologies will be largely market driven, how these technologies impact the transport sector will depend in a large part on how governments, private players, and users react to their introduction. Key concerns include a recognition that increasingly autonomous vehicles will have an impact on the relative value of public transport, shifting the sector's employment from drivers and manual labor toward more technology jobs, creating an uncertain impact on energy use and climate change, and potentially driving an even deeper wedge into the digital divide.

In addition, a number of technical and legal questions remain that must be settled before 5G can be fully adopted into transport systems—questions surrounding the safety and allocation of legal responsibilities of autonomous vehicles, continuing disagreements on technical standards and network ownership, cybersecurity risks and international geo-political disputes concerning technologies, and the overall costs.

What does this mean for developing countries?

While the rollout of 5G is happening first in developed countries, a few pilot efforts are underway in the developing world with the first developing countries expected to rollout 5G coverage in 2021. In many developing countries 5G will likely be implemented initially in urban centers and along key road corridors, thus facilitating its impact on transport. This may be underscored by a mutually reinforcing aspect between 5G and transport, as transport sector use cases may drive the development of 5G networks where they are otherwise only marginally financially justified. Nevertheless, many technologies leveraging 5G for the transport sector will require extensive geographic 5G coverage. As such, only a few low- and middle-income countries may benefit in the short term, such as China and select countries in Southeastern Asia, Eastern Europe or Latin America.

How, and whether, developing countries prepare themselves for this oncoming reality will have a significant impact on how it affects their transport sector. The digital divide is real, and without significant intervention, the highest quality of network coverage will likely not reach the most remote corners of the globe for the foreseeable future. In some cases, ensuring universal coverage will require public sector involvement. In others, a targeted, impact-driven prioritization—such as implementing 5G along key corridors and within urban centers—could help capture the majority of coverage benefits. Simply copying the solutions from developed countries or allowing markets to develop naturally might not be enough to address the digital divide. Indeed, even where such rollout is possible, the long lifespan of vehicles (and the tendency for older vehicles to stay on the roads longer in developing countries) suggests that reaching a critical mass of connected vehicles in developing countries is potentially decades away.

The lag in deploying connected vehicles only highlights the opportunity for developing countries to drive forward in other ways. 5G-enabled handset-based solutions will likely reach developing countries in the near term, providing transport users with enhanced information via improved passenger information systems, communication of road hazards, real-time emergency information and similar applications, and assisting transport operators and authorities with enhanced data for real-time decision making and traffic control. Other applications will require only limited network coverage in urban centers, along rail lines, or in ports.

How these applications develop, whether they reach the poorest countries and regions in the short or medium term, and whether they have an ambiguous or definitively positive impact in the transport sector, will be driven by how the policy environment evolves, both within these countries and globally. The deployment of 5G-enabled transport will be guided by two sets of policies, those governing the telecommunications sector, and those within transport.

On the telecom side, 5G applications in transport raise new questions of network ownership and may drive a change in existing network infrastructure development models and oversight. Infrastructure sharing, meaning the joint development of network infrastructure to benefit multiple sectors, is already an important consideration, and the development of fiber optic cables along transport and energy corridors has shown clear cost savings for telecommunication sector development, while enabling deployment of digital transport solutions. Such joint projects will only become more important, and the policy environment governing their development more complicated, as connectivity moves more thoroughly into transport considerations. Because global allocation of a dedicated spectrum for ITS applications within the same 5.9 GHz band will dramatically facilitate global development of 5G-enabled transportation, the broadband spectrum itself will need to be carefully considered for transport applications. The intersection of these sectors will bring non-traditional market players into the telecom sector and incentivize the use of public-private partnerships (PPPs) for network ownership and operation.

The rise of connected and autonomous vehicles presents important opportunities for reducing energy use, releasing road space for public-use purposes, improving safety, and reducing the time people spend commuting. Digitalization of public transport could ensure an improved commuting time with better entertainment opportunities for users, and improved planning tools for authorities, operators, and users by using real-time mobile and vehicle data, as well as collaboration with private MaaS operators. In logistics, advancements in tracking and tracing, truck platooning, improved rail and port operations, streamlined last mile delivery, and more, could dramatically improve the efficiency of freight.

Finally, regarding transport, the coming transformations will increase the challenges on policy makers while empowering them with new tools and leverage. Despite a predicted dramatic improvement in road safety, autonomous vehicles present complex questions of liability and risk. In cities, the digitalization of public transport and the inclusion of private MaaS operators will require innovation-friendly governance with flexible approaches toward new mobility modes and the use of big data to improve management and planning. Regarding the use of limited public space in cities, if the regulatory environment does not catch up to new realities, autonomous vehicles will create new incentives for empty miles and wasted energy, with impacts on curb use, parking, e-tolling, congestion charging, and more. Lastly, as vehicles frequently cross borders, deploying 5G-connected international corridors will require regional collaboration and integration, potentially creating digital corridors or ITS observatories inside the regional organizations.

01 INTRODUCTION

As growing and evolving demand resonates with rapidly advancing technology, the transportation sector is undergoing a series of profound changes. At least five major innovations are revolutionizing the sector: (1) the advent of the sharing-economy and sharing platforms in transport and mobility; (2) the rapid improvement of electric batteries and the development of other alternative fuels for motor vehicles; (3) the advances in machine-learning techniques associated with big data that enable unprecedented real-time information processing; (4) the surge in eCommerce and express door-to-door delivery of goods and services; and (5) the advances in autonomous vehicles (AVs).

The rapid changes happening within the transport sector are only accelerating—the transport industry will likely evolve more in the next ten years than it has in the previous fifty. The hype for AVs is ushering in the new era for mobility and new business models such as Mobility as a Service (MaaS) and Transport as a Service (TaaS).[1] In order to shift transport to a more sustainable trajectory, the number of vehicles on the world's streets must drop; the growing wireless connectivity provides an opportunity: to improve public transport, advance its efficiency and comfort, and secure it as a mobility mode of choice. Still, significant advances are required to reach the full AV vision, explicitly in the underlying technology—artificial intelligence (AI), sensors, communications—and in the enabling environment where it will be implemented.

The roll out of fifth-generation (5G) mobile standards will only accelerate this pace of change, creating an opportunity to push current advances forward and revolutionize others. Indeed, if any sector best exemplifies the benefit of 5G for the development of new vertical applications, it is transport. The implementation of 5G implies a radical change in the transport experience of today, not only from the point of view of transporting people, but also of the movement of goods and freight management. Although the full impact of 5G on transport is impossible to predict, three major use cases can already be identified: (1) the realization of the promise of AVs, (2) the increasing efficiency of logistics, and (3) a revolution in urban mobility driven by smart cities and connected transport.

In addition, the potential positive impacts between transport and 5G deployment may run in both directions. Initial indications show 5G will have a significant benefit for transport, with the potential return on investment in certain specific deployments under four years, thus facilitating the wide adoption of 5G technologies. In fact, if leveraged systematically, transport could be the sector that removes the barrier currently limiting the deployment of wireless broadband technologies in developing countries.

The already realized advances in information and communications technology (ICT) open a set of opportunities for improving mobility and transport; more changes are expected with the advent of 5G. Whether these changes are positive or negative will depend on policies, regulations, and a host of other factors. Safe, sustainable, efficient, and affordable solutions can be developed—especially in emerging countries—if we manage to make financially feasible and well-regulated solutions that allow for leapfrogging and handling of any potential repercussions.

Transport has certainly been wirelessly connected for many years. Trucks can be tracked using General Packet Radio Service (GPRS) transmitters, trains and ships connected via satellite, and packages tracked via mobile apps and readers. Even when discussing direct communication between vehicles, some technologies are already available. Hundreds of private companies around the world have already benefited from advances in ICT, with many transport innovators emerging in the transport sector, such as ride hailing, eCommerce, peer-driver information sharing or electric mobility, among other examples.

However, in many emerging economies such advances made with the advent of fourth generation (4G) technologies and the emergence of smartphones, have yet to generate consistent improvements in the user experience. While the lack of uptake is driven by many factors, one key issue is that many cities and countries have rigid policy and regulatory arrangements in the transport and mobility sectors, which create challenges for entrepreneurs in launching new services and for the public sector to leverage this wave of innovation. Consequently, many advances only benefit private mobility, as public transport operators and regulators adapt slowly to new innovations and frequently default to banning new mobility options rather than accepting and effectively regulating newcomers. To ensure that new mobility also benefits lower-income users, innovation solutions for mobility must be better regulated, with public sector players negotiating with new players to identify win-win transport options for users.

Incorporating these lessons from the roll out of 4G services into 5G applications could drive clear benefits. The financial and economic return on digital transport solutions is evidenced by looking at the market value of companies built on them. However, the key questions involve understanding how much society as a whole is gaining from the current innovations in mobility, and how much society could benefit if innovation-tolerant institutions were ready to include technology as applied to mobility—especially considering the rapid advancement likely to come with 5G. The public sector must ask the following questions:

- How 5G can be used to generate positive externalities?
- How 5G-related innovations can promote public transit, road safety, and clean energy sources instead of increasing congestion and reducing space for people in cities?
- How 5G can improve the equality of opportunities for their citizens, such as enhancing security and mobility for women, reducing barriers for people with disabilities, and meeting the particular needs of low-income users or those in situations of vulnerability?

The public sector must be willing and able to regulate, bringing benefits from innovation related to 5G to these areas that could have the greatest social impact, while also limiting negative repercussions. Indeed, evidence from previous innovations shows that gains in technological advancement will be focused on specific individuals without proper regulation, ignoring the types of social gains which might benefit societies more broadly. The impacts of previous digital evolutions have been much greater for individual motorized transport than for collective transport or in active modes; only collaboration and regulation from public sector can manage the 5G evolution successfully.

Purpose of the report

Undoubtedly, addressing the full impact of digital technologies on transport goes far beyond the scope of a single report. As such, this paper focuses on envisioning what the oncoming deployment of 5G will mean for transport. The report provides an overview of the relevant features of 5G, discussing how these will be implemented within the transport sector, and then discussing three potential use cases—including (1) connected and autonomous vehicles, (2) urban mobility and MaaS, and (3) freight and logistics. After presenting a description of key impact factors, the following chapters explore potential (and expected) costs, benefits, and challenges. The paper concludes with a discussion of the potential impacts and use cases developing countries could encounter, along with policy challenges and opportunities facing decision makers in developing countries as they prepare for a 5G-enabled transport network.

Importantly, the report's authors acknowledge that 5G is still in the preliminary deployment phase, and can only estimate its full potential impact on both the transport sector and in general. Undoubtedly, aspects of this intersection—which seem important today—will amount to little, and the eventual key impact channels may differ from what is presented here. That said, the analysis presented throughout this report is based on the current best understanding of the evolutionary nature of both the technology and the sector. The analysis intends to present an indicative understanding for decisions makers in the transport sector, familiarizing them with the terminology, opportunities, and challenges that will become increasingly important as 5G-enabled transport becomes a reality.

NOTES

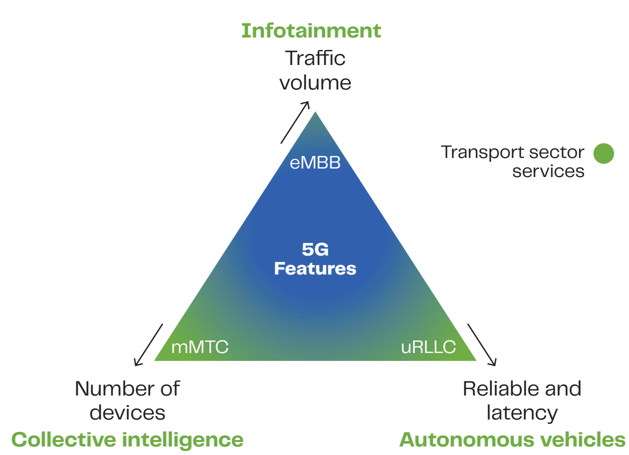
1. Mobility as a Service (MaaS) describes a shift away from personally owned modes of transportation toward mobility provided as a service. This is enabled by combining transportation services from public and private transportation providers through a unified gateway that creates and manages the trip, which users can pay for with a single account. The key concept behind MaaS is to offer travelers mobility solutions based on their travel needs. A related concept, transport as a Service (TaaS), goes beyond the mobility of people and integrates the movement of goods.

02 RELEVANT FEATURES OF 5G FOR TRANSPORT

5G is a fifth-generation wireless mobile communications technology. Applied to the transport sector, 5G will allow for a dramatic increase in the types, capacities, and numbers of connected devices. Such connectivity will undoubtedly influence a wide variety of services, mainly through 5G New Radio (NR)—the 5G standard for the radio access network. However, three main challenges must be solved before we can enable a truly networked society: (1) handling a higher traffic volume; that is, a higher rate of data; (2) managing the massive growth in the number of connected devices; and (3) creating a more reliable and low-latency transmission of goods and people; that is, all shipments and vehicles arrive—in a safe and timely manner—at their destinations.

The effort to meet these challenges has resulted in three broad 5G-enabled communication types (Marsch et al 2018): (1) enhanced mobile broadband (eMBB), which requires super-high data rates and wider bandwidths, for example, infotainment services in vehicles with multimedia provisioning and onboard video connectivity to assist in emergency response; (2) massive machine-type communications (mMTC), which requires low bandwidth, low energy consumption at the device, and high connection density, including the collection of measurements from roadside sensors to create a shared knowledge (collective intelligence) of traffic conditions; and (3) ultra-reliable, low-latency communications (uRLLC), which requires very low latency, and very high reliability and availability, for example, to coordinate autonomous vehicle (AV) trajectories or negotiate efficient, timely cross-junctions. Figure 2.1 illustrates the relevant features of these broad communication types, which are also discussed in more detail below.

FIGURE 2.1. Relevance of 5G Features for Transport



Expanded bandwidth

The expanded bandwidth feature is related to the eMBB concept. Increasing the available bandwidth is essential for transmitting more bits per second; 5G needs spectrum to support these three transport use cases, using three key frequency ranges, namely: sub-1 gigahertz (GHz) spectrum; 1 to 6 GHz spectrum; and above 6 GHz spectrum, also known as the millimeter wave band. Sub-1 GHz is best for widespread coverage and will be the main spectrum in rural areas as well as in low-income countries when costs of deployment should be kept at a minimum. The sub-1, or below GHz band is also preferred for the support of wireless Internet of Things (IoT) services. The 1 to 6 GHz spectrum presents a good balance between coverage and capacity, with between 3.3 and 3.8 GHz the preferred band for initial 5G deployment in current networks. Finally, the millimeter wave band offers higher spectrum availability and allows for ultra-high broadband speeds. Currently, the 6 GHz and 28 GHz bands are the preferred options in the above 6 GHz spectrum.

As compared with 4G bandwidths of up to 20 megahertz (MHz) for Long-Term Evolution (LTE), 100 MHz for LTE-Advance, or up to 640 MHz in LTE-Advanced Pro, the maximum bandwidth for 5G NR ranges up to 100 MHz for below 6 GHz spectrum and up to 400 MHz in the millimeter wave band, with the possibility of aggregating two carriers and reaching a maximum bandwidth of 800 MHz.[1] This spectrum is large enough to guarantee the provision of new mobility services based on immersive video.

Greatly expanded numbers of connected devices

In addition, mMTC devices must support high connection density and ultra-high efficiency, to deal with the massive number of connected devices stemming from AVs and roadside infrastructure, including lights, signals, pedestrian walks, and more. In order to support a high number of devices with limited resources, the 5G NR standard is expected to offer important changes in the signaling protocols and consumption of resources, in such a way that these sensors' batteries could last up to 10 years. At this time, it is impossible to further discuss the 5G mMTC features, since the specifications have not yet been developed. However, the clear intention is to be much more ambitious than previous legacy technologies, aiming for a 10-times greater maximum capacity of connected devices per cell. Such changes are already being developed by the Third Generation Partnership Project (3GPP), the body responsible for standardizing 5G. Within the 4G LTE specification—including the narrowband IoT (NB-IoT) technology—the improvements seek to cover Day 1 mMTC services for 5G by satisfying the proposed requirements, such as extra coverage and extended battery life.

In addition to these prominent features, 5G is also expected to deliver two additional and important changes for the transport sector: (1) allocation of dedicated resources for critical functions through network slicing, and (2) ease of data sharing.

Network slicing

Network slicing enables the same physical network infrastructure to deliver dedicated capacity for different services, and is required to provide uRLLC services. Network slicing creates isolated network

slices specifically designed to fulfill a specific set of service-level requirements established by an end-user application. This technology is becoming increasingly important in many areas, including the automotive and aviation industries, and is expected to become a basic 5G service. Its significance within AVs lies in the possibility—not without its challenges—of segmenting 5G services to match device and application requirements, therefore covering customized, unique needs of the industry. As shown in figure 2.2, due to strict requirements in terms of latency and reliability, operators are actively pursuing the adoption of network slicing in the transport sector.

Network slicing would allow for:

- Integrating the quality guarantees of 5G V2X communication services with other mobile broadband services, thus enabling AVs to connect to the Internet and other cellular devices.
- Increasing the reliability of the V2X network through this integration, allowing data transmission via both the Vehicle-to-Vehicle (V2V) path and the Vehicle-to-Infrastructure (V2I-I2V) path using the network as a repeater. Although this redundancy path does not solve the important problem of interoperability between vehicles connected to different mobile network operators, the redundant reliable paths do improve safety.
- Improving efficiency and reducing cost of cellular devices by introducing asynchronous transmission modes, which would remove the tight time constraints seen under previous generations of cellular technologies.

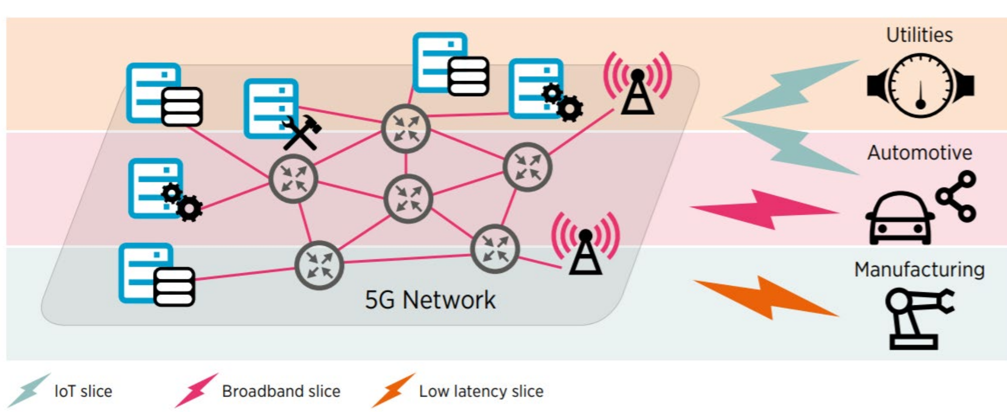
Although this report is not specifically technical in nature, it is important to highlight here that 5G contemplates its deployment with two options, either by connecting only the new 5G radio interface to an LTE network core, known as non-standalone mode (NSA), or by including both the radio interface and the new 5G network core, a deployment option known as standalone deployment (SA). Using an LTE network core does not allow 5G to realize its full potential, mainly in terms of the number of connected devices (mMTC), reliability, and low latency (URLLC), so that only purely eMBB-type services can be well deployed in an NSA solution. Thus, the benefit of the 5G on the transport sector can only be obtained with the SA solution.

Easy data sharing

The 5G feature of easy data sharing comes as a consequence of the massive amount of data collected from mMTC communications. Within the core network, sharing is enhanced via the network exposure function (NEF) (Kekki et al 2018). The NEF allows third parties to use data from the 5G network through defining a standardized interface—the main improvement over previous technologies—and allowing data access from outside the operator network. In the past, every operator and data consumer had to agree on a common language. With the language standardization through NEF, data exposure is simplified and boosted. NEF's programmable platform allows creation of new applications based on collaboration, opening the door for network operators and others to put data to use, maximize innovation, minimize the time to market, and create new services for consumers and enterprises while leveraging the increased data encryption capabilities built into the 5G architecture. In addition, monetizable services could bring additional revenues to players investing in 5G data-sharing applications.

Although the NEF is not specific to the transport sector and could be used by any vertical application, it holds a specific interest for third-party logistics (3PL) players. One could imagine, therefore, a scenario in which 3PL players could invest in deploying their own 5G communications network for transport and then offering Transport as a Service (TaaS) to third parties accessing the exact position of means of transport and network-connected merchandise. This would improve transport efficiency and ultimately allow for live

FIGURE 2.2. Example of Network Slicing to Support Various Industries



Source: GSMA 2017.

traceability of goods, thus connecting producers, consumers, and transporters. The existence of the NEF entity opens the door for 3PL to emerge as new market players in the more mature 5G era. It is still early to conclude how this new player could come to collaborate with vendors and operators, but likely their role would be in the form of a virtual mobile operator, running their service over a neutral carrier. Similarly, in cities, publicly developed 5G networks could be leveraged to enable specific data access for Mobility as a Service (MaaS) providers, thus increasing the traffic network efficiency and improving the transport management. The 5G is not just enabling more advanced applications and services but also transforming the market ecosystem and business models.

Low latency

Among these three important types of communication use cases enabled by the 5G, uRLLC is of special relevance for the transport sector. To unlock the potential of autonomous driving, the previous focus on network capacity, without much attention to latency or reliability, must shift toward low-latency, ultra-reliable 5G networks. AVs will need to respond to stimuli at least as quickly as a human driver, on the order of 1 to 2 milliseconds. 5G will promote the communication capabilities to a next level and also provide a long-term roadmap for the enhancement of vehicle-to-everything (V2X) communications. However, despite the current major advances in AV technology, the challenges of integrating converging communications technologies and networks, such as vehicle automation, connectivity, wireless charging via cloud devices, the wireless IoT, big data, and machine learning, must also be addressed when developing AVs. Automotive original equipment manufacturers (OEMs) have been addressing these challenges together with telecommunications services, mostly focusing on connectivity and business models, while academia is exploring how artificial intelligence (AI) can create new mobility horizons. These efforts are moving quickly, with the first complete version of 5G specifications for cellular-based V2X (C-V2X) communications due for release in September 2020. Looking forward, the first commercial tests should roll out in one to two years.

NOTES

1. The relatively low maximum bandwidth and number of carriers for 5G New Radio is a current limitation of 3GPP standards; the aim is to extend capacity in future releases of the 5G specifications, for up to 16 carriers.

REFERENCES

GSMA (Groupe Speciale Mobile Association). 2017. "An Introduction to Network Slicing." GSMA. Accessed May 2020. https://www.gsma.com/futurenetworks/wp-content/uploads/2017/11/GSMA-An-Introduction-to-Network-Slicing.pdf.

Kekki, Sami, Walter Featherstone, Yonggang Fang, Pekka Kuure, Alice Li, Anurag Ranjan, Debashish Purkayastha, Feng Jiangping, Danny Frydman, Gianluca Verin, Kuo-Wei Wen, Kwihoon Kim, Rohit Arora, Andy Odgers, Luis M. Contreras, and Salvatore Scarpina. 2018. "MEC in 5G Networks." ETSI White Paper 28. ETSI (European Telecommunications Standards Institute), Valbonne–Sophia Antipolis, France. Accessed May 2020.

Marsch, Patrick, Ömer Bulakçı, Olav Queseth, and Mauro Boldi, eds. 2018. 5G System Design: Architectural and Functional Considerations and Long Term Research. Chichester, West Sussex, United Kingdom: John Wiley & Sons.

03

TRANSLATING 5G INTO THE TRANSPORT SECTOR

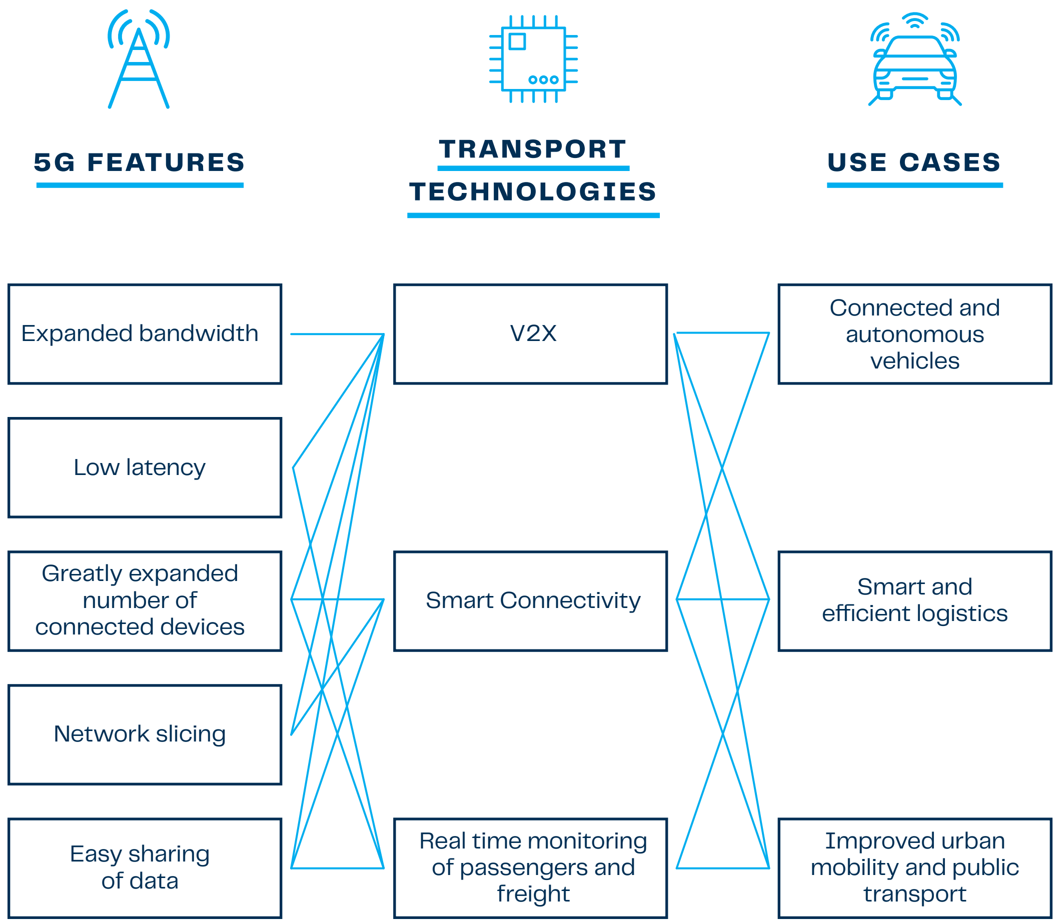
The characteristics of 5G presented in the previous chapter create a number of opportunities for transforming the transport sector. These use cases include (1) enabling revolutionary advancements in the potential connectivity of autonomous vehicles (AVs), (2) increasing the capacity and efficiency of "smart" connected infrastructure and devices, and (3) improving data availability in transport operations and management. This section explores the ongoing and future advances along these three tracks from a technical angle, with deeper implications addressed later in the report.

The linkages established between the 5G features and new transport technologies through these three opportunities illustrate the importance of 5G in developing the transport sector. Figure 3.1 shows these linkages between features and applications. This report uses these transforming opportunities to link 5G technology with the transport sector.

Experts anticipate the application of vehicle-to-everything (V2X) communications to enhance intelligent transportation systems (ITS) will be one of the most useful realizations of 5G. Potential benefits include the promise of efficient road traffic management, reduction in collisions and better safety outcomes, diminished driving times, improved fuel efficiency, and pollution prevention, among others. This is why the Third Generation Partnership Project (3GPP), the body tasked with standardizing 5G, in its progressive development of the standard has chosen to prioritize specifying the integration of V2X into 5G. Other promises of 5G explained throughout this text—especially those related to massive wireless tracking—have not yet been specified, making it impossible to provide more than a qualitative analysis. As such, the discussion of these potential applications is less detailed.

It is important to note that existing wireless technologies already support a range of applications within the transport sector, in terms of handheld user-facing applications (such as passenger information systems, routing, traffic monitoring, or ride sharing) as well as the host of use cases that rely on Internet of Things (IoT) devices, Although this paper is intended to focus on the implications of 5G connectivity, some discussion of developments based on existing technology is included where it helps illuminate the evolution toward future 5G applications.

FIGURE 3.1. **Linkages between 5G Features, Transforming Opportunities and New Transport Applications**



VEHICLE-TO-EVERYTHING COMMUNICATIONS

As shown in figure 3.2 (taken from figure 3.1), 5G will allow for a dramatic expansion in the communications capacities of vehicles by leveraging expanded bandwidth, reducing latency for real-time communications, enhancing reliability, expanding the number of connected devices, boosting stability via network slicing, and making data sharing easier.

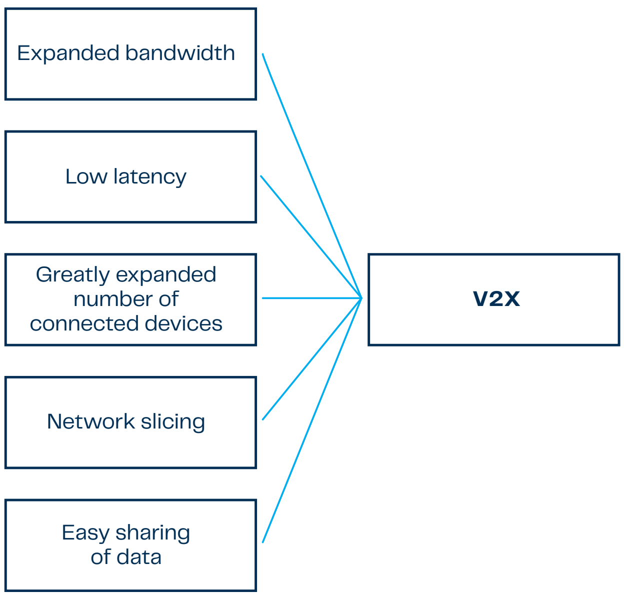
The advent of V2X communication technologies has delivered a host of new use cases. V2X, a communications system that interconnects a road vehicle to any entity that may concern it, is a broad concept encompassing a range of communications channels, including the subcategories described in table 3.1.

Currently, there are two V2X approaches, using two different underlying technologies. The first approach, known as dedicated short range communication (DSRC), supports V2X connectivity based on a variant of Wi-Fi technology standardized as IEEE 802.11p. This technology is known in America as wireless access in vehicular environments (WAVE) and in Europe as ITS-G5. The second approach is based on cellular technologies, known as cellular-based V2X (C-V2X). Proposed by the 3GPP, it was originally based on 4G LTE technology but has recently been upgraded to leverage 5G potential. It should be noted that, despite its promise, the integration of 5G into the ITS discussion is still in the early stages, since this technology is yet not completely established (due to the ongoing COVID-19 outbreak, the V2X standard has been delayed until late 2020).

Both WAVE and C-V2X support direct communication between vehicles (V2V) as well as communication with infrastructure (V2I).

Services based solely on V2V communications require only the availability of a radio module in each vehicle—that is, the transmitter and a spectrum[1] allocated to the service. However, in order to support V2I applications, WAVE could require deploying a specific network along supported roadways when necessary. In comparison, for V2I applications, either 4G- or 5G-enabled C-V2X technologies could make use of pre-existing cellular networks already deployed by any operator, which would greatly reduce deployment cost.[2]

FIGURE 3.2. 5G Features Applicable to V2X



Exploring the future V2X applications empowered through 5G requires some understanding of the applications V2X communications could bring to the transport sector using current technologies. Assessing the services enabled by V2X under a "Day 1, 2, and 3" model (Asselin-Miller et al 2016) disaggregates those already viable from those which will be implementable in the medium to long term. A brief explanation of this "three-day" model follows:

- ***Day 1 services:*** consider the exchange of status data to enhance predictive driving
- ***Day 2 services:*** enhance vehicle awareness through the exchange of sensor data
- ***Day 3 services:*** are based on the exchange of intention data, which facilitates a better coordination of vehicles to allow autonomous driving

WAVE was initially designed with Day 1 services in mind, while 4G LTE C-V2X could be considered as either a Day 1 or Day 2 enabling technology. Finally, Day 3 services rely on 5G-enabled C-V2X. Of course, future technologies may eventually accommodate Day 3 services, but to date only 5G offers the technology necessary to make this possible. The sections below look at these scenarios in more detail.

TABLE 3.1. V2X Subcategories

VEHICLE-TO-VEHICLE	V2V	Direct communication between two vehicles
VEHICLE-TO-INFRASTRUCTURE	V2I	Communication between a vehicle and fixed infrastructure, such as traffic lights, infrastructure monitoring and control devices, parking services, etc.
VEHICLE-TO-PEDESTRIANS	V2P	Communications between vehicles and pedestrian devices, alerting pedestrians of vehicle movements and warnings for vehicles
VEHICLE-TO-DEVICE	V2D	Communication between vehicles and non-V2V enabled vehicles and cyclists
VEHICLE-TO-NETWORK	V2N	Communications with the cellular network, either to facilitate other types of V2X communications, or to access Internet resources

Day 1: V2I based services

Leveraging either WAVE or C-V2X standards, Day 1 services are viable in the near term and build off of existing technologies without centralized, cloud-based services.

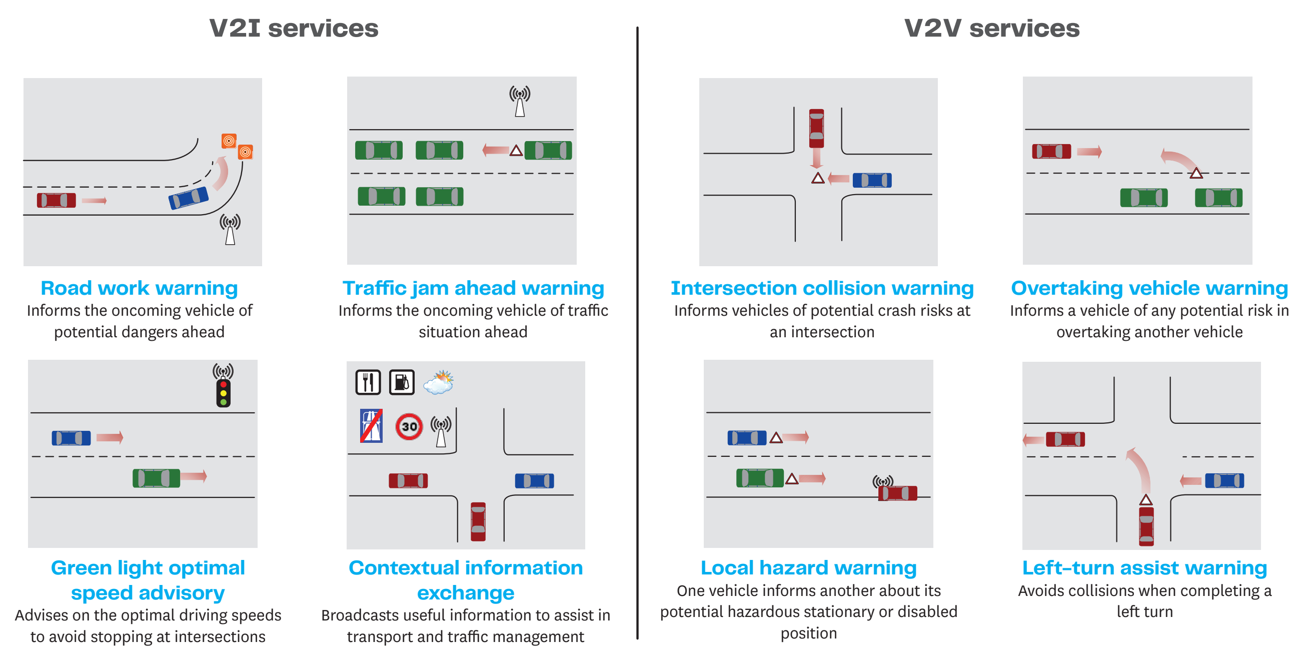
Day 1 services, based on V2I communications, could include the following:

- ***Road work warning***—provides information on current roadwork and associated constraints. The information can be sent by a nearby Roadside Unit (RSU) or via cellular node with C-V2X technologies, if coverage exists in the area.
- ***Traffic jam ahead warning***—uses the infrastructure to warn incoming vehicles of a traffic jam ahead. Requires the existence of a back-end service with the capacity for detecting traffic congestion based on recurrent position-related messages sent from vehicles.
- ***Green light optimal speed advisory (GLOSA)***—allows a traffic light to broadcast timing data associated to its current state, together with speed advisories vehicles can follow to pass through intersections without stopping.
- ***Contextual information exchange***—shares information from various sensors with the vehicle or the infrastructure, including information on tolls, traffic lights, speed limits, weather conditions, fueling stations, parking, and more. In this line, for instance, public transport could be connected to control operations centers to assist with passenger management.

Similarly, Day 1 services based on V2V communications could include the following (and are also illustrated in figure 3.3):

- ***Intersection collision warning***—exchanges information between two vehicles about their positions and dynamics to help detect the risk of collision in an intersection.
- ***Overtaking vehicle warning***—measures the potential risk, detected by an overtaking vehicle, of an oncoming vehicle. Based on information broadcasted by other vehicles, likely the vehicles to be passed.
- ***Local hazard warning***—shares information, collected by one vehicle, with other vehicles about any abnormal stationary or disabled position that could cause a traffic risk.
- ***Left-turn assist warning***—shares information about other vehicles' locations and movements to identify potential risks in completing a left-turn maneuver.

FIGURE 3.3. Day 1 V2X Services



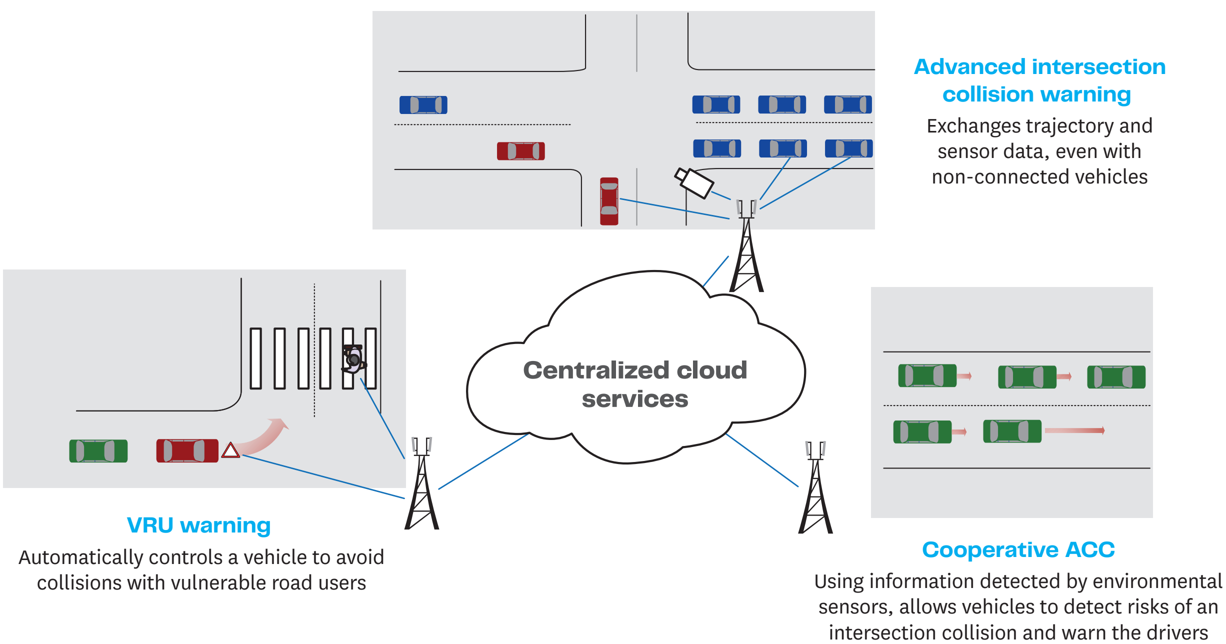
Day 2: ITS leveraging centralized cloud services

In the Day 2 deployment phase of V2X-enabled ITS services, environmental sensing will play a new role, in which all vehicles and the cloud share information about detected objects. This will allow vehicles to recognize obstacles not detected by their own sensors. This cooperative awareness will also permit semi-automated reactions, like automatic braking for vulnerable road user (VRU) protection or cooperative adaptive cruise control (C-ACC). Day 2 services will likely require C-V2X connectivity, leveraging an associated Internet connection with a cloud service, ideally located in the network edge, for cooperative knowledge sharing. As shown in figure 3.4, among the main services identified for Day 2, the following may be the most significant:

- ***Cooperative adaptive cruise control (C-ACC)***—uses V2X communications to obtain the lead vehicle's motion and coordinate traffic, improving on current adaptive cruise control (ACC) and allowing for dynamic changes. Infrastructure could suggest the required speed adopted by the ACC as well as the activation or deactivation point.
- ***Vulnerable road user warning***—informs the driver about a possible collision with vulnerable road users, such as pedestrians, motorbikes or bicycles. In extreme cases, the vehicle could automatically brake to avoid the collision. A similar solution could be based on giving priority at traffic lights to public transport and pedestrians by detecting their proximity.
- ***Advanced intersection collision warning***—shares information about non-cooperative vehicles detected by environmental sensors. Allows vehicles to detect the risk of an intersection collision and warn the driver accordingly.

Such services could also be leveraged for other road users, such as cyclists (Hawkins 2018), providing support for enhanced safety.

FIGURE 3.4. Day 2 V2X Services

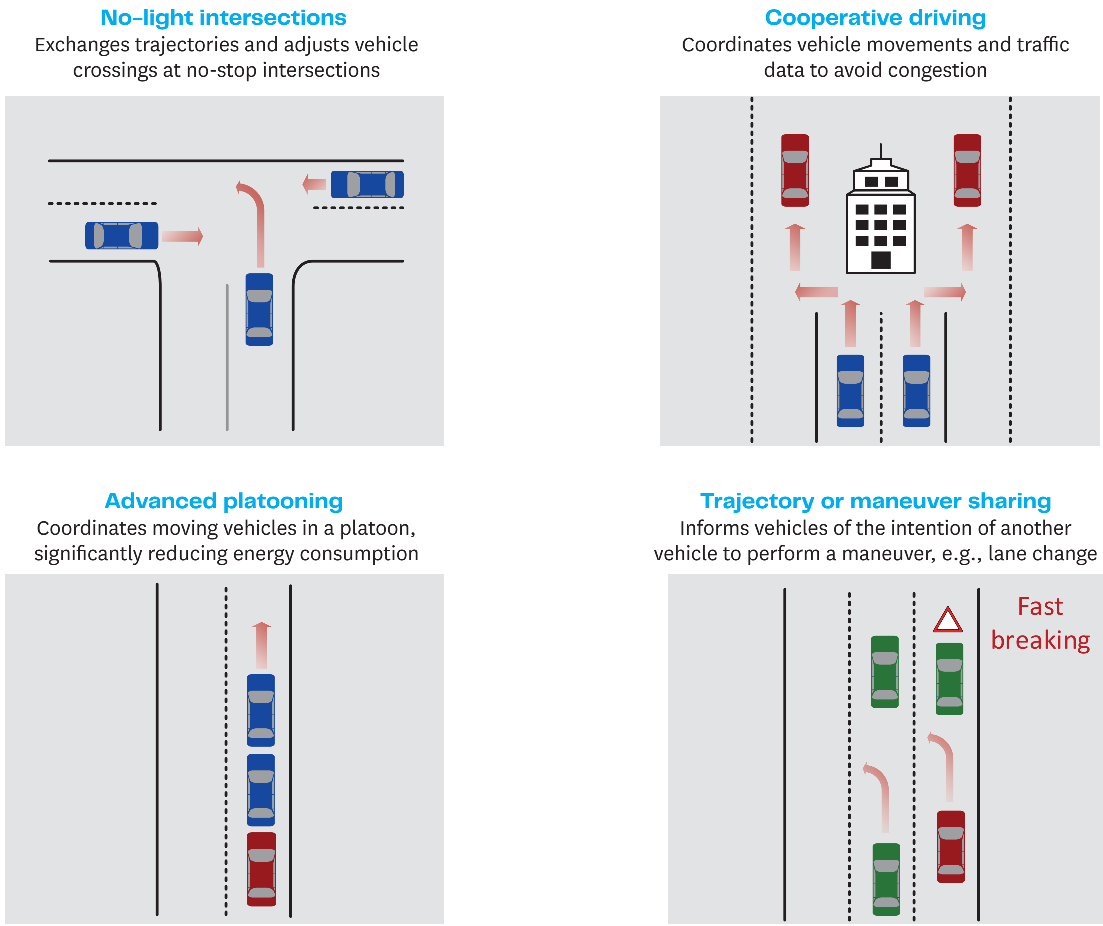


Day 3: 5G-enabled cooperative driving and autonomous vehicles

5G offers the opportunity to improve many existing technologies, would allow the consolidation of Day 1 and Day 2 services, and would enable the implementation of Day 3 services based on cooperative driving and, thus, full automation (see figure 3.5). The expected time in which these services will be introduced depends on the development time and availability of vehicles with automated driving capabilities (as determined by standards set by the Society of Automobile Engineers, or SAE, Levels 3 and 4, explained below). Connected AVs could share information and intended actions with other vehicles, infrastructure, and connected devices in order to coordinate maneuvers and avoid conflicts. A good example of such Day 3 services is cooperative lane merging, although additional services can be identified, such as:

- ***No-light intersections*** (an extension of GLOSA)—allows vehicles to cooperatively adjust speeds and cross intersections without collisions, making traffic lights at city intersections increasingly redundant. Policies to prioritize users and coordinate vehicles would also be able to stop traffic when pedestrians or bicycles signal an intention to cross.
- ***Cooperative driving***—shares common destination knowledge for all moving vehicles in an area, allowing route managers to avoid congestion in advance.
- ***Trajectory or maneuver sharing***—permits a vehicle ready to perform a maneuver to notify other vehicles about its imminent occurrence, allowing coordinated reactions.
- ***Advanced platooning***—coordinates vehicles to operate safely as a platoon on a highway, with longitudinal and lateral control, maximizing driving efficiency. The next step in cooperative adaptive cruise control, such platooning allows trucks to drive within less than 1 meter of each other, improving fuel economy and safety.

FIGURE 3.5. Day 3 V2X Services in the 5G Era

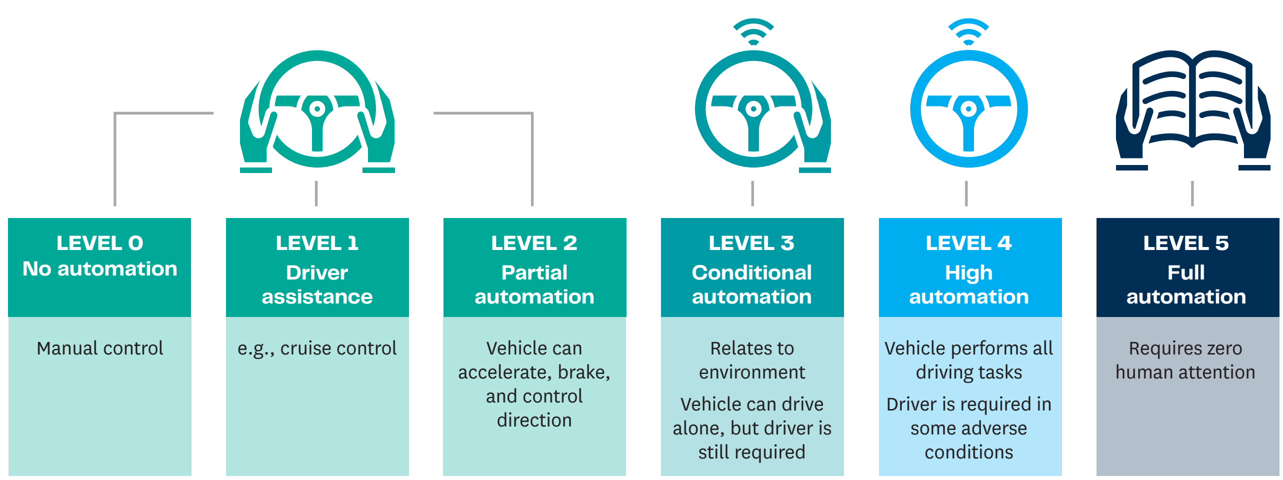


Currently, autonomous vehicles cannot detect obstacles outside their fields of vision, nor are they aware of traffic occurring more than a half-mile down the road, not to mention the driving intentions and routes of the surrounding vehicles a few feet away. This affects their ability to safely operate in dense urban landscapes, some of the most difficult scenarios for validating AVs. To overcome this, 5G combined with artificial intelligence (AI), big data, and cybersecurity appear as technological enablers, allowing AVs to constantly and safely access and interpret the data collected by numerous surrounding vehicles and roadside units. As a result of this cooperation and massive data processing, the huge swathes of additional data being collected by other vehicles and sensor sources will allow the vehicle to react to changes in the road surface, weather, traffic conditions, and intended actions of other vehicles. Therefore, 5G is needed to provide not only the required low latency (referred to as ultra-reliable low latency communications, or URLLC) and the high broadband communications (referred to as enhanced mobile broadband, or eMBB) necessary for real-time communication among vehicles and the infrastructure, but to support the billions of connected IoT devices (referred to as massive machine-type communications, or mMTC) which will provide a constant flow of information. The eMBB feature will allow, for example, advanced entertainment options as well as some advanced security-related services, such as the eagle view, which allows a vehicle to see what is happening beyond the vehicle in front of it. The uRLLC feature will allow for the rapid exchange of messages between vehicles and infrastructure, enabling rapid completion of complex decisions, improving road safety, and allowing vehicles to make more reliable decisions than humans. Finally, the mMTC feature will connect smart devices to the collective intelligence system that includes not only vehicles, but also traffic lights, road signs, sensors, pedestrians, public transport, etc.

Autonomous vehicles are being developed by a wide range of actors, from the auto industry (Ford, Hyundai, Tesla, etc.), to the telecom sector players adding further features (Ericsson, Korea Telecom, etc.), to companies such as Uber and Alphabet (Google), among others. Still, the current state of technology is far from achieving full automation. As of 2020, the most advanced Tesla car features a SAE Level 2, which requires some kind of driver assistance, for example, cruise control or lane exit correction. Audi delivered its first-generation A8 luxury sedan able to reach SAE Level 3 in October 2019, although the model is not yet commercially available at the writing of this report. The A8 model allows the vehicle to connect with traffic lights, implementing adjustable speeds to avoid stopping. SAE Level 3 means that the vehicle would be able to drive itself most of the time, but still require the involvement of a person in several complex scenarios.

Figure 3.6 shows the five levels of driving automation, as determined by SAE International.

FIGURE 3.6. SAE Levels of Driving Automation



Source: Graphic based on SAE International's standards for driving automation levels; for more information, go to http://sae.org.

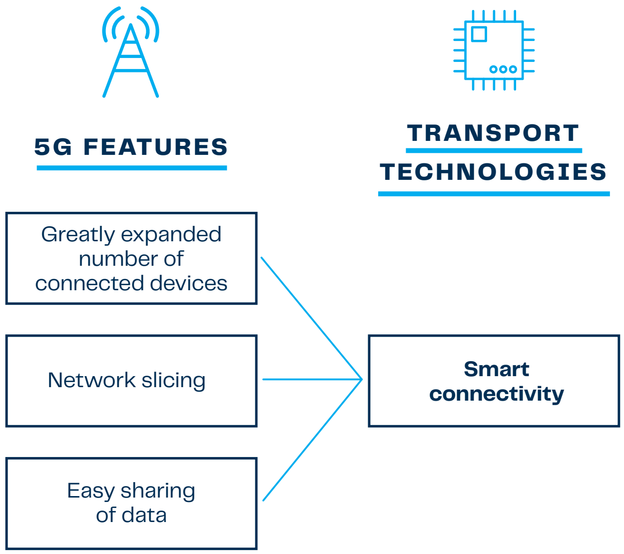
SAE Level 4 autonomy is able to handle all scenarios and does not rely on a driver in all but the most adverse conditions. SAE Level 5 means full autonomy without human interaction in all complex situations, such as removing the steering wheel from the vehicle. Experts anticipate the first prototypes of SAE Level 5 will appear in 2030, with a massive deployment of SAE Level 5 around 2050. Reaching Levels 4 and 5 will require the achievement of significant milestones. While it is not yet clear which technology these vehicles will employ, especially in terms of V2X communications (WAVE versus C-V2X, as discussed earlier), experts agree 5G will play a fundamental role, at least with regard to massive sensors integration in the cloud-shared knowledge. To guarantee security, communication between pedestrians and the vehicle must, necessarily, be done through a cellular connection and, in addition, with very low latency. In addition, 5G offers unique elements able to execute edge computing with a guaranteed transmission, which also makes it an ideal technology for communications among vehicles with different road sensors or information points. Still, other challenges are pending, such as the connectivity problem between vehicles and multiple operators.

SMART CONNECTIVITY

While the features of 5G mentioned above will contribute to enabling smart connectivity—expanding the quantity and quality of coverage in the transport environment—of particular importance will be network slicing, expanding the quantity of connected devices, and facilitating the sharing of data. (see figure 3.7).

Technically, smart connectivity systems are platforms that support a highly flexible connectivity infrastructure that can dynamically adapt toward seamless and secure end-to-end interworking with computing resources and with a range of innovative devices. In the transport context this implies a proliferation of access points throughout the infrastructure and vehicles, providing ubiquitous connectivity for users, containers, infrastructure, cars, trains, and all other aspects of the transport environment.

FIGURE 3.7. 5G Features Applicable to Smart Connectivity



With 5G, the Internet will move from being available anywhere and anytime in a device to being available everywhere at any time through most devices. Interactions will differ; the mobile screen will no longer be the only possible interface for interaction with the Internet, vehicles, and goods, as devices will be connected and interact with each other. In fact, connection to the Internet will be transparent for the end user, with 5G embedded in the system in a way that obscures it. The most natural next step toward this vision is to distribute access points everywhere, in such a way that the distance to the end user is reduced to a few feet and ideally always within line of sight conditions. The shorter the link length the better for propagation, interference confinement, and feasibility of using higher frequency bands. This ultra-dense network could work, provided the new access points are deployed taking advantage of other upgrades on the infrastructure, such as on top of traffic lights or light posts. Lowering costs per device is critical to the economic viability of this smart infrastructure, and this is where the flexibility in 5G protocols excels in enabling access points to serve as low-cost transceivers.

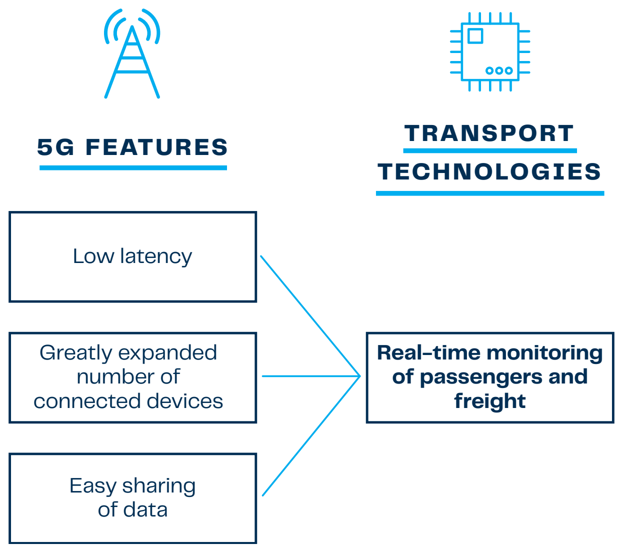
Another option that is gaining considerable interest is to deploy 5G access points on public transport vehicles themselves. These mobile cells can be integrated into the operator's network using 5G wireless bridges over the millimeter waved bands and guarantee better service within the wagons themselves in a more cost-effective manner than installing Wi-Fi in the vehicles (McKinnell 2019).

Such connectivity will enable a rapid expansion in the use of connected devices for infrastructure monitoring and maintenance, allowing for a more targeted and responsive approach by infrastructure owners. In instances of natural disasters, such connectivity will contribute to response and recovery efforts.

By enabling a proliferation of connected devices, reducing latency, and facilitating data sharing, 5G opens the door for a dramatic step forward in the tracking of goods as well as in identifying and meeting the needs of transport users (figure 3.8).

Improvement in monitoring the public through the advanced location mechanisms incorporated in 5G will allow better management of public transport, although associated privacy concerns will need to be addressed. For example, the allocation of vehicles to different routes may be modified to better respond to fluctuating demand, or the sequences of traffic lights could be modified to prioritize public transport. Advanced automatic ticketing schemes could enable not only contactless payment, but payment systems where the simple presence of a rider on a bus or shared bike is enough to identify and process payments. However, this requires a level of connectivity not possible under the current mobile standards. 5G will be the door to this new era of sustainable and efficient public transport, supporting citywide or countrywide Mobility as a Service (MaaS) schemes with enhanced safety and entertainment measures onboard and in stations. Increased connectivity of devices and the public's interaction with improved transport payment options will also allow a more granular collection of data on differentiated user mobility patterns, which can support better and more inclusive transport planning.

FIGURE 3.8. 5G Features Applicable to Real-Time Monitoring of Passengers and Freight



REAL-TIME MONITORING OF PASSENGERS AND FREIGHT

In terms of logistics, 5G could potentially be a strong enabler of new technologies. A survey by Moor Insights & Strategy (2015) reveals that 90 percent of logistics and shipping providers identify supply chain visibility as one of today's biggest logistics challenges. Increased visibility for fleet and cargo owners directly translates to decreases in delays and losses, ultimately saving time and money. With 5G and broader adoption of sensors, location tracking to the unit level can improve end-to-end visibility and reliability in product level delays and unforeseen travel circumstances, thus reducing revenue leakage and losses, including losses due to theft. In logistics, particularly in "just-in-time" scenarios, any time savings and enhancement in tracking brings significant cost efficiency. As an example, a good planning of the fleet resulting in the reduction of empty miles has a direct impact on fuel waste and, therefore, on the direct costs of operation. Therefore, technological advances, such as advance tracking, drone delivery, or AVs (trucks, cargo boats, and goods trains), propels growth in the logistics market.

Currently, logistics providers increasingly use IoT devices to track cargo, but 5G networks, characterized by low latency, will translate into real-time tracking (and 1 millisecond (ms) latency in reporting). Logistics providers will be able to (1) provide live status updates to their customers, (2) understand potential delays when shipping, (3) use AI to optimize fleet routes, based on the latest data, and (4) forecast exactly when goods will arrive. These benefits will also help increase location intelligence, optimize transport, minimize delays, and help customers better prepare to receive goods. 5G IoT devices can track more than shipments; they can also be attached to individual items for precise identification and location, significantly improve warehouse shelving, inventory management, and picking and packing operations, with a detailed understanding of exactly where a specific product is at all times. In addition, 5G tracking technology enhances warehouse management, while streamlining inbound logistics and outbound distribution. Items can be environmentally monitored at the product level by dedicated IoT sensors, subsequently gathering real-time information on measures like temperature, humidity, light levels, gas levels, and any other areas that could impact the quality or safety of sensitive products. With more detailed product monitoring, logistics providers will be able to: (1) ensure freshness of food and other perishable items; (2) help manage the safety of products that could be compromised, like chemicals or raw materials; and (3) deliver items to the quality the customer expects.

Furthermore, 5G can help improve last-mile delivery issues by seamlessly supporting new technologies, such as drones. For example, a remote pilot could fly a drone using video, or drones could become fully autonomous, with 5G supporting their sensors and communications. Self-driving vehicles can also help with last-mile delivery, enabling vans and cars to navigate to the customer's location. In the future, dedicated delivery robots could transport goods within cities, while autonomous public transport vehicles could respond in a more efficient real time manner to the ever-evolving transport needs of residents.

NOTES

1. In this context, "spectrum" refers to the portion of the electro-magnetic spectrum allocated to a specific radio-based technology (such as 4G LTE, 5G, or even FM radio or television). This spectrum must be allocated by national authorities, defining the specific channels and bandwidth established for each technology. While the influence of the country-specific policies is limited to a prompt and efficient allocation of the spectrum, the specific technology deployed in vehicles will be largely determined by market concerns and economies-of-scale. While outside of the scope of this paper, the current technical opinion is that C-V2X technologies will end up dominating the market, since they not only allow the inclusion of ITS services, but support other services that rely on Internet access, such as infotainment or cloud services.

2. The report authors have attempted to approach V2X from a technology agnostic perspective, seeking to inform policy makers of the status of ever-evolving technology options without recommending one specific technology. Policy makers may develop policies which favor either C-V2X or WAVE, or adopt a neutral stance, allowing industry and market self-regulation to decide on the most appropriate technology for transitioning to connected autonomous vehicles. Notably, in the technological dispute some evidence from both sides might not be as rigorous as needed; consequently, developing firm recommendations might not be possible at this stage.

REFERENCES

Asselin-Miller, Nick, Marius Biedka, Gena Gibson, Felix Kirsch, Nikolas Hill, Ben White, and Kotub Uddin. 2016. *Study on the Deployment of C-ITS in Europe: Final Report: Framework Contract on Impact Assessment and Evaluation Studies in the Field of Transport OVE/3/119-2013-Lot No 5 "Horizontal."* Report for DG MOVE MOVE/C 3. No. 2014–794. Ricardo Energy & Environment, London. https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf.

Hawkins, Andrew J. 2018. "Can 'Bicycle-to-Vehicle' Communication Help Make Cycling Safer?" *The Verge*, January 9. Accessed May 2020. https://www.theverge.com/2018/1/9/16870614/ford-trek-tome-bicycle-to-vehicle-communication-ces-2018.

McKinnell, Ellie. 2019. "This Is the Reason Why London Buses Don't Have Wi-Fi Yet." MyLondon.com, December 3. Accessed May 2020. https://www.mylondon.news/news/zone-1-news/reason-london-buses-dont-wifi-17353812.

Moor Insights & Strategy. 2015. "Can Jabil Revolutionize the Supply Chain?" White Paper commissioned by Jabil. https://www.jabil.com/dam/jcr:66273b14-209e-4ed5-8938-6fcf71049f82/can-jabil-revolutionize-the-supply-chain.pdf.


80
80
SELF DRIVING MODE
250
Rear view
16.5°
16.5

04

THE 5G-ENABLED TRANSPORT SECTOR

Although the technical fifth-generation (5G) standards continue to be developed, there is little doubt the innovations enabled by this technology will dramatically change the transport sector. There is little doubt the transport sector is undergoing a digital revolution, even without the advent of 5G. Ticketing is moving online, taking advantage of Fintech developments, multimodal transfers are connecting a variety of public transport services, and the transport of goods has been revolutionized by eCommerce. Vehicles are also becoming smarter, with systems providing ever higher standards of safety, navigation, and voice control. In cities worldwide, evolving business models are providing transport users with options they have never before enjoyed, with Mobility as a Service (MaaS) and new mobility options available at the touch of a screen.

The transport ecosystem now not only includes automakers, but also car-sharing services, public transportation, computing, and infrastructure providers. The market for connected vehicles is expected to grow by ten percent a year in Europe and almost thirty percent a year in China (Grijpink et al 2020). Although potential use cases of 5G are endless (table 4.1 collects the most significant transport-specific pilots so far), some aspects of the transport sector can be more clearly foreseen, especially those building on the already ongoing innovations and revolutions based on current technology, such as the growth of Transport as a Service (TaaS) and connected and autonomous vehicles (CAV) as mobility options for moving passengers, revolutions in the public transport sector and intelligent transport systems (ITS), and increasingly interconnected and multimodal freight.

From a business model perspective, the advent of hyperconnected and 5G-enabled vehicles will transform the transport business. Apart from MaaS, new opportunities will also arise based on the data generated by the proliferation of AVs—effectively super-efficient, moving sensors. New services based on big data aggregation, for example, real-time variable cost of car rides or media-intensive cybersecurity surveillance services, will allow for new business models to develop and thrive. Within the logistics sectors, the tracking of goods and increasingly efficient operations, including autotomized vehicles, will streamline and restructure how various transport modes operate, as well as facilitate multimodal operations.

This chapter identifies some of the clear trends in the transport sector, which will be empowered through 5G connectivity.

TABLE 4.1. Selected 5G-Enabled Transport Pilots

DATE	PLACE	PARTNERS INVOLVED	C-V2X USE CASE OR TOPIC	PRESS RELEASE URL
March 2018	Munich	Bosch, Huawei, Vodafone Germany	Real-time integration of 5G C-V2X with adaptive cruise control driver assistance system	1
July 2018	United States	Colorado Department of Transportation, Panasonic	Roadside units with real-time information about road conditions such as traffic delays, icy conditions, and crashes through continuous and automatic communications between individual vehicles and roadside infrastructure	2
December 2018	Japan	Continental, Ericsson, Nissan, NTT DOCOMO, OKI, Qualcomm	Lossless data transfers between vehicles traveling at up to 500 km per hour, even at distances of over 450 meters	3
January 2019	United States	Audi, Ford, Ducati, Qualcomm	Cooperative driving: four-way stops	4
January 2019	United States	Applied Information Inc.	C-V2X ITS technology deployed in over 500 U.S. communities, applied to traffic signals, emergency vehicle traffic signal preemption, transit bus traffic signal priority, school zone flashing beacons, variable message signs, work zone safety systems	5
February 2019	Czech Republic	T-Mobile, Deutsche Telekom, Skoda, C-Roads project	Direct communication among vehicles and between a vehicle and infrastructure	6
February 2019	Spain	Telefonica, Ericsson, Ficosa, Seat	Safer driving in a city (e.g., detection of cyclists when turning right or of a pedestrian at a zebra crossing	7
February 2019	Germany	Continental, Vodafone	"Digital safety-shield" for cyclists and pedestrians, using C-V2X direct communication and edge computingin the first 5G deployments	8
May 2019	Finland	5G-Drive project	Green light optimal speed advisory (GLOSA), intelligent intersection	9
June 2019	China	China Mobile, Huawei	19 potential usage applications so far, including emergency brake warnings from nearby vehicles, and a parking assist, including autonomous driving assistance and green waves for buses	10
June 2019	Australia	Telstra, Lexus Australia	Connected vehicle safety systems, including emergency braking alerts, in-vehicle speed limit compliance warnings, right-turn assist for vulnerable road users, and warnings when surrounding vehicles are likely to violate a red light	11
July 2019	China	BMW China, China Unicom	Autonomous cars using 5G networks	12
September 2019	United States	Sprint, HAAS Alert	Accident prevention	13
September 2019	Spain	Telefonica, DGT, Seat	IoT technology to increase cyclist safety on the road	14
November 2019	Italy	TIM, FCA, Ericsson, et al	Demos by the 5G Autonomous Association on 5G applied to safety	15
February 2020	Finland	Nokia, Lufthansa Technik	5G private wireless network, remote engine parts inspection for its civil aviation customers	16
March 2020	China	Nokia, China Mobile	Landslide monitoring and early warning system, real-time monitoring of sensors and warning	17
March 2020	Belgium	Nokia	Private 5G network and cloud computing for the Belgium port of Zeebrugge	18

Note: URLs for press releases listed in table: 1. https://www.huawei.com/en/press-events/news/2018/3/huawei-vodafone-bosch-smart-cars; 2. https://www.codot.gov/news/2018/july/cdot-and-panasonic-take-first-steps-to-turn-i-70-into-connected-roadway; 3. https://www.ericsson.com/ja/press-releases/2/2018/1/leading-automotive-telecom-and-its-companies-unveil-first-announced-cellular-v2x-trials-in-japan; 4. https://www.qualcomm.com/news/releases/2019/01/07/audi-ducati-and-ford-host-live-interactive-demos-las-vegas-using-c-v2x; 5. https://www.traffictechnologytoday.com/news/connected-vehicles-infrastructure/applied-informations-c-v2x-its-technology-now-deployed-in-over-500-us-communities.html; 6. https://www.t-press.cz/en/press-releases/press-news-archive/t-mobile-is-testing-cv2x-data-technology-for-vehicles-and-infrastructure.html; 7. https://www.telefonica.com/en/web/press-office/-/telefonica-and-seat-show-5G-connected-car-use-cases-for-safer-driving-in-a-city-environment; 8. https://www.continental.com/en/press/press-releases/2019-02-21-mwc-2019-vodafone-163980; 9. https://static1.squarespace.com/static/5bf2b77d75f9eefcd937cb5c/t/5d1a2dcf22c1f70001355277/1561996778142/3.+Uwe+Herzog.pdf; 10. https://5Gaa.org/news/5Gaa-brings-together-key-actors-to-share-advances-on-c-v2x-deployment-in-china-at-mwc-shanghai-2019/; 11. https://www.premier.vic.gov.au/connected-vehicle-trial-hits-the-road-in-australian-first/; 12. https://technode.com/2019/07/11/bmw-china-unicom-5G/; 13. https://www.telecompetitor.com/sprint-completes-5G-vehicle-to-everything-pilot/; 14. https://www.volkswagenag.com/en/news/2019/09/seat_cyclists_safety.html; 15. https://5Gaa.org/news/5Gaa-live-demos-show-c-v2x-as-a-market-reality/; 16. https://www.globenewswire.com/news-release/2020/02/27/1991601/0/en/Nokia-deploys-5G-private-wireless-network-for-Lufthansa-Technik-virtual-inspection-trial.html; 17. https://www.developingtelecoms.com/telecom-technology/iot-m2m-ai/9341-nokia-partners-with-china-mobile-to-deliver-iot-based-highway-landslide-alert-platform.html; 18. https://www.telecompaper.com/news/nokia-completes-first-phase-of-5G-ready-network-deployment-in-belgian-port-of-zeebrugge--1331836.

THE TREND TOWARDS CONNECTED AND AUTONOMOUS VEHICLES

5G-enabled cars will differ from today's cars in a number of ways, and the business models governing the transport sector will also be very different. As these trends will be mutually reinforcing and unlikely to happen independent from each other, this section addresses this broader transformation and the impact of its different components, one of which is, without a doubt, the connectivity offered by 5G.

As of March 2020 no connective and autonomous vehicles (CAVs) have the ability to operate without a safety driver on any street, in any weather, and with pedestrians and human-driven vehicles around. The main obstacles to overcoming these challenges include: (1) improved artificial intelligence (AI) algorithms, (2) more coordinated services and infrastructure (for example, external connectivity to the cloud or mobile cellular networks), and (3) policies and regulations to support CAV infrastructure. These challenges have not prevented experts from forecasting the impact of CAV on energy consumption, a topic of notable analysis in recent years. To this end, it is important to forecast when the four technological innovations posited by the CAV paradigm (electrification, autonomy, connectivity, and sharing) will be adopted, as discussed in figure 4.1.

Additionally, a prominent seminal study by Brown et al (2014) focused exclusively on energy issues and AVs. This was later extended to assess the effect on the environment (Wadud et al 2016; Stephens et al 2016), travel demands (Wadud et al 2016), and sustainability (Taiebat et al 2018), as well as to include CAVs in the analysis of Stephens et al (2016) and Taiebat et al (2018). At the end of the 2010 decade, with the advent of 5G connectivity technologies making possible highly-coordinated driverless scenarios, a succession of all-encompassing studies such as Fleming and Singer (2019), Taiebat et al (2019), and Lee and Kockelman (2019) appeared, which is proves the common understanding that CAVs will have a role in future ITS.

See Chapter 6 for a deep analysis of these dimensions.

FIGURE 4.1. The Four Technological Innovations in the CAV Paradigm

ELECTRIFICATION	Electrification refers to the increasing trend in electrical drivelines (the main components that generate power and deliver that power to the road surface), and according to estimations by J.P. Morgan (2018) will represent one-third of all vehicles in 2025 and approximately two-thirds in 2030, hybrid vehicles included.
AUTONOMY	Autonomy deals with the goal of a vehicle being able to sense its environment and moving safely with little or no human input. In this regard, a recent survey by J.D. Power (2019) shows that automotive and technological industry experts predict the self-driving robo-taxi will not be technically viable until 2025. This survey also anticipates the first fully AVs will be in the consumer market around 2030. In addition, in 2035 10 percent of the vehicles will be AVs.
CONNECTIVITY	Connectivity alludes to the list of innovative mobile communication technologies, prominently 5G, that will make possible novel and useful driving techniques on the CAV. If past history is indicative of future performance, most wireless air interface technologies have had a lifespan of about 8 to 10 years. However, the case for 4G LTE is still unclear. Back in late 2009, the first commercial LTE network was launched in the city centers of Stockholm and Oslo by TeliaSonera, but according to latest edition of the Ericsson Mobility Report (Jonsson et al 2019), LTE is still growing globally since it achieved markedly prevalence back in 2016. This report also expects that by 2022 LTE will hit its peak globally. After that, Ericsson believes that LTE will decline by the end of 2025, when 5G will cover up to 65 percent of the global population and handle 45 percent of global mobile data traffic.
SHARING	Sharing denotes the paradigm shifting dimension of the CAV as property, from individual privately owned to publicly shared vehicles. Because of its potentially disrupting nature, it is not especially surprising that the transition from personal vehicle ownership to shared driverless mobility will not come quickly. According to a 2016 report by Deloitte on the future of mobility (Corwin et al 2016), the market for personal mobility could transform radically over the next 25 years. The report still predicts about 88 percent personally-owned driver-driven cars of the 2025 market, but envisions the shift happening finally and almost completely, and by 2050, shared mobility will account for 80 percent of the market, especially if steered by the implemented policies.

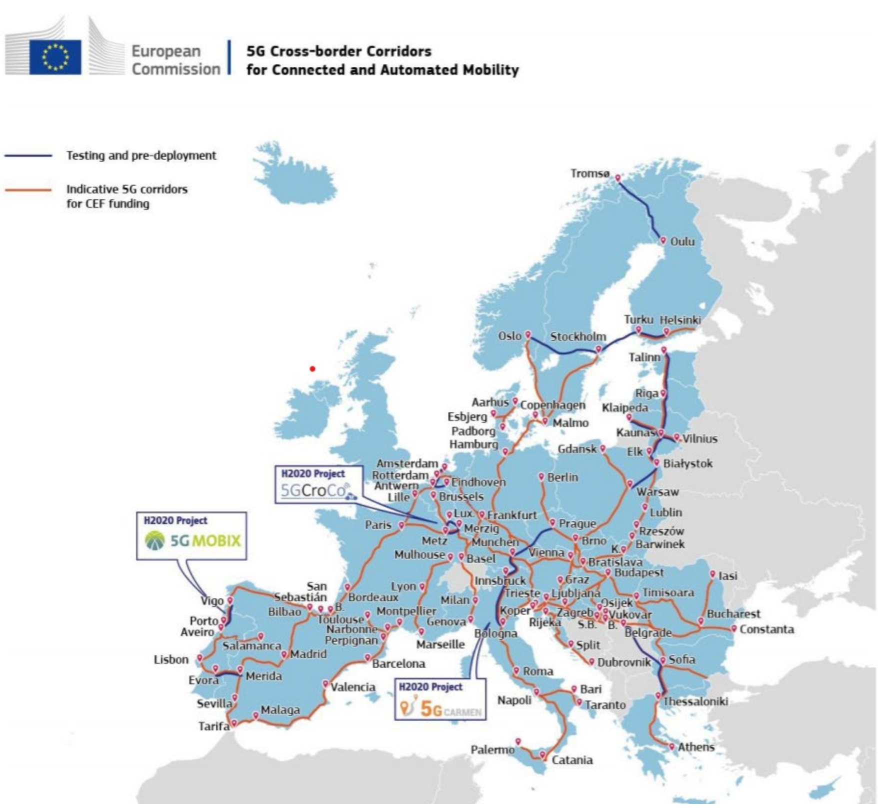
The case of Europe's 5G corridors

5G corridors make Europe the biggest experiment area rolling out the 5G technology. Within the European 5G vertical strategy, connected and automated driving (CAD) is considered a flagship use case for 5G deployment along European transport paths, in view of creating complete ecosystems around vehicles beyond the safety services targeted by the cooperative intelligent transport system (C-ITS) roadmap of Europe. In 2018, the 5G European network signed further regional agreements on 5G corridors. Following those new agreements, a pan-European network of 5G corridors (figure 4.2) is emerging with hundreds of kilometers of motorways where tests will be conducted up to the stage where a car can operate itself with a driver present, and under certain conditions (SAE Level 3 automation). Notable examples include: The early cooperative ITS joint corridor between Amsterdam, Frankfurt and Vienna; another joint corridor announced by France, Germany, and Luxembourg between Luxembourg, Metz and Merzig; followed by Norway, Finland, and Sweden with the E8 corridor between Tromsø (Norway) and Oulu (Finland), and the E18 corridor between Helsinki, Stockholm, and Oslo; and the Netherlands and Belgium join in with the Rotterdam–Antwerp–Eindhoven corridor. Furthermore, work continues on developing corridors between Spain and Portugal, while Greece, Bulgaria and Serbia continue to expand the Thessaloniki–Sofia–Belgrade corridor on the Brenner pass motorway toward Italy.

In addition to these initiatives, three Horizon 2020 projects were launched in November 2018 to conduct large-scale 5G connectivity testing and trials for CAD over cross-border corridors, under the umbrella of the 5G Public-Private Partnership (5G-PPP). Benefiting from a nearly €50 million funding, for a combined total budget of €63 million, the three projects cover three 5G cross-border corridors (highlighted in figure 4.2):

- ***5G-CARMEN:*** spans 600 km of roads across an important north–south corridor from Bologna to Munich via the Brenner Pass
- ***5GCROCO***: stretches over highways between Metz, Merzig, and Luxembourg, crossing the borders of France, Germany, and Luxembourg
- ***5G-Mobix:*** runs along two cross-border corridors between Spain and Portugal, a short corridor between Greece and Turkey, and six national urban sites in Versailles (France), Berlin and Stuttgart (Germany), Eindhoven-Helmond (Netherlands), and Espoo (Finland)

FIGURE 4.2. European 5G Cross-Border Corridors



Source: European Commission 2020.

These efforts in Europe highlight the importance of regional collaboration for advancing technical specifications and requirements along with enhancing peer-to-peer learning. Creating regional observatories or platforms to discuss the implementation of new ITS at the regional level could also be considered.

SMART AND EFFICIENT LOGISTICS

The logistics market is expected to register a compound annual growth rate of more than 3 percent in the next three years, reaching a market size of around US$12,256 billion by 2022 (Sonawane 2017). The movement of goods between the provider and the receiver requires accurate goods flow management in order to meet customer requirements and reduce transportation costs. In this context, any action that could strengthen the capabilities of logistics will have a significant influence on the sector.

The 5G technology incorporates three fundamental dimensions for increasing logistics efficiency. On the one hand, 5G enables the operation of autonomous vehicles, by land, by sea, or by air. On the other hand, 5G simplifies many communications and signaling processes, and includes a simplified radio configuration, known as Light New Radio (NR), which is precisely designed to reduce costs (US$5 per device) and increase battery life of devices, up to 10 years. 5G is specially designed for massive machine-type communications (mMTC), allowing what is known as the wireless Internet of Things (IoT) on a large scale. This capacity, within logistics management, will allow for locating all containers, pallets, packages, or other transport units throughout the distribution chain. The on-demand transportation service enabled by this live-tracking of goods and transport units requires the maximum penetration of third-party logistics (3PL) players, which are typically not well introduced in developing countries. Because of their capacity to adapt their equipment and systems quickly, 3PL should prioritize bringing 5G technologies into the logistics field. Finally, the impact of autonomous vehicles may be seen first in the logistics sector, as long-haul trucking presents one of the simplest and most controlled contexts for autonomous vehicle application.

Third-party logistic players must be incorporated in the national transport ecosystem. The use of 3PL companies has managed to reduce empty miles in logistics from 40 percent to 20 percent (Agenbroad et al 2016). Moreover, the inclusion of 5G massive machine-type communications in logistics, allowing the real-time monitoring and tracking of transport units, together with the brokerage provided by 3PL, is estimated to increase truckers' revenue by 15 percent, while costs of shippers could be reduced by up to 70 percent. The impact of 5G on logistics management will be much less without the incorporation of these intermediate players, necessary to maximize the use of transportation resources.

The use case of logistics can be divided into three components: railways, truck transport in roadways, and port management. Analysis of these three elements follows.

5G in the rail network

In the rail sector, deployment of 5G capacity could bring a number of benefits, including reliable communications for safer and more efficient operation, the possibility of providing passengers with on-board broadband multimedia services, and increased capacity of trains in the rail network.

In addition, safety-critical train operations will require an updated technology, as the only cellular technology specifically designed for train communications is based on GSM (GSM-R), which will be obsolete by 2030. Thus, considering the fifive-year time frame for migration of the rail network, the rail industry will need a long-term solution by 2025. The International Union of Railways (UIC), the railway standards-setting organization, is already considering a new standard called the Future Railway Mobile Communications System (FRMCS) that will not only replace the old systems, but also introduce new capabilities consistent with 5G features. This presents a strong opportunity case for 5G to take over this replacement, as it will allow the widespread deployment of IoT in rail, and will enable real-time monitoring of energy and asset information for the whole network, including ticket-office queues, real-time train load rates and information to better distribute passengers, rolling stock, power grid, peak electricity consumption, or wear of axles or other technical components of the trains. 5G is necessary to monitor and manage the increase in the amounts of data and connected devices, as current technologies lack the required capacity. Moreover, 5G would enable railway operator sensors and actuators to be combined with other smart-city specific sensors, which would improve the system's collective intelligence.

With respect to the density of trains in the railway, systems such as the U.S. Positive Train Control (PTC) technology are deployed in various regions, all with the same function—to automatically stop a train to prevent train-to-train collisions. The minimum separation between trains depends on the weight, size, and speed of the train, and also on the total latency in the communication chain. With current satellite-based solutions, the latency is up to 20 seconds (Tse 2008); reducing this time to a milliseconds range while increasing the reliability to 99.999 percent could have a positive impact in security and, subsequently, on the efficient use of rail network even with unmanned trains. With conventional signaling, this distance between trains is currently very high, with a low flow rate on the railway line. 5G will facilitate reducing space between two trains and improve the flow. Only 5G can transfer the large amount of data required to make the proper calculation, since the inhomogeneity of trains requires the transfer of thousands of parameters from different sensors.

Conditional maintenance is another important matter. Once all metrics collected from sensors are collected in real time, train status will be softly monitored, resulting in the prompt and on-demand reparation of train assets.

5G for trucking

5G is expected to improve trucking in two ways: by increasing efficiency, and enabling real-time monitoring and tracking.

Trucks are especially well-suited to benefit from platooning (box 4.2 discusses a platooning trial in Japan), where one truck follows closely behind another, creating a convoy that moves simultaneously.

BOX 4.2. Japan Puts Truck Platooning to the Test

Since 2017, Japan's Ministry of Internal Affairs and Communications has encouraged 5G system trials, including a collaborative trial led by SoftBank on truck platooning. Truck platooning involves multiple trucks driving together in a convoy, controlled as a unit by using intervehicle communication. Globally, several tests to implement truck platooning are underway; Volvo is one of the leaders around this use case.

Several social issues can be resolved through use of truck platooning. Platooning enables trucks to drive closer together to reduce wind resistance, which can reduce fuel consumption and reduce CO_2 emissions. Evidence indicates a platoon of three trucks traveling 4 m apart at 80 km/h consumes 15 percent less fuel. If the distance between trucks is reduced to 2 m, the fuel consumption could be reduced by 25 percent. Reducing the distance between vehicles can also increase the traffic capacity of roads, mitigating congestion and further reducing CO_2 emissions.

This specific trial in Japan tested the ultra-low latency radio capabilities of 5G for two use cases: (1) communication between vehicles involved in platooning, and (2) remote monitoring and operation of the entire truck platoon. The trial results confirmed that 5G communications met the requirements for advanced truck platooning.

The lead truck makes decisions for the overall platoon, while the subsequent trucks automatically react and adapt their movements to follow the leader's actions. The closer trucks are to each other, the better the energy efficiency; however, maintaining such distances requires increasingly critical vehicle-to-vehicle (V2V) communications, mostly in terms of reliability and latency. With the low latency and reliability inherent in 5G communications, the distance between trucks could be reduced to less than 1 meter. Under such conditions, reductions in air friction may reduce fuel consumption by up to 16 percent (ERTICO 2016). A study by Scania finds a slightly lower benefit, down to 12 percent (Liang et al 2015), still a significant savings.

Despite the close distances involved, 5G-enabled platooning offers potential safety benefits as well. With a response time much faster than the human reaction time, such a configuration improves safety by making braking automatic and simultaneous, avoiding an accordion effect and, thus, rear-end collisions. All in all, 5G platooning can improve the efficiency of highway traffic, and reduce traffic jams and pollution.

This is likely one of the first applications of 5G-enabled transport to come to market, first along highways and dedicated corridors, and subsequently in more complex environments. Current state-of-the-art platooning technologies can be classified as SAE Level 2 driving automation, with communications standards expected to be completed by 2021 and market introduction expected by 2023. Further evolution toward SAE automation Levels 3 and 4 are expected to come to market by 2030, in which platooning could operate in complex scenarios, including cities. By that time, the deployment of the 5G should be complete. This is a real game-changing model. Having trucks working for 24 hours would be possible with a three-truck platoon, whereby the three drivers work on a rotating basis, with one controlling the platoon while the other two drivers rest. This would be possible with low 5G coverage with truck platooning based on V2V communications.

With respect to real-time monitoring of trucks, 5G offers enormous potential. Already in place in some countries (such as the electronic logging devices recently mandated in the United States) using 3 and 4G technologies, the introduction of 5G will allow for a dramatic increase in capacity. For instance, the interconnection of a huge number of sensors and low-latency connectivity would allow real-time decision making, potentially stopping a truck before mechanical failure could cause a crash or detecting abnormal behavior in the driver, signaling it may be time for a stop. The insurance industry could also deploy diagnostic plug-ins to collect data about truck-driver behavior, under the condition of reduced fees. Moreover, 5G will also provide better geolocation tracking thanks to the use of beamforming pilot signals, which, together with assisted GPS solutions, could allow better tracking in narrow streets, tunnels, or under other situations in which the GPS signal is often lost.

5G in port management

Finally, regarding port management, although only limited progress has been made in few use cases, two initial 5G tests have been implemented in the port of Rotterdam (Netherlands) and Bari (Italy).[1] The test in Rotterdam focused on the massive deployment of wireless sensors, allowing for the real-time monitoring of the movement of goods and the production of industrial processes in the port. To increase sensor reliability, a 5G dual band network (operating in the 700 MHz and 3,500 MHz bands) was deployed in the port. The test included analysis of the role of ultra-high definition video surveillance, alongside AI, was analyzed for the detection and management of loading and unloading cargo. Results indicated that maintenance was better predicted, and the additional information given to the inspectors allowed almost automatic failure detection. Finally, unmanned robots were used to inspect gas leaks. Substituting the human process with a machine-assisted process increased the inspection's accuracy and reliability, in addition to making the process safer. In addition, human inspectors were equipped with an advanced communication helmet that connected the team via video with experts who could offer timely recommendations on the any needed repairs. According to the inspectors, this advanced connectivity reduced the decision time from a few days to a few minutes.

5G in aviation

Despite the wide-ranging impacts of 5G on the transport sector, applications for aviation will likely be limited to issues of unmanned aerial vehicles (UAVs) and the lower skies. While the aviation sector is developing more sophisticated communication technologies, they will not be based on 5G standards since commercial flights operate at altitudes outside the coverage of cellular technologies, and over oceans where such technologies are not deployed.

For better results, the drone industry requires a quick drone-to-computer (or drone-to-cloud) data transfer to decrease data processing time, and therefore, it requires a low-latency connection for live view or live video streaming. In terms of UAVs, 5G may have an impact along two key channels: (1) low latency will allow for better traffic management in crowded airspace and urban environments, enabling UAVs to respond more nimbly to remote instructions and adjust their routes based on changing conditions and air traffic; and (2) greatly expanded bandwidth will enable the streaming of high-resolution video back to a base station. Such bandwidth ensures better sensors, navigation, and guidance systems which all lead to reliable, time-sensitive drone platforms.

The deployment of 5G wireless technologies will allow cities and regions around the world to modernize and make their transport and mobility more efficient, improving public transport operations and planning, even introducing dynamic transport planning, reducing traffic congestion, and giving much more space for cyclists and pedestrians (increasing social distancing in times of pandemic). 5G will also enhance users' safety and onboard experiences while commuting, improve targeting of users with special needs, and generate more revenues by increasing public transport ridership or through a best use of MaaS platforms—as in the cases of Jelbi in Berlin and Whim in Helsinki. With 5G, cities could provide public transport users with better information, single payment and ticketing procedures for several transport modes, and increased onboard wireless connectivity.

In many cities, a number of innovations have already been integrated into the planning of mobility systems, for instance: (1) georeferenced user information to minimize travel times for individual or collective motorized transport (public or private); (2) crowd sourcing with advances in algorithms (big data, analytics, or machine learning, and IoT); (3) larger storage and processing capacity (especially with cloud processing), which has allowed breakthroughs in the efficiency and effectiveness of urban mobility; and (4) AI programs on integrated mobility control centers that analyze mobility patterns and provide instant solutions for improving planning and traffic flows.

Such innovations can provide support for establishing technology-based integrated management systems able to process data coming from billions of devices and to improve the efficiency of public transport, ease congestion, and share transport and traffic information among users. While technologically possible, enhanced and flexible institutional coordination and efficient regulations among transport stakeholders is key to deploying such systems.[2] Otherwise, they will continue to operate separately, with a private-owned system driven by profits, which does not provide benefits for the city as a whole. Only by ensuring the coordinated integration of a city's public transport systems, as some models have shown,[3] will the MaaS concept become a reality (Busvine 2019), by leveraging a variety of transport modes to deliver efficient mobility for urban residents. Already important in the 4G era, transport system integration will be ever more crucial with the roll out of 5G.

Unfortunately, many cities are not using the available innovations to improve urban mobility patterns, at least not on a mass scale. Many transport agencies and public transport companies continue to rely on old technologies and distrust investments in technology because of previous failures. Today, many cities still have control centers (if they exist at all) that rely only or mostly upon street cameras that focus mainly on traffic management, without taking advantage of the increasingly dense mobile and vehicle data.

Developing an integrated mobility system

Mobility as a Service (MaaS) is the concept or idea of integrating various forms of transport services into a single mobility service accessible on demand, including mass-transit public transport services. For the user, MaaS offers added value with a single application (or several apps competing among each other) to provide access to mobility, with a single payment channel instead of multiple ticketing and payment operations. In order to meet a customer's request, a MaaS operator facilitates a diverse menu of transport options, be they public transport, ride-, car-, or bike-sharing, taxi, car rental or lease, or a combination of options. A successful MaaS service also brings new business models and ways to organize and operate the various transport options, with advantages such as access to improved user and demand information and new opportunities to serve unmet demand for transport operators. The aim of MaaS is to be the best value proposition for its users, providing an alternative to the private use of cars that could be more convenient, more sustainable, and cheaper, while liberating public space for other users, such as public transport, cyclists, or pedestrians.[4]

MaaS has many benefits for cities and their citizens if well-regulated, improving ridership habits and numbers, reducing congestion, increasing transit network efficiency, and increasing public space. The implementation of the MaaS concept may be even more impactful following the COVID-19 pandemic—with public transport vehicles reducing their load capacity to ensure social distancing—making the need for efficiency more crucial than ever, if regulated to disincentive use of private cars, MaaS would provide users with cheaper mobility or better service for the same tariff when well-integrated with efficient public transport systems and with other private-owned networks, resulting in reduced emissions as more users rely on public transit components or CAVs in a MaaS network.

Real-time information about the myriad of transport solutions (metro, suburban rail, bus, minibuses, docked bike sharing, floating car-, bike-, and moto-sharing services, floating or docked scooters, cable cars, taxis, etc.) and their integration is key for driving development of sustainable modes. Making this happen requires better physical and digital interconnection among transport modes and better regulation of the transport demand from users. 5G has a role to play in providing accurate data from users that will allow the transport operators to modify their offerings according to changing demand. MaaS platform apps for transport systems where all options and modes are integrated can only grow in efficiency and dynamic demand responsiveness when more capacity for data is available, especially for users on the move; this is main reason why 5G will essentially push for more—and more competition between—MaaS platforms.

Thanks to this surge in efficiency, the adoption of 5G by the urban mobility sector will likely lead to new players creating more jobs in cities, generating opportunities for young graduates to develop their careers in the connected mobility industry. For example, the proliferation of 5G in transport applications will likely spur creation of new market players that will become third-party virtual transport service providers (for example, MaaS platforms competing among each other and with city-owned MaaS platforms) similar to how mobile virtual network operators changed the telecom space. These virtual transport service providers could leverage the network slicing feature of 5G networks to offer specialized and customized services—especially MaaS apps in cities and eCommerce delivery options. For example, large megaregions in emerging countries with successful MaaS platforms can adapt the platforms elsewhere, potentially creating a unicorn[5] that will support the digital economy. These ideas could develop further than the MaaS in urban environments and virtual transport service providers can be created to serve national or regional markets of interurban passenger transport services.

In addition, the growth in 5G-enabled smart connectivity may improve users' ability to impact their urban mobility experiences. It will facilitate the collection of user feedback on the quality of public transport, moving from face-to-face surveys into new ways of considering users' opinion, as the new players in mobility (and elsewhere) have demonstrated. For instance, ride-hailing customers evaluate drivers at the conclusion of each ride, and the feedback is used to give preference to well-reviewed drivers. Already being implemented under current 4G technologies, such services will certainly expand under 5G; for instance, by using improved location tracking and a massive amount of IoT sensors to identify users of various transport modes (including cyclists, pedestrians, or users of free public transport options) and by collecting feedback on user experience. Moreover, ensuring that socially vulnerable people or those with disabilities can communicate effectively with transport agencies and operators is key for addressing their particular challenges. This, in fact, would allow better targeting of public transport subsidies for people in economic need. Effectively capturing users' opinions through fast and reliable technology can also support the improvement of physical infrastructure. Through applications such as geofencing, audits to help measure women's safety can be facilitated, providing real-time feedback by targeting specific areas in public spaces. This can be particularly useful in supporting environmental design focused on violence prevention to increase women's safety.

5G and the public transport value proposition

Onboard enhanced connectivity will allow commuters to enjoy entertainment or work as if they were in their houses, thus reducing the perception of cost of time. In the short to medium term, this provides a clear advantage for public transport over private cars. However, with the imminent availability of CAVs and consequent liberation of the driver, this dynamic may disappear. Enhanced connectivity onboard public transport vehicles will also enhance security onboard, as vehicles could share the real-time video feed with the city's operations control center or service providers—potentially capturing sexual violence, robberies, assault, or other violence, or a medical emergency—and enabling the timely dispatch of emergency services, if needed. This recommendation has been highlighted in several reports, including the World Bank study on women's mobility in Latin America (Dominguez et al 2020). With 5G enhanced connectivity, the control center, police, or any other service could respond faster in case of emergency if the bus driver or rider pushes the panic button, as defined in the appropriate protocols. This will promote a safer perception of public transport, especially for women or groups in vulnerable situations (Metea 2019).

Most importantly, 5G would enable large amounts of data from mobile transport users through creation of dynamic transport demand management tools, such as the continually evolving origin–destination (OD) matrix that shows almost real-time transport demand and allows operators to adjust the transport options offered to users. Cities already use cell phone data when developing OD matrices as part of urban mobility planning, but 5G offers more data, and in real-time. In parallel, enhanced monitoring and control of the public transport fleet would improve transport operators' ability to adjust options and plan services by analyzing data collected from connected users; this data would then become the best proxy for transport sector users, helping to create the dynamic transport demand matrix in any city. The first apps or chat bots designed to understand users' future travel needs have already appeared during the COVID-19 pandemic, a global experience that perfectly illustrates the increasing need for a dynamic OD matrix; in the near future, 5G will bring exponentially more relevant data.

5G will offer transit operators thousands of minute-by-minute data gatherings, with information on users' transport needs and the best-suited modes for each user, even with large numbers of active users in the system at the same time. This data will help increase system utilization and allow for dynamic routing and scheduling of transport services, which is even more crucial during and after public health crises—such as the COVID-19 pandemic and its requirement for social distancing—when many essential workers must still rely on public transport to get to work. In times when buses and trains are running at lower occupancy, better demand management and on-time planning can be the key to keeping cities and transport systems running. This will particularly benefit certain

population groups, such as low-income women living in peripherical areas where the few and unreliable transport services put them at risk—from longer wait times in unsafe areas or from interactions with informal modes of transport, which often cover an unsatisfied demand (Dominguez et al 2105).

In relation to commuting, enhanced MaaS and public transport, 5G connectivity will help reduce traffic congestion, especially if the 5G can also support investment and deployment of smart traffic lights and other vehicle-to-infrastructure (V2I) communications. Congestion could be reduced by 40 percent, saving drivers and operators in medium-sized cities approximately US$100 million annually (Al Amine et al 2018). If upgraded with intelligent transport services available to cars, traffic management systems will be the main tool for reducing congestion, thanks to 5G's ultra-fast speeds, as buses would be able to platoon in "convoys" if the demand is needed. This, in turn, would increase standardization of buses and reduce the need for articulated or other special vehicles, thus increasing the road vehicle capacity and providing substantial energy savings for transport operators. The same can be applied to cars or trucks, and with autonomous cars in the longer term, smart traffic management systems would be able to prioritize public transport and non-motorized transport (pedestrians and cyclists) (Botello et al 2019). The improved traffic lights systems will help cities deploy MaaS and provide more time and priority for active users of both MaaS and public transport, promoting these transport modes while at the same time reducing congestion, delivering additional productivity and quality-of-life for citizens, and most importantly, freeing up public space for the citizens to use.

Lastly, regarding the multimodal journey planners for intercity or international trips, 5G would also support the capacity of users to access multimodal trip websites allowing them to book door-to-door trips.

5G and the deployment of non-motorized transport

With COVID-19, many cities are, more than ever, encouraging citizens to use bicycles, creating many emergency cycle paths and even building more lines for the long term. As explained above, 5G can support the increase of active transport modes in the city via smart traffic management and traffic light systems. 5G-based augmented reality (AR) can also enable tools that will make cycling in the city safer, as the AR will inform cyclists of dangers in the same way vehicle-to-everything (V2X)-equipped cars would alert the driver of potential dangers. This will increase the perception of safety and could eventually increase bicycle ridership. In addition, bikes can even connect directly with emergency services, for instance, via an e-call service for urban cyclists.

5G will also encourage more use of peer-sharing of information, with the development of more cyclist-specific smart mobility platforms.[6] Bikers on these platforms can upload information on road conditions, building sites, or unexpected incidents such as road accidents, which the platform then shares with other cyclists; 5G would enable the smartphone or the smart bicycle to upload this information independently.

Finally, 5G can support the new mobility transport modes by potentially skyrocketing the use of either bicycle or scooter sharing schemes. By making these schemes more interoperable with the other modes of public transport and by providing operators with much more detailed data on current and planned trips, services can be more supportive of the integrated MaaS offering.

Smart connectivity for public transport operations and traffic control

Currently, many cities do not have a proper control center for public transport and traffic, or one that is integrated with digital technologies. In any successful control center, the main benefit comes from integrating all players—including emergency services such as the fire department, civil workers, police, bus agents, traffic agents, etc.—in the same site or at least under the same digital or cloud platform. Expanding this potential, 5G supports integration of a much wider cloud of sensors (such as those on infrastructure, public transport, connected vehicles, or mobile phones), all actively gathering and sharing larger amounts of data instantly. This enables smarter monitoring and enforcement across modes and services. The ability to effectively manage larger loads of data is key even if the entire control center system is integrated in the cloud alone, rather than at a physical location.

Integrating control centers will help ensure effective fleet management that benefits users. 5G has a role to play in this by sending, recurrently, the transport vehicle's GPS location and other information (loading factor, speed, dangerous situation onboard, etc.). This information will increase the users' perception of safety and will also provide good quality onboard entertainment content or wireless access to work, an added value over other transport modes.

The indiscriminate use of individual transport increases congestion in cities, creating issues for all road users (including bus users if buses operate in mixed traffic lanes with other vehicles) and increasing emissions. The development of CAVs could only exacerbate this challenge if their proliferation erodes the value offered by public transport, while private ownership of cars remains the norm and congestion is not regulated. Currently, most private vehicles are owned by single users, and despite vehicle owners paying property taxes on car ownership, such taxes are insufficient to address the negative externalities created by private cars, build and maintain roads, and support other mobility options. Many cities handle congestion through license plate restrictions, which have been shown to be of limited benefit for long-term regulation of urban congestion (Cantillo and Ortúzar 2014). Regulators will need to find ways to move from control (the plate mechanism) to command (for example, the congestion tool), thus managing more effectively the transport demand. They will also need to explore incentive schemes that allow for an increase in the use of collective and active modes in general, that once again depend on the business model adopted by the government—and, ultimately, on governance. Indeed, 5G has a role to play in deploying these new models by allowing a massive amount of data to travel more quickly between a huge number of sensors, the cloud, and across various databases to enable and subsequently enforce new congestion restriction models, including the potential to restrict the amount of CAVs entering cities with the ultimate goal of reducing the urban space used by vehicles while increasing the space available to pedestrians and other modes.

Regarding governments and the affordability to finance deployment of the 5G network and the related ITS services, public-private collaboration is seen as one of the main enablers to make use of the infrastructure sharing concept. Taxing the negative externalities such as pollution and use of road space for private cars could be one of the modes for partially financing deployment of the infrastructure needed to advance digital transport and mobility in urban environments. The way forward includes using the "dig once" policy for infrastructure sharing, creating a network owned or regulated by the public sector to allow different uses, along with cost sharing. Some cities have started to think ahead on implementing these types of solutions, focusing on innovation-friendly regulations.

As explained previously, 5G will enable the deployment of many V2I systems, which could offer a strong case for infrastructure sharing. Such systems will connect, for example, vehicles with traffic lights and other infrastructure and services, providing information on parking spots, speed limits, sensors to signal wrong-way traffic, restricted areas, limited use areas, or loading zones, potentially providing tools for reserving such spaces if needed. In addition to the traffic light systems being modernized as mentioned above, all urban furniture (bus stops, traffic lights, or street lighting poles) can serve as a host for installing the neutral host 5G receptors in densely populated areas in cities (Tomás 2019), where the 5G will require ultra-dense networks. An upcoming study in Sao Paulo, Brazil, will analyze the financial and technical feasibility of deploying the 5G network along with the smart traffic lights and traffic management systems.

In regards to traffic management systems, many cities are creating more space for cyclists and pedestrians in downtown areas and in many neighborhoods, by restricting the access for private cars to neighborhood residents only. Zone access control, together with enforcement of traffic lights violation and possible establishment of congestion charging areas or a low-emissions zones, can be easily done with current technology; however, 5G will improve license-plate recognition and will provide much faster response to any violation, thus reducing the number of cars entering restricted or congested areas. This technology can also assist urban freight delivery in booking parking spaces and increase their productivity when delivering, through smart freight space management, needed more than ever with the expected substantial increase in eCommerce.

For this reason, cities should use 5G to reduce public space dedicated to cars, making public parking areas available for car sharing, for bike sharing, for scooters, for loading and unloading of goods, and most importantly, increasing space for use by the public or even the private sector (restaurants, terraces, etc.). Shifting the use of urban space, together with the decrease in work-related commuting—thanks to the increase in teleworking, or working from home—can have a huge impact in the way the cities are organized geographically. Cities can grow several sets of new urban centers, providing easier access to services and jobs for people that live in neighborhoods offering few job opportunities to residents. The new mobility patterns enabled by 5G's enhanced connectivity—if the city decision makers apply favorable territorial and mobility policies — can transform the city from a radial central business district (CBD) shape into a multicentric shape of many neighborhoods connected by public transport, where pedestrians and cyclists enjoy ample public space, thus increasing the number of small-business jobs. Again, this is one of the main comments reflected in the study about women's mobility (Dominguez et al 2020), that many women were reluctant to accept jobs located at long distances from their places of residence. Acknowledging the urban model will only change with the advent of connected mobility, increasing the space for pedestrians, cyclists, and public transport users can have a deep impact in the way citizens move themselves and, in the end, transform the urban and economic fabric.

These potential changes will bring more jobs closer to where people live, increasing job accessibility for residents while reducing the need for long commutes on public transport or by private car. However, private car trips will continue to exist, and public parking spaces will still be needed; however, these spaces can be better managed by using real-time information to identify empty on-street parking spaces, adjusting parking prices depending on demand, and allowing drivers to reserve parking spots—directing the driver to an open space, identified by a low-cost 5G sensor on a street lamp. Combined with the smart metering systems already deployed in some areas, advanced wireless connectivity could increase parking revenue by up to 30 percent, while also helping reduce congestion and idling (Woetzel et al 2018).

The ability to identify and reserve open parking spaces for car-sharing users and last-mile freight logistics services through use of low-cost sensors and apps for the loading and unloading space management, can increase parking revenue, reduce the demand from private cars by reducing the available options, and indeed reduce the time delivery vehicles need to find parking, which both reduces congestion and benefits all commuters and residents by encouraging only essential, economy-boosting traffic downtown.

Finally, in relation to the affordability of 5G for users, public transport operators, and government authorities, adopting the technology features available with 5G can reduce operational costs and maintain affordable tariffs by facilitating more efficient, better services in response to real-time demands. In addition, improved demand-management of ticketing and smart-card systems helps identify people who are most economically or socially vulnerable, and helps ensure they receive tariff subsidies to make their transport expenses more affordable.

NOTES

1. For details on the Bari (Italy) 5G project, see: https://www.telecomitalia.com/en/press-archive/market/2017/NS-5G-Bari-e-Matera.html.

2. For more information, see Here Mobility's "Smart Urban Mobility: A Quick Start Guide." https://mobility.here.com/learn/smart-city-mobility/smart-urban-mobility-quick-start-guide.

3. Vilnius, Vienna, Berlin, Helsinki, along with some other cities, have fully integrated MaaS functioning platforms.

4. Definition provided by the Mobility as a Service Alliance: https://maas-alliance.eu/.

5. Unicorn denotes start-up companies with a market value larger than US$1 billion.

6. Smart Cyclist-specific mobility platforms have recently been piloted in Cologne, Germany; Porto, Portugal; and Trikala, Greece.

REFERENCES

Agenbroad, Josh, Dave Mullaney, and Zhe Wang. 2016. ***Improving Efficiency in Chinese Trucking and Logistics***. Boulder, CO: Rocky Mountain Institute. Accessed June 2020. https://rmi.org/wp-content/uploads/2017/03/China_Trucking_Charrette_Report_2016.pdf.

Al Amine, Majed, Kenneth Mathias, and Thomas Dyer. 2018. "Smart Cities: How 5G Can Help Municipalities Become Vibrant Smart Cities." Accenture. Accessed June 2020. https://www.accenture.com/us-en/insights/strategy/smart-cities.

Botello, Bryan, Ralph Buehler, Steve Hankey, Andrew Mondschein, Zhiqiu Jiang. 2019. "Planning for Walking and Cycling in an Autonomous-Vehicle Future." ***Transportation Research Interdisciplinary Perspectives*** 1 (June): 100012. doi: 10.1016/j.trip.2019.100012.

Brown, Austin, Jeffrey Gonder, and Brittany Repac. 2014. "An Analysis of Possible Energy Impacts of Automated Vehicles." In ***Road Vehicle Automation***, edited by Gereon Meyer and Sven Beiker, 137–53. Lecture Notes in Mobility Series. Switzerland: Springer International. doi: 10.1007/978-3-319-05990-7_13.

Busvine, Douglas. 2019. "From U-Bahn to E-Scooters: Berlin Mobility App Has It All." ***Reuters***, September 24. Accessed May 2020. https://www.reuters.com/article/us-tech-berlin-idUSKBN1W90MG.

Cantillo, Víctor, and Juan de Dios Ortúzar. 2014. "Restricting the Use of Cars by License Plate Numbers: A Misguided Urban Transport Policy." ***DYNA*** 81(188): 75-82. doi: 10.15446/dyna.v81n188.40081.

Corwin, Scott, Nick Jameson, Derek M. Pankratz, and Philipp Willigmann. 2016. "The Future of Mobility: What's Next?" Deloitte Insights, September 14. Accessed May 2020. https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/roadmap-for-future-of-urban-mobility.html?id=us:2el:3pr:prwhatnext:eng:cons:091516.

Dominguez, Karla, A. Machado, B. Alves, V. Raffo, S. Guerrero, and I. Portabales. 2020. "What Makes Her Move? A Study of Women's Mobility in LAC Cities." Washington, DC: World Bank Group.

Dominguez, Karla, D. Arango, B. Alves, and J. Mc-Cleary Sills. 2015. "Violence against Women and Girls Resource Guide." Transport Brief. Washington DC: World Bank; IDB Global Women's Institute.

ERTICO. 2016. "ITS for Commercial Vehicles: Study of the Scope of Intelligent Transport Systems for Reducing CO_2 Emissions and Increasing Safety of Heavy Goods Vehicles, Buses and Coaches." ERTICO–ITS Europe, Brussels. Accessed May 2020. http://erticonetwork.com/wp-content/uploads/2016/09/ITS4CV-Report-final-2016-09-09.pdf.

European Commission. 2020. "Cross-Border Corridors for Connected and Automated Mobility (CAM)." Last updated February 6, 2020. Accessed May 2020. https://ec.europa.eu/digital-single-market/en/cross-border-corridors-connected-and-automated-mobility-cam.

Fleming, K., and M. R. Singer. 2019. "Energy Implications of Current Travel and the Adoption of Automated Vehicles" Technical Report NREL/TP-5400-72675. National Renewable Energy Lab (NREL), Golden, Colorado. doi: 10.2172/1510712.

Grijpink, Ferry, Eric Kutcher, Alexandre Ménard, Sree Ramaswamy, Davide Schiavotto, James Manyika, Michael Chui, Rob Hamill, and Emir Okan. 2020. "Connected World: An Evolution in Connectivity Beyond the 5G Revolution." McKinsey Global Institute Discussion Paper. McKinsey & Company. https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5G-revolution.

J.D. Power. 2019. "Mobility Pipe Dreams? J.D. Power and SurveyMonkey Uncover Shaky Consumer Confidence About the Future." Press Release, July 20. Accessed May 2020. https://www.jdpower.com/business/press-releases/2019-q2-mobility-confidence-index-study-fueled-surveymonkey-audience.

J.P. Morgan. 2018. "Driving into 2025: The Future of Electric Vehicles." Published October 10, 2018. Accessed May 2020. https://www.jpmorgan.com/global/research/electric-vehicles.

Jonsson, Peter, Stephen Carson, Greger Blennerud, Jason Kyohun Shim, Brian Arendse, Ahmad Husseini, Per Lindberg, and Kati Öhman. 2019. "Ericsson Mobility Report November 2019." Ericsson, Stockholm. Accessed May 2020. https://www.ericsson.com/en/mobility-report/reports/november-2019.

Lee, Jooyong, and Kara M. Kockelman. 2019."Energy and Emissions Implications of Self-Driving Vehicles." Presentation No. 19-01927, presented at Poster Session 1360: "Current Issues in Transportation Energy," at the 98th Annual Meeting of the Transportation Research Board, Washington, DC, January 14. https://www.caee.utexas.edu/prof/kockelman/public_html/TRB19EnergyAndEmissions.pdf; http://auvsilink.org/AVS2018/Posters/Kara%20Kockelman_Energy%20and%20Emissions%20Implications%20of%20Self-Driving%20Vehicles.pdf.

Liang, Kuo-Yun, Jonas Mårtensson, and Karl H. Johansson. 2015. "Heavy-Duty Vehicle Platoon Formation for Fuel Efficiency." ***IEEE Trans. Intell. Transp. Syst***. 17 (4): 1051–61. Accessed June 2020. https://people.kth.se/~kallej/papers/vehicle_ieeetits16formation.pdf.

Metea, Julie. 2019. "School Bus Wi-Fi Is a Turning Point in Transportation Technology." ***School Transportation News***, September 23. Accessed May 2020. https://stnonline.com/special-reports/school-bus-wi-fi-a-turning-point-in-transportation-technology/.Sonawane, Kalyani. 2017. "Fleet Management Market By Vehicle Type (Light Commercial Vehicle, Heavy Commercial Vehicle, Aircraft, Railway, Watercraft), Component (Solution, Services), Communication Technology (GNSS, Cellular System), Industries (Retail, Government, Transportation & Logistics, Automotive, Manufacturing, Construction, And Energy)—Global Opportunity Analysis and Industry Forecast, 2014–2022." Allied Market Research. https://www.alliedmarketresearch.com/fleet-management-market.

Stephens, T.S., J. Gonder, Y. Chen, Z. Lin, C. Liu, and D. Gohlke. 2016. "Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles." Technical Report NREL/TP-5400-67216. National Renewable Energy Lab (NREL), Golden, Colorado. doi: 10.2172/1334242.

Taiebat, M., A. L. Brown, H. R. Safford, S. Qu, and M. Xu. 2018. "A Review on Energy, Environmental, and Sustainability Implications of Connected and Automated Vehicles." ***Environmental Science & Technology*** 52 (20): 11449–65. doi: 10.1021/acs.est.8b00127.

Taiebat, Morteza, Samuel Stolper, and Ming Xu. 2019. "Forecasting the Impact of Connected and Automated Vehicles on Energy Use: A Microeconomic Study of Induced Travel and Energy Rebound." ***Applied Energy*** 247: 297-308. doi: 10.1016/j.apenergy.2019.03.174.

Tomás, Juan Pedro. 2019. "Japanese Carriers to Install 5G Base Stations on Traffic Signals: Report." ***RCR Wireless News***, June 5. Accessed May 2020. https://www.rcrwireless.com/20190605/5G/japanese-carriers-install-5G-base-stations-traffic-signals-report.

Tse, Terry. 2008. "Safety Analysis of Communication Timeout and Latency in a Positive Train Control System." Research Results Series, Report No. RR08-01. U.S. Federal Railroad Administration. Accessed June 2020. https://railroads.dot.gov/elibrary/safety-analysis-communication-timeout-and-latency-positive-train-control-system.

Wadud, Zia, Don MacKenzie, and Paul Leiby. 2016. "Help or Hindrance? The Travel, Energy and Carbon Impacts of Highly Automated Vehicles." ***Transportation Research Part A: Policy and Practice*** 86 (April): 1–18. doi: 10.1016/j.tra.2015.12.001.

Woetzel, Jonathan, Jaana Remes, Brodie Boland, Katrina Lv, Suveer Sinha, Gernot Strube, John Means, Jonathan Law, Andres Cadena, and Valerie von der Tann. 2018. "Smart Cities: Digital Solutions for a More Livable Future." McKinsey Global Institute. Accessed June 2020. https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/smart-cities-digital-solutions-for-a-more-livable-future.

05

5G ADOPTION, STANDARDIZATION, AND TIMELINES

The transport sector, especially autonomous vehicles, is frequently identified as one of the key areas where 5G will have a major impact. This potential is demonstrated through significant work in the sector, with ongoing efforts from established automotive, telecom, and technology companies as well as a host of startups. As their respective approaches differ significantly, an eventual rationalization of the market will likely be required, especially as the nature of transport implies that such connected vehicles will move from jurisdiction to jurisdiction. To allow free movement of goods and people, city- or country-specific solutions will need to be integrated with those of neighboring cities and countries.

In October 2018, Verizon, in the United States (U.S.) launched the first 5G services based on fixed wireless access, that is, the end user was a fixed receiver and the 5G connectivity was used to provide wireless Internet at home. In April 2019, SK Telecom in the Republic of Korea became the first operator to offer 5G as a mobile service. Today, nearly 5 million subscribers in the Republic of Korea are 5G-supported and the network carries about 20 percent of the country's total mobile traffic. Still the Republic of Korea's 5G coverage hovers around 50 percent, the highest coverage in the world. A year has passed since the availability of the first 5G-enabled handheld devices and only a few countries have established commercial service, mainly the Republic of Korea, United States, Japan, China, and some countries in Europe. From this group, only the U.S. is deploying in the low band of spectrum for nationwide coverage (T-Mobile covers 200 million people), and in the millimeter wave band for hotspots such as New York City.

Looking at low- or middle-income countries, only a few are running trials, such as Kenya, Pakistan, and Sri Lanka. Such advanced access is far from the norm in many countries, with a lack of broadband mobile access in many areas. About 40 percent of the world's population can only access 2G services (Grijpink et al 2020), while twenty countries or territories have no access to 4G services at all. Although we are already seeing some countries with very ambitious 5G deployment plans, such as Republic of Korea, the United States, Japan, and China, analysis of the past 4G deployment process allows us to estimate 5G deployment in developing countries will likely start around the end of 2021 or the beginning of 2022. This process will last approximately two or three years, ending in 2025, unless current technological tensions affect the global production of 5G devices and infrastructures.

We will see the beginning of the 5G deployment in a large number of World Bank client countries between 2021 and 2022, with deployment generalized by 2025

C-V2X versus WAVE

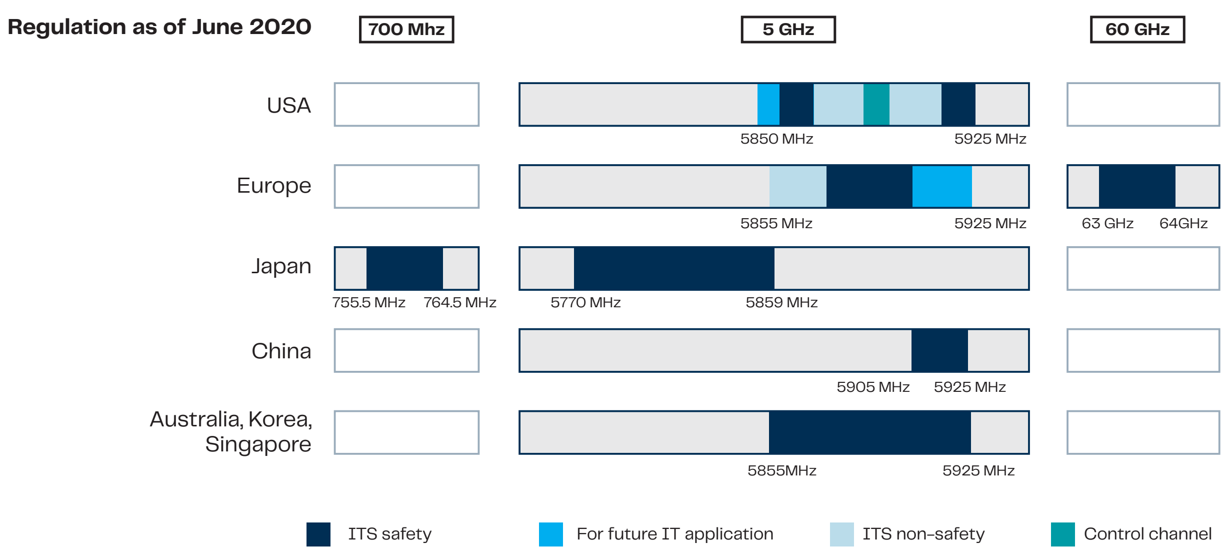
With respect to the regulation of cellular-based vehicle-to-everything communications (C-V2X) in the world, the situation remains fluid as of the drafting of this report. In 1999 the United States decided to allocate a portion of the 5.9 gigahertz (GHz) spectrum for dedicated short-range communications (DSRC), with wireless access in vehicular environments (WAVE) as the selected technology. Although a proposal was developed to require the technology's implementation by 2025, this proposal never came into practice. The U.S. government is considering the option of opening the 5.9 GHz band for other purposes, allowing for the use of C-V2X technologies, such as 5G NR. Also, the allocation of additional bands is under study. To date, this research study is still ongoing.

The European Union (EU) followed a singular track. In March 2019 the European Parliament opted for following the same approach as the U.S. government and chose DSRC as the technology to be enforced in Europe by 2025. However, the European Council, which holds veto capacity over the European Parliament, decided in July of 2019 to force neutrality, allowing the incorporation of the C-V2X technologies, including long-term evolution (LTE) in its version Release 14 or 5G new radio (NR) in its version Release 16, to be alternative technologies for vehicle-to-everything (V2X) communications. The mandate from the European Council to the European Parliament sought to modify the March regulation; however, no final decision has been made.

In both cases, the U.S. and the EU seem to be ready to regulate considering industry requests. The decision is certainly complex. On the one hand DSRC-WAVE is a mature technology and could be used in the near term to start saving lives. On the other hand, it only operates in short range and, therefore, requires a significant investment and number of roadside units (RSU) to be deployed to guarantee vehicle-to-infrastructure (V2I) services—and is an expensive option from the operation point of view. Cellular-based V2X, on the other hand, offers better efficiency and could count on the support of a pre-existing cellular network. It is also expected to offer reduced deployment expenditures, presenting significant mid-term benefits. Moreover, since April 2018 all new vehicles in Europe must be able to connect to the emergency services in case of a crash (eCall), the cellular chipset is already installed in many vehicles, and therefore, in terms of system design, it is better to include the V2X communications capacities in the same unit. In fact, the Qualcomm chipset 9150, currently being installed in new vehicles for C-V2X, does not currently support the cellular link, though it is likely evolving in this direction.

Certainly C-V2X has a strong support from industry. The 5G Automotive Association (5GAA), a group formed by automakers and telecom operators, openly supports the choice of C-V2X. The industry is so certain both the U.S. and the EU will accommodate the connected vehicle through cellular technologies that several pilot tests have occurred in recent years. In 2016, BMW, Ericsson, and SK Telecom made the first 5G trials with moving vehicles up to 160 kilometers per hour (km/h). In 2017 AT&T, Ford, Qualcomm and Nokia

FIGURE 5.1. Spectrum Allocation to Date



completed the first world trial of C-V2X in San Diego. Panasonic, Ford, and Qualcomm made similar tests in 2018 in Colorado. In 2018 the EU funded three European projects dedicated to the 5G connected vehicle.

C-V2X technology has been available for LTE in Release 14 since June 2017. However, the development of its application in 5G NR is still not completed. Despite the Release 16, the C-V2X description was completed in December 2019, and will be available in June 2020 when the full standard is available.

With respect to the status of the spectrum allocation in the world, only a few regions have allocated spectrum for vehicular communications, with some consensus on the use the 5.875 to 5.905 GHz band for intelligent transport systems (ITS). The lack of definition from many countries, and discrepancies between countries in the specific band where an allocation has been made, negatively affects the ability of original equipment manufacturers (OEMs) to implement V2X technologies and also limits the potential to apply an economy of scale. Japan, for instance, opted to allocate a portion of the spectrum in 5.7 GHz band, not coinciding with the U.S. or EU option, and in the 700 MHz band. The current status of the spectrum adoption is represented in figure 5.1.

In all cases the spectrum allocated for V2V modes of ITS is unlicensed, and therefore its use is not conditioned to spectrum auctions and governments are not expected to receive income from its allocation. It is also true that automotive OEMs indicate the available spectrum in the 5.9 GHz band is not enough for Day 3 services. In this sense, and being technically required, some business models are based on the assumption that a portion of the conventional cellular spectrum, owned by mobile network operators, will have to be used, incurring costs as it has been allocated and auctioned for private use. This is a big challenge for governments, which have to balance the necessary investment, use of spectrum, and adequate business models so that 5G arrives appropriately and as quickly as possible to the transport sector.

Clearly, the current uncertainties on the use of spectrum and technologies in most of the world are not good for the development of the CAV. In fact, full rollout has been frozen by the lack of clarity on whether 5G (through C-V2X) or WAVE will emerge as the final technology of choice for V2X communications. The delay also stems from doubts about the business models. However, since manufactures can make systems to leverage either technology, as they utilize the same 5.9 GHz bandwidth, a clear decision is needed. In addition, as the two technologies have different capacities, the design of vehicle systems and decision algorithms will depend on the technology chosen. Only once these questions of spectrum allocation and technological solutions come into focus, and 5G coverage becomes widespread, will the promise of autonomous vehicles begin to be realized, thanks in large part to the improved comfort and better performance of safety mechanisms.

Finally, the cross-sectoral nature of the upcoming changes, is encouraging the formation of new partnerships. As explained previously, the Fifth Generation Automobile Association (5GAA) illustrates the need to join and coordinate efforts between automakers and telecom operators, also important since the use of 5G technology will require extensive rollout of 5G access points to enable autonomous vehicles to operate outside narrow coverage zones. A decision on who owns and operates such technology will be a key consideration, with different options on the table.

REFERENCES

Grijpink, Ferry, Eric Kutcher, Alexandre Ménard, Sree Ramaswamy, Davide Schiavotto, James Manyika, Michael Chui, Rob Hamill, and Emir Okan. 2020. "Connected World: An Evolution in Connectivity Beyond the 5G Revolution." McKinsey Global Institute Discussion Paper. McKinsey & Company. https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5G-revolution.

06 IMPACTS OF 5G-ENABLED TRANSPORT

The benefits of 5G in the transport sector can be approached from diverse points of view, and consensus holds that 5G will have a positive impact on the economy. Furthermore, due to its unique low-latency feature, 5G will enable the full deployment of autonomous vehicles (AVs) and is therefore expected to significantly reduce fuel consumption and road fatalities. With respect to logistics, the possibility of expanding the tracing capacity and means of transporting goods will increase transport efficiency. Finally, with regard to public transport, 5G is expected to boost the Mobility as a Service (MaaS) concept (even beyond city limits), better manage fleets, adapt transport to the real locations of people and their mobility needs, and improve provision of multimedia services along passenger routes.

Providing connectivity to the underground, or allowing a large volume of passengers to consume high-speed data in the same space are challenges that only 5G can face with guarantees of success. Furthermore, the possibility of connecting surveillance cameras in urban or intercity transport, as well as connecting the sensors of public transport vehicles, will greatly improve public transport security and fleet management. Such technologies will also create new policy tools for decision makers, such as enabling the deployment of intelligent transport system (ITS) technologies for the automated collection of road-user fees based on negative externalities (use of urban space and GHG emissions), which will improve their ability to implement and finance targeted strategies for reducing congestion, carbon emissions, and other transport-driven externalities.

ECONOMIC GROWTH AND POVERTY

A recent report published by Ericsson estimates that 5G will contribute US$700 billion dollars to the world economy in 2030 (Ericsson 2019). Of this total, 31 percent is estimated to have a direct relationship with transport. For some sectors, such as logistics, a compound annual growth rate of 76 percent is expected.

Considering direct and indirect impacts on the macroeconomy, 5G is estimated to increase the global gross domestic product (GDP) by 5.4 percent by 2030 (Ericsson 2019). This implies, under the current value of the world's GDP of US economy of US$85.91 trillion dollars,[1] 5G will have an estimated impact of US$4.64 trillion on potential global sales activity across multiple industrial sectors by 2030. Other more long-term predictions place the impact of 5G at US$13.2 trillion dollars by 2035, of which 5.4 percent would be directly related to transportation (Raconteur 2020). Potential creation of unicorns in logistics, MaaS, and infrastructure-sharing management can drive huge investments and high salaries to cities where those companies will evolve. And with emerging cities presenting even greater challenges, if regulation can enable innovation, successful companies might blossom in middle-income countries rather than in already developed countries.

However, the potential impact of 5G-enabled transport on poverty and the bottom 40 percent could be more mixed. As elaborated in the discussion on employment below, the introduction of 5G into the transport sector will likely displace a wide range of workers, from truck drivers, to factory workers, data entry clerks, informal transit operators, motorcycle taxi drivers, and many more. These jobs will be replaced by new jobs requiring new skills in new locations, presenting challenges for those currently employed in these jobs. Conversely, if well regulated, the efficiency gains promised by 5G could accrue to those most reliant on strained public transport networks, allowing better access to jobs and services, lower transport costs, and even modify the urban economic geography in cities in the long term to distribute jobs equally.

ROAD SAFETY

Every year the lives of approximately 1.35 million people are cut short as a result of a traffic-related collision. Between 20 and 50 million more people suffer non-fatal injuries, with many incurring a disability as a result of their injury. Road traffic accidents cost countries an average of 3 percent of GDP. The World Health Organization (WHO) estimates pedestrians comprise 22 percent of all road traffic deaths, totaling more than 275,000 deaths worldwide. According to a 2016 cost calculation by the European Union, an estimated 135,000 people were injured due to road crashes in European countries, creating a direct social cost (rehabilitation, healthcare, material damages, etc.) of at least €100 billion (Asselin-Miller et al 2016; Kabashkin et al 2018).

Under Sustainable Development Goal (SDG) 11.2, countries aim to provide access to safe, affordable, accessible, and sustainable transport systems for all, with improved road safety. Collectively, the world should strive to eliminate deaths and serious injuries on roads by 2030. Analyzing the reasons for road accidents, human errors (mainly alcohol, high speed and distractions) account for an estimated 80 to 90 percent of total vehicle-related collisions (Deme 2019), indicating the vast majority of road deaths could be avoided by removing the human factor. AVs play a fundamental role here, in the move toward fewer road fatal crashes.

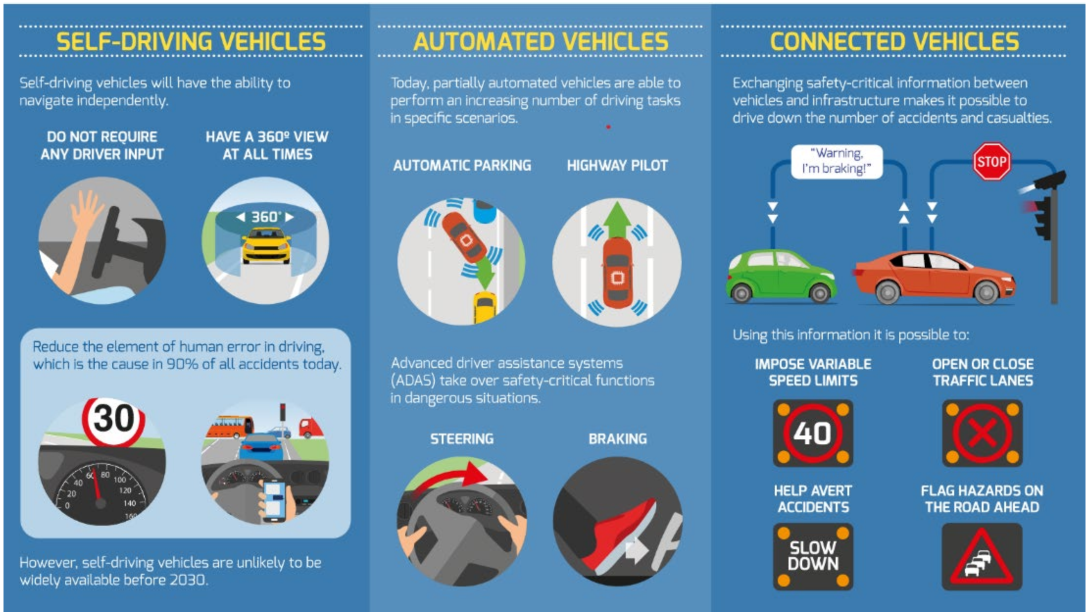
Connected autonomous vehicles (CAVs) are expected to increase road safety by removing the driver from the equation, thus reducing the element of human error, which is responsible for up to an estimated 94 percent of all crashes today. If such estimates are correct, and the introduction of connected autonomous driving can reduce collisions to such an extent, this implies AV technologies could save up to 1.3 million lives, more than US$4 trillion in GDP losses, hundreds of thousands of pedestrian deaths, and tens of millions of people from serious injuries.

Increasingly, cooperative intelligent transport systems (C-ITS) facilitate communications between connected vehicles and their surroundings, including infrastructure. C-ITS can detect the flow of traffic, its speed, and density. The information collected by sensors and vehicles can then be used to signal vehicles about speed limits, help determine whether to open or close traffic lanes, and help avert accidents. These vehicles come equipped with sophisticated onboard sensors, cameras, GPS, radar, and safety systems that can capture information and process it in real time, thus reducing the impact of accidents. Building on the smart video technologies available today, the increased bandwidth offered by 5G will enable a vast network of connected sensors, including both vehicle and road-network cameras. Combined with the processing power of edge computing, intelligent systems will be able to, for example, use vehicle and surrounding video data for predictive routing, real-time road hazard and accident alerts, and much more. Smart vehicles could, furthermore, communicate with cyclists, pedestrians, and other road users to improve safety. For instance, vehicle-to-pedestrian (V2P) technologies could enable cars to automatically stop at traffic crossings or alert pedestrian devices when a car is approaching at unsafe speeds. This technology can promote real-time vehicle tracking and routing, while improving safety for road users. Figure 6.1 illustrates the potential impacts of self-driving, automated, and connected vehicles on road safety.

However, several high-profile fatal collisions involving AVs have demonstrated that vehicular automation is not enough to completely ensure road safety. Due to this, autonomous driving combined with connected vehicle technologies are being sought to achieve the zero fatalities goal over the medium and long term. Currently, the goals of future driving can no longer be understood nor achieved without information and communications technology (ICT), with 5G playing a fundamental role in enabling full connectivity between persons, vehicles, and the road.

In regards to motorcycles or other two- or three-wheeled vehicles, 5G will connect them to other vehicles and to road conditions. 5G's special sensitivity to road conditions and the difficulty of larger vehicles to see them provides an additional opportunity to improve motorcycle safety.

FIGURE 6.1. **Connected Automated Vehicles and Improved Road Safety**



Source: Road Safety Facts. "How Can Automated and Connected Vehicles Improve Road Safety?" Available online at https://roadsafetyfacts.eu/how-can-automated-and-connected-vehicles-improve-road-safety/.

ENERGY USE

As outlined previously, future 5G-enabled vehicles will differ from those on the road today in a number of ways. Assessing the impact of the 5G connectivity alone makes little sense in light of the projected wider changes. Bringing in the host of expected impacts—from changing power sources, to changing business models—and in conjunction with the impacts of 5G connectivity, creates an opportunity for a more realistic assessment. However, the integration of vehicle electrification, autonomous operation, connectivity, and car-sharing models will be complex, and either drive down energy use in the transport sector, or lead to a more ambiguous impact.

Vehicle electrification

Although power plants might experience more energy consumption because of the increased electricity demands of vehicle electrification, this paper does not cover the *upstream energy generation* from power plants; instead, the analysis focuses on energy consumption from vehicles themselves. Indeed, global vehicle forecasts already contain a sensible assumption about the power source for CAVs, that these cars will be primarily electric vehicles. As an alternative to the popular internal combustion engine (ICE) vehicles—with engines that generate power by usually burning petroleum products such as gasoline, diesel fuel or fuel oil—the electrified vehicle ecosystem comprises a spectrum of technologies according to the degree of electrification, as detailed in figure 6.2.

The International Energy Agency (IEA) anticipates EV numbers will grow from 3 million to 125 million by 2030 (IEA 2018). Hydrogen FCEV potential aside, the J.P. Morgan outlook (2018) says that in 2025, 32 percent of all vehicles will operate with a certain degree of electrification (9 percent of this total will be BEVs, 3 percent PHEV, 20 percent HEV and BAHV), while 68 percent will be pure ICE. In 2030, the estimates EVs will comprise 59 percent of all vehicles (18 percent BEVs, 2 percent PHEVs, 39 percent HEV and BAHV), while 41 percent will be pure ICE. On the other hand, as shown in figure 6.3, IEA also projects significant hydrogen FCEV sales volumes—but only in the long term, even with a favorable climate-policy scenario, representing a market share of about 17 percent by 2050 (with 35 million annual unit sales). These estimates for the hydrogen FCEV align with the current long-term perspectives expressed by experts in their respective studies (Tanç et al 2018).

As technologies advance and energy and carbon dioxide regulations come into force, the future will feature more vehicles with some sort of electrification. Several prominent reasons support this automation through electrification synergy. For example, a growing trend toward electrical drivetrains facilitates an easier introduction of automation. Apart from this, future useful applications (such as automated plug-in of vehicles and wireless transfer and sharing of car battery) will help in integrating the AVs into a vehicle/grid ecosystem. Studies collectively suggest that electrification of vehicles

The autonomous and shared car, empowered through 5G technology, could potentially save up to 75 percent in energy use

BOX 6.1. 5G and the Potential Energy Savings of Platooning and Vehicle Sharing

Looking at the potential energy saving associated with 5G-connected autonomous vehicle road operations, Inter-American Development Bank (IDB) analysis of platooning techniques shows a significant reduction in power consumption—whether fossil-based fuel or electric power—of approximately 30 percent. By combining platooning with a vehicle-sharing component to improve journey efficiency, the energy savings could scale up to 75 percent. IDB estimates a savings per year and per vehicle of more than US$3,000.

However, the transition to vehicle sharing will likely be difficult. Instituting active policies that prioritize circulation or parking of shared vehicles will help introduce the vehicle-sharing concept with greater success.

could bring an improvement in CAVs compared to conventional counterparts from –20 percent (Taiebat et al 2019) to –70 percent (Lee and Kockelman 2019) in terms of energy efficiency alone, thus vehicle electrification will have a straightforward impact on net energy consumption.

The expected energy savings could also result in significant fuel economy improvement, when compared to the conceivable rise in the reference price for petroleum products from 2020 to 2050—an estimated increase of +20 percent for gasoline and +30 percent for diesel, as predicted by U.S. Energy Information Administration (EIA 2020).

Autonomous driving

Studies jointly agree that vehicle automation powered by artificial intelligence (AI) and advanced sensors will result in CAVs operating more efficiently and safely than the typical human-driven vehicle. However, due to the potential for higher speeds and increased usage, autonomy alone would actually be expected to increase the overall energy use of the sector.

The potential of AV for driving at faster speeds with closer spacing to the preceding vehicle, while ensuring proper safety, may lead to speed-limit increases on certain highways, and because of aerodynamic drag, will have a negative impact on fuel economy, thus consuming more energy, estimated at a +7 percent, +22 percent (Wadud et al 2016) or even +30 percent (Brown et al 2014).

Additionally, AVs may diminish or even remove the burden of the driving task, so that those who were unable to drive a vehicle could ride in AVs. For example, senior adults and persons with physical disabilities could take advantage of the increased mobility options offered by AVs. A first attractive business case, in which fully AVs sense their environment and move safely with little or no human input along a restricted set of predetermined routes, will be rolled out by transportation companies (such as taxi and car rental companies) to provide low-cost, on-demand mobility services via a smartphone app. Such app-based taxi booking in smartphone platforms is another factor that would increase trip frequency with previously underserved populations and produce a sort of "magnet effect" in former public transport users, and non-drivers alike. This will expand the adoption of the autonomous vehicle and consequently increase energy consumption, which is estimated from +4 percent (Taiebat et al 2018) to +14 percent (Lee and Kockelman 2019).

Finally, the energy demands of sensing and computing equipment decrease the overall energy efficiency of AVs (Taiebat et al 2018), on the order of +5 percent to +10 percent (Lee and Kockelman 2019).

5G-connected vehicles

The list of innovative, 5G-enabled driving techniques applicable to the connected vehicle is long, with vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications potentially coordinating interactions among multiple vehicles and infrastructure types. This will open the door to platooning (for reduced air resistance), connected and smart intersections that enable the syncing of the traffic flow with traffic lights, congestion mitigation, improved crash avoidance, and integration with mass transit and ITS, among others. On the other hand, 5G-enabled vehicle technology will enable even higher efficiencies derived from less idling and speed fluctuations, green-driving, and eco-routing, as well as a reduced number of cold-engine starts.

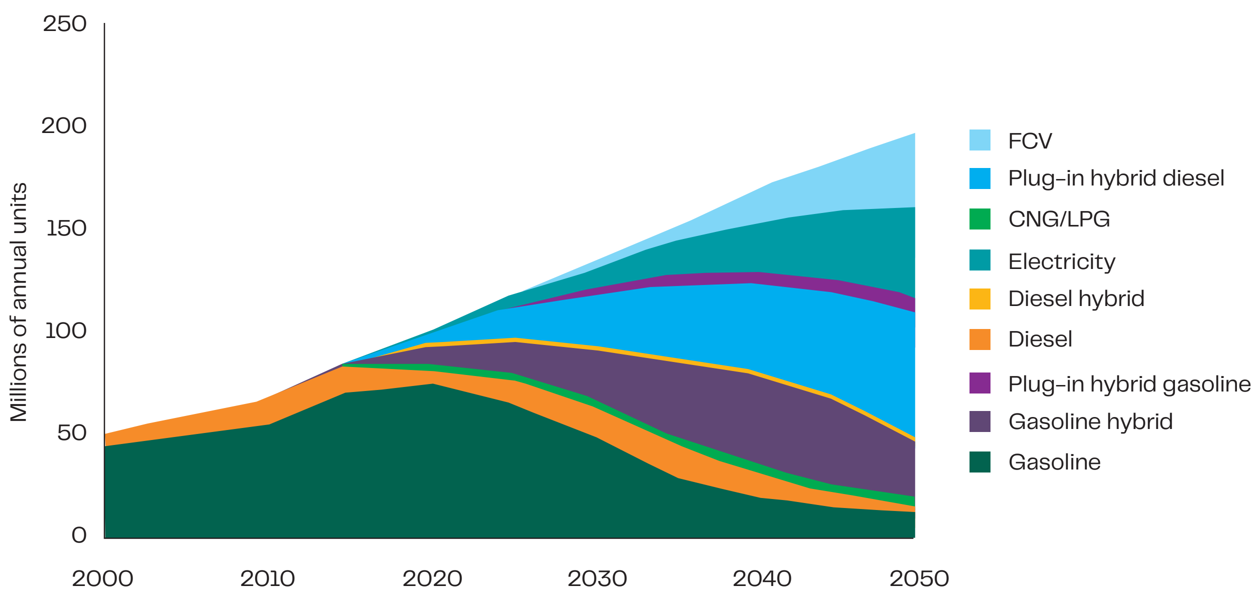
Studies agree that deriving smart routing that uses V2I coordination to select the most energy-efficient route (such as a route with fewer stops, shorter distances, or reduced congestion) has the potential to save energy, in the order of –5 percent to as much as –20 percent, as reported by Brown et al (2014) and Stephens et al (2016), although the upper bound estimate could increase up to –25 percent in light of new progress of the applied AI techniques.

When smart intersections powered by 5G can be operated with CAVs, speed control of individual vehicles may be continuously adjusted and monitored to obey existing rules and intersection conditions. The introduction of V2I in intersections may reduce energy wasting situations such as stop delays by watching the traffic and checking the trajectory of each vehicle and reserving the intersection for the vehicle that has the right of way at any given moment.

FIGURE 6.2. Spectrum of Electric Vehicle Technologies

MILD HYBRID	A ***mild hybrid,*** also known as battery-assisted hybrid vehicle (BAHV), sits between a conventional gasoline vehicle and a full hybrid. This vehicle type has an ICE that uses a modest battery, and a motor-generator allowing the engine to be turned off whenever the car is coasting, braking, or at a full stop. BAHV may employ regenerative braking and some level of power assistance but does not have an electric-only mode of propulsion.
FULL HYBRID	A ***full hybrid***, also known as hybrid electric vehicle (HEV), uses the combined efforts of both an ICE and a battery-powered electric motor intended to achieve either better fuel economy than a conventional vehicle or better performance (for example, while merging or climbing a hill, without burning additional fuel). The vehicle may also be able to drive for brief periods solely on electrical power, with the gas engine turned off, but all power is generated onboard, without the need for plugging-in the battery.
PLUG-IN HYBRID ELECTRIC VEHICLE	A ***plug-in hybrid electric vehicle (PHEV)*** sits somewhere between a full hybrid and a full electrical vehicle. These are vehicles with a battery that can be recharged by plugging into an external source of electric power as well as by its onboard engine and generator. Compared to a regular hybrid, the PHEV battery has a much higher capacity, for extended all-electric driving.
ELECTRIC VEHICLE	An ***electric vehicle (EV)*** or battery electric vehicle (BEV) is at the extreme end of vehicle electrification. It has no gasoline engine (no fuel tank, no fuel cell, no exhaust pipe, and no engine oil) and uses chemical energy stored in rechargeable battery packs to power an electric motor drive system 100 percent of the time. EVs are recharged via plugging into an electrical outlet or charging station, which restores the onboard battery.
FUEL-CELL ELECTRIC VEHICLES	In parallel, a ***fuel-cell electric vehicles (FCEV)*** uses a fuel cell, usually compressed hydrogen—instead of a battery or in combination with a battery or super-capacitor—to generate electricity to power its onboard electric motor. FCEVs are classified as zero-emissions vehicles (emitting only water and heat), and centralize pollutants at the site of the hydrogen production—typically derived from reformed natural gas—but could be obtained from any primary energy source (including renewable biomass, wind and solar energy, as well as nuclear energy, and decarbonized fossil fuels).

FIGURE 6.3. Projection of Vehicle Sales Volume (Assuming Current Rates of Motorization Continue)



Source: Arena et al 2017.

The expected energy reduction ranges from –13 percent to as much as –44 percent (Lee and Kockelman 2019).

Additionally, the 5G-connected vehicle will enable smoother driving cycles, since coordination with infrastructure will reduce driving situations that impair fuel or battery consumption and durability, such as maintaining the ideal cruising speed while allowing for acceleration and deceleration ahead of time, being able to anticipate downstream traffic conditions, and enriching control techniques with efficient eco-driving skills while incorporating traffic conditions received via communication and sensors. On the whole, this would represent a reduction from –10 percent to –20 percent of current energy use.

Additionally, on-demand CAV would reduce the trips that do not match with client demands, such as searching for a parking lot or space, potentially diminishing the energy consumption by around –5 percent (Taiebat et al 2018; Lee and Kockelman 2019).

Finally, despite the clear gains of connectivity in terms of energy use, the equipment itself needed to support the enhanced vehicle-to-everything (V2X) capacity will require more energy, on the order of 2 to 5 percent[2] higher than in today's vehicle electronics systems. Although worth mentioning, this consumption is negligible compared to the potential benefits of increased connectivity. In addition, the connected infrastructure necessary to support such CAVs will increase the associated energy demand, although compared to the potential gains, the impact is likely minor (Pihkola et al 2018).

Car sharing

Car sharing shifts the paradigm from privately owned vehicles to a model where carpooling is offered through shared vehicles, and could disruptively cut the costs of driving, even for long distances. As shared mobility serves a greater fraction of local transport necessities, households with multiple vehicles will begin decreasing the number of cars they own, while others might eventually abandon ownership altogether. Because of their pioneering technological aspects, CAVs are the ideal choices to support this scenario.

Studies agree that if future CAVs were privately owned, energy would be impacted differently than if passengers used AVs through a service for ride hailing or ride sharing (Fleming and Singer 2019). In fact, apart from the improved fuel economy derived from sharing a car among more than one person, the contrast between privately-owned vehicles with underused occupancy and the potential for shared vehicles to have the "right-size" to match individual trip requirements could realize considerable reduction in average energy demands, which is estimated to be from –5 percent to –12 percent (Lee and Kockelman 2019) and up to –45 percent (Wadud et al 2016).

Considering that even a shared AV cannot avoid driving around empty at certain moments after its passengers exit, (for example, looking for possible passengers or seeking free parking), there is an associated energy waste associated with this part of the cycle, which has the potential to impact the traffic flow as shared vehicles increase in popularity. The literature (Taiebet al 2019) estimates the energy cost of shared CAVs without passengers from +6 percent to +14 percent (Lee and Kockelman 2019), but it also indicates room for improvement where minimizing this figure would be a key to shared-vehicle success.

Finally, the experts concur that the shared CAV will increase long-distance travel. Just as when using public transport, and without driving tasks, the riders could focus on consuming media, using their smartphones or resting and relaxing. This will reduce the averseness of passengers to long-distance trips (anticipating that this could reallocate as much as 25 to 35 percent of the demand for air travel to roads for trips of 500 miles or more (Taiebat et al 2018), with a realistically estimated energy consumption increase from +6 percent to +18 percent (Lee and Kockelman 2019).

The success of car sharing as a viable transport option, and the possibility of having autonomous public transport, will directly affect the number of drivers using this type of public transport. Driving-related jobs will tend to disappear, or rather be reconverted to other types of tasks, such as cleaning, maintenance, refueling or trip planning.

Estimating the overall impact

Bringing the above aspects together, and considering a reasonable timeline for adopting the technological enablers for the CAV—electrification by 2025, full autonomy by 2027, 5G CAV by 2030, and shared CAV by 2050—figure 6.4 illustrates the energy consumption reduction expected in the most optimistic estimations. The figure shows the aggregated energy reductions of –77.5 percent in 2025, –75 percent in 2027, –94 percent in 2030, and –96 percent in 2050.

Considering the most pessimistic analysis, figure 6.4 also shows the most conservative estimations for energy reductions stemming from the adoption of CAV technology. In this case, the aggregated energy reduction estimates range from –28 percent in 2025, +11 percent (no reduction) in 2027, –19 percent in 2030, and +0 percent in 2050.

A comparison of more or less pessimistic studies reveals certain very relevant conclusions:

- Studies agree changing the fuel model is necessary and that electric cars will bring a more or less significant reduction in energy consumption
- Non-connected AVs will increase the onboard energy consumption due to the need for higher computation extra sensors, although they will produce greater efficiency in time and work capacity
- Studies agree connectivity will improve energy efficiency, safety and travel time

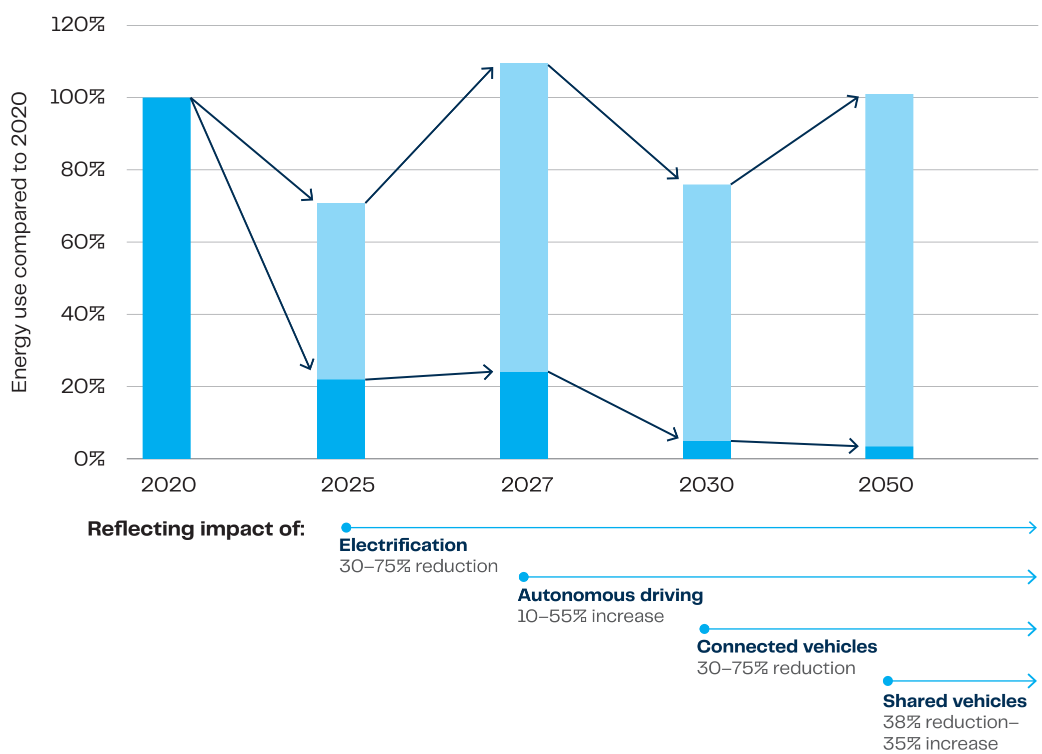
- Among the pessimistic studies, which conclude that energy consumption will remain relatively stable in the long term, and the optimistic studies, which speak of a 96 percent reduction in energy consumption, we can likely expect the new 5G-enabled driving model comes with an energy reduction somewhere between these two positions.

Finally, and importantly, while overall energy use is significant, the impact on greenhouse gas (GHG) emissions will be at least as or more critical. Decarbonizing the transport sector can only happen through efficiency gains and transitions to the new fuel sources outlined above; the climate impact of electric vehicles will depend on greening the energy mix supplying their electricity. User behavior, however, and whether public transport and sharing business models that reduce or even eliminate empty trips dominate the transport mix, will determine the scale of impacts. The optimistic and pessimistic scenarios outlined above only reinforce the potential variation in possible climate outcomes. As the introduction of AVs could actually add to kilometers traveled and increase congestion, regulations governing transportation systems will become even more important.

EMPLOYMENT

Automation technology enabled by the 5G could endanger many of the jobs as we know today. A 2016 report from the Organisation for Economic Co-operation and Development (OECD) found that on average, across OECD countries, 9 percent of jobs are automatable, though statistics vary widely between countries (Arntz et al 2016). For instance, the share of automatable jobs is 6 percent in the Republic of Korea and Estonia, and 12 percent in Austria and Germany, which reflects variations in workplace organization, previous investments in automation technologies as well as differences in the education of workers across countries. In contrast, Frey and Osborne (2017) revealed that 47 percent of jobs in the United States are at a high risk of automation over the next few decades. In the same study it was revealed the jobs that exhibit higher probability of automation are specifically those involving *transportation and material moving*, in which up to 93 percent of current employment is expected to disappear. Although the specific share of jobs differs between reports—the share is reduced to 80 percent in Heyman (2016)—there appears to be a consensus around the fact that automation enabled by 5G will require a significant upskilling in the transport sector workforce. It should be noted that changing business models are likely to have an impact on the number and types of vehicles needed, also impacting the demand for workers in the automotive manufacturing sector.

FIGURE 6.4. Vehicle Energy Consumption Expected in the Most Optimistic and Most Conservative Estimation, Relative to 2020



However, if we focus on developing countries and emerging markets, the risk is much higher. As stated by Arntz et al (2016), the number of jobs subject to automation reaches 69 percent in India, 72 percent in Thailand, 77 percent in China, and up to 85 percent in Ethiopia. The more manual, unregulated, and informal the job, the more exposed it is to possible automation. It should be noted that not all of the *at-risk jobs* will necessarily result in employment losses since the adoption of technologies is a slow process, which in the case of transportation could last around 15 years and, during this time, workers can adjust by switching tasks.

The 5G technological revolution will generate additional jobs through demand for new technologies and through higher competitiveness. It is estimated that 5G will increase global gross domestic product (GDP) by 5.4 percent by 2030, based on assessments that the digital economy will represent 15.5 percent global GDP (Huawei and Oxford Economics 2017) and that 5G will increase revenues derived from the information and communications technology sector (ICT) by 35 percent (Ericsson 2019). Applying Okun's Law to these numbers (Farole et al 2017), we can conclude that the total balance of employment will be positive with some net job creation.

In summary, while some jobs will become obsolete, more will be created, resulting in a minor but positive net balance. A good example of the veracity of this conclusion is a Swedish report on the effect of automation in Sweden's transport sector (Heyman et al

5G will create countervailing pressures on employment, with unequal distribution of winners and losers

TABLE 6.1. New Skills Demand and New Job Opportunities Created Because of Automation in the Transport Sector

NEW SKILLS	NEW JOBS
Analytical thinking and innovation	Data analysts and scientists
Active learning and learning strategies	AI and machine learning specialists
Creativity, originality, and initiative	General and operations managers
Technology design and programming	Big data specialists
Critical thinking and analysis	Digital transformation specialists
Complex problem-solving	Sales and marketing professionals
Leadership and social influence	New technology specialists
Emotional intelligence	Organizational development specialists
Reasoning, problem-solving, and ideation	Software and applications developers and analysts
Systems analysis and evaluation	Information technology services
	Process automation specialists
	Legal and public sector professionals specialized in digital economy and business
	Innovation professionals information security analysts
	eCommerce and social media specialists
	User experience and human–machine interaction designers
	Training and development specialists
	Robotics specialists and engineers
	Client information and customer service workers
	Service and solutions designers
	Digital marketing and strategy specialists

These new job opportunities will come at the price of phasing out current skills/jobs as shown in table 6.2.

2013), which concludes that the average job destruction totaled about 20 percent per year for the period from 1990 to 2009. More specifically, during this time approximately 3.2 million jobs were eliminated; conversely, during the same time period 3.4 million jobs were created, leading to a net growth in the number of jobs in the country. A summary of other voices on this topic follows below.

Table 6.1 shares the new skills demand and job opportunities related to the transport sector for the coming years, according to a jobs report published by the World Economic Forum (Leopold et al 2018).

Finally, according to the International Transport Forum, automation in the transport sector will not destroy the job market. However, low-skilled workers are likely to suffer greater pressure from increasing automation as their jobs are more likely to be automated compared to highly skilled workers. Moreover, looking toward the future, the modern economy will continue to create new jobs, especially in the service sector. However, the required adjustments can lead to poor wage developments and social upheaval in the short run, especially for developing countries. 5G, together with AI and robotics, are expected to be the main drivers of the economy's next steps toward modernization.

As mentioned above, low-skilled and low-income individuals face an increased risk of losing jobs to automation. An OECD report (2013) indicates almost 60 percent of people with a primary education are at high risk of losing their jobs due to automation, while this percentage is reduced to 2 percent and less than 0.5 percent for university graduates and PhD profiles. The challenge grows even larger in emerging markets. In Morocco, for example, the labor market is characterized by many challenges such as a lack of inclusion of youth and women, with 70 percent of young men and 93 percent young women unemployed or pursuing education or training, and just 55 percent of secondary school-aged youth in school, leaving an important share of the population at risk due to automation (World Bank 2018).

Addressing these challenges in an effective manner will require enhancing the digital literacy of the existing workforce, or perhaps absorbing highly skilled workers from other industries. Public agencies overseeing transport operations and regulations, will need to develop new skills to allow them to identify, evaluate, and eventually deploy the potential uses of 5G in the transport sector. Solutions will also require improving the overall digital literacy of the transport user population, allowing them to fully leverage the proliferation of new tools

For this reason, according to Blix (2017), developing countries will face the following four main challenges in the future:

1. Increase the number of qualified workers in order to support the automation revolution
2. Ensure sufficient training with required skills for less qualified workers, as improved skills have been the main component of helping individuals and societies to adapt to technological change
3. Invest in human capital, particularly early childhood education, to develop high-order cognitive and socio-behavioral skills in addition to foundational skills
4. Control informal employment, which is rising in developing countries (Djankov et al 2019)—98 percent in Nepal, 89 percent in Senegal, 63 percent in Togo, 75 percent in Vietnam, and 57 percent in Mexico (2019).

TABLE 6.2. Declining Skills and Jobs That Will Become Redundant Due to Automation in the Transport Sector

DECLINING SKILLS	REDUNDANT JOBS
► Manual dexterity, endurance, and precision	► Data entry clerks
► Management of personnel	► Administrative and executive secretaries
► Quality control and safety awareness	► Assembly and factory workers
► Coordination and time management	► Client information and customer service workers
► Technology use, monitoring, and control	► Material-recording and stock-keeping clerks
	► General and operations managers
	► Postal service clerks
	► Mechanics and machinery repairers
	► Car, van and motorcycle drivers

NOTES

1. GDP statistics taken from World Bank Data: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

2. Authors' own calculation.

REFERENCES

Arena, Fabrizio, Daniele Spera, and Fabio Laguardia. 2017. "What's in the Future for Fuel Cell Vehicles." Arthur D. Little, Boston. https://www.adlittle.com/en/insights/viewpoints/what%E2%80%99s-future-fuel-cell-vehicles.

Arntz, Melanie, Terry Gregory, and Ulrich Zierahn. 2016. "The Risk of Automation for Jobs in OECD Countries." OECD Social, Employment and Migration Working Papers 189. OECD, Paris. doi: 10.1787/5jlz9h56dvq7-en.

Asselin-Miller, Nick, Marius Biedka, Gena Gibson, Felix Kirsch, Nikolas Hill, Ben White, and Kotub Uddin. 2016. Study on the Deployment of C-ITS in Europe: Final Report: Framework Contract on Impact Assessment and Evaluation Studies in the Field of Transport MOVE/M3/119-2013-Lot No 5 "Horizontal." Report for DG MOVE MOVE/C 3. No. 2014–794. Ricardo Energy & Environment, London. https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf.

Blix, Mårten. 2017. "Structural Change and the Freight Transport Labour Market." International Transport Forum Discussion Paper 2017-12, prepared for the Roundtable on Commercial Vehicle On-Board Safety Systems, January 5–6, 2017, Washington, DC. OECD, Paris. https://www.itf-oecd.org/structural-change-and-freight-transport-labour-market.

Brown, Austin, Jeffrey Gonder, and Brittany Repac. 2014. "An Analysis of Possible Energy Impacts of Automated Vehicles." In ***Road Vehicle Automation***, edited by Gereon Meyer and Sven Beiker, 137–53. Lecture Notes in Mobility Series. Switzerland: Springer International. doi: 10.1007/978-3-319-05990-7_13.

Deme, Debela. 2019. "Review on Factors Causes Road Traffic Accident in Africa." ***Journal of Architecture and Construction*** 2 (3): 41-9. https://www.sryahwa-publications.com/journal-of-architecture-and-construction/pdf/v2-i3/4.pdf .

Djankov, Simeon, Federica Saliola, Ciro Avitabile, Rong Chen, Rong, Davida Louise Connon, Ana Paula Cusolito, Robert V. Gatti, Ugo Gentilini, Asif Mohammed Islam, Aart C. Kraay, Shwetlena Sabarwal, Indhira Vanessa Santos, David William Sharrock, Consuelo Jurado Tan, and Yucheng Zheng. 2019. ***World Development Report 2019: The Changing Nature of Work***: ***Main Report***. Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/816281518818814423.

EIA (U.S. Energy Information Administration). 2020. "Annual Energy Outlook 2020: Petroleum." January 29, 2020. Accessed May 2020. https://www.eia.gov/outlooks/aeo/; https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Petroleum%20and%20Other%20Liquids.pdf.

Ericsson. 2019. "5G for Business: A 2030 Market Compass." Ericsson, Stockholm. Accessed June 2020. https://uk5G.org/media/uploads/resource_files/the-5G-for-business-a-2030-compass-report-2019.pdf.

Farole, Thomas; Esteban Ferro, and Veronica Michel Gutierrez. 2017. "Job Creation in the Private Sector: An Exploratory Assessment of Patterns and Determinants at the Macro, Sector, and Firm Levels." Working Paper. World Bank Group, Washington, DC. http://documents.worldbank.org/curated/en/214701505483434627.

Fleming, K., and M. R. Singer. 2019. "Energy Implications of Current Travel and the Adoption of Automated Vehicles" Technical Report NREL/TP-5400-72675. National Renewable Energy Lab (NREL), Golden, Colorado. doi: 10.2172/1510712.

Frey, Carl Benedikt, and Michael A. Osborne. 2017. "The Future of Employment: How Susceptible Are Jobs to Computerisation? ***Technological Forecasting and Social Change*** 114 (January): 254–280. doi: 10.1016/j.techfore.2016.08.019.

Heyman, Fredrik. 2016. "Job Polarization, Job Tasks and the Role of Firms." ***Economics Letters*** 145 (August): 246–251. doi: 10.1016/j.econlet.2016.06.032.

Heyman, Fredrik, Pehr-Johan Norbäck, and Lars Persson. 2013. "Where Are Jobs Created? A Report on the Dynamics of the Swedish Business Sector in 1990–2009 to the Expert Group on Public Economics. Volume 3. Expert Group on Public Economics (ESO), Stockholm. [Original Swedish: "Var skapas jobben? En ESO-rapport om dynamiken i svenskt näringsliv 1990–2009. Expertgruppen för studier i offentlig ekonomi." Vol. 3]. https://eso.expertgrupp.se/rapporter/20133-var-skapas-jobben-en-eso-rapport-om-dynamiken-i-svenskt-naringsliv-1990-till-2009/.

Huawei and Oxford Economics. 2017. "Digital Spillover: Measuring the True Impact of the Digital Economy." Huawei Technologies Co., Ltd., Shenzen, China. https://www.huawei.com/minisite/gci/en/digital-spillover/.

IEA (International Energy Agency). 2018. ***Global EV Outlook 2018***. Technology report. IEA, Paris. Accessed May 2020. https://www.iea.org/reports/global-ev-outlook-2018.

J. P. Morgan. 2018. "Driving into 2025: The Future of Electric Vehicles." Published October 10, 2018. Accessed May 2020. https://www.jpmorgan.com/global/research/electric-vehicles.

Kabashkin, Igor, Irina Yatskiv, and Olegas Prentkovskis, eds. 2018. ***Reliability and Statistics in Transportation and Communication: Selected Papers from the 17th International Conference on Reliability and Statistics in Transportation and Communication, RelStat'17, 18–21 October, 2017, Riga, Latvia.*** Lecture Notes in Networks and Systems Series. Springer International. https://www.springer.com/gp/book/9783319744537.

Lee, Jooyong, and Kara M. Kockelman. 2019."Energy and Emissions Implications of Self-Driving Vehicles." Presentation No. 19-01927, presented at Poster Session 1360: "Current Issues in Transportation Energy," at the 98th Annual Meeting of the Transportation Research Board, Washington, DC, January 14. https://www.caee.utexas.edu/prof/kockelman/public_html/TRB19EnergyAndEmissions.pdf; http://auvsilink.org/AVS2018/Posters/Kara%20Kockelman_Energy%20and%20Emissions%20Implications%20of%20Self-Driving%20Vehicles.pdf.

Leopold, Till Alexander, Vesselina Stefanova Ratcheva, and Saadia Zahidi. 2018. ***The Future of Jobs Report 2018***. Insight Report Series. Geneva: World Economic Forum Centre for the New Economy and Society. https://www.weforum.org/reports/the-future-of-jobs-report-2018.

OECD (Organisation for Economic Co-operation and Development). 2013. "Technical Report of the Survey of Adult Skills (PIAAC)." OECD, Paris. https://www.oecd.org/skills/piaac/_Technical%20Report_17OCT13.pdf.

Pihkola, Hanna, Mikko Hongisto, Olli Apilo, and Mika Lasanen. 2018. "Evaluating the Energy Consumption of Mobile Data Transfer—From Technology Development to Consumer Behaviour and Life Cycle Thinking." ***Sustainability*** 10 (7): 2494. doi: 10.3390/su10072494.

Raconteur. 2020. "5G." Special Report. ***The Times***, February 19. Accessed May 2020. https://www.raconteur.net/5G-2020.

Stephens, T.S., J. Gonder, Y. Chen, Z. Lin, C. Liu, and D. Gohlke. 2016. "Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles." Technical Report NREL/TP-5400-67216. National Renewable Energy Lab (NREL), Golden, Colorado. doi: 10.2172/1334242.

Tanç, Bahattin, Hüseyin Turan Arat, Ertuğrul Baltacıoğlu, and Kadir Aydın. 2019. "Overview of the Next Quarter Century Vision of Hydrogen Fuel Cell Electric Vehicles." ***International Journal of Hydrogen Energy*** 44 (20): 10120–28. doi: 10.1016/j.ijhydene.2018.10.112.

Taiebat, M., A. L. Brown, H. R. Safford, S. Qu, and M. Xu. 2018. "A Review on Energy, Environmental, and Sustainability Implications of Connected and Automated Vehicles." ***Environmental Science & Technology*** 52 (20): 11449–65. doi: 10.1021/acs.est.8b00127.

Taiebat, Morteza, Samuel Stolper, and Ming Xu. 2019. "Forecasting the Impact of Connected and Automated Vehicles on Energy Use: A Microeconomic Study of Induced Travel and Energy Rebound." ***Applied Energy*** 247: 297-308. doi: 10.1016/j.apenergy.2019.03.174.

Wadud, Zia, Don MacKenzie, and Paul Leiby. 2016. "Help or Hindrance? The Travel, Energy and Carbon Impacts of Highly Automated Vehicles." ***Transportation Research Part A: Policy and Practice*** 86 (April): 1–18. doi: 10.1016/j.tra.2015.12.001.

World Bank. 2018. "Labor Market in Morocco: Challenges and Opportunities." World Bank Group, Washington, DC. http://documents.worldbank.org/curated/en/477441523251051211.

07 COSTS AND POTENTIAL REVENUE FOR 5G-ENABLED TRANSPORT

The superior connectivity offered by 5G will accelerate the development, commercial use, and reliability of automated vehicles (AVs). Moreover, current AVs require huge computation consumption due to the amount of data to be processed coming from their LiDAR systems,[1] video cameras, and other sensors. The ultra-high speed that 5G brings to road infrastructure will allow the captured data to be computed in the cloud, alleviating consumption in every vehicle, improving total energy efficiency, and sharing knowledge of road and traffic conditions.

The first use of AVs will be on highways, where traffic is more predictable, and journeys are longer. For safety levels to be high enough, cars must be connected, most likely with 5G. To achieve such a level of connectivity, the infrastructure network must provide more transmission points along major transport routes. Such transmission units are referred to as roadside units (RSU).

While it is not yet entirely clear how 5G will eventually be deployed to support transport applications, this chapter seeks to develop an initial estimate of the overall cost for equipping a transport corridor based on the density of RSUs needed to support various potential intelligent transport system (ITS) services based on vehicle-to-infrastructure (V2I) interaction. In addition, the main business models to recover the investment is presented and assessed for an example road length. While the results are not generalizable across an entire transport network, and do not necessarily reflect the true implementation costs for technologies still being developed, this assessment is intended to show the investment costs associated with equipping road networks with 5G infrastructure will be likely justified by the efficiency gains generated, and that the transport use case may be a key consideration in driving 5G rollout more broadly.

The deployment cost of specific roadside units for provisioning V2I-based ITS services along a 51-kilometer stretch of road would be in the range from US$1 to US$5 million. This cost could be reduced up to 65 percent if the mobile operator agrees to use conventional bands for distributing ITS messages. In this case, specific regulations or PPP agreements result in a reduced investment effort, although the cost of fiber optic deployment could also be recovered through rentals to third parties. Moreover, an appropriate income model could result in a return on investment between two and five years for well-traveled corridors, depending on the sharing case.

The transport sector needs a specific infrastructure deployment, the cost of which will depend on the collaboration with the coexisting network

Methodology

In order to estimate the cost of deploying a new ITS infrastructure, it is necessary to determine the density of RSUs needed along a road. A key determinant of this required density is the selection of the ITS services and use cases to be supported (for example, emergency vehicle approaching, traffic jam ahead warning, etc.). For each service, certain performance metrics—including data rate, latency, reliability, coverage range, among others—are associated with an appropriate RSU density. To simplify the assessment, the key considerations include only data rate and reliability metrics.

The set of cooperative ITS (C-ITS) services can be divided into different classes. A common classification considers the phase of C-ITS deployment in which the service would be used (C2C-CC 2019). As described in Chapter 3, Day 1 services consider the exchange of status data to enhance predictive driving, Day 2 services enhance vehicle awareness through the exchange of sensor data, while Day 3 services are based on the exchange of intention data, which allows better coordination of the vehicles to allow autonomous driving. To obtain the service requirements for each day, we considered both their classification (C2C-CC 2019) and the requirements set (5GAA 2019) for different use cases. Based on these references the requirements considered in this assessment are shown in table 7.1. The table also shows the minimum received power required to meet the service requirements given an RSU with a sensitivity of −90 decibel-milliwatts (dBm) (Lindberg et al 2019).

Another key element for calculating the RSU density is the type of road considered, such as road classification, vehicle density, travel speed, the availability of road infrastructure to place RSUs, road geometry, the type and number of surrounding buildings, etc. All such parameters may have an impact on the capacity and coverage of a certain ITS service given a density of RSUs. For the sake of simplicity, in our methodology the full set of roads is divided into a small number of road types, with each type characterized by specific values of the abovementioned parameters. The assessment follows an approach (5GAA 2019) whereby five types of roads are considered: motorways, urban A roads, urban minor roads, rural A roads, and rural minor roads. Although this classification comes from an analysis of UK roads, the general approach holds for various road classification models.

For each road type, a different analytical modeling of the radio channel propagation is required. Specifically, this analysis uses two different models whose description can be found in Karedal et al (2011). The first, two-ray model provides accurate results in scenarios where the main power contributions originate from a direct ray and a reflection on the ground, that is, in scenarios surrounded by fields or low height buildings. This model is used in all types of roads considered except for urban minor, in which the height of surrounding buildings may not fit with the two-ray model. Therefore, in that type of road we use the model developed for highways (Karedal et al 2011). Given that the highway model is not deterministic and does not consider the combination of multiple scattered rays, we consider that effect adding a fast-fading margin of 7 dB. In the two-ray model case, the additional margin is not necessary since that model already considers the impact of the combination of independent rays. Concerning obstruction losses due to other vehicles located between the transmitter and the receiver, we assume a vehicle antenna height of 1.5 m in the receiver and a worst-case scenario in which the obstruction is due to a truck. In that case, losses of 6 dB are assumed when the transmitter height is 3 m, while 3 dB are assumed when the transmitter height is larger. Table 7.2 charts this configuration.

TABLE 7.1. Data Rate Requirement for Each C–ITS Deployment Phase

DEPLOYMENT PHASE	DATA RATE REQUIREMENT (MEGABITS PER SECOND)	RELIABILITY REQUIREMENT (PERCENT)	MINIMUM RECEIVED POWER (DECIBEL-MILLIWATT)
Day 1	3 Mbps	99.99%	−85 dBm
Day 2	6 Mbps	99.9%	−82 dBm
Day 3	30 Mbps	99%	−67 dBm

TABLE 7.2. Radio Channel Propagation Modeling for Each Type of Road Considered

TYPE OF ROAD	RSU HEIGHT (METERS)	CHANNEL MODEL PARAMETERS	OBSTRUCTION LOSSES (DECIBELS)	FAST-FADING MARGIN (DECIBELS)
Motorway	6 m	Two-ray model	3 dB	0 dB
Urban A	6 m	Two-ray model	3 dB	0 dB
Urban minor	3 m	Karedal model for highway	6 dB	7 dB
Rural A	2.5 m	Two-ray model	6 dB	0 dB
Rural minor	3 m	Two-ray model	6 dB	0 dB

TABLE 7.3. Additional Assumptions for RSU and OBU

RF PARAMETER	VALUE
RSU antenna gain	8 dBi
Vehicle antenna gain	4 dBi
Vehicle antenna height	1.5 m
OBU sensitivity	–90 dBm

Note: RF = radio frequency; dBi = decibels relative to isotropic; m = meter; dBm = decibel-milliwatt.

TABLE 7.4. Maximum Inter-RSU Distance for Each Type of Road and ITS Deployment Phase

TYPE OF ROAD	MAXIMUM INTER-RSU DISTANCE (METERS)		
	DAY 1	DAY 2	DAY 3
Motorway	4,010	3,374	1,422
Urban A	4,010	3,374	1,422
Urban minor	2,560	1,733	246
Rural A	2,178	1,833	773
Rural minor	1,066	897	378

In order to obtain the largest distance between RSUs that fulfills the required service level for each ITS service, it is necessary to assume some radio frequency (RF) characteristics for the RSU and onboard unit (OBU). Shared in table 7.3, the assumptions made in this assessment align with those in Lindberg et al (2019).

Using the above-mentioned assumptions, the maximum inter-RSU distances for the deployment of new RSUs are shown in table 7.4 for the different deployment phases and types of roads.

The number of RSUs required to cover a selected area can be obtained by using the maximum inter-RSU distance and the length of roads in a specific area.

Example corridor

In this study, an example road segment has been selected for analysis (see figure 7.1).[2] The length of this stretch of road is 51 km and the type of road can be assumed as urban minor. This road segment has been selected as an example only, and the included calculations and results are intended to provide an indicative result, not actual or predicted costs on this specific road segment.

This segment has heavy traffic, including private vehicles, public transport, and freight. The total number of vehicles passing per day is estimated at 22,940, distributed by various types of vehicles as indicated in table 7.5.

Assuming a length of 51 km and the inter-RSU distance shown in table 7.6, the number of RSUs to be deployed is as follows:

Once the number of RSUs required is calculated, capital expenditure (CAPEX) and operational expenditure (OPEX) values can be estimated assuming that all the investment in the network and the fiber backhaul deployment, which is the most expensive part, is carried out by a single operator.

A business period of ten years is considered, for example, from 2025 to 2035. The calculations include an estimation of the deployment costs and revenues with this horizon of ten years. The main cost contributions for the network investment are as follows:

- RSU, including hardware and installation, with a cost per unit of US$7,750 (€7.200) (5GAA 2019).
- Fiber backhaul provision, with a total cost of US$24,800 per km (€23.000) (Laya et al 2019).
- Network operation, calculated as the 10 percent of the CAPEX.

Figure 7.2 depicts two examples of infrastructure required for the deployment. Typically, RSU are installed over pre-existing signaling arches.

For operator revenues, the same assumption (Laya et al 2019) is made, considering a charged fee of US$0.50 per 100 km and per vehicle. For this stretch, this represents paying US$0.255 per passing vehicle.

With respect to the deployment rate, the network will be deployed at 55 percent the first year, with additional RSU deployment at 5 percent each year, from the second until the last. The fiber deployment rate in the first year will see 80 percent of fiber rolled out,

TABLE 7.5. Number of Vehicles per Day in the Machakos Turnoff–JKIA Stretch

CAR	MINIBUS	LARGE BUS	TRUCKS			TOTAL
			LIGHT	MEDIUM	HEAVY	
7,660	3,720	1,024	3,520	1,800	5,210	22,934

Source: World Bank 2019.

TABLE7.6. Number of RSU as a Function of Service Type

DAY 1	DAY 2	DAY 3
20	30	208

FIGURE 7.1. Segment Selected for the Deployment Analysis

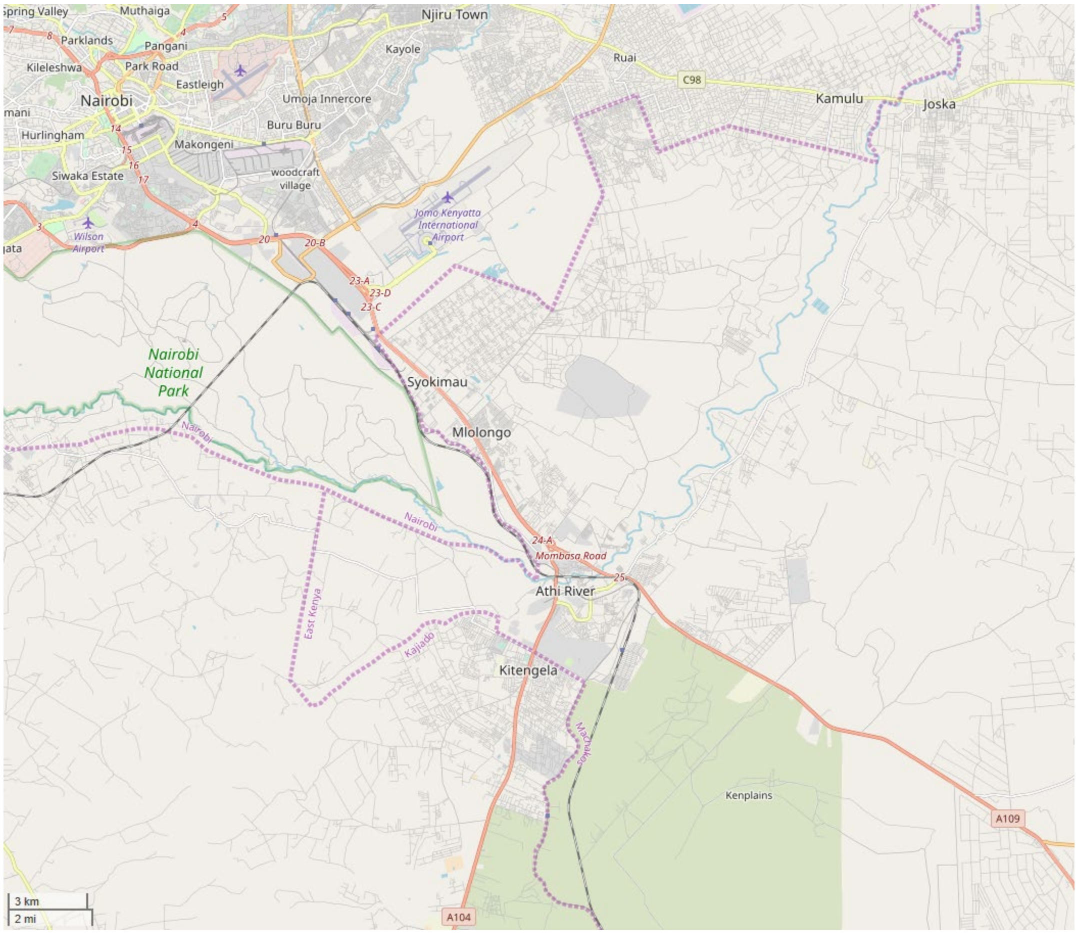
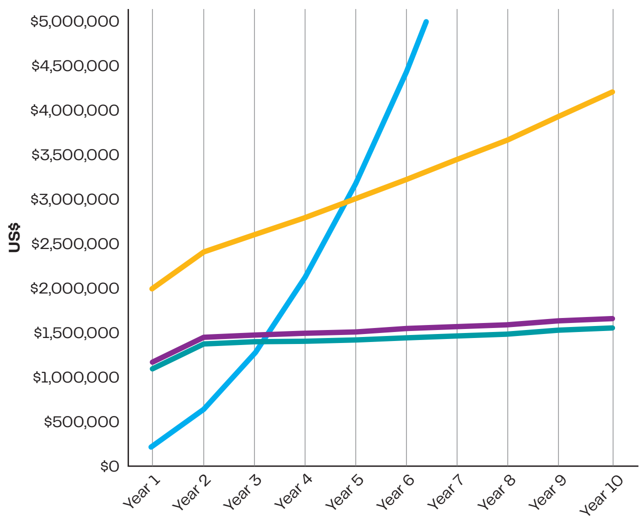


FIGURE 7.2. Examples of RSUs Deployed in the United States

A. RSU INSTALLED ON MERIDIAN AVE (TAMPA, FLORIDA)

B. RSU DEPLOYED IN WASHINGTON STATE

FIGURE 7.3. Accumulated Costs and Revenues without Cellular Support for Day 1 to Day 3 Services



with the remaining 20 percent deployed during the second year. Regarding the penetration rate of the connected autonomous vehicle (CAV)—from year 1 to 10—an additional 10 percent of vehicles will acquire connectivity and start paying for the service, reaching 100 percent in the last year.

Costs evolutions are also considered, with CAPEX decreasing each year by 3 percent, while OPEX will see an annual 3-percent increase.

Figure 7.3 shows the accumulated costs and revenues of a first case, in which the pre-existing cellular network is not used. As observed, payback periods between three and five years are expected, even for "Day 3" services in which the density of RSU is important.

Nevertheless, where there is a pre-existing cellular network, and part of the road is covered by RSU infrastructure, the costs could be reduced, although fiber optic deployment represents the biggest component of the CAPEX, which includes a minimum required investment. Figure 7.4 represents the accumulated costs and revenues, assuming a 50 percent road coverage by the cellular network. The payback period is reduced by almost a year for the Day 3 deployment case, which involves a much denser roll-out; however, Day 1 and Day 1 cases provide no significant benefit through this joint operation.

However, the greatest results sensitivity lies in the cost of fiber optic deployment. Thus, figure 7.5 shows the deployment and return on investment costs when the deployment cost is shared between two operators at 50 percent. This represents a reduction in the one-year return on investment for all considered deployments, so that in approximately two years, the deployment necessary for Day 1 services could be amortized.

FIGURE 7.4. Accumulated Costs and Revenues with 50 percent of Cellular Support for Day 1 to Day 3 Services

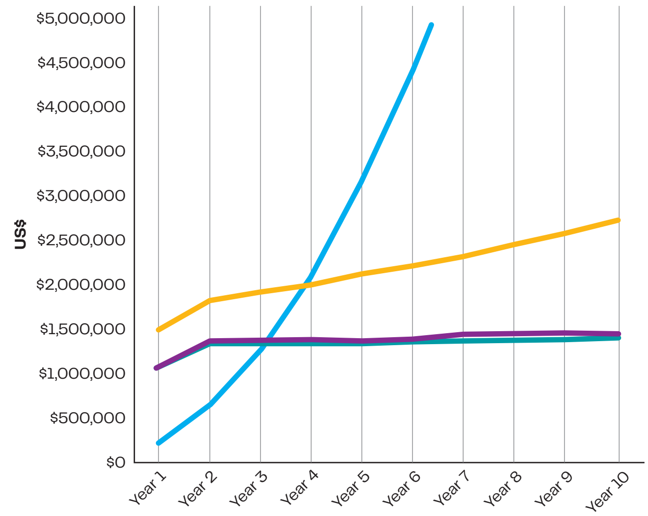
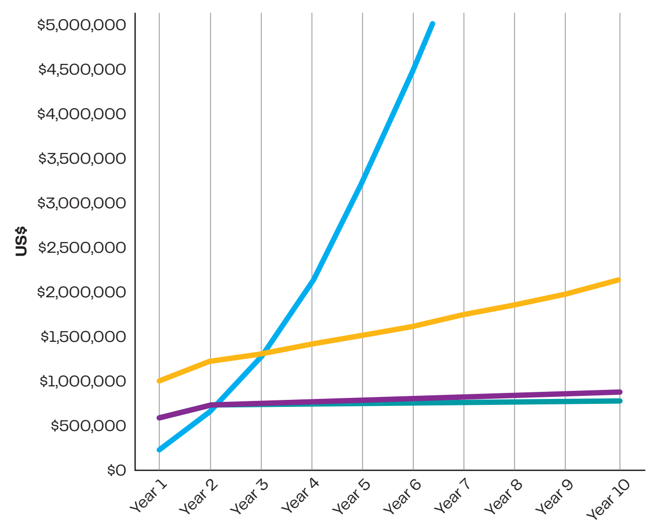
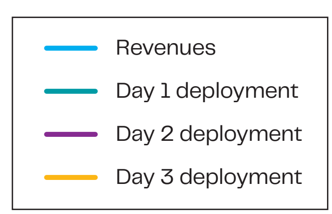


FIGURE 7.5. Accumulated Costs and Revenues with 50 Percent of Cellular Support and 50 Percent Cost Sharing for Day 1 to Day 3 Services





NOTES

1. LiDAR, which stands for laser imaging, detection, and ranging, is a laser-based range finding system for sensing the surrounding environment, based on the duration time and wavelengths or returning pulses of light.

2. The demonstration section included is a 51 km stretch of the Mombasa Road (A-104/A-109) in Kenya.

REFERENCES

5GAA (5G Automobile Association). 2019. "C-ITS Vehicle to Infrastructure Services: How C-V2X Technology Completely Changes the Cost Equation for Road Operators." White Paper. 5GAA, Munich, Germany. Accessed June 2020. https://5Gaa.org/wp-content/uploads/2019/01/5GAA-BMAC-White-Paper_final2.pdf.

C2C-CC (CAR 2 CAR Communication Consortium). 2019. "Guidance for Day 2 and Beyond Roadmap." White Paper 2072. C2C-CC, Braunschweig, Germany. Accessed June 2020. https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_WP_2072_Roadmap Day2AndBeyond.pdf.

Karedal, Johan, Nicolai Czink, Alexander Paier, Fredrik Tufvesson, and Andreas F. Molisch. 2011. "Path Loss Modeling for Vehicle-to-Vehicle Communications." *IEEE Transactions on Vehicular Technology* 60 (1): 323–28. doi: 10.1109/TVT.2010.2094632.

Laya, Andrés, Konstantinos Manolakis, Gorka Vélez, Mikael Fallgren, Shane He, John Favaro, Panagiotis Syros, Michele Paolino, Bessem Sayadi, Baruch Altman, Mohamed Gharba, Markus Dillinger, Leonardo Gomes Baltar, and Jose F. Monserrat. 2019. "Business Feasibility Study for 5G V2X Deployment." White Paper. 5G-PPP Automotive Working Group, Heidelberg, Germany. Accessed June 2020. https://bscw.5G-ppp.eu/pub/bscw.cgi/d293672/5G%20PPP%20 Automotive%20 WG_White%20Paper_Feb2019.pdf.

Lindberg, Per, Taimoor Abbas, Yunpeng Zang, Andres Laya, Mikael Fallgren, A. E. Fernandez, A. Servel, O. Sancier, R. Comte, E. Le Fur, M. Bouillon, M. Gharba, Zexian Li, and Guillaume Vivier. 2019. "Deliverable D2.2: Intermediate Report on V2X Business Models and Spectrum." Document No. 5GCAR/D2.2, v2.0, February 28. Fifth Generation Communication Automotive Research and innovation (5GCAR). Accessed June 2020. https://5Gcar.eu/wp-content/uploads/2019/03/5GCAR_ D2.2_v2.0.pdf.

World Bank. 2019. "Kenya: National Urban Transport Improvement Project." Implementation Completion and Results Report, No. ICR4798. World Bank Group, Washington, DC. http://documents.worldbank.org/curated/en/702181563299068935.

08

CHALLENGES AND LESSONS LEARNED

As 5G is still in its infancy, lessons which can be distilled from initial pilots will be used to guide future implementation. This chapter outlines a set of challenges and risks already identified for the transport sector.

CHALLENGES

Public transport and use of limited urban public space

Public transport offers passengers the key advantages of low-cost mobility and the ability to spend commuting time on tasks other than driving. However, in some cases the lack of flexibility and individual efficiency presents a major drawback. The rise of 5G and increasingly autonomous private cars risks threatening some of public transport's main advantages, as better management of road space and greater fluidity of traffic can boost the shared autonomous car service, while reducing the need to drive provides private vehicle users with the same opportunity to use transit time for other purposes. While such gains are not necessarily negative, an increasing reliance on private vehicles could threaten public transport ridership and increase congestion in city centers as well as space used by private cars, which would raise serious questions of sustainability, access for the poor, and safety. Adapting to the new paradigm will require new thinking, new policies, and a stronger understanding of how transport modes can fill various mobility needs. Traffic prioritization, demand management, preferential parking policies and strict regulations prioritizing urban space for pedestrians, cyclists, and public transport could be increasingly important tools for urban transport decision makers.

Preparing workers for new jobs

As elaborated previously, 5G-enabled transport will likely have a small net gain in overall jobs, especially as more efficient transport facilitates job creation in other sectors. That said, the jobs created will require skillsets separate from those lost and are likely to move to new locations. Informal jobs lost in the poorer parts of the world could be replaced by more technology-focused jobs in developed countries. Thus, governments must identify these impacts early on and begin to prepare their citizens for an increasingly digital future.

The demand for sustainability

As identified in the discussion surrounding 5G and energy use in Chapter 6, the changes impacting the transport sector could have significant benefits in terms of energy use and climate change. Although the benefits of 5G on transport energy use are fairly and decidedly positive, it is important to recognize they are part of a wider ecosystem. In the most pessimistic of scenarios, the many forces facing transport could have little net benefit at all, as increasing connectivity and automation could simply drive up the number of empty trips. Policy makers must grapple with these questions in coming decades, although the data availability features of 5G may provide a key tool unavailable to today's decision makers.

Widening the digital divide

As with the introduction of any new technology, the deployment of 5G represents a significant economic investment, but one that undoubtedly brings significant long-term benefits derived from increased transport efficiency. If only the richest countries are able to undertake that investment, an obvious risk would be a deepening digital divide between the richest and poorest countries. Therefore, governments must find joint investment options, including with the private sector, that will facilitate and support this technological leap forward.

Concerns about autonomous vehicles

Due to the rapid rate of technological change, in many countries concerns persist that autonomous vehicle (AV) technologies remain immature and underdeveloped, which requires stronger safety measures and consumer protection (Udall 2018). While concerns of public safety are important and potentially justified, a tradeoff exists, as the technology will never mature unless companies are able to receive authorization to test their autonomous cars on public roads.

Not a single technology for V2X

Another issue constraining progress toward automation is the lack of political and industrial consensus for choosing one vehicle-to-everything (V2X) technology for use in all vehicular communications, leaving automakers wondering which technology to implement into their onboard radio units: wireless access in vehicular environments (WAVE), fourth-generation long-term evolution (4G LTE), cooperative vehicle-to-everything (C-V2X) Release 14 or the new fifth-generation new radio (5G NR) Release 16. The automotive industry is pressing to protect their interests and ensure the lower impact into the complexity of the car, while backward compatibility becomes a potential issue for the future, with most concerns centering around C-V2X technologies. Questions surrounding the coexistence and compatibility of several wireless technologies are also affecting the market launch of connected autonomous vehicles (CAVs). Policy makers and regulators should guarantee interoperability and minimize uncertainty for the car manufacturing industry. Moreover, the adoption of 5G to address a plethora of non-V2X-specific ITS services is fundamental in modernizing the transport sector. Therefore, the introduction and deployment of 5G should not be hampered by delays in the industrial decision process.

Need for agreement between operators on how and who will provide the C-V2X network

While the European commission has agreed the use of a multi-operator communication environment offers the best approach for providing a C-V2X network, the issue remains largely unexplored. Under the C-V2X model, vehicles could connect to any network and every operator will be in charge of a specific area. However, no common agreement has been reached on how to manage this type of shared network infrastructure, especially when facilitating the movement of vehicles across international borders, which could potentially lead to a reconsideration of the roaming business model. The deployment of a specific road safety network is another option under discussion. Here, the network slicing feature of 5G could also play a fundamental role. Under this model, regulation or economic incentives, or a combination of both, should be applied to make use of pre-existing networks to alleviate deployment costs.

The cybersecurity of the automotive industry is not yet mature

As with any device connected to the Internet, CAVs can be attacked by cybersecurity threats. These cybercrimes in the automotive field could have three goals: (1) harm the vehicle or the driver, (2) hurt the manufacturing company, or (3) steal or modify sensitive information (whether personal customer data or corporate intellectual property (IP) data). With privacy a major concern for direct V2X communications, the automotive industry has developed good solutions centered on the use of pseudonyms. The industry must continue to work with governments to regulate cybersecurity and make further progress in reducing threats.

Even the most sophisticated of the world´s leading automotive brands struggle with cyber threats. In 2018, Tesla's Amazon Web Services cloud account was attacked and used to mine cryptocurrency, potentially revealing sensitive data such as vehicle telemetry. Uber fell victim to a malware targeting of its Android app where hackers accessed users' personal information and location. Such attacks underline the vulnerabilities facing the transport sector. More robust security controls will be needed to prevent data breaches across the entire CAV ecosystem.

International uncertainties

The CAV represents the confluence of two industrial sectors of great relevance: the automotive sector and the information and communications technology (ICT) sector. Both sectors, with enormous financial pressure, are subject to global economic uncertainty, which can greatly affect their normal operations and development. Global trade disputes have already led to disruption in the 5G technology proliferation and the cancellation of many commercial relationships between companies across borders. Such disputes have a real impact on the pace of development of 5G standards. On the other hand, global megatrends such as climate change or the COVID-19 pandemic also drive dramatic changes in the global economy, highlighting the inflection point facing the transport sector. For example, COVID-19 has drastically reduced the normal flow of traffic of people and goods, rendering the impact scale on macro economy difficult to predict, leaving many transport systems and operators to face an existential crisis in terms of financial and operational models.

The cost of CAVs is still high

Due to the additional communication units, antennas, technology, and computation resources, the cost of a CAV is still much higher than a conventional vehicle. For example, in the case of electric vehicles, the additional cost with respect to internal combustion engine (ICE) vehicles is around US$10,000, which could become an important barrier to its introduction in the markets of low-income countries.

Moreover, the IP costs are also expected to be extremely high for 5G. Already, 4G shows a high cost factor in smartphones and communication devices in vehicles, but indeed 5G is expected to be much more expensive, which could be a significant hindrance for low-income countries.

Industrial diversity problem

Current 5G market shows a huge dependency on a handful of companies regarding technology availability. Only a few dedicated companies offer network equipment, with OpenRAN (a vendor-neutral disaggregation of radio access networks, or RAN) still in a very early stage. For chip sets the situation is even more dramatic with only two companies providing solutions. The challenge of this monopolistic situation can also be aggravated by the current global COVID-19 pandemic, which may pose a problem with respect to the increase in prices for equipment. To minimize this risk, nations must guarantee sufficient plurality in the provision of equipment and a good balance between continents.

LESSONS LEARNED

The first flagship 5G networks might technically be live, but as of May 2020 they generally only exist in select cities and are hotspot based. Though handset companies announced 5G-enabled smartphones in mid-2019, the first releases of these high-end handsets arrived in the second-half of 2019.

With that said, major 5G deployments across the globe, implemented by Tier-1 mobile network operators and market-leading network vendors, are underway. The foremost example is the 5G launch in the Republic of Korea (Samsung 2019), with Samsung as infrastructure vendor, and all three Korean mobile operators sharing the 5G deployment costs, which will generate an estimated US$1 billion savings over a decade. In April 2019 5G covered dense urban areas in 85 Korean cities, increasing availability of immersive media, cloud and virtual reality (VR) gaming and many other 5G services for general customers, with autonomous vehicles emerging as a key strategic service. The successful reception of 5G unlimited data plans and compelling 5G services (5G subscriber numbers are currently estimated at over 4 million) predicts a complete nationwide coverage within the next two to three years in the Republic of Korea, by mid-2022. On the technological side (chipsets, network equipment, core, and even software tools), this accomplishment could be attributed to a key factor: the high interoperability of the introduced novel infrastructure. For example, in the existing Korean carrier cellular sites, backward compatibility with 4G is normal when migrating from 4G to 5G, in order to protect previous investments from operators, while 5G core solutions are virtualized to support legacy 4G and next-generation 5G services.

With the global 5G rollout still in its infancy worldwide, and as transport's use of such technology will rely on wide network availability, it is too early to draw a comprehensive set of lessons. However, globally, 4G C-V2X technology is commercially available today, and experience with ongoing pilots on Advanced Driver Assistance Systems (ADAS) using 4G enabled technologies offers some insights. Main conclusions include::

- Recent testing confirms that the range and reliability of C-V2X communication between vehicles is enhanced in comparison to WAVE (5GAA 2018). Technologically speaking, 5G NR-based C-V2X will provide the best of both approaches: direct short-range communication in unlicensed bands and long-range communication with coexisting 4G and 5G, while also supporting ad-hoc vehicle communication in situations with no cellular coverage.
- In this line, according to Groupe Speciale Mobile Association (GSMA) Europe and the Fifth Generation Automobile Association, or 5GAA (GSMA 2019), C-V2X technology is positioned to radically transform the transport sector and how vehicles and drivers interact with the most vulnerable road users such as pedestrians and cyclists.
- C-V2X will also be instrumental in digitizing transportation by providing highly-reliable, real-time information flows to improve road safety, traffic efficiency, and environmental safety.
- China is leading the deployment of C-V2X with more than 20 trials and pilot C-V2X projects taking place across 100 kilometers of roads in 10 provinces (5GAA 2019). The United States is gaining impulse, with Ford committed to deploying C-V2X in all new U.S. vehicle models beginning in 2022, and joint demonstrations with Ducati and Qualcomm Technologies (Ducati 2019) with a four-way stop use case providing insights on the level of cooperative driving possible with C-V2X. In Europe, ubiquitous support is expected, for example, Bosch, Huawei, and Vodafone Germany successfully tested C-V2X on the A9 freeway in Germany, using pre-standard 5G networks (Huawei 2018).
- A good summary of the increasing capabilities and superior performance possible with C-V2X can be read in Qualcomm (2017), where Qualcomm reports that 4G C-V2X and 5G C-V2X have great support for target use cases, allowing for the possibility of high-speed mobility with increased communication range and typically more frequent transmissions. These results anticipate that 5G C-V2X will play a critical role in enabling the deployment of fully autonomous vehicles, which will ultimately transform the transport sector.

REFERENCES

5GAA (5G Automobile Association). 2018. "V2X Functional and Performance Test Report; Test Procedures and Results." Technical Report P-190033. 5GAA, Munich, Germany. Accessed June 2020. https://5Gaa.org/wp-content/uploads/2018/11/5GAA_P-190033_V2X-Functional-and-Performance-Test-Report_final-1.pdf.

5GAA (5G Automobile Association). 2019. "5GAA Brings Together Key Actors to Share Advances on C-V2X Deployment in China at MWC Shanghai 2019." Press Release, June 27. Accessed June 2020. https://5Gaa.org/news/5Gaa-brings-together-key-actors-to-share-advances-on-c-v2x-deployment-in-china-at-mwc-shanghai-2019/.

Ducati. 2019. "Ducati Presents, Together with Audi and Ford, Car-to-Bike Communication Technology at CES in Las Vegas." Ducati.com (UK site), January 8. Accessed June 2020. https://www.ducati.com/gb/en/news/ducati-presents-together-with-audi-and-ford-car-to-bike-communication-tech.

GSMA (Groupe Speciale Mobile Association). 2019. "C-V2X, the Future of Connected Transport, is Live Today." Press Release, September 13. Accessed June 2020. https://www.gsma.com/gsmaeurope/whats-new/c-v2x-the-future-of-connected-transport-is-live-today/.

Huawei. 2018. "Huawei Collaborates with Vodafone and Bosch to Enable Smart Cars to Communicate with Each Other." Press Release, March 14. Accessed June 2020. https://www.huawei.com/en/press-events/news/2018/3/Huawei-Vodafone-Bosch-Smart-Cars.

Qualcomm. 2017. "Accelerating C-V2X Commercialization." Accessed June 2020. https://www.qualcomm.com/media/documents/files/accelerating-c-v2x-commercialization.pdf.

Samsung. 2019. "Case Study: 5G Launches in Korea—Volume 1: Key Success Factors for Early 5G Launch." White Paper. Samsung Electronics Co., Ltd., Gyeonggi-do, Korea. Accessed June 2020. https://images.samsung.com/is/content/samsung/p5/global/business/networks/insights/white-paper/5G-launches-in-korea-get-a-taste-of-the-future/5G-in-Korea-Vol-1-Get-a-taste-of-the-future.pdf.

Udall, Tom. 2018. "Udall, Senators: Self-Driving Car Bill Needs Stronger Safety Measures, Consumer Protections." Press Release, March 14. Accessed May 2020. https://www.tomudall.senate.gov/news/press-releases/udall-senators-self-driving-car-bill-needs-stronger-safety-measures-consumer-protections.

09 POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES

According to the McKinsey Global Institute (Grijpink et al 2020), only a quarter of the global population will have access to 5G coverage by 2030. Still, the opportunity that the fifth-generation (5G) mobile network will bring to the global economy will reduce the unconnected or underconnected population (with only 2G service) from 40 percent today to 20 percent by 2030. In spite of this progress, more than 300 million people, mostly in rural areas of low-income countries, could still lack network coverage.

Wireless technologies have still connected the whole world, and disparities among countries persist. Apart from the countries leading deployment of 5G (Republic of Korea, United States and Japan), China, Canada, and the European Union are currently deploying in selected major cities. India has modernized its mobile networks at an incredible speed, but 5G connectivity is expected in its major urban cities only. However, the main risk lies in the continuing widening of the urban-rural connectivity gap within countries. If policy makers do not intervene, operators will naturally limit their network deployments to the areas where they can earn the most from their capital investment. The financial situation and market maturity will determine each country's timeline for deployment. If we look at the past history and extrapolate the deployment pace of 4G, the first 5G deployments in developing countries will likely happen between the end of 2021 and beginning of 2022. This does not represent an issue for transport sector since the connectivity will run in parallel with the appearance of connected vehicles, but still, any further delay at this point could potentially affect the economic growth 5G could bring to low-income countries.

Connectivity implies a window of hope for economic growth in developing countries. By 2030, many areas without connectivity will have the opportunity to gain global connectivity via 5G or older networks, bringing billions of people online. By enabling more people to plug into the global flows of information, greater human potential and prosperity would be unlocked in many developing countries. The potential of 5G in transport is enormous, but certainly the challenges are huge too, and the risk of 5G and connected autonomous vehicle (CAV) technology failing to reach all developing countries represents a significant threat.

With previous mobile generations, mobile network operators (MNOs) typically aimed for nationwide or near-nationwide coverage. However, the huge costs of deploying 5G, combined with the expectations of reduced incremental revenue, mean that full coverage will be difficult to achieve in low-income countries, at least with the revenue models available today. Nevertheless, the vast majority of technologies leveraging 5G for the transport sector will require extensive rollout of 5G across a wide area. As such, the opportunity to leverage these technologies for development impacts in some lower income countries may be quite limited, with only a few countries—such as China and those in Eastern Europe—expecting rollout in the coming years.

Closing these divides between high-income and low-income countries requires the public sector or other private investors to support nationwide coverage to ensure the CAV successful penetration. Indeed, developing countries need to find additional revenue growth for MNOs from different sources, not only private end customers, to increase returns and justify the effort of connectivity upgrades and new deployments imposed by national-wide 5G coverage. In fact, new players are expected to become connectivity providers, ranging from broadcast infrastructure companies to technological giants, such as Facebook or Google. Also, third-party logistics (3PL) players could build their own private networks, mainly to cover last-mile connectivity services.

Apart from using the transport business to drive revenue increase, network sharing should be augmented to reduce the cost of 5G deployment. The adoption of innovative business models enabled by innovations such as network slicing (which enables the same physical network infrastructure to deliver dedicated capacity for different services) should be promoted by public bodies to help guarantee widespread 5G coverage. In addition, with the potential savings of 50 percent in energy consumption, CAV could be the perfect reason to deploy 5G, though the question remains when those cars will be available.

Indeed, even where an extensive rollout is possible, the long lifespan of vehicles (and the tendency for older vehicles to stay on the roads longer in developing countries) suggest that reaching a critical mass of connected vehicles in developing countries is potentially decades away. Indeed, in the United States, the average lifespan of a vehicle on the road today is almost 12 years, and even if the industry were to begin manufacturing only connected 5G vehicles, it would still take more than 20 years to replace the entire vehicle fleet with CAVs. The focus should then be on 2040. Putting aside the self-driving capabilities, according to McKinsey (Grijpink et al 2020), by 2030 connected vehicles—likely connected via wireless access in vehicular environments (WAVE), long-term evolution (LTE), or 5G—will be 100 percent in Europe and the United States, mostly due to regulation, and around 90 percent in China. However, focusing on the rest of the world, the percentage of connected vehicles in 2030 will be less than 40 percent.

A focus on handheld applications, public transport, and logistics

Due to the likely delay in rollout of connected vehicles and the limited coverage, two potential applications of 5G in transport may dominate in developing countries in the short to medium term: (1) mobile phone-based solutions and (2) interventions covering limited spatial areas.

Phone-based applications are already being developed to address a number of challenges facing transport users. One potential use case involves those tools to collect and share information with users, such as enhanced passenger information systems in public transport, communication of road hazards, real-time information on urban mobility options, improved emergency services, tracking of goods on a real-time basis, and more. Such solutions may build upon offerings already available through 4G services by expanding the detail, timeliness, and reliability of the information provided. Other applications will provide improved information for transport systems and decision makers, for instance, using the improved richness of available data to guide traffic control or dynamic public transport routing, to enable multimodal and streamlined public transport ticketing. This could even support the creation of congestion tolls that would tax the negative externalities and co-finance the development of infrastructure.

Another type of application that might develop in the relative short term in developing countries are those with limited spatial coverage. In cities, for instance, 5G coverage could allow for improved traffic control systems, parking management, real-time data collection and dispatch of emergency services, infrastructure monitoring, and more. Urban public transport, in particular, could benefit from a targeted 5G network, providing customers the types of services mentioned above, as well as improved infotainment options, dynamic routing, and potentially autonomous buses.

Similar to the above, logistics services may be built out in discrete geographies, leveraging limited coverage where possible. In some cases, the deployment of limited 5G networks could be driven by the transport sector itself, such as in ports or along rail lines. Logistics companies may also drive investment in 5G in specific localities to align local systems, global value chains, and systems where a business case is justified. In cities, urban delivery companies will continue to innovate their offerings, and will build on the potential benefits of 5G networks as they come online.

Affordability and accessibility

Governments and the private sector will need to find ways to deploy infrastructure in the most cost-efficient manner. Infrastructure sharing is key to reducing costs related to the implementation of 5G and the intelligent transport services related to its deployment through PPP-style contracts. Additionally, public transport operators and authorities can reduce the costs of running the services by providing more efficient services in response to real-time demand management when using the new technology features more readily available with 5G than with 4G. And finally, all those efficiency gains can reflect in having a better service with lower or equal tariffs compared with today, although better demand management of ticketing and smart card systems can ensure that the most vulnerable people can have access to subsidies to ensure the system remains affordable for all users.

Emerging countries will need to develop their digital skills to reduce the gap when deploying the 5G network, but with the right set of skills and innovation-friendly policies, other countries can show that leapfrogging the transport and mobility sectors is possible; innovative companies can become global by adapting local solutions to other environments, thus creating jobs and providing economic growth in the digital and mobility sectors. The lack of new jobs and economic growth would eventually become the cost of not deploying the 5G network, as failing to develop the digital and mobility sectors would deepen the digital gap in between countries worldwide.

In those countries as well, the geographical barriers of 5G coverage in low-income areas will need to be considered by the government and the private sector when deploying infrastructure and services, keeping in mind that people generally have a high willingness to pay for mobile connectivity. In addition, the accessibility of jobs and services in low-income areas can be associated with the lack of jobs and opportunities in those specific areas, rather than with the availability of public transport to the city's central business district (CBD). Teleworking and new mobility patterns that might evolve from connected mobility could improve job creation all around the city neighborhoods, envisioning the 15 minutes' city idea, rather than keeping the radial structure of concentrating jobs and wealth in the CBD. 5G-enabled mobility will ensure that cities can reserve much more space for pedestrians and cyclists, allowing many city centers to appear if 5G and a strong set of policies are developed. This type of urban fabric connects with the literature studying mobility of low-income people or the mobility of women—comprising a higher percentage of public transport users—who often elect not to work in certain areas of the city because of lengthy and dangerous commutes.[1] 5G-enabled mobility will provide more efficient public transport services, accessible and affordable Mobility as a Service (MaaS), and especially, with the right policies set in motion, 5G can change the way our cities are designed, bringing jobs and services within the reach of all neighborhoods.

APPLICABILITY TO THE SUSTAINABLE DEVELOPMENT GOALS

Providing ***universal and affordable access to the Internet in least developed countries*** is one of the targets of Sustainable Development Goal 9; however, it is not the only goal in which the role of the 5G could be crucial. Box 9.1 outlines some of the clearest contributions.

BOX 9.1. How 5G Applies to the SDGs

Safe roads for passengers and drivers can save a family from plunging into poverty after losing the income earner. In low-income countries, the majority of poor people are farmers. By improving the transport infrastructure, the variety of goods sold at market can be increased, which encourages farmers to sell their products to bigger markets. In addition, improving the efficiency of urban transport systems will reduce transport costs for residents, providing lower-cost access to more jobs and services than before.

As most food waste in developing countries happens during transport from farm to market, providing interventions to improve the availability of reliable and sustainable transport can have a real impact on food security. In developing countries, 45 percent of the land area is located more than five hours away from the main market, while the local agriculture only covers food needs (Seiber 2009). Moreover, traders, using a hired vehicle, incur three times the cost for traveling on a gravel track compared with traveling on a paved road. Therefore, improving the connectivity and the transport quality could reduce distribution costs, while at the same time enhancing the supply chain of food, avoiding food losses during its transportation to far destinations.

The implementation of a well-planned transport network can increase road safety and reduce the amount of traffic road crashes. As outlined previously, one of the most important potential impacts of 5G in transport could be to reduce the incidence of traffic-related collisions, potentially saving more than a million lives a year, and preventing tens of millions of non-fatal injuries (WHO 2020). Moreover, air pollution can be decreased by reducing demand for transport and improving its efficiency.

5G-enabled transport has the potential to increase global GDP by more than US$200 billion by 2030 (Jonsson et al 2019), while improving outcomes for transport users. Avoiding traffic congestion has a direct impact on the economy due to time and fuel wastage in slow traffic, as well as reducing the effective access to job opportunities. Therefore, good quality, efficient, and affordable transport promotes inclusive growth and a strong business environment.

Transport is intricately linked with climate change through direct reduction of CO_2 emission and other greenhouse gases. As elaborated previously, the deployment of CAVs and other 5G-enabled applications has the potential to substantively reduce GHG emissions. Moreover, efficient road planning favors time-saving paths and reduces fuel consumption. In terms of adaptation to climate change, the real-time data, smart logistics, and dynamic routing empowered through 5G applications provide an opportunity for improved resilience and disaster response.

POLICY IMPLICATIONS

How these applications develop, whether they reach the poorest countries and regions, and whether they have a clearly positive impact in the transport sector or not, will be driven by how the policy environment evolves. The policy recommendations are therefore organized in the following questions raised by World Bank clients with respect to required actions:

- impacts on public transport in urban areas and use of urban space
- flexible software development and licensing
- network ownership
- infrastructure sharing
- spectrum sharing
- data governance
- the market ecosystem
- public-private partnerships

Impacts on public transport in urban areas and use of urban space

Cities and countries need to set up efficient incentives and regulations to ensure that public transport agencies, operators, and users have a more innovative approach in their decisions. With the advent of 5G, the public sector can set legal and financial incentives and ease the regulatory framework for the public transport companies and private MaaS operators to obtain real-time video and data (empowered through 5G) from buses or other vehicles, to help ensure better monitoring and enforcement in an open and dynamic environment. This is something that many public transport agencies failed to do during the 4G era, but might be able to modernize and adapt during the 5G rollout, allowing real-time video transmission from vehicles to control centers.

The unregulated growth of CAVs threatens the urban transport fabric, as the potential for empty miles could lead to more congestion, erode the value proposition, and render the traditional congestion mitigation measures ineffectual. 5G has a role to play in developing new models by allowing data to travel more quickly between sensors and the cloud and across various databases in order to enable and subsequently enforce new congestion restriction models (for example, restricting the number of CAVs entering cities, or automatically prioritizing denser modes in moving through city streets). The ultimate goal of such policies should be to eventually reduce the share of urban space used by vehicles and devolve the space to pedestrians and other uses.

Flexible software development and licensing

A general problem creating issues for the public sector, when considering its approach toward innovation, is the past experience of using obsolete and outdated equipment with closed protocols and licensed software with closed codes. Currently, some of the most innovative companies are relying on free software or third-party developers for support, as well as for open protocols and open codes. However, rigid rules for procurement make this path particularly difficult for the government. Many government agencies face a lack of available and up-to-date software licenses for the number of technicians needed to perform the work, which leads them to abandon potentially viable innovative solutions.

When deploying 5G for transport, cities should find ways to move to this “free and open” standard for equipment and software, or partner with private companies to profit as much as possible from already deployed innovations. For instance, traffic lights not centralized and connected to traffic centers, bus validators for travel cards, or ticket systems still using closed protocols make it difficult for control boards to communicate with each other, or with offline ticketing systems. The public sector must rely on efficient third-party collaborators to help them innovate and use all available data in the city to provide more efficient mobility management and planning. Without start-ups and digital disruptions, without the latest cloud-based software, new modalities of transport management and new modalities of payment will not be possible. The City of London’s partnership with a digital company to develop a new system and participate in future profits could be replicated to foster innovation elsewhere. Especially when thinking ahead to the next ten years (and beyond) of mobility, cities should keep these partnerships with innovative companies in mind. The public sector must incorporate innovation-friendly approaches when deploying 5G for transport in the middle and long-term, or risk losing its transport users to the more connectivity-minded and user friendly MaaS options.

Network ownership

Certain models for alternative network ownership, such as the micro-operator and private network concepts, relate to the provision of local connectivity only. Therefore, they do not meet the transport sector requirement for a broader reach. However, other non-local network ownership models are more suited for the transport sector, for instance, in some higher-income countries, multiple operators will deploy independent networks. In others, likely middle-income countries, multiple operators will deploy connectivity over shared networks, implementing different types of sharing (see a more detailed description below). In lower-income countries, where identifying mobile network operators (MNOs) interested in assuming huge deployments costs can be difficult, a neutral host—often the road operator, broadcasting company, or even the government—could provide infrastructure for virtual MNOs. *A priori*, there is no optimal choice, but the assessment must be made on a case-by-case basis. A number of factors, such as population density, scarcity of available deployment sites, timing of the network deployment or the highway construction, and network sharing regulations, among others, have an impact on the suitability of one solution over another.

It is, however, important to highlight that, even if the large investment requirement presents a significant entrance barrier, the opportunity to include transport use cases as mechanisms to introduce new sources of incomes can serve as an immense incentive for operators to accelerate deployment. In addition, as explained earlier, the 5G network slicing technology makes the role of neutral operators especially interesting, offering connectivity to infrastructure-less operators. This is where governments can also take measures to deploy networks that allow small operators to deploy with a lower investment risk, thus reducing the capital investment cycles.

On the other hand, OpenRAN (learn more at https://telecominfraproject.com/openran/) represents a promising option for reducing cost even further and including new players (Abeta et al 2019). The OpenRAN technology challenges the dominance of the traditional big vendors and allows baseband units to run virtually on any general-purpose hardware. This, together with a collaborative community providing software development and support, has created a competitive and innovative ecosystem for 5G. OpenRAN technology is already being considered in 2020, with several big operators undertaking trials, to explore security concerns and examine the code more closely.

Infrastructure sharing

Undoubtedly, infrastructure sharing between telecom operators is beneficial for the transport sector due to the implied cost reduction, which, as explained above, could foster investment for 5G network deployment. This network deployment is needed in some developing regions to provide basic coverage, but also in more developed regions to provide Day 3 automation services not supported by current deployments.

Such telecom Infrastructure sharing may take different forms, from the sharing of passive infrastructure (physical sites and power systems, for instance), to the sharing of the radio access network's electronic infrastructure (for example, antennas, transceivers, and others) and core network (servers, for example). Each specific type of sharing comes with its own issues. Passive sharing is the less challenging mode, though its main issue is the additional free space required at physical sites for placing equipment from different operators. Nevertheless, finding enough space is not an issue in case of new deployments, which can be dimensioned according to the needs imposed by sharing. Though passive sharing offers easy implementation, it is less financially beneficial than some options. Other sharing alternatives provide greater cost savings, though they also bring their own challenges, some of them regulatory. For example, ensuring competition within the network is a key point for regulators, and sharing agreements will likely require approval. Additionally, network operation is more complex. Other common issue is that some sharing implies a long-term commitment between MNOs, which be a roadblock for some operators. Another challenge is ensuring a consistent quality of services provided across the MNOs sharing resources.

Infrastructure sharing can also involve issues with network resilience against failures in individual network nodes, as the reduced number of independent networks implies a lower capacity of users to access communication services if individual networks fail. However, on the other hand, infrastructure sharing enables the provision of better connection quality by each MNO, if they invest the cost savings derived from network sharing in the improvement of their equipment. This improved quality comes with higher network reliability and capacity.

Additionally, and with clear implications for transport, backhauling sharing models whereby fiber optic cables are deployed in a coordinated way along other network infrastructure. These "dig once" policies allow significant cost reductions for the deployment of fiber optic infrastructure. While certain areas have existing optical fiber backhaul deployed along roads, commercial agreements are typically hard to manage, and new regulations are needed to ensure this sharing remains accessible to the transport sector and to the conventional MNOs. In any case, sharing options should be encouraged to reduce additional deployment costs. Of course, this sharing could work the other way around too, making the deployment for road coverage much cheaper.

Finally, and in preparation for use in 2030, any plans for large transportation infrastructure must from now on include considerations for 5G. The use case of the roadways is evident. Since future roads must be connected, and have roadside units along the whole track to enable wireless transmission of ITS messages, fiber optic runs along the road, with separate transmission points between 1,500 and 4,000 meters. In addition, fiber optics must be deployed in parallel to the roadway to prepare the infrastructure for a later deployment of the 5G. Similarly, any rail track must be equipped with parallel optical fiber and transmission points, to connect trains and sensors to the train management system. Finally, in case of investing in the implementation of traffic lights at the cross junctions in

From now on, all railway structures, roads, and signaling elements in cities should take into account questions of connectivity urban or interurban roads, they too should be connected, because 5G transmission points at intersections are essential to preventing accidents and improving traffic flow.

Spectrum sharing

More important for the transport sector is that regulatory uncertainty should be resolved as soon as possible. Spectrum availability, access rights to public infrastructure, and power supply are challenges that could prevent mobile network operators from meeting the required deployment needs. Moreover, regulation on spectrum sharing and power density could also have a major implication on the entrance of investors as well as the timeframe for deployment in the country.

The issue of sharing the ITS spectrum, has yet to be addressed, since to date the assigned ITS spectrum is unlicensed, although the assignment of new spectrum for Day 3 services is being studied and the option of a shared spectrum is on the table. The main issues surrounding spectrum sharing are also related to regulation. Sharing agreements may need the approval of national regulatory agencies (NRAs), and spectrum sharing implies a high level of sharing subject to this control. NRA must ensure the effective competition between the operators, the quality of the connectivity provision, and the efficient use of the spectrum. In addition, in case of resource pooling, that is, the same spectrum is used by several operators via some type of stock market, variation of licensing terms could be needed. The difficult articulation of the shared spectrum, especially when it comes to nodes in continuous mobility, raises doubts about its possible application in the specific field of transport.

Data governance

The digitalization of transport raises important questions concerning how data is generated, managed, stored, and used. One of the overarching themes characterizing the transport sector is that data will become increasingly central to the planning, operations, and monitoring of the transport system, underscoring the importance of having a strong data governance structure in place early in the process.

In terms of data sharing, open data standards are important to allow all stakeholders to leverage the growing data availability. For example, logistics and shipping providers identify that supply chain visibility is one of the biggest challenges for logistics today. However, having the data made available is only the first part of a longer challenge of end-to-end supply chain visualization. Without clear data standards, sharing, and collaboration between the different actors in the network, the advancements in technology will not effectively benefit the widest range of users.

Spectrum allocation is the first obstacle that governments have to overcome

BOX 9.2. The First Obstacle: Spectrum Allocation

5G will reach its full potential if and only if sufficient harmonized spectrum is allocated in a timely way and with long-term license duration. Developing countries should allocate spectrum without the intention of doing business, but rather offering it in exchange for the investment entrance that allows for the public-private partnerships (PPP) offering greatest benefit to society.

Regarding specific spectrum, the globally harmonized 5.9 gigahertz (GHz) band (5,855 to 5,925 megahertz (MHz) should be first be allocated to intelligent transportation systems (ITS) services. Other bands, mainly the 700, 800, or 900 MHz bands, could be used to support vehicle-to-network (V2N) communications, required to reduce the deployment costs for most of the envisioned 5G services. Cellular coverage extension at these bands will not only be important for ITS services, but will also be helpful to provide coverage in rural areas, and thus ensure greater penetration of the general 5G service in the population.

Due to the high deployment cost, the millimeter bands are not recommended for use with vehicle-to-infrastructure (V2I) communications in developing countries, although their use for vehicle-to-vehicle (V2V) or vehicle-to-pedestrian (V2P) applications will depend on the development of the industry.

The points above raise important questions of user privacy. Given that most of this data will be related to location and personal use, the need for a strong policy of data privacy will become even more important. Tools, such as the creation of digital data trusts, will be needed to provide privacy for users while, at the same time, allowing data to be used in an effective way. The massive adoption of Internet of Things (IoT) devices, combined with the proliferation of 5G, will generate large amounts of data that could be mined by transport sector players. This presents opportunities to leverage this type of big data for improved planning and management in the transport sector, and with clear privacy regulations in place, for monetization and use in the industry.

Market ecosystem

The 5G era is expected to usher in the entry of new types of services and players. Indeed, the 5G ecosystem will transform the traditional transport chain into the future of autonomous vehicles (AVs). This technological race does not only involve vehicle manufacturers and Tier-1 suppliers, but also involves new sectors such as road infrastructure companies, technology companies, and 5G network infrastructure providers. According to Grijpink et al (2020) in the next decade, three scenarios could be developed: (1) vehicle manufacturers and their suppliers establish platform alliances to share research and development (R&D) and deployment costs, while retaining ownership of a common operating system and data platform, (2) a major technology player or a group of technology players dominate the market for vehicle operating systems and cloud services, and (3) multiple technological players compete with their own functional platforms, with a smaller ecosystem revolving around each.

As for emerging market players such as automotive and spare parts manufacturers, they could consider adopting open platforms and hardware, using application developers and other partners with complementary capabilities to provide CAV-related services. On the other hand, 5G infrastructure providers must expand their vision of providing a basic connectivity service and develop specific services and new applications for the transport sector. The technology-driven convergence of sectors will also introduce new players into other aspects of the transport system. For instance, the increasing adoption of smart payment systems in transit networks has already begun to introduce financial institutions as an integral part of the systems themselves. With the growth of smart connectivity and mobile money, telecom companies may increasingly become intrinsically connected to transport systems.

However, car manufacturers, suppliers, technology, and infrastructure players as well as service providers have not yet captured the full value of connectivity, whether in terms of revenue, safety, or operational efficiency. Thus, the underlying challenge is the development of new connected services that will require companies to take a different organizational approach, forcing them to move away from rigid and isolated operations toward a flexible and dynamic market where industry 4.0 could play a fundamental role.

Public–Private Partnerships

A Public-Private Partnership (PPP) is considered a form of structured cooperation between public and private parties in the planning, construction, and exploitation of infrastructural facilities in which they share or reallocate risks, costs, benefits, resources, and responsibilities. This model has been effectively implemented worldwide and used extensively in the construction of toll roads, where a government grants a license for exploitation to a private company, which then deploys and manages an effective toll-road communication infrastructure.

With respect to 5G, to date, governments around the world have followed various PPP approaches aimed at encouraging the deployment of 5G. In some countries, direct investment and subsidies for operators have been applied, like in the United States, with the US$9 billion 5G subsidy program for rural America. In others, the support is offered through extensive investment in research and development (R&D) programs, such as the 5G Infrastructure Public-Private Partnership (5G-PPP) a joint initiative between the European Commission and European ICT industry (https://5G-ppp.eu/). In another example, the World Bank is supporting the municipality of São Paulo (Brazil) to understand the feasibility of establishing a PPP around infrastructure sharing to deploy 5G infrastructure along the renovation and modernization of the city's traffic lights network, which includes connecting it to a centralized monitoring and control center. Lastly, in other cases, PPPs models have initiated more indirect action, for example through accelerating spectrum auctions and allocating spectrum chunks with reasonable conditions.

Box 9.3 highlights the role of PPP collaboration in deploying 5G in developing countries.

In developing countries, private public collaboration is essential

BOX 9.3. 5G and Public–Private Collaboration in Developing Countries

Innovative business approaches and incentivized investments are needed in developing countries to support mobile operators as they expand to meet specific connectivity needs in the transport sector. PPP models should be explored, in which cooperation agreements comprising at least two or more stakeholders from the same or different sectors might need to be consolidated to share the passive or active infrastructure network elements. The 5G-PPP in Europe is a great example to follow (learn more at https://5G-ppp.eu).

5G technology, thanks to its concept of network slicing, allows the deployment of neutral operators, who offer various services (potentially operated by different actors), while sharing the same infrastructure. This type of infrastructure sharing heavily reduces costs of deployment and operation and breaks the barriers for the entrance of network operators. In this context, governments could offer an economically profitable ecosystem, with benefits for both private and public sector stakeholders.

NOTES

1. See the World Bank blog post, "Building Equality into Intelligent Transport Systems in China," available online at https://blogs.worldbank.org/eastasiapacific/building-gender-equality-into-intelligent-transport-systems-in-china.
See also: http://documents.worldbank.org/curated/en/2016/09/26796511/assessment-gender-impacts-2016f

REFERENCES

Abeta, Sadayuki, Toshiro Kawahara, Anil Umesh, and Ryusuke Matsukawa. 2019. "O-RAN Alliance Standardization Trends." ***NTT DOCOMO Technical Journal*** 21 (1): 38–45. Accessed June 2020. https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol21_1/vol21_1_006en.pdf.

Grijpink, Ferry, Eric Kutcher, Alexandre Ménard, Sree Ramaswamy, Davide Schiavotto, James Manyika, Michael Chui, Rob Hamill, and Emir Okan. 2020. "Connected World: An Evolution in Connectivity Beyond the 5G Revolution." McKinsey Global Institute Discussion Paper. McKinsey & Company. https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/connected-world-an-evolution-in-connectivity-beyond-the-5G-revolution.

Jonsson, Peter, Stephen Carson, Greger Blennerud, Jason Kyohun Shim, Brian Arendse, Ahmad Husseini, Per Lindberg, and Kati Öhman. 2019. "Ericsson Mobility Report November 2019." Ericsson, Stockholm. Accessed May 2020. https://www.ericsson.com/en/mobility-report/reports/november-2019.

Seiber, Niklas. 2009. ***Freight Transport for Development Toolkit: Rural Freight***. Infrastructure Study. Report 57969. Washington, DC: World Bank. Accessed June 2020. http://documents.worldbank.org/curated/en/140791468315544452/.

WHO (World Health Organization). 2020. "Fact Sheet: Road Traffic Injuries." who.int, February 7. Accessed May 2020. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries.

WORLD BANK GROUP