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

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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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