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ORIGINAL ARTICLE

The 7 challenges of road management towards sustainability and development

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ABSTRACT

The expansion of road networks, taken place during the last decades, was driven by technological progress and economic growth. The most innovative products of this trend—modern motorways and international road corridors—provide an excellent level of service, traffic safety and necessary information to travelers. However, despite this undeniable progress, major impediments and respective challenges to road authorities and operators still remain. The present paper analytically presents the main current challenges in the road engineering field, namely: a) financing new projects, b) alternative energy resources, especially renewable energy, c) serviceability, including maintenance of road infrastructure, traffic congestion and quality of the network, d) climate change hazards due to greenhouse gas emissions increase, e) environmental impacts, f) safety on roads, streets and motorways, and g) economy and cost-effectiveness. In each country and over each network, challenges and concerns may vary, but, in most cases, competent authorities, engaged in road development policies, have to deal with most of these issues. The optimization of the means to achieve the best results seems to be an enduring stake. In the present paper, the origin and the main features of these challenges are outlined as well as their tendency to get amplified or diminished under the actual evolving economic conditions worldwide, where growth alternates with crisis and social hardship. Moreover, responses, meant to provide solutions to the said challenges, are suggested, including research findings of Aristotle University and innovative technological achievements, to drive the transition to a more sustainable future.

Keywords: *road transport; infrastructure; economy; serviceability; engineering; sustainability*

1. Introduction

During the first decades of the 21st century, and despite the lack of financing and the severe criticism from environmentalists, road networks went on expanding worldwide. This expansion of road infrastructure and related transportation activities offers job opportunities, social welfare and economic growth. It is estimated that this trend will produce some 25 million km of new roads by 2050, most of them in developing countries (Campbell et al., 2017). It is widely recognized that an operational road network is a key leverage to inclusive economic growth and to poverty alleviation. This role is reflected in the Sustainable Development Goals for 2030, which set targets for improving the ability to access transportation and for developing the quality, reliability, safety, sustainability and resilience of roads, bridges and other infrastructure

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(World Road Association, 2016a).

Direct benefits of road transport investments include travel time and cost savings as well as short-term job creation effects, mainly in the construction sector. Indirectly, it seems that these investments have a facilitator role, as accessibility increases productivity, which results in increased trade activity and provides cohesion between the regions through reduced transport costs (Goetz, 2011). However, it must be absolutely clear that although road transport is a precursor of economic growth and of regional development, it is not a reliable indicator of a growing or flourishing economy by itself. It is the rate of public and private investments in industry, commerce, tourism, services and agriculture and the sustainable exploitation of local resources that define the health of the economy on the regional or national scale.

The importance of the road transport sector within the economy is considerable, not only in direct terms—that is, the transport of raw materials, goods and industrial products—or in derivative economic terms, such as the source of social and national wealth, but also in terms of support given to other economic activities. The value added by road transport is estimated to account for 3% to 5% of Gross Domestic Product (GDP) on a global scale, which is by far the largest share among all transport modes (European Commission, 2017).

2. Road transport and technological progress

The road sector is considered to be a central element in the global economy and in modern lifestyles by supporting the increased need for mobility and freight around the world. The successful operation of roads and transportation activities is one of the essential prerequisites for a healthy economy, as it improves connectivity and accessibility and provides intermediate services to facilitate interactions between production facilities and consumers' centers.

The boost observed in the road construction domain has been driven by innovation and technological progress. New materials, products, equipment and techniques have been introduced in the road engineering industry. The construction of tunnels, viaducts, bridges and earthwork has been facilitated by innovative techniques and modern powerful equipment. Subsequently, new road links, especially motorways, ring roads and international corridors, are fully operational and offer a high safety level and excellent serviceability. These undeniable facts could lead to a reasonable conclusion: at present, there are no problems and flaws in the road engineering domain. However, this conclusion hardly reflects the current situation in most developing and many industrialized countries. The economic crisis hit hard many economies and generated difficulties in financing new projects, as well as in upgrading existing links. The recorded expansion of road transport operations has been associated with significant direct, indirect and cumulative impacts on the environment—issues that have become more important in recent years. In several Western European countries, transport infrastructure is so dense that allows too limited space for other production activities.

Moreover, climate threats keep on creating major problems for all industrialized and developing countries, while road safety is always at stake despite significant progress in many European countries. In this regard, local and national authorities, road operators and policy stakeholders are continuously facing major issues linked to the operations over the network and to the integrity of the infrastructure, which are real challenges in an evolving world.

3. Road infrastructure challenges

3.1. Financing road construction projects

Roads are essential to economic development on national and local scale. In this perspective, major road links and motorways are constructed to push forward development and growth. However, roads are also prerequisites for social well-being, ensuring access to services, education and health establishments in regions and provinces, where no obvious profit is expected. Financing road construction projects that have an infinitesimal rate of return is a challenge, especially in developing countries.

In the case of toll motorways, the challenge of financing construction projects is different but still remains. Traditionally, the construction of toll motorways is a profitable investment but, in times of recession, funding may be rare or non-existent. Powerful national economies may be able to efficiently tackle the problem but weaker economies can hardly find the financing sources for road construction projects, the drivers of economic development.

3.2. Energy consumption in transport

Transport remains dependent on oil; oil-derived fuels account for about 94% of final energy demand. Road transport is responsible for the largest amount of transport energy consumption, which accounts for three-quarters of total transport energy use. In contrast to other modes of transport, the figures for energy demand for road operations keep rising. In Europe, the fraction of diesel fuel of road transport kept on increasing from 52% in 2000 to over 70% in 2014, which reflects the increasing dieselization of Europe's vehicle fleet since that time (European Environmental Agency, 2015).

Moreover, highway infrastructure is also an energy consumer in its own right. Specifically, the highway network requires energy for lighting, signage and operation of a multitude of data collection and digital information hardware. Thus, the energy challenge to road transport is of major importance: road operations consume a great amount of fossil fuels and this constitutes an issue of non-sustainability, demanding urgent alternative solutions.

3.3. Road serviceability

Road serviceability is a general term which includes pavement ride quality, level of safety, traditional and electronic information and service stations. Road capacity and level-of-service may also be included in a wider concept of serviceability. Drivers and travelers demand high standards of road performance and look forward to improved serviceability over time. Undoubtedly, this requires human and capital resources, not only for the on-site operations but also with view of anticipating maintenance needs and planning effective engineering interventions.

According to the findings of a Euro barometer survey conducted by the European Commission on the quality of transport in the EU, respondents considered congestion (60%) and maintenance (59%) to be the most serious problems about roads in Europe (European Commission, 2014). Indeed, road infrastructure suffers from two external costs that are borne largely by drivers: congestion and roadway defects; both of them affect the quality of service and the reliability of the road network.

Congestion is a complex phenomenon, influenced by socio-economic, technical and even human factors. It may be handled by different sets of measures including road widening, construction of alternative routes and shift to public transport. Road deterioration and pavement distress call for maintenance planning and expenditures in many European road networks.

In industrialized and developing countries, witnessing the development of motorway networks, the stake of road serviceability over national and regional networks is critical, since financing maintenance or rehabilitation operations on these networks may be a secondary option. However, the lack of resources may also downgrade a toll motorway requiring obviously urgent maintenance (**Figure 1**).

3.4. Climate change impacts on roads

The road sector is vulnerable to climate change impacts. Climate change and extreme weather events pose a significant challenge to the safety, reliability, effectiveness and sustainability of road transportation systems. Tsunami waves, wildfires, floods and hurricanes constitute a big risk for passengers, vehicles and goods, as well as for the integrity of the transport infrastructure. Since reliable road transport is an essential driver of economic growth and social wellbeing worldwide, national road authorities and motorway operators must adapt the infrastructure to climate change and increase the resilience of road transport to extreme weather.

Real concerns about adapting road infrastructure to extreme climate events have been observed in most industrialized countries since the early 2000s. However, despite the scientific elaboration of risk assessment methods and of suitable engineering measures, it seems that, to date, climate threats have hardly been efficiently confronted or reduced. The need for alternative and more effective measures and for sufficient financial resources is persistent.

3.5. Environmental impacts

The increasing demand for road transport, travel choices and innovative transport infrastructure has been associated with environmental impacts, such as air pollution and noise exposure, changes

Figure 1. Poor road serviceability due to surface cracks: Urgent need for maintenance on toll motorway.

in land use, fragmentation of habitats and effects on biodiversity and on wildlife.

Moreover, reducing greenhouse gas (GHG) emissions from transport has become a growing concern for the scientific community monitoring climate change. Transport emissions in Europe have increased in recent years and account for around one-quarter of the EU's total GHG emissions. The transport sector remains the only major European economic sector in which GHG emissions have increased compared with the 1990 levels (European Environmental Agency, 2017). Specifically, the road transport sector is a major, and a quickly growing, source of greenhouse gas emissions; it was responsible for almost 73% of all GHG transport emissions in 2013. In this context, alternative options to reduce greenhouse gas emissions have been implemented on regional and local levels in many Western European countries.

3.6. Safety on roads and highways

Estimates by the World Health Organization suggest that road crashes kill 1.25 million people—nearly 2,400 road fatalities per day—and injure up to 50 million (World Health Organization, 2015). Road crashes are a leading cause of death among those aged 15–29. The United Nations has adopted several resolutions on road safety and proposes actions to tackle the global road safety crisis. *The Decade of Action for Road Safety* 2011–2020 has generated substantial activities around the world. The Sustainable Development Goals include a target of 50% reduction in road traffic deaths and injuries by 2020 (World Health Organization, 2015). Over the last decade, enormous progress in reducing the number of fatalities was recorded in OECD/high-income countries, but in low-income countries the respective picture is different. Moreover, it seems that the occurrence of pile-up accidents on motorways has hardly been properly addressed. Projections of future traffic fatalities suggest that the global road death toll will grow significantly and, thus, the challenge of road safety remains.

3.7. Economy and cost-effectiveness

Among all transport modes, road transport occupies a significant place in short- and medium-distance travel operations. However, the unit cost of transportation (per ton × km), compared with other modes of transport, remains high and is getting higher and cost-ineffective as the travel distance increases. Road transport cost comprises direct costs (fuel, capital depreciation, maintenance, motorway tolls, ferry fares and wages) and external costs (noise, congestion, infrastructure damages, health and environmental issues).

Similarly, travel by car, no matter attractive for other reasons, is an expensive option in most cases. Direct and indirect costs may rise significantly in the case of congestions, delays and road closures. Road operators, by implementing innovative technology, strive to reduce the cost of travel for the benefit of road users, transportation agencies and the environment.

4. Responses and remedies

4.1. Unsolicited project proposals and value engineering

Normally, public authorities, in times of lack of public resources, invite proposals for projects to be implemented through the PPP (Public-Private Partnership) modality. Proposals submitted by private parties in response to such a request are called solicited proposals. Sometimes, private parties may also submit proposals without any request from the public authorities for such proposals. These proposals are called unsolicited project proposals. Unsolicited PPP projects have been implemented in many countries but others do not entertain such proposals because of ethics problems, especially the risks in terms of competition and transparency (United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), 2008).

Often, such proposals are based on innovative project ideas. The difficulty with unsolicited proposals, however, rests in getting the right balance in encouraging private companies to submit innovative project ideas without losing the transparency and efficiency gains of a competitive tender process. Considering the merits of unsolicited proposals that they may often have, some governments have developed systems to transform unsolicited proposals into competitively tendered projects, reserving to the proponent a bonus point in the bidding process (ESCAP, 2008).

Value engineering also appears as an innovative concept to be taken into account by the tendering authorities. The concept consists of maximizing the performance-to-cost ratio of a project or an asset (Marinelli et al, 2018), either by improving the performance or by reducing the cost. In fact, this may be regarded as another version of a cost-benefit analysis, although value engineering is much more than this: it is a search for non-obvious, alternative, cost-effective solutions and it increases the value of, and fully exploits, the asset.

In the case of urban or peri-urban road infrastructure, the issue of increasing road capacity, due to high traffic volume, often arises. In Thessaloniki, Greece, the Ring Road is congested and needs significant widening. Since the Ring Road lies between an urbanized area and a forestry zone, this widening is practically impossible. The first option was to build a 2×2 motorway on a new alignment and in a tunnel section—a very costly solution. By a "think different" approach, a cross-cantilever bridge (**Figure 2**) seems to be equally operational, at 25% of the cost of the tunnel solution and requiring shorter construction time.

Figure 2. Photorealistic visualization: The cross-cantilever bridge over the Ring Road.

4.2. The energy-harvesting road

Energy-efficient transportation needs to be encouraged on three different levels: system efficiency, travel efficiency and vehicle efficiency. Corresponding to these three levels of energy efficiency in transport, three basic strategies exist to improve energy efficiency (Boehler-Baedeker and Hueging, 2012):

- Avoiding increased transport activities and reducing the current demand for transport
- Shifting demand to more efficient modes of transport
- Improving the vehicles and fuels used

Additionally, highways and their associated infrastructure have the potential to provide opportunities for the production of energy. The area of land directly associated with highways (in highway ownership) is significant and provides an asset in the context of potential energy generation. PIARC Report 2014presents the different technologies available to generate energy in the highway context and qualitatively assesses the opportunity to reduce the energy used by existing highway infrastructure (World Road Association, 2014). These technologies are thermal collection using specific pavement appliances, photovoltaic collection, wind microgeneration and LED lighting solutions, and they enable highway facilities to create energy or reduce energy consumption. To date, however, all these technologies are at the experimental stage.

At Aristotle University of Thessaloniki (AUTH), research on the triboelectric generation of energy is ongoing. Laboratory tests on asphalt surfaces and the settings of electrical conductors (**Figure 3**) show that low-intensity electric current may be produced by the effect of a rolling wheel on an asphalt layer (Barkas et al., 2019). The objective of the research is to define and design the assemblage to be installed on a pavement surface in the urban road network with a view of producing energy and charging the neighboring street lighting.

Figure 3. Laboratory device for triboelectric energy generation.

4.3. Recycled and re-utilized pavement materials

The integration of recycled materials in pavement construction is a multi-aspect practice. Certainly, the environmental impact of this practice prevails but it is also important to enlighten the engineering and the economic aspects of recycling in pavement construction. The Federal Highway Administration (FHWA) recognizes the need to increase the highway industry's overall use of recycled materials (FHWA, 2002). There are several reasons to develop a recycling-friendly strategy in road construction:

- Cost-savings potential
- Life-cycle cost and engineering performance
- Reduction in landfill
- Stewardship of our environment

In current practice, a variety of materials are re-utilized in pavement construction, namely, fly ash, steel slag, glass, rubber tires, demolition waste, old asphalt layers and others. Most of them exhibit totally satisfactory performance as substitute pavement materials, while the main drawbacks for a wide range of applications seem to be the need for pre-processing and the transport cost.

At Aristotle University, ongoing research has been conducted on prospective reutilization of industrial by-products, especially fly ash (Tsohos and Mouratidis, 2002), steel slag (Kehagia, 2008) and bauxite residue (Kehagia, 2014). More recently, the feasibility and the possibility of introducing recycled plastics in pavements are also examined. Laboratory research has provided promising results and, in all cases, the integration of these recyclable materials in road structures has been tested in pilot and real construction projects. Fly ash is a hydraulic binder and may be used in the construction of semi-rigid pavements, while steel slag aggregates are incorporated in anti-skid asphalt layers. In fact, the re-utilization of fly ash and steel slag in road structures constitutes the current practice in some European countries, mainly because of the lack of natural resources in several regions. Research and pilot projects by Aristotle University, dealing with the use of bauxite residue as construction material, reveal the exceptional performance of this by-product and provide road engineering structures of high quality, strength and durability (Mouratidis and Pernientaki, 2018).

4.4. Strategies for climate-change adaptation of road infrastructure

With respect to the adaptation of road infrastructure to aggressive climate events, significant progress has been recorded during the last decades. Since the early 2000s, road adaptation to climate change has been a persistent challenge to the national road authorities in Europe and in other industrialized countries. Gradually, the concern about climate hazards has been amplified and respective action plans have been elaborated at national and international levels (World Road Association, 2016b). Protection measures, especially against flooding, implemented in various countries are reported to have produced beneficial effects on network integrity (European Environment Agency, 2014).

However, it must be clearly stressed that the current situation in the industrialized world is far from being ideal or even significantly improved. Severe wildfires, devastating floods and heavy snowfall occur all the time in Europe and elsewhere, more often without effective responses. Looking at images of catastrophic weather events, the feeling of helplessness may easily be sensed.

Figure 4. Wildlife overpasses on motorway and railway in Central Greece.

Sometimes, seeking for engineering adaptation measures in the context ofa severely ravaged network may be regarded as a pointless issue.

However, despite occasional ineffectiveness or inadequacy of engineering measures to fight climate threats, research efforts and strong commitment in this direction must go on. A somehow different approach to confront extreme climatic events and strengthen road infrastructure has been developed at Aristotle University (Mouratidis and Kehagia, 2018).

This approach suggests alternative engineering actions, such as restoring the initial balance on a broader contextual scale of the road link, elaborating realistic solutions and value-engineering measures, establishing preparedness and readiness of emergency services andusing new technologies for forecasting and anticipating imminent risks. All of them, in the case of climate threats, may constitute powerful and effective weapons.

4.5. A low-carbon and more sustainable road infrastructure: The Green Highway

A better understanding of the fundamental relationships between the physical environment (topology, geology, geographical location, climate, hydrology, natural vegetation and animal life) and road activities and infrastructure is crucial (Rodrigue, 2017). Sustainable road transport planning balances economic, social and environmental objectives and, under this perspective, the Green Highway may be a solution.

Research at Aristotle University has considered a more holistic innovative transport infrastructure, resulting in a "Smart Highway" model, appropriate to 2-lane roads but also to motorways (**Figure 4**). The model's scope is to diminish energy needs, road accidents and interventions, hence restoring operability and serviceability using low-cost techniques. The model is articulated over three different sets of measures:

- Energy consumption, including auto-fluorescent markings, auto-dimming lighting and solar islands at rest areas

- Road safety and serviceability, including rumble strips on straight segments, asphalt anti-icing additives and perpetual asphalt pavements
- Geotechnics and environment, including borrowed-soil spraying on rock slopes, versatile wood screens and balancing ponds

4.6. Real-time safety management system

Real-time safety condition assessment and warning systems are the most innovative applications of digital technology. They are systems receiving and processing images of traffic conditions in realtime and they evaluate accordingly the accident risk (Oh, 2007). They adequately inform and warn drivers, through variable message signs or by in-vehicle displays (connected vehicles), about the current safety level on the road.

Accident risk on motorways may be generated by ghost vehicles, a stopped car or an object on the roadway, inconsiderate driving, merging difficulties, off-lane border driving and others. The digital software identifies eventual risk-prone situations and the system transmits the warning signal. The application of these systems may prove beneficial in the case of congested motorways and black spots on national roads.

The Laboratory of Highway Engineering of AUTH has conducted research on this topic and identified ten major criteria of accident risk to be introduced in a safety management software (Mouratidis, 2019). In brief, these criteria are 1) excessive speed, 2) headway vs. speed/tailgating, 3) critical merging conditions at intersections, 4) deceleration ahead/accident, stopped vehicle and pavement distress, 5) border or off-lane driving, 6) inconsiderate driving/unsafe lane change, 7) ghost vehicle, 8) rainwater, snow or ice on the roadway, 9) low visibility/fog and 10) extreme weather such as snowstorm, rainstorm, tornadoor strong wind.

In the case of long-dated motorways, previous data from collisions and crashes may also be used in the safety condition analysis.

4.7. Transition to infrastructure and logistics for electric vehicles

The advent of electric vehicles is a topic gradually getting closer attention in the field of road transport infrastructure. At a first approach, the innovative technology of electric vehicles seems to address the critical issue of pollution in urban centers. However, the economic impact of this technology, on an individual or on a collectivity scale, will prove important as well.

It is well known that the electricity costs per mile to operate a plug-in electric vehicle, or PEV, (in charge-depleting mode) are likely to remain much lower and less volatile than the fuel costs for conventional vehicles. Moreover, although the main incentive for the purchase of an electric vehicle is its environmental footprint, it seems that financial reasons have more weight in the purchase decision than factors such as environmental protection (FHWA, 2015).

The transition to road infrastructure-friendly to electricity will principally depend on the progress of the automotive industry in terms of vehicle autonomy and cost. It is certain that industrial research will gradually overcome the technical drawbacks related to batteries and plug-in settings but the real challenge is the provision of electric power generated by renewable energy sources and the gradual reduction or abandonment of fossil fuels.

5. Conclusion

Capacity, safety and comfort are the main characteristics road users demand from a road infrastructure, which is continuously evolving to integrate new technological achievements for the benefit of passengers, drivers and vehicles. These new technological achievements revolve around high-quality materials, safety devices and intelligent transportation systems. Despite the decisive steps towards a technological and engineering boost in road construction, road authorities have to tackle new challenges: decarbonization of road transport, environmental constraints and electronic information. In general, the challenges of transport on a global scale are not only important but also crucial: negligence or reluctance to suggest responses and to take measures are likely to widen the gap between the industrialized world and the weaker economies.

Remedies presented in this paper are the results of technological research in this field and the findings of engineering research at Aristotle University. Some are more mature and ready for implementation, while others at the exploration stage. The solutions are not only in the direction of technological improvement, but they are supposed to promote a sustainable future for the road transport system in a world of social fairness and equity.

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