Risk management prospects with the digitalisation of road infrastructures

V. Sousa[1*], I. Meireles[2]

The digitalisation movement in general, and in road infrastructures in particular, open exciting prospects for implementation of a holistic, quantitative risk management. A framework for integrating risk, performance, and quality in a sustainability-oriented management of roads is presented. The potential benefits for risk management from digitalisation are discussed, both for the road assets and service.

Introduction

Since the 1950's, risk management have been moving from a research topic or area/case specific topic to an embedded, widespread formal professional practice in various fields. The publication of the ISO 31000 family of standards in 2009, which was recently revised (ISO, 2018), represented the culmination of international consent. On 2014, the publication of the ISO 55000 family of standards (ISO, 2014) linked the importance of risk management on (physical) asset management. These standards set out an internationally consensual framework for risk-informed performance-base asset management, particularly relevant for asset intensive organisations such as road administration or departments of transportations.

According to the ISO 31000 (ISO, 2018), risk is the "effect of uncertainty on objectives" and is often quantified as the combination between the likelihood and the consequences of an event. Uncertainty is "the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood" (ISO, 2018). In its essence, the source of uncertainty can be epistemic or aleatory (Walker et al., 2003). Epistemic uncertainty derives from the information/knowledge limitations about the systems and contexts. This type of uncertainty can be divided into model and statistical uncertainty (van Gelder, 2000) and can be reduced by knowledge increase. Aleatory uncertainty reflects the natural random nature of many natural and man-made phenomena and behaviour. This type of uncertainty can be divided into space-related (where) or time-related (when) (van Gelder, 2000) and can only be quantified.

In this conceptual context, there are motivating prospects for risk management from the digitalisation of road infrastructures. Digitalisation will, among other benefits, provide more and better information that may contribute to reduction of epistemic uncertainty and accurately quantify the aleatory uncertainty. The present contribution presents a framework for integrating risk and performance concepts in a sustainability-oriented asset-management framework and illustrates some of the potential benefits for risk management from digitalisation of road infrastructures.

Sustainability-oriented management framework

Historically, organisations and institutions guided their projects and operations by balancing cost, conformity/scope and time, the so called "Iron Triangle" in project management. The emergence of sustainability and sustainable development concepts has been promoting the change for a more holistic set of drivers that take into consideration a wider contextual perspective. As a result, various organizations already explicitly and quantitatively balance economic, environmental, and ethical (or social) aspects in their decision-making processes, both by internal option and by external demands (e.g., regulations, standards).

Still, a fully sustainability-oriented management is not yet embedded, not event in an ideal world guidance. Focusing on asset management, the ISO 55000 (ISO, 2014) definition of asset management as the "coordinated activity of an organization to realize value from assets", complemented by the statement that the "realisation of value normally involve balancing costs, risks, opportunities and performance benefits", reveals a financial-oriented management perspective. The externalisation of cost as a separate vector attributes a distinct level of relevance when compared to other vectors of the decision-making process.

Conciliating the definition of quality set in the ISO 9001 (ISO, 2015) – "degree to which a set of inherent characteristics of an object fulfils requirements" with risk and performance, a possible perspective is that quality can be measured by the balance between performance and risk (Figure 1).

Adapting the management model proposed by Spedding and Rose (2008), a sustainability-oriented, performance-based, risk-informed management framework is

[1] CERIS; Department of Civil Engineering, Architecture and Georesources, IST-University of Lisbon, vitor.sousa@tecnico.ulisboa.pt
[2] RISCO; Department of Civil Engineering, University of Aveiro,

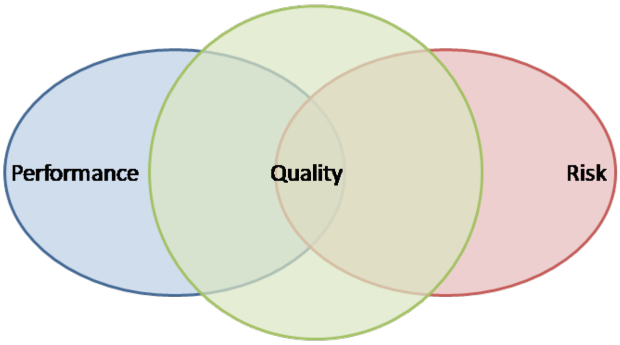

Figure 1. Conceptual integration of quality, performance and risk

Source: Sousa (2012), p. 28,

proposed in Figure 2. For asset-intensive organisations, such as road administrations, management of the physical assets will drive the core of the organisational decisions, projects, and activities.

In this framework proposal, a risk-informed approach is adopted, rather than a risk-based alternative. Contrary to the ISO 55000 (ISO, 2014) recommendation for implementing "risk-based, information-driven, planning and decision-making processes," it is the author's opinion that decision-making processes in the majority of business sectors should be performance based and risk informed. In the specific case of road assets, their management should be oriented towards sustainability (promoting greener, safer, and cheaper equitable transportation) based on estimated performance, and informed about the associated

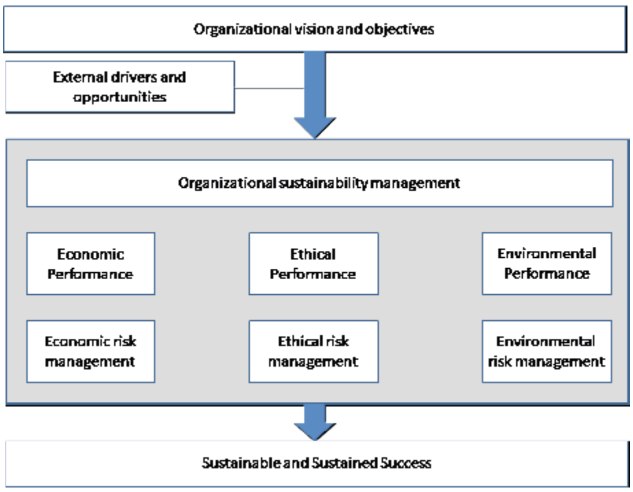

Figure 2. Sustainability-oriented, performance-based, risk-informed management framework

Source: Sousa (2012), p. 29

risks. Making a decision based mainly on the level of risk seems only adequate in specific sectors of activity, such as insurance or investment banking. This does not imply the nonexistence of performance and risk thresholds that automatically exclude alternatives. There are and always will be constrains in all vectors of sustainability that cannot be violated, regardless of the final overall balance between performance and risk.

Risk management in digital road infrastructures

The digitalisation of road infrastructures can be grouped into two main groups (Cruz and Sarmento, 2018): i) assets-related; and ii) service-related. Within asset-related, digitalisation is taking place in the processes for designing (e.g., Chong et al. 2016 - building information modelling), building (e.g., RazaviAlavi and AbouRizk 2017 - construction site simulation), and using (e.g., Agnisarman et al. 2019 - automated inspection systems) the assets. The within asset-related digitalisation is also taking place on the assets directly (e.g., Alavi et al. 2016 - embedded continuous health monitoring sensors). Service-related digitalisation of road infrastructures is driven by the evolution in the transportation paradigm, implying also a change in the supporting infrastructures. Digital payment systems are already a reality in many toll roads around the globe, along with various communication and safety-related features. A recent example are the "smart" highways awarded by Highways England that will provide real-time management of traffic flow capability (https://www.vinci-construction-projets.com/en/realisations/m5-smart-motorway/). Sensors will send traffic information, enabling modulation of speed limits via dynamic signage. The emerging paradigm shift towards electric and autonomous vehicles will demand a new dimension of digitalisation of road infrastructures in the near future. In Sweden, a section of 2 km of a public road has been electrified by embedding an electric rail in the pavement to enable charging of the batteries of electric cars while in movement (https://www.theguardian.com/environment/2018/apr/12/worlds-first-electrified-road-for-charging-vehicles-opens-in-sweden). While the technology used in the Sweden case requires contact, there are various initiatives to build wireless inductive charging pavements (e.g., García-Vázquez, 2017). Within the important relation between transportation and energy, the digitalisation of road infrastructures may also include using it for energy harvesting (Venugopal et al. 2018).

Service-related digitalisation represents new features for the road infrastructures. With it, new different assets will be required in addition to the existing that entail their specific level of uncertainty. These new assets may not increase the level of risk of the existing road infrastructure assets but will certainly enlarge the risks portfolio for road management. An important question herein is the role of the road infrastructures on autonomous driving and its relation to safety-related issues. Assets-related digitalisation adds new functions to road infrastructures (e.g., electric vehicle charging, energy harvesting).

On the other hand, assets-related digitalisation will tend to reduce the level of risk in the management of road infrastructure assets. The digitalisation of the road infrastructures assets life-cycle will provide more and better information about them. Combining technologies such as BIM, GIS, autonomous inspection, and continuous health and traffic monitoring in current digital platforms will provide an unprecedented level of spatial and temporal resolution. These platforms allow for integration of this information with complementary data relevant for road infrastructure assets (e.g., climatic data from satellites, geotechnical profiling, identification and characterisation of underground and limiting infrastructures). This integrated information will enable a better understanding about how endogenous and exogenous variables interact and affect road assets and transportation service performance. In particular, physical-based models use constraints due to knowledge limitations, and the inexistence of the information needed for running them will be mitigated. Combined with the plethora of artificial intelligence tools developed (e.g., artificial neural networks, support vector machines, genetic algorithms, simulated annealing, ant colony optimization), there is significant potential for developing hybrid models. These models combine physical-based approaches with statistical-based approaches to increase the accuracy of the performance forecasts. As a result, the level of risk from epistemic uncertainty will decrease. Additionally, the road digitalisation movement enables building up of data to inform quantitatively the uncertainty left unexplained and/or the naturally random. This represents an improvement in informing the magnitude of the aleatory uncertainty.

Final remarks

Digitalisation of road infrastructure will have a dichotomous effect on the risk management. The digitalisation derived from the evolution of the transportation paradigm and the accumulation of functions demanded in road infrastructures will certainly expand the list of risks associated with the road infrastructures. This expansion may not represent an increase in the overall level risk but will certainly change the nature of risk. For instance, interaction between cars and with the road infrastructure in the scope of autonomous driving will transform the nature of safety-related risks. Assets-related digitalisation prospects are for the reduction of the level of risk traditionally associated with road infrastructures, as a result of the decrease in epistemic uncertainty. Even for the remaining level of risk, the digitalization process will provide better information for the decision-making processes because of more accurate quantification of the aleatory uncertainty.

Finally, the digitalisation of road infrastructures contribute to a holistic management approach required by a sustainability-oriented context. In Europe, the sustainable development principles are being progressively embedded at various levels and sectors of society and require more integrated and complete performance and risk assessments. Digitalisation is a relevant tool to identify, analyse and evaluate the complexity of the economic, ethical, and environmental dimensions of the man-made infrastructures and activities.

References

Agnisarman, S.; Lopes, S.; Madathil, K. C.; Piratla, K.; Gramopadhye, A. (2019). A survey of automation-enabled human-in-the-loop systems for infrastructure visual inspection. Automation in Construction, 97:52–76.

Alavi, A. H.; Hasni, H.; Lajnef, N.; Chatti, K. (2016). Continuous health monitoring of pavement systems using smart sensing technology. Construction and Building Materials 114 (2016) 719–736

Chong, H. Y.; Lopez, R.; Wang, J.; Wang, X. (2016) Comparative Analysis on the Adoption and Use of BIM in Road Infrastructure Projects. Journal of Management in Engineering, 36(6).

Cruz, C. O.; Sarmento, J. M. (2018) Maximizing the value for money of road projects through digitalization. Competition and Regulation in Network Industries, forthcoming.

García-Vázquez, C. A.; Llorens-Iborra, F.; Fernández-Ramírez, L. M.; Sánchez-Sainz, H.; Jurado, F. (2017). Comparative study of dynamic wireless charging of electric vehicles in motorway, highway and urban stretches. Energy 137(Suppl C):42-57.

ISO (2014). ISO 55000:2014. Asset management: Overview, principles and terminology. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO (2015). ISO 9000:2015. Quality management systems: Fundamentals and vocabulary. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO (2018). ISO 31000:2018. Risk management: Guidelines on principles and implementation of risk management. International Organization for Standardization (ISO), Geneva, Switzerland.

Prasanth Venugopal, P.; Shekhar, A.; Visser, E.; Scheele, N.; Mouli, G. R. C.; Bauer, P.; Silvester, S. (2018). Roadway to self-healing highways with integrated wireless electric vehicle charging and sustainable energy harvesting technologies. Applied Energy, 212:1226–1239.

RazaviAlavi, S.; AbouRizk, S. (2017). Site Layout and Construction Plan Optimization Using an Integrated Genetic Algorithm Simulation Framework. Journal of Computing in Civil Engineering, 31(4).

Sousa, V. F. (2012). Risk management in construction: Application to urban drainage systems. PhD Thesis, IST - Technical University of Lisbon, Lisbon, Portugal. (in Portuguese)

Spedding, L.; Rose, A. (2008). Business risk management handbook - A sustainable approach. CIMA publishing, Elsevier: Oxford, Burlington, MA, USA.

van Gelder, P. H. A. J. M. (2000). Statistical methods for the risk-based design of civil structures. PhD thesis, Delft University of Technology, Delft, The Netherlands.

Walker, W. E.; Harremoës, P.; Rotmans, J.; van der Sluijs, J. P.; van Asselt, M. B. A.; Janssen, P.; Krayer von Kraus, M. P. (2003). Defining uncertainty: A conceptual basis for uncertainty management in model-based decision-support. Integrated Assessment, 4(1):5–17.