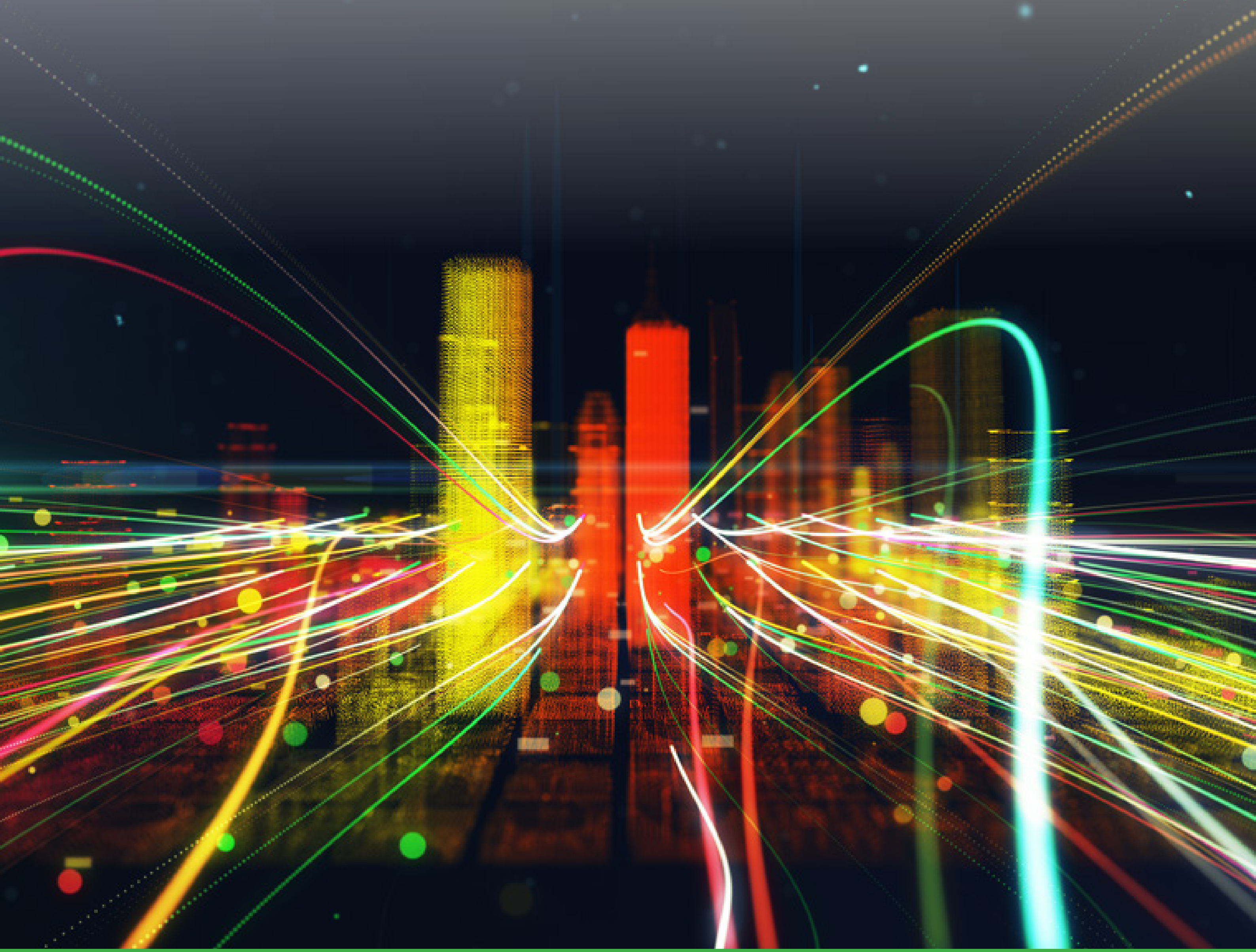

Digitalising infrastructure

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contents

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"Digitalising infrastructure"

In this special issue we focus on the digitalisation of infrastructure. Digitalisation is, of course, transforming all kinds of industries. Content industries (music, newspapers, the audiovisual sector and so on) were the first to be digitalised and then disrupted by digital platforms. Network industries are also now being digitalised, in distinctive ways.

Digitalisation can reduce the cost of the construction and the operation of infrastructure. As sensors are installed in infrastructure producing massive data, infrastructure managers can also reduce maintenance costs. Furthermore, big data can help infrastructure managers to better control traffic flow. Machine learning algorithms can be used to predict peaks in infrastructure use, and then different tools can be employed to manage demand (dynamic pricing) and even supply (software-defined networks). In this special issue, different infrastructure industries are analysed. Common challenges will be identified, as well as the specificities of each sector.

This special issue presents a set of four papers developed by members of the *Digitalizing Infrastructure Group of Experts* (DIGEX). DIGEX was founded in 2018, within the Florence School of Regulation, and is managed by Juan Montero and Matthias Finger

The first contribution, authored by **Montero**, identifies common themes across different types of infrastructure. It identifies how digitalisation can reduce design costs, and the construction and maintenance of infrastructure. Furthermore, it identifies how digitalisation enables infrastructure managers to reduce costs for the use of infrastructure and, more importantly, allows them to increase efficiency in capacity management by better controlling both capacity supply and demand.

Tsvetkova, **Gustafsson** and **Wikström** identify how digitalisation is transforming the infrastructure of ports and how, as a result, port managers are under growing pressure to provide prompt service.

Espinosa describes how the drinking water sector is using digital technologies to obtain better-quality information on the condition and the functioning of the infrastructure that they manage and the quality of the water that they supply.

Cruz and **Sarmento** explain how digital technologies are being deployed on road networks, reducing costs there.

Editor of this special issue is Juan Montero.

The articles of this special issue are based on the authors' submissions for the book 'A Modern Guide To The Digitalization Of Infrastructure' (Edward Elgar), which will be published in mid 2021.

dossier

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Digitalizing infrastructure

Juan Montero*

Infrastructure is being transformed by digitalization in a specific and distinctive way. Common experiences from different network industries show how digitalization reduces the costs of the design, construction, maintenance, charging and of the operation of infrastructure.

Digitalization

The major technological transformation of our days is digitalization. Technology allows for the creation of a mirror image of reality. A data layer is being laid over the top of reality, which virtually recreates it. Algorithms can then identify opportunities to improve the organization of the system, increasing efficiency. The underlying reality can also be transformed and improved. This has clear applications for infrastructure.

Sensors can be installed in physical assets, sensors that capture and transmit data to the infrastructure manager. This data can recreate, in the data layer, infrastructure status (location, attrition, damage, collapse, etc.), as well as the use of infrastructure for the provision of services (capacity, traffic flows, payments, etc.).

Digitalizing infrastructure depends on the availability of underlying infrastructure: high-speed internet access particularly is a key enabler for other digital technologies. The development of 5G wireless networks across a given territory, not only in densely populated areas, but also in the remote areas crossed by infrastructure, is a fundamental challenge for infrastructure digitalization.

Algorithms allow for the full exploitation of Big Data (Domingos, 2015). Sophisticated algorithms are necessary to put the massive amounts of data created by sensors into order, and to make resulting data relevant. Furthermore, algorithms now incorporate machine learning tools, or “artificial intelligence”. They are no longer a set of fixed commands, rigidly linking a fact to a consequence. On the contrary, algorithms browse through the available data, learning from previous experiences and dynamically linking facts to consequences. Algorithms improve with each interaction, and they are becoming predictive (Agrawal, Gans and Goldfarb, 2018).

Algorithms are increasingly used for infrastructure management. They are used to create the virtual mirror image of a given piece of infrastructure, which is useful in reducing design, construction and maintenance costs. Furthermore, intelligent algorithms can predict and manage traffic flows (be it cars on roads, electricity in energy networks, etc.), as well as adapting capacity, optimizing the load factor and, therefore, reducing infrastructure costs.

Digitalisation, algorithms and automation can significantly improve efficiency. This means a reduction in the investment necessary for the construction and maintenance of infrastructure and, also, improvements in efficiency, as the ability to manage capacity and traffic flows grows.

Cost reduction in the design & construction of infrastructure

Technology can reduce the cost of the design and the construction of infrastructure. Automated computer design can reduce design costs. Technology can further enhance design and construction methods by better coordinating all the participants in a network. Building Information Modelling (BIM) is described as “a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building’s life-cycle” (Succar, 2009).

BIM can reduce construction costs. In the case of roads, cost reduction through BIM technology in the design and construction of infrastructure has been estimated to offer 15% to 20% savings over the traditional design system (Blanco and Chen, 2014).

Cost reduction in infrastructure maintenance

Technology can also reduce the cost of infrastructure maintenance. Traditionally, managers would plan the

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necessary interventions in infrastructure based on the average life expectancy of each element ("preventive maintenance"). Managers would, then, intervene if a fault were detected ("corrective maintenance"); this intervention would naturally come too late if the fault had led to a collapse in the infrastructure.

Technology is transforming maintenance. The Internet of Things (IoT) allows for the installation of sensors in all elements in a given infrastructure. In this way, the infrastructure manager can monitor the status of these elements, and maintenance can be tailored to the real conditions of the infrastructure, making "conditions-based maintenance" possible for infrastructure. Intelligent algorithms can even make use of existing data to predict maintenance needs, enabling "predictive maintenance" (Daneshkhah, Stocks and Jeffrey, 2017).

Maintenance costs can be reduced. After all, interventions now take place when they are really necessary, rather than being based on a conservative theoretical analysis or costly break-downs. An example: for railways rolling stock, it has been estimated that "condition-based maintenance" can reduce costs from 10% to 15%, while predictive maintenance can reduce costs by a further 10% (McKinsey, 2016).

Cost reduction in charging for infrastructure use

Technology can also reduce the costs of charging for infrastructure use. Charges for infrastructure use are usually related to the volume of use of the infrastructure (the number and duration of telephone calls, the kilometres of highway used, the kilowatts of electricity employed, etc.). Metering infrastructure usage generates a cost. The cost is higher when measuring takes place on the periphery of the network, as is the case with electricity, gas and water networks. Meters have to be installed in each point of consumption and information has to be transferred to the infrastructure manager for invoice production. Furthermore, measuring and charging can disturb the traffic flow. Take, for instance, road tolls, which have traditionally obstructed traffic and created congestion at peak times.

Technology is reducing costs by digitalising meters. So-called "smart meters" are reducing costs for charging users in the electricity industry. Meters in themselves, and the associate communications technology, may have a substantial cost. However, they can significantly reduce meter-reading costs, as well as general maintenance costs and costs generated by electricity theft. The experience with water meters is somewhat different, as the low price of water does not always justify this kind of investment, other than in areas with water scarcity. Smart meters can also reduce external costs. In Taiwan, it has been found that electronic tolling in road transportation can reduce congestion (-60.1%) and CO2 emissions (-12.4%) (Tseng, Lin and Chien, 2014).

Cost reduction in infrastructure operation

Technology is not only about transforming the construction and maintenance of infrastructure. It also means transforming infrastructure operation and in particular the key feature in infrastructure management, namely the control of the load factor. Digital technologies allows infrastructure managers to have more control of demand, in the form of traffic flows, but also supply, in the form of dynamic capacity management. Efficiency can be increased as spare capacity is reduced while avoiding congestion.

Controlling demand to avoid congestion is a key element in infrastructure management. Infrastructure presents obvious network effects: the larger the number of users, the lower the cost for each of them as fixed costs are more widely shared pool for distributing the high-fixed-sunk costs of operating a given infrastructure set. As a network industry, infrastructure may also face negative network externalities, particularly in the form of congestion. Distributing traffic evenly across time and space (load factor) is one mechanism for reducing congestion without reducing infrastructure use.

Technology provides instruments for adapting demand to capacity. As infrastructure managers have new tools to predict traffic flows (e.g. predictive algorithms), they can incentivise the use of infrastructure in off-peak periods. Infrastructure managers have always tried to manage demand. The novelty now is that infrastructure managers can predict peak/off-peak usage in real time with far more accuracy, looking at time of the day and year, weather, specific events, etc. They can build more complex pricing schemes, based on metering and billing. For example, smart meters in electric networks are increasing the pricing sophistication of the service, with incentives being made to reduce consumption when demand is peaking.

Infrastructure managers can also respond to fluctuations in demand in real time through dynamic pricing. They can automatically adapt their metering and billing systems. They can also inform users in real time so that these consumers can make their own decisions. Infrastructure managers can reduce congestion, too, by distributing traffic across the network in ways that are more efficient. Discounts can be offered to users if they take alternative roads, or if they take alternative railway services, possibly with a detour. This kind of network management is possible if the infrastructure manager has better knowledge in real time of how the network is being used; or if he or she is able to predict the same effectively and has the ability to respond in real time with new alternative capacity and new prices.

Digital technologies do not only allow for demand to be adapted to capacity, they also allow capacity to be adapted to demand. Software-Defined Networking (SDN) can dynamically adapt capacity to demand by virtualising infrastructure and by providing capacity as a service, rather than as a fixed asset.

SDN decouples the physical infrastructure layer from the control layer, and uses software to dynamically adapt the capacity in the physical layer to existing demand. If a customer demands more capacity, it is provided in real time. If a customer demands only a little capacity at a given time, the excess capacity is used to serve other customer. This is particularly useful in managing bandwidth in large data centres. In the same line, Deep-Packet Inspection (DPI) allows for the prioritization of traffic supporting critical applications over non-time-sensitive traffic. The "bandwidth on demand" services are already a reality (Kreutz et al., 2015).

The concept of SDN is being exported from telecoms, and it is expanding into other infrastructure industries such as electricity. It was originally employed with the provision of electricity to data centres, as a way to ensure the supply of electricity to critical applications. But SDN is now proposed as a solution to help dynamically manage electricity networks. For example, at times of low load, the voltage and operating frequency of the network can be reduced, lowering network operation costs.

The concept of SDN can also be exported to transportation. A smarter management of capacity can take the form of smaller vehicles to provide mass-transit services when demand is found to be low. Larger vehicles and a greater flow of vehicles can be dynamically assigned when a demand peak is identified in real time through sensors and predictive algorithms.

Greater control over the load factor allows infrastructure managers to adapt existing infrastructure capacity to cope with growing demand without congestion. This ability can also be used with unpredictable events, such as black-outs and accidents. Costs can be reduced very substantially.

Conclusion

Technology can significantly reduce costs for the infrastructure manager. Even if the implementation of new technical solutions has a cost in itself, an investment has been shown to pay off in many different contexts. Technology can reduce the cost of design, construction, maintenance and traffic charging. An example: it has been estimated that a 30% average reduction in CAPEX can be expected in the road industry from the implementation of the best technologies (Oliveira Cruz and Miranda Sarmento, 2018).

Digital technologies enable infrastructure managers to achieve better efficiency by better matching capacity supply and demand. Technology provides new tools for dynamic pricing, empowering infrastructure managers to reduce peaks in demand. Technology even empowers infrastructure managers allowing them to adapt capacity supply to demand forecasts.

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The digitalization of port infrastructure[1]

Anastasia Tsvetkova*, Magnus Gustafsson** and Kim Wikström***

Ports, a critical link in sea logistics, are currently undergoing a digital transformation. In this paper, we review recent digital innovations that affect the way port infrastructure and operations are managed and discuss their effect on the business models of future smart ports.

Introduction

Highly fragmented industries characterized by extreme information asymmetries are the first to be affected by the 'platform revolution' (Sarkar 2016). In that respect, sea logistics is a sector in need of improved efficiency (Gustafsson et al. 2015). The digital transformation, coupled with a transition to a platform economy, have the potential to facilitate just such a change. One of the main effects of digital platforms in this transformation is the shift towards multi-sided markets and the facilitation of network effects.

Ports, the interface between sea and land logistics, have historically provided services to multiple players, including vessel operators, cargo owners, land logistics operators or port operators like stevedoring companies. With the advent of 'smart ports', there is the potential to provide more value through data-based services and data-driven business models. The general trend of 'infrastructure as a service' will greatly affect the business models of ports, as the information about infrastructure use becomes more valuable than the possession of that infrastructure. In a platform economy, the competitive advantage changes from the control of valuable resources to the ability to orchestrate information flows and to organize activities among ecosystem actors (van Alstyne et al. 2016).

The increasing volumes of data generated regarding maritime transport creates opportunities for the appearance and growth of new business models and the 'port as a service' types of platforms. Incumbent actors such as the port authorities have a choice to either proactively use the enabling technologies to reinvent their own business models or they risk having their value proposition commoditized in the fourth industrial revolution. In this paper, we review the recent digital developments related to ports and discuss their effects on the transformation of sea logistics and, in particular, on port operations.

Management of port infrastructure

Port infrastructure includes port terminal infrastructure, that is, static structures such as buildings, docking areas, roads, warehouses and power supply; there is also port operational equipment such as the vehicles or machinery needed to provide port services, for example, towing and cargo stowage.

Monitoring static terminal infrastructure to ensure safe and continuous operation is one of the main tasks of port authorities. Smart sensors, advanced computing and video analytics help the port authorities to more efficiently monitor large and diverse infrastructures in port, including networks, roads, railways, restricted areas and warehouses, quays, banks, water depth and locks (Frost & Sullivan 2020). Port infrastructure can be monitored through connected camera and computer image analytics that detect damaged land-based infrastructure. Since water depth and berth status are crucial in moving and mooring vessels within the port, sounding drones with ultrasonic sensors or cameras can constantly monitor the depth and berth and provide data for dredging and maintenance operations (Frost & Sullivan 2020). With the resulting data and algorithms, it is possible to automate the planning of control operations and maintenance actions, and switch to prescriptive maintenance.

Following the same trend, predictive and prescriptive maintenance is also discussed and partly carried out with the management of cargo handling equipment in ports. Sensor and other information reported from cargo-han-

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dling cranes is analyzed in order to improve crane maintenance, repair and operations. The data analytics algorithms developed by cargo handling equipment suppliers can be further improved by collecting global crane data rather than by focusing in on individual pieces of equipment.

Following the development of the building construction sector, BIM can be applied in the design and management of port infrastructure, as well as in 3D models of assets and when enabling the assessment of collected data. In the process, an asset's current and historical data are gathered in order to enhance infrastructure management, which is based on predictive maintenance. The development of digital twins for ports can also aid in the strategic planning of infrastructure investments, port design, and terminal capacity based on the analysis of cargo flow through ports (Lind et al. 2020).

Efficient port operations

Ports vary depending on their capacity, the type of cargo they can receive and their role in the logistic chain. For instance, there are larger 'hub' container ports and smaller final-destination or 'hinterland' ports. Nonetheless, a key criterion for port efficiency is vessel turnaround time. Ports generally aim to reduce vessel turnaround time to increase earnings for port actors by serving as many vessels as possible and by being an efficient link in the longer supply chain and thus ensuring that chain's competitiveness. Smaller ports require a competitive edge as they do not have many ship-calls to efficiently connect land and sea transport and to guarantee the reliability and swiftness of the supply chains related to the hinterland industries they serve.

While some of the vessels' time in port is used for loading or unloading cargo, a great deal of time can be spent waiting, for example for berth or cargo-handling equipment and for customs clearance. Thus, the main applications for port-related digitalization will be on improving port calls through better coordination and communication among the multiple actors involved in sea transportation, port operations and land logistics. Second, there are digital innovations aimed at optimizing vessel and cargo flows through ports. While coordination requires data sharing, optimization requires data analysis such as predictive and prescriptive analytics to predict events and to plan optimal resource allocations (Lind et al. 2018).

There are a number of inefficiencies in how port calls are currently organized. Most ports apply the principle of 'first come, first served' for arriving vessels. This often leads to a 'rush to wait' situation, as vessels arriving in the port area at the same time, increase their speed in order to be first in line at the berth. Queuing in ports can also take several hours or even days if a vessel arrives outside of a port's working hours (Gustafsson et al. 2016). This unproductive time could be avoided or otherwise used, for example for slow steaming, through a timely exchange of information between different parties regarding the vessel's estimated time of arrival (ETA) and the availability of port quays and cargo-handling equipment. For instance, studies show that reducing the nominal speed from 27 to 22 knots (by 19%) can result in bunker savings of approximately 58% (Gustafsson et al. 2015, 2016). Algorithms predicting vessel arrival times and port infrastructure availability are the basis for real-time queuing and slot-booking systems in ports that can help solve the 'rush to wait' challenge. However, in this case, technical solutions are not enough. Companies need to change how they handle issues like work routines and contracts. There are already standard slow steaming and virtual arrival clauses, developed, for instance, by BIMCO, a renowned maritime association, but these are hardly used due to potential arbitration complications and missing reference cases.

Then, to facilitate the coordination necessary for efficient port calls, communication between actors must be drastically improved. These actors include port authorities, ship operators, shippers, port operators, port agents and many others. A vast number of different hardware and software systems from different time periods are currently employed to transmit data from ships to ports during a port call. The result is often a lack of data sharing and interoperability (Inkinen et al. 2019). There are initiatives for solving this problem by digitizing information exchange, such as through the European Maritime Single Window and the use of blockchain technology. Blockchain has been explored in Rotterdam and a few other leading ports globally due to its potential to flatten out multiple registration and control processes. This can involve up to 25 separate entities in relation to a single transport transaction (Lambert et al. 2019).

To further decrease vessel turnaround time, it is crucial to synchronize sea and land logistics by managing cargo flows in and to ports. Otherwise, the benefits of efficient 'digital calls' will be diminished due to delays in cargo stowage. Predictive algorithms based on things like data from container tracking sensors allow for improved planning of cargo arrival, storage and loading on vessels. One particular solution for ensuring smooth traffic flow and for alleviating the congestion caused by land transportation are sensors on roads leading to ports. Combined with data from drivers' devices, it tracks travel times and adjusts traffic lights or signage to facilitate smooth traffic flows to ports.

Achieving synchromodality in ports is a challenge due to significant differences in the logics of ship-to-port synchronization, port-to-port synchronization, and port-to-hinterland synchronization (Lind et al. 2018). Therefore, there is an increasing interest in platform-based digital solutions, which collect data from various sources and from actors involved in logistics, and then there is the possibility of providing custom analytics for specific actors to make informed decisions.

In this spirit, the Port of Rotterdam recently launched the company PortXchange to promote the Pronto digital platform service offered to ports, shipping companies and terminals. The aim of the company is to improve the efficiency of port calls and to help their clients reduce emissions with a joint platform enabling optimal planning, execution and monitoring for port call activities. Moreover, the port has been developing the Internet of Things. This employs a broad network of sensors to provide accurate and up-to-date water and weather data to help the port authority plan and manage shipping operations more effectively. The use of the system is expected to decrease waiting times, to optimize berthing and to accelerate loading times.

Another example of a digital platform for port operations is one developed by a start-up called Awake.AI. The platform combines data on sea and weather conditions, vessel port situational information, port infrastructure availability and cargo flow. It also provides relevant data and analytics for various actors (port authorities, ship operators, terminal operators and cargo owners) so they can improve their operations. In that respect, the company positions their platform as a 'smart port as a service' and sees this platform as a pre-requisite for the wide implementation of autonomous shipping.

To achieve real improvements in efficiency, it is crucial that digital platforms for sharing information and predicting vessel and port operations be implemented in ports, and, also, that the interoperability of data be ensured. Network effects can, then, be achieved, and the efficient use of maritime transport infrastructure drastically increases. Data on port operations, combined with vessel and cargo-related data, is an important input for system-level digital innovations such as platforms for finding optimal routes and vessels for transporting cargo. While these solutions aim to optimize the end-to-end logistic chain, they ultimately affect how much and how well port infrastructure is used.

Conclusions

The implementation of digital solutions in ports discussed in this paper empowers import and export companies; it also encourages infrastructure operators to provide the best availability and the promptest service in ports. Ultimately, ports will become links in an agile hyperconnected global logistics system. Here there is the possibility of getting around current problems including products idling in storages, too many unsold products, and products, unnecessarily, crisscrossing the world (Montreuil 2011).

Digitalization can potentially enable smart ports and facilitate new business models for port actors. However, it is important to note that technical solutions are not a panacea for all the bottlenecks and outdated practices in sea logistics. In fact, the implementation of digital solutions often proves challenging due to the established structure of the relevant business ecosystem and institutionalized lock-ins (Tsvetkova et al. 2019). Thus, maritime transportation will undergo a system-level transformation, where digitalization has an important role or even acts as a catalyzer. However, there is still a need to redefine the value creation and capturing of logics, business models and their interconnections in the ecosystem, as well as the roles, the contractual and the legal frameworks that shape industry architecture (Tsvetkova et al. 2017). The question remains: which actors will lead this transformation, which incumbents will reinvent their role and business models, and which will cease to exist? The business models of future smart ports will have a strong influence on how logistics chains will be transformed.

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Digitalisation in the drinking water sector

Brenda Espinosa Apráez*

The need to obtain more precise and timely information to ensure a safe and reliable water supply has driven water utilities to embrace digitalisation. This article presents some of the technologies behind smart water supply management and identifies a number of challenges that come along with digitalisation in the drinking water sector.

Introduction

Water supply is one of the most critical network industries, given its direct link with basic human needs. Ensuring the availability and sustainable management of water and sanitation is, indeed, one of the goals (the number 6) in the United Nations 2030 Agenda for Sustainable Development. Achieving this goal does not come without difficulties, as there are certain factors that compromise, increasingly, the availability, the quality and the accessibility of water. The steady growth in global population and climate-change-related extreme weather conditions risk water scarcity. In addition, water infrastructure is ageing and will require repair or replacement in the coming decades. Water quality is, more and more, threatened by pollution resulting from industrial and agricultural activities, as well as by the higher temperatures, flooding and drought caused by climate change.

The need to obtain more precise and timely information to tackle the abovementioned challenges has motivated water utilities to embrace digitalisation. This has been facilitated by the growing availability of sensing tools and computing capabilities at a cost that, conversely, tends to decrease (Lloyd Owen 2018 p. 76).

The technologies behind digitalisation in the drinking water sector

The term 'smart water management' is commonly used to encapsulate the digitalisation of the drinking water sector. Smart water management is understood as the use or integration of Information Communication Technologies (ICT) in water management (International Telecommunication Union 2014 p. 4; K-water 2018 p. 25). Smart water management encompasses an array of technologies that allow for data acquisition and integration, modelling and analytics, data dissemination, data processing and storage, management and control and visualization and decision support (International Telecommunication Union 2014 p. 4).

In its 2014 report, the International Telecommunication Union classified smart water management tools in six main categories, with possible overlapping areas. These categories are shown in Table 1.

Category	Examples
Data acquisition and integration	Sensor networks, smart pipes, smart meters
Modelling and analytics	'MikeURBAN'
Data dissemination	Radio transmitters, WIFI, Internet
Data processing and storage	Cloud computing
Management and control	SCADA, optimization tools
Visualization and decision support	Web-based communication tools

Table 1. Types of smart water management tools
Source: author's own compilation, based on International Telecommunication Union (2014, p. 4)

A detailed description of all the technologies used for smart water management is not within the remit of this article. The most common technologies will be briefly explained.

Smart water metering

In general terms, smart meters are "a component of the smart grid that allows a utility to obtain meter readings on demand (daily, hourly or more frequently) without the need of manual meter readers to transmit information" (Arniella 2017 p. 15). While traditional (mechanical accumulation) meters require manual readings taken usually once or twice per year, smart water meters allow for more frequent, higher resolution and remotely accessible (consumption) data (March et al. 2017 p. 2). As such smart meters open up a number of possibilities for water utilities and consumers: precise consumption measurement; facilitating leak detection or other causes of water loss; improved data to balance water demand; application of

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dynamic prices; and water conservation initiatives, among others (see Espinosa Apráez and Lavrijssen (2018 p. 162)).

The literature usually distinguishes between two types of smart meters: (1) automated meter reading (AMR); and (2) automated or advanced metering infrastructure (AMI) (see e.g. Arniella 2017; Lloyd Owen 2018). AMR was the first approach taken to make water meters smarter. Mechanical ('dumb') meters were "complemented with a system with datalogger and communication equipment, which allows readings to be taken using portable equipment (walk-by) or using vehicles (drive-by) which circulate through the streets of a city, scanning the nearby meters" (Sempere-Payá et al. 2013 pp. 248–9). AMI goes one step further and allows for two-way communication between the meter and the utility company, allowing meter readings to be directly sent to the utility (Sempere-Payá et al. 2013 p. 249). Some authors report that only AMI can be truly considered smart metering, to the extent that what makes metering 'smart' is the connection of the meter to the communication network (Lloyd Owen 2018, p. 86). Other authors consider true smart metering to be only the evolved versions of AMI, which allow for real time communication using private communication networks combined with a new generation of meters, "interval water meters" (Sempere-Payá et al. 2013 p. 249).

Sensor networks

Guaranteeing the quality of drinking water is a vital obligation of water utilities. Water quality is assessed against certain standards related to, among others, microbiological, chemical and organoleptic parameters. The monitoring of water quality has been traditionally carried out by collecting samples at given points of the network, which are then analysed in a laboratory to assess whether they meet the relevant standards. This approach has its limitations: it does not allow for real-time monitoring of water quality (i.e., there is a time gap between the sampling and the detection of contamination); the samples are taken at a small number of locations and sampling is labour-intensive (Lambrou et al. 2014 p. 2765).

Sensor networks mitigate these limitations. They entail the installation of different types of wireless sensors inside the water pipes, to measure, in real-time, parameters such as temperature, conductivity, pH, pressure, turbidity, dissolved oxygen, etc. (Lambrou et al. 2014). The data collected with these sensors are sent to the utility company which can then take prompt action if there are contamination issues. The data can also be used to create models to predict changes in the water quality and/or the need for pipe maintenance, and to optimise water treatment processes (Carminati et al. 2020 p. 4).

District metered areas (DMAs)

DMAs are a method of measuring water loss where the water distribution network is divided into several subsystems, where water supply and consumption are measured separately from the rest of the system (Arniella, 2017 p. 18). They are a combination of several tools (hardware and software), including: (smart) water meters; geographical information systems; different types of sensors (pressure, temperature, etc.); hydraulic models; and algorithms. DMAs can be used to identify deviations from normal flows and pressures. They enhance pressure management and pinpoint leakages along the distribution network (Arniella 2017 p. 20). Some sources refer to further subdivisions within DMAs, which, with the help of smart meter data, can help to find leakage points, not only in the distribution network, but also in the home of the consumer, allowing utilities to proactively communicate this to the consumer (K-water 2018 p. 93).

Modelling

Developing models and algorithms based on the data collected with smart meters and other sensing technologies can help water utilities on several fronts. For example, hydraulic modelling can be used for pipe network analysis, which helps to plan future infrastructure expansion and to validate the design of new or rehabilitated pipelines (Arniella 2017 p. 28). Modelling can also be used to predict changes in water quality in the distribution network, caused by chemical or biological factors, loss of system integrity, etc. (Arniella 2017 p. 29). Another use of modelling in the management of the drinking-water infrastructure are water demand forecasts.

Supervisory Control and Data Acquisition (SCADA)

SCADA is a technology that enables the remote monitoring of a system or parts of the same. By means of processing information, SCADA can generate reports or alarms useful for operation and maintenance (Temido et al. 2014 p. 1631). With the help of sensors and other data-collecting devices, SCADA can monitor and control various assets and processes involved in water supply from source to tap (Arniella 2017 p. 27; Temido et al. 2014 p. 1634).

The previous paragraphs provided a brief description of some of the most common technologies used for smart water management in the drinking water sector. All these technologies allow for better-quality data about the condition and functioning of infrastructure and drinking water quality. Having more accurate and (near-to) real time data allows infrastructure managers to perform better assessments of the present situation, and means that they can react faster to problems and disruption, while predicting and preparing for future scenarios. Hence, digitalisation is expected to have a positive impact on the design, monitoring and maintenance of infrastructure, as well as other benefits, such as the enhanced management of water demand, improved water quality monitoring and better customer service.

Although digitalisation is growing in the drinking water sector, some sources note that the level of maturity and the openness to innovation is lower than in other sectors, such as energy and telecommunications (see e.g. Lloyd Owen 2018 p. 58). It is, nevertheless, likely that digitalisation in the drinking water sector will keep growing. Smart water technologies offer more efficient ways to deal with the challenges posed by water scarcity, water pollution and ageing infrastructure, compared to non-digitalised approaches. In addition, it is expected that the price of smart water technologies will decrease as their development and use becomes more widespread. Finally, yet importantly, smart water management is climbing up the agenda of national and supra-national policymakers, as a key strategy to tackle the threats to the sufficient and safe supply of water,[2] contributing to the achievement of Sustainable Development Goals.

New challenges

Digitalisation brings interesting opportunities for improving the provision of drinking water, but at the same time, it brings challenges for utilities and policymakers. Key challenges from a public policy perspective are outlined here.

Financial challenges

Even if the cost of smart water technologies tends to decrease over time, the initial investments required to fully digitalise the management of drinking water infrastructures are high compared to less 'smart' approaches. This is more challenging when utilities are only financed by the tariffs they charge to consumers, and the price of water is rather low (K-water 2018 p. 99). Against that background, access to additional sources of financing, in particular public funding, seems to be crucial for spurring digitalisation in the drinking water sector (K-water 2018 pp. 459–460).

Privacy and data protection

Smart meters are a key component of smart water management. Since they are installed at the homes of consumers and since they capture personal data,[3] water utilities must pay close attention to the limitations and requirements arising from privacy and personal data protection regimes. Thus, digitalisation comes along with the need for technical and organizational measures to safeguard the rights to privacy and personal data protection of consumers; there is also the challenge of reconciling these rights with the requirements of a smart water supply.

Cybersecurity

Digitalisation creates or worsens exposure to cyber-attacks, compromising the availability, the confidentiality and the integrity of the data and the infrastructures used to process data. For example, when using ICT to monitor, but also to remotely operate drinking water infrastructure, the absence of such systems can lead to the absence of water supply, with disastrous consequences. In view of such risks, water utilities will have to put in place technical and organizational measures to prevent and effectively overcome cybersecurity incidents.

Interoperability and (data) standardization

Ensuring that the different components of the water system are interoperable and that data from different internal and external sources can be combined and used properly is key for smart water management. Interoperability and standardisation in the drinking water sector are less developed than in other sectors. This stands in the way of achieving the potential for the digitalisation of drinking water utilities and hinders collaboration among utilities and between utilities and other actors in the broader water sector by means of data sharing (Lloyd Owen 2018 p. 215).

Conclusions

With the help of smart meters, sensors, DMAs, modelling, SCADA and other technological developments, water utilities can obtain better-quality information on the conditions and functioning of the infrastructure that they manage and the quality of the water that they supply. This helps water utilities to improve the design, monitoring and maintenance of infrastructure, as well as ensuring that the water they supply meets the required quality standards for human consumption. In addition, smart water technolo-

[2] See e.g. K-water (2018).

[3] According to the General Data Protection Regulation (Regulation (EU) 2016/679) applicable in the European Union, 'personal data' means "any information relating to an identified or identifiable natural person" (Art. 4 (1)).

gies enhance the interaction between water utilities and consumers.

There is already a significant amount of research on the technical feasibility and opportunities for digitalisation in this sector. However, a broader adoption of smart water technologies will be for the future. It is expected that digitalisation in the drinking water sector will keep growing as technologies become more widespread and cheaper, and as governments start to actively support smart water management.

Digitalisation in the drinking water sector offers interesting opportunities, but comes along with certain challenges related to financial aspects, cybersecurity, data protection and privacy and interoperability, among other matters. These challenges ought to be considered and addressed by water utilities and policymakers to steer smart water management in the right direction.

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Digitalization and road assets: Consequences for construction, asset management and operation

Carlos Oliveira Cruz*, Joaquim Miranda Sarmento**

Roads are a central element in transportation systems, enabling economic and social development, fostering territorial cohesion, and facilitating the movement of people and cargo. As in other sectors, digitalization is opening up significant changes in the way infrastructure is built, operated and financed. These changes will have a profound impact on the entire lifecycle of a given piece of infrastructure, from the design and/or construction phase, to its operation and transfer. This research provides an overall overview of the main technological developments which affect or that will perhaps affect road infrastructure in the short, medium, and long-term. Savings can represent almost 30% of capex and opex. Overall, savings and increases in revenue can represent as much as 20% to 40% of current revenues. Findings show that digitalization and technological development can significantly affect the economic performance of roads, thus enhancing its value for money.

Introduction

Road networks have always played a fundamental role in ensuring the free movement of people and goods, connecting regions and facilitating economic trade. Roads enable economic activity, reducing the costs of movement, facilitating market access, and fostering the movement of labour, thus allowing for a more efficient allocation of resources. Furthermore, a better road system, particularly one based on motorways, provides several positive externalities, such as reductions in travel time and accidents (Sarmento, Renneboog & Matos, 2017a). Fundamentally, roads are an economic enabler, with spillover effects in increased productivity. Governments look to road networks as a critical foundation for economic and social development. As such, road development has been among worldwide investment priorities, particularly in the European Union (EU).

The management of roads is moving from a service-based perspective, towards a consumer-based perspective, offering solutions to improve and optimise travel, and to provide additional services, such as electric charging points, and integrated mobility solutions (Cruz and Sarmento, 2018).

Together with these various trends, there is a broad change which will possibly have higher disruption potential – digitalization. Digitalization enables the integration and diversification of traditional mobility functions, allowing for a shift in focus from infrastructure to users. The entire road networks involve several distinct types of roads: motorways (which are generally referred to as the "principal network", or "level 1 road system"), regional roads, and municipal roads.

Public infrastructure, and in particular, capital-intensive infrastructure (such as roads, bridges, or railways), have been slowly incorporating technological advancements to improve their social, economic, and environmental performance (Finger & Razaghi, 2016; Cruz and Sarmento, 2017). Despite the relevance of efficiency gains associated with the construction and the operation of road projects, major advances will rely on "digitalization".

This paper presents and discusses technological advances in the construction and management of road assets.

Design and construction

Infrastructure-related digitization is directly associated with achieving higher value for money in the construction and management stage of road projects. This involves being able to construct and develop projects at a lower cost, which can be achieved through an increase in the (low) productivity levels of the construction sector (e.g. BIM and IoT). Additionally, this means being able to rethink and optimize the way roads are managed (e.g. smart asset management), and being able to develop additional value-creating options in infrastructure (e.g. electric charging). This section will provide an overview of the main developments in each of these areas, as well as a detailed discussion on its impact in terms of maximizing money value in road projects.

Building information modelling (BIM) and collaborative design

Road projects are, firstly, a construction project. Typically, the investment associated with the construction accounts for approximately 50% to 70% of the overall

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life-cycle costs of a road project over a forty-year period. The remaining investments concern typical maintenance costs (e.g. replacement of pavement, cleaning of hydraulic passages, etc.) as well as those operating costs related to accident assistance, toll collection, signalling, and communications, among others. With most investment going into construction, road projects have the typical problems of the construction sector. Construction is frequently identified as being a sector where productivity growth, over the last 50 years, has remained low compared to other manufacturing and industrial-based industries.

Therefore, the study of digitalization in the road sector also involves a broader analysis of construction digitalization, given that the advances achieved in construction will have an impact on roads. It is not our objective here to go over all the advances in construction. However, we will focus on those advances that have a direct impact on the construction and maintenance of roads. Cost overruns typically involve an increase in investment of 20-30% (Sarmento and Renneboog, 2017b); and one of the main reasons for such overruns is the lack of communication between the design, planning, and execution, along with the interface risk between them.

Unlike other incremental developments in project design, such as automated computer design, BIM technology has disruptive potential. It is not simply a contribution to the digitalization of information. It also involves a redesign of project management and patterns of collaborative design. This is not project development based on a sequential supply chain, where several teams develop their own technical work (e.g. geologists, geotechnical engineers, road engineers, structural engineers, hydraulic engineers, telecom and signaling expeerts, etc.). Rather, BIM allows for the easier and better integrated participation of all stakeholders involved in the design and management of roads.

The overall improvement in collaborative work and the use of BIM systems will bring about, it has been estimated, an increase in productivity and the mitigation of project errors, meaning 15-20% lower costs. The advantages with having a shared platform allows for an improvement in the design management, scheduling and assignment of teams, quality control, performance management, and documental management.

Other drivers affect the performance of construction activities. A rise in transparency and an improvement in contractual agreements are current trends which will, in the long run, contribute to improving sector productivity. Technology and digitalization also play a role in these trends, e.g. it is easier to create and implement key performance indicators if more data is available through digitalization. For this paper, though, we have not considered these contributions. Rather, the authors have limited themselves to drivers of change that are a direct result of digitalization.

The internet of things and intelligent monitoring

As mentioned above, a pre-requisite for smart asset management is the ability to collect and process real-time data. Innovations in the field of the internet of things have had profound implications at the level of asset management. The traditional maintenance paradigm was based on the principles of preventive and corrective maintenance. Most, if not all, of the existing road projects have an associated maintenance plan which stipulates the several levels of maintenance to be performed each year for road subsystems.

"Lidar" (laser-based surveying method) detection and ranging will improve the ability to analyse (in 3-D) terrains and simulate terrain, a significant advantage when planning and designing new roads.

Intelligent monitoring will allow for effective and efficient crew tracking, and thus improve performance analyses. In road projects this is particularly relevant, as these linear infrastructures often have more than one distant active construction site. However, the benefits of intelligent monitoring are not limited to construction optimisation. During the operation phase, the use of digital sensors, remote sensing systems, and GIS-based systems, permit the real-time monitoring of the several types of road system (e.g., pavement, tunnels, bridges, etc.). In fact, the ability to have on-time data regarding asset conditions is bringing about a structural change in the way maintenance is performed.

Asset management

Traditionally, maintenance has been about a priori planning. The infrastructure manager would design a maintenance plan for the identification of maintenance actions to be performed in a given year. This is what is usually known as "preventive maintenance". Irrespective of the condition of the asset under maintenance, the manager would carry out the planned action according to the calendar. In this case, the owner would verify the compliance of the maintenance plan, checking whether all the planned actions had been executed according to plan. Together with "preventive maintenance", the infrastructure manager could also carry out "corrective maintenance" actions, if, and when unplanned intervention was necessary because a component had shown wear and tear earlier than expected. Digitalization is leading to the emergence of a new trend in infrastructure maintenance: condition-based asset maintenance.

Condition-based asset maintenance makes use of real-time data and sophisticated algorithms (e.g. artificial intelligence) and/or GIS-based tools to predict the evolution of the conditions of an asset and to plan necessary interventions accordingly (Daneshkah et al., 2017). The combination of data collectors (sensors) and data processing techniques (algorithms) allows managers to preventively detect potential deficiencies and to act to avoid them. The potential savings from using this type of technology are various. First, it enables managers to maintain infrastructure at a nearly constant predetermined level of quality; second, it allows for maintenance optimisation ; and, third, it provides more data that can be useful for the planning of other infrastructure.

Tolls and operation

Electronic Tolling

In Europe, a large number of road-charging schemes are in operation. We can divide these schemes according to: the type of charge concept (real tolls vs. shadow tolls vs. availability payments); the type of vehicles and respective toll-oriented classification; the method of calculation for tolls (based on type of vehicle, time of day, level of congestion, etc.); or even between tolls based on the extension and tolls based on road location. As a result, the EU exhibits a diverse and heterogeneous set of toll regimes. However, there is a common trend moving from traditional toll booth payment methods towards electronic payment. The EU is concerned with the heterogeneity of road-charging schemes, as these can be a barrier towards the complete interoperability of road infrastructure, thus obliging international users to use multiple on-board units (OBU) in different countries.

Several technologies are emerging (Steer Davies Gleave, 2015). These include: i) Automatic Number Plate Recognition (ANPR), which is also referred to as 'Video Tolling'; ii) Dedicated Short-Range Communications (DSRC) technology; iii) Radio Frequency Identification (RFID); iv) Global Navigation Satellite Systems (GNSS) technology; v) Tachograph-based technology, and; vi) Mobile communications (GSM and smartphones) tolling systems. These technologies have the potential to significantly affect CAPEX and OPEX.

Traditional manual tolling usually involves an investment of around one to four million Euros per lane, with an annual operating cost of 370,000 Euros to 840,000 Euros per lane. Additionally, for payments with a credit card, 1 to 4% of annual card revenue is received as an extra. When using self-service machines, investments are similar. However, the operating expenses are lower, in the range of 160,000 to 630,000 Euros per lane, per year (all data from Steer Davies Gleave, 2015). For GNSS-based tolling, the CAPEX is around 200,000 to 450,000 Euros per lane with the OPEX being a fixed cost related to customer relationship services, which can add from three to six million Euros per year.

However, the benefits of electronic tolling are not limited to a reduction in OPEX and CAPEX. Several other opportunities are unlocked by payment digitalization. The main one being the possibility of implementing dynamic toll regimes that can enforce a pricing model based on marginal costs to mitigate congestion. Traditional pricing policies have regarded tolls as financing mechanisms. As congestion grows, the role of tolls as a mechanism for regulating demand becomes central. The application of dynamic digitalized tolling regimes enables the calculation and collection of variable tolls based on real-time traffic flows.

Electric charging

With the advent of electric vehicles (EV), roads will have to adapt to EV requirements. Several approaches are under development. The most minimalistic approaches involve the construction of EV charging points, which could replace and/or complement existing fuel stations (Dong et al., 2019). There has been a growth in charging solutions. These are integrated into existing infrastructure (e.g. fuel stations or parking infrastructure), but they are also to be found in new infrastructure-specific solutions (e.g. the Mobi-E concession in Portugal, a concession building and managing electric charging points in urban areas).

Electric corridors

Yet, there are other disruptive solutions under development, one of them being the construction of electrified corridors, using either the pavement or an overhead gantry (Dong et al., 2019). Recently, in Sweden a two-kilometre stretch of road was unveiled that uses electric rails to transfer energy and charge an EV, with a mechanical arm (Taljgard et al., 2017). The potential of this technology is vast, as it provides the ability to charge cars while they are in circulation, thus eliminating EV bottlenecks (long charging periods and a relatively low autonomy when compared with traditional fuel engine vehicles). This innovation, though, comes at a high cost, as it is estimated that the cost per kilometre of building such a solution would be more than US 1.2 million. However, these are experiments, and one should expect a significant reduction in costs once this system goes mainstream.

Conclusions

There are enormous challenges ahead regarding the digitalization in the road sector. The fact that roads hold the largest share of passengers and cargo movement, with road transport being the largest contributor to CO2 emissions, are all putting pressure on governments to enact public policies that accelerate road sector digitalization.

However, there are also strong economic incentives for infrastructure managers starting to incorporate technology, big data, and IoT in road infrastructures. Digitalization has the potential to significantly reduce CAPEX and OPEX, and also to increase revenues and capacity. Bearing in mind that many countries invest significant amounts in road systems, this represents an additional leverage to encourage governments to facilitate digitalization.

We have estimated in Table 1 the potential impact on CAPEX, OPEX, revenues, and capacity if these technologies were incorporated in a road project.

Technology	Potential impact	Source
BIM/collaborative construction planning	Reduction of 27-38% in Capex	Mckinsey (2017)
IoT / intelligent monitoring		
Asset management		
Electric charging	Not available	--------------------
Electronic tolling	Reduction of 50% on toll collection costs (Opex)	Steer Davies Gleave (2015)
Traffic management/congestion pricing	Up to 20% on revenues	Li et al (2017)
Automatic accident detection	Reduction of 25% on assistance costs (Opex)	Fernandes et al. (2016)
Autonomous vehicles	Up to 20% capacity increases	Schranck et al. (2012)

Table 1. Analysis of potential impacts and level of development
Source: Authors' own compilation

There is real potential to improve the economics of roads. As the average cost of motorways can easily run to hundreds of thousands of Euros, a reduction of 30% in CAPEX can have a profound economic impact on road projects. The same principle can be applied to OPEX, or even to the ability to increase revenues. These changes (CAPEX and OPEX reduction, as well as an increase in revenues) might mean that it will be easier, from an economic perspective, to develop road projects. However, the advent of autonomous vehicles and the expected impact regarding capacity increases will possibly represent a major step backwards in road network development. If capacity increases, then we will need fewer roads. This is particularly relevant in countries where levels of road usage are low when compared with road density. The same might happen if dynamic congestion pricing is implemented. This tolling mechanism will enforce the payment of a higher toll during congestion periods, increasing the generalised cost of travel, thus forcing users towards public transport.

Finally, it is important to note that the potential of digitalization will be greater for greenfield road projects. Those existing systems that have not been designed in a "technology-friendly" context have more limited potential, or at least they do in the case of infrastructure-based innovations. With regards to service-related innovations, there is still significant room for improvement.

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Network Industries Quarterly, Vol. 23, issue 1, 2021 (March)

Greening of Infrastructure Assets

This special issue of Network Industries Quarterly is dedicated to the greening of infrastructure assets. Despite the unprecedented challenges brought about by the COVID-19 pandemic, the European Commission has reaffirmed its commitment to the objectives of the European Green Deal and to transforming Europe into the first carbon neutral continent by 2050. Delivering this ambition will necessitate the revision of regulatory and taxation frameworks, as well as the deployment of clean and innovative technologies. These in turn, will have to be supported by massive public investments and increased efforts to direct private capital towards climate and environmental action, while avoiding lock-in into unsustainable practices and infrastructures.

Though the specific approaches to 'greening' of infrastructure assets may vary across the network industries, a set of questions pertaining to technology, regulation and funding will have to be addressed in all of them. In this issue of the Network Industries Quarterly, our invited authors critically examine these questions, by drawing on the concrete examples of the greening of airports, ports and railway stations.

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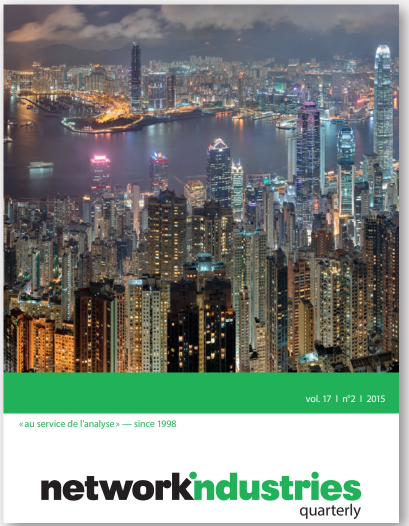

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