CETRA[2024] 15-17 May 2024, Cavtat, Croatia
8th International Conferenceon Road and Rail Infrastructure

ROAD INFRASTRUCTURE MANAGEMENT USING MODERN TECHNOLOGICAL APPROACHES IN THE LIGHT OF LIMITING BARRIERS

Stefan Sedivy[1], Martina Jackova[1], Ingrid Zuziakova[1], Zuzana Florkova[1], Peter Danisovic[2]
[1] University of Zilina, Research Centre & Slovak Republic
[2] University of Zilina, Faculty of Civil Engineering, Slovak Republic

Abstract

The construction sector is characterized by low productivity and backwardness compared to other sectors. The subfield of road infrastructure management is no exception. Although new innovative elements appear gradually, e.g. based on Construction 4.0, Lean Construction philosophy, Cross Asset Management or Circular Economy. However, it is still not enough for the shift in the quality of road network management to be sufficiently visible. The effort of the research team is to gradually apply the most modern technological elements to the process of diagnosing the condition of the road network, which can introduce systematicity into the process of monitoring and evaluating the condition of the road network. These are based on an interconnected system of georadar technologies, road surface scanning, bearing capacity monitoring, building sensor systems in road construction and complex data processing. However, these activities encounter certain risks and weak points, which will have to be gradually dismantled. Among the selected ones, it is possible to include mistrust on the part of road administrators, whether it is the state road administrator, regional administrators or cities and municipalities. At the same time, technological limits and questions about the economic return of introducing modern approaches to the processes in question are gradually emerging. This leads the research teams to believe that it is necessary to find an optimal balance when introducing innovations in this selected sector.

Keywords: pavement, sustainability, barriers, innovation, management

1 Introduction

The construction and efficient maintenance of road infrastructure is a global concern that affects social and economic development in all countries [1]. This sector can be seen as one of the most obvious combinations of two strong industries, those being transport and construction. Both sectors require significant interest in the context of the application of measures aimed at ensuring their sustainability. While for transport it is the trend towards greening vehicles, improving safety and reducing travel times, for construction it is minimising waste from construction activities, keeping energy and resource consumption low and efficient maintenance throughout the life cycle of the road [2, 3]. A combination of the above priorities needs to be addressed in the sustainable management of road infrastructure management. Management is to be a comprehensive process on the part of the responsible authorities in managing, planning and coordinating the necessary activities to ensure sustainable operation, maintenance and development of the road network. It includes the continuous monitoring and design of maintenance activities to maintain the roadway in the required structural and functional conditions and to minimise life cycle costs [4, 5].

DOI: https://doi.org/10.5592/CO/CETRA.2024.1639

Sustainable pavement management must be subordinated to three aspects: economic development, environmental protection and social development. Sustainability, which is based on reconciling these economic, environmental and social aspects, has become a major theme for infrastructure managers. The economic and environmental impacts of road maintenance are not negligible. As maintenance should be technically appropriate, infrastructure managers need to integrate technical, economic and environmental aspects into the assessment of maintenance alternatives during the life cycle of the pavement [6]. These aspects include additional sub-levels and areas that need to be considered. These are effective planning and appropriate budgeting, pursuing responsible identification of current as well as long-term needs and goals, and allocation of funds according to realistic time requirements. It also includes the regularity of repair and maintenance of the road network, in order to ensure the established reliability of the roads, eliminate traffic congestion and maintain the necessary level of safety. In addition to the above key aspects related to the sustainable development of the road network, categorised more as technical and economic measures, it is also necessary to name other objectives pursued by the managers. These include social and environmental considerations, where the implementation of measures to reduce the level of negative impacts on the environment and society, to achieve greater inclusion for disadvantaged groups or to involve local authorities and affected populations in decision-making processes related to the construction, maintenance and development of the road network are pursued. Another element that needs to be included in policies related to sustainability is the area of innovation and technological development. Effective management of road infrastructure management should include keeping up to date with the latest trends in technical and process innovations in the construction sector, taking into account the needs applicable to road infrastructure management. Taking into account the wide range of factors described above will make it possible to achieve high quality road network development, quality being a key factor in the reliability of the road network in terms of both user needs and efficient public administration. Proper pavement maintenance planning can be considered as a strategic approach to achieve rationalisation of capital expenditure, reliable risk management, maintenance of performance, achieving stakeholder satisfaction and conservation of natural resources. All these challenges should be effectively addressed at all stages of the pavement life cycle by collecting data and performing analyses [7]. One of the tools to ensure the sustainability of road infrastructure is pavement management system (PMS). Proper decision making processes by utilizing PMS can reduce the overall construction and maintenance costs [8]. In general, a PMS consists of a set of procedures and tools designed to assist decision makers in identifying the most appropriate strategies for monitoring and maintaining roads in the desired condition. It can be seen as a process and software tool that enables the systematic collection, processing and analysis of road surface condition data. Its main objective is to optimise the planning of maintenance and repair of road infrastructure based on the current condition and forecasts of future developments. It includes diagnostics of the condition of road surfaces, identifies problem sections and prioritises them on the basis of their condition and forecasts of their future development. Contributes inputs for responsible maintenance planning, optimises resource allocation based on needs and priorities. Recently, there are new views that the PMS should also proactively address opportunities for innovation in the sector, either to improve services for users or to accelerate the achievement of more significant environmental effects. For example, the concept of a circular economy index as part of the PMS [9] or the application of artificial intelligence elements in conjunction with significant technological developments based on sensor systems is quite interesting. These new initiatives are also based on a gradual increase in the scientific background, where the links between sustainability, efficient road network management and innovation can be found to be gradually growing. This claim can also be supported by a quick review of the available literature.

An initial search was conducted in the SCOPUS database, which is more suitable for examining technically oriented studies. The algorithm was as follows TITLE-ABS-KEY (road AND sustainability AND innovation) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “ENVI”) OR LIMIT-TO (SUBJAREA , “SOCI”)) AND (LIMIT-TO (PUBSTAGE , “final”)). The result was 293 documents, and based on the links between their keywords, it is possible to illustrate the links in the monitored concepts.

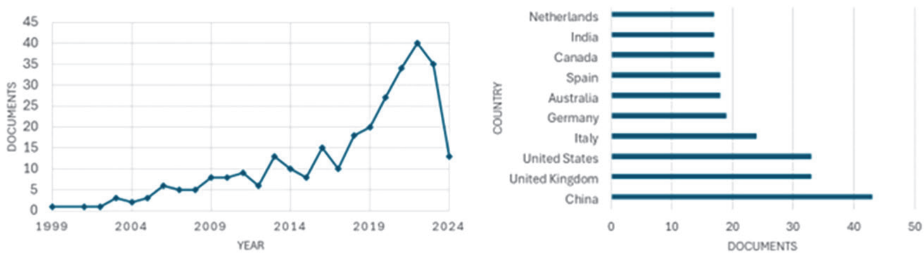

Figure 1 An overview of the growth of publications on the topic of innovation and sustainability in relation to pavements

It can be argued that the need to ensure a higher level of sustainability puts pressure on PMS to innovate. It is generally known that this effect strengthens the process of road infrastructure management and maintenance. Innovation in PMS increases the ability to use resources more efficiently and minimize environmental burdens. There have been some attempts in the past to operate efficient knowledge-based PMS. These have been somewhat successful but have produced some inaccurate results. With the advent of new concepts in society such as Intelligent Cities and Smart Infrastructure and innovative technologies such as the Internet of Things, artificial intelligence or machine learning, there are increasing efforts to overcome these shortcomings [9].

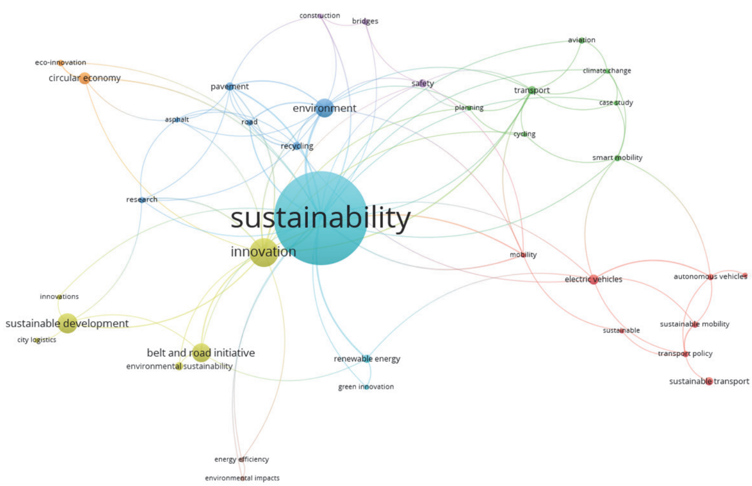

Figure 2 Overview of the links between sustainability and innovation in research papers via VOS Viewer

VOSviewer software was utilized to assess the articles under consideration and produce a visual representation of the keyword power. The frequency of occurrence is indicated by the nodes’ size. The node curves show where they frequently appear in the same publication. The frequency of two keywords occurring together increases with the distance between two nodes.

2 Technological innovation applicable in pavement management systems

The role of technological innovation is to help transform established ways towards sustainability. These are mainly tools based on digitalization, big data, intelligent automation and energy saving [10]. It is no different in the road infrastructure management sector. The implementation of technological advances should overcome the already inadequate characteristics of construction products, organizational fragmentation, increase the mutual iteration and integration of all stakeholders, promote environmental effects and strain to increase economic requirements [11]. PMS is a tool that provides a systematic method for collecting, storing, analyzing, and modeling pavement condition data for decision making associated with resource optimization within a pavement network. In the context of increasing the sustainability rate of the whole area, managers are forced to increasingly reflect on the incoming technological as well as process innovations. Among the selected ones, those oriented towards monitoring the condition of the roadway and its surroundings can be included. Automated pavement defect detection systems are increasingly sought after by pavement managers to increase the qualitative efficiency of field surveys in terms of potential human error, reduce human resource costs associated with maintenance, and respond to the time-consuming nature of manual surveys [12, 13]. The availability of pavement data at a time when decisions about maintenance investments need to be made also plays an important role for their deployment [14]. The last decade in the detection of data about the pavement and its immediate surroundings has been characterised by the deployment of several types of technological tools and innovations. Among the most widely used can be counted the approaches of a non-destructive detection tool based on Ground Penetrating Radar(GPR) combined with a mobile laser system, which are characterized by their speed of deployment, the possibility of continuous measurement and ease of operation [15-17]. Huge developments in computer vision, deep learning techniques and advances in artificial intelligence have opened up new possibilities for automated fault detection [13]. Whether it be drones or other autonomous machines that can present the recorded data in a point cloud format, for example [18, 19]. Modern sensor systems, which are installed either in the road structure or in its surroundings, also play a significant role in detecting road conditions. These are, for example, sensors that monitor the bearing capacity and stresses in the pavement layers or the structure itself, the temperature and moisture profile of the road, or the propagation of defects in the layers that cannot be captured visually [20].

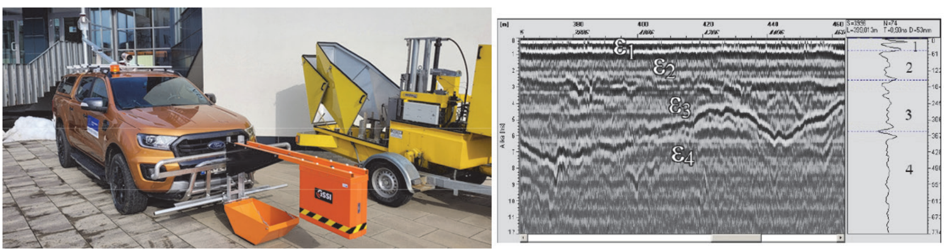

Figure 3 Demonstration of a diagnostic technique for monitoring the condition of roads and the result of a GPR measurement

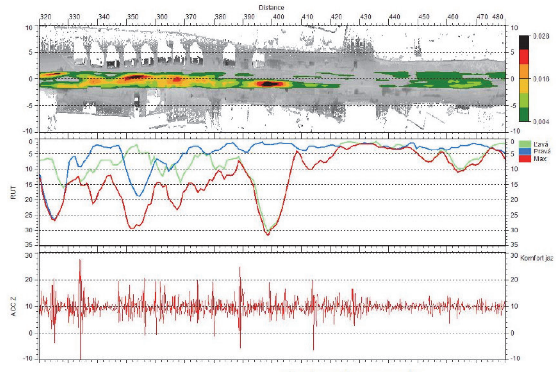

Figure 4 Result from the measurement of pavement unevenness and RUT

The research team is currently applying a number of devices within its own research activities to carry out the collection of input data from the road environment. These are several mobile platforms equipped with non-destructive GPR devices in 2 measurement frequencies, cameras, infrared cameras, Lidar systems, technologies for measuring road defects (unevenness, cracks) or sensors that sense the road surroundings (e.g. in order to evaluate the quality of drainage). At the same time, research activities are applying devices for measuring deflection in the form of a trailer-mounted deflectometer. Also, drone technology is deployed for additional measurements or data is collected manually by means of specially adapted back packs. At the same time, various technologies are deployed as complementary tools to monitor selected physical properties and processes in the roadway. Some of the selected ones can include e.g. horizontal and vertical temperature profiles in order to better understand the deformation patterns. The above technological tools represent an important but still only an initiation phase in the improvement of PMS-related processes. The structured data needs to be further processed and evaluated through software tools in order to produce recommendations applicable to the real environment. Currently, it can be assumed that the BIM environment, as part of the tools coming from the Construction 4.0 measures, will become the one that will capture all the road condition data collected. In addition to the basic data from non-destructive measurements, data collected by the road authorities on road markings, directional and elevation ratios, but also data from sensor systems installed along the infrastructure will have to be integrated here [21]. A digital model populated with road condition data will be the most important input for planning maintenance management as well as improving the maintainability of the road network [22].

3 Results and conclusion

Despite the considerable benefits of research into innovative road network condition monitoring, there are significant barriers to making better use of the knowledge gained. The research team, in consultation with public road managers and based on its own experience, has summarised the most significant barriers. The first of these is the financial requirements associated with the application of new technological tools to PMS. Managers have limited budgets to provide or rent modern technology and prefer the cheaper approaches to road condition monitoring currently in use. This means manual data collection or data collection by automated methods on selected road sections that are most at risk. However, this approach is significantly detrimental to the introduction of a systematic approach for a realistic assessment of the rate and extent of degradation of the road network. It also undermines the ability to reliably produce predictions for the justified allocation of funds for repair and maintenance. The second major barrier is resistance to the changes that technological development brings. Each new innovation brings changes in established practices, where staff with low skills in particular are unable to reap the full benefits on offer. The challenges associated with the integration of technical innovations and new practices may translate in the long term into complications on the sustainability side of operations in the context of their interoperability and interfacing with other software tools. At the same time, there is the financial and personnel factor of technical maintenance, repair and protection of the technological innovations themselves. In the case of sensor systems situated in the road environment, the main obstacle is the need to deal with gentle removal in the event of structural interventions in the road and reinstallation. Sensor systems are also demanding in terms of power supply, processing of large volumes of unstructured data, communication facilities and protection against damage. One of the oft-repeated criticisms from administrators is the assertion of the need to recruit and retain new staff who have the skills to work with innovative technologies, who understand the data being collected, and who can bring decisions to bear on the road repair and maintenance processes based on that data. The social factor is also an issue, which follows the employment of mainly the least skilled workers and the low motivation factor to grow professionally. The selected managerial barriers include risks associated with the failure to implement innovative PMS approaches in the real environment and some legislative barriers associated with the protection of data from misuse. Managers agree that innovation belongs in PMS. However, the solution to eliminate barriers must be a new approach that allows all new knowledge to be actively transferred. This means that research teams need to present the benefits of non-destructive measurements even more widely, highlight the benefits of sensor systems, and increase the education of relevant staff and managers. Otherwise, there is a risk that technological advances will once again bypass the processes present in PMS and the whole sector will once again move away from the more productive industries that have stepped forward to increase their sustainability through innovation.

This paper was supported by the Slovak Research and Development Agency under the contract No. APVV-22-0040.

References

[1] Nieto, X., Solla, M., Marecos, V., Lorenzo, H.: Applications of the GPR Method for Road Inspection, Non-Destructive Evaluation of Structures and Infrastructure, Edition: Structures and Infrastructures Series, 11 (2016), DOI:10.1201/b19024-14

[2] Cellura, M., Guarino, F., Longo, S., Mistretta, M.: Modeling the energy and environmental life cycle of buildings: A co-simulation approach, Renew. Sustain. Energy Rev., 80 (2017), pp. 733–742, DOI: 10.1016/j.rser.2017.05.273

[3] Vanegas, J.A., DuBose, J.R., Pearce, A.R.: Sustainable technologies for the building construction industry, Symposium on Design for the Global Environment, Atlanta, GA, USA, 8–19 July 1996.

[4] Santos, J., Ferreira, A.: Life-cycle cost analysis system for pavement management at project level, Int. J. Pavement Eng.,14 (2013), pp. 71–84

[5] Babashamsi, P., Yusoff, N.I.M., Ceylan, H., Nor, N.G.M., Jenatabadi, H.S.: Evaluation of pavement life cycle cost analysis: Review and analysis, Int. J. Pavement Res. Technol., 9 (2016), pp. 241–254

[6] Torres-Machí, C., Chamorro, A., Pellicer, E., Yepes, V., Videla, C.: Sustainable Pavement Management: Integrating Economic, Technical, and Environmental Aspects in Decision Making, Transportation Research Record, 2523 (2015) 1, pp. 56-63, DOI: 10.3141/2523-07

[7] Teicholz, P.: BIM for Facility Managers, John Wiley & Sons: Hoboken, NJ, USA, 2013.

[8] Loprencipe, G., Pantuso, A., Di Mascio, P.: Sustainable Pavement Management System in Urban Areas Considering the Vehicle Operating Costs. Sustainability, 9 (2017) 453, DOI: 10.3390/su9030453

[9] Wasiq, S., Golroo, A.: Development of a Circular Economy Index for a Pavement Management System, Int. J. Pavement Res. Technol, 2023, DOI: 10.1007/s42947-023-00304-z

[10] Li, L., Wang, L., Zhang, X.: Technology Innovation for Sustainability in the Building Construction Industry: An Analysis of Patents from the Yangtze River Delta, China, Buildings 12 (2022) 2205, DOI: 10.3390/buildings12122205

[11] Pow, C.P., Neo, H.: Seeing Red Over Green: Contesting Urban Sustainabilities in China, Urban Stud., 50 (2013), pp. 2256–2274

[12] Chen, J., Zhao, N., Zhang, R., Chen, L., Huang, K., Qiu, Z.: Refined Crack Detection via LECSFormer for Autonomous Road Inspection Vehicles, IEEE Transactions on Intelligent Vehicles, 8 (2023) 3, pp. 2049-2061, DOI: 10.1109/TIV.2022.3204583

[13] Maluya, M.M.O., Aleluya, E.R.M., Opon, J. G., Salaan, C.J.O. : Lane Tracking for Autonomous Road Pavement Inspection with Unmanned Aerial Vehicles, 6th International Conference on Applied Computational Intelligence in Information Systems (ACIIS), Bandar Seri Begawan, Brunei Darussalam, pp. 1-6, 2023, DOI: 10.1109/ACIIS59385.2023.10367228

[14] Roberts, R., Menant, F., Di Mino, G., Baltazart, V.: Optimization and sensitivity analysis of existing deep learning models for pavement surface monitoring using low-quality images, Automation in Construction, 140 (2022) 104332, DOI: 10.1016/j.autcon.2022.104332

[15] Yan Xu, Y, Hua, D., Wang, J., Li, J.: Research on application of Ground Penetrating Radar in road Inspection, IOP Conf. Series: Earth and Environmental Science 781 (2021) 022019, DOI 10.1088/1755-1315/781/2/022019

[16] D'Amico, F., Bertolini, L., Napolitano, A., Bianchini Ciampoli, L., Manalo, J.R.D., Gagliardi, V., Calvi, A.: A possible implementation of non-destructive data surveys in the definition of BIM models for the analysis of road assets,Transportation Research Procedia, 69 (2023), pp. 187-194, DOI: 10.1016/j.trpro.2023.02.161

[17] Panah, R.S., Kioumarsi, M.: Application of Building Information Modelling (BIM) in the Health Monitoring and Maintenance Process: A Systematic Review, Sensors, 21 (2021) 837, DOI: 10.3390/s21030837

[18] Tovanche-Picon, H., Garcia-Tena, L., Garcia-Teran, M.A.: Intelligent road surface autonomous inspection, Evol. Intel, 2023, DOI: 10.1007/s12065-023-00841-3

[19] Urano, K., Hiroi,K., Kato,S., Komagata, N., Kawaguchi, N.: Road Surface Condition Inspection Using a Laser Scanner Mounted on an Autonomous Driving Car, IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops), pp. 826-831, Kyoto, Japan, 11-15 March 2019, DOI: 10.1109/PERCOMW.2019.8730820

[20] Gaspar, G., Dudak, J., Behulova, M., Stremy, M., Budjac, R., Sedivy, S., Tomas, B.: IoT-Ready Temperature Probe for Smart Monitoring of Forest Roads, Applied Sciences, 12 (2022) 743, DOI:10.3390/app12020743

[21] D'Amico, F., Bianchini Ciampoli, L., Di Benedetto, A., Bertolini, L., Napolitano, A.: Integrating Non-Destructive Surveys into a Preliminary BIM-Oriented Digital Model for Possible Future Application in Road Pavements Management, Infrastructures, 7 (2022) 1, DOI: 10.3390/infrastructures7010010

[22] Moradi, M., Assaf, G.J.: Designing and Building an Intelligent Pavement Management System for Urban Road Networks, Sustainability, 15 (2023), 1157, DOI: 10.3390/su15021157