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SCIENTIFIC RESEARCH-BASED VIEW IN CONSTRUCTION PROJECTS: CREATING INTELLIGENT INFRASTRUCTURE

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ABSTRACT

Among the top ten construction projects in 2023, Crossrail 2 – London in the UK is the first, Mumbai International Airport in India is the second, and the third is the Grand Ethiopian Renaissance Dam in Ethiopia. The first two projects are transport investments and the third is the largest hydroelectric energy investment in Africa. Crossrail 2 was estimated to cost £32,6 billion in 2016. In 2019 Crossrail 2 related reports suggested that the scheme might add up to more than £45billion. At Navi Mumbai International Airport the estimated cost of the project was US$ 600 million, this has since grown to US$2,0 billion. The Grand Ethiopian Renaissance Dam is estimated to cost close to 5 billion US$. These hugely expensive projects impose a significant burden on society. How can those infrastructural investments be implemented so that the infrastructure to be built can be used safely and economically for several decades?

KEYWORDS

infrastructure development projects, trustworthy AI, railway 4.0, smart transport

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INTRODUCTION

Our research is motivated by the fact that the planning, implementation and operation of infrastructural (e.g. transport [1-4], energy [5], telecommunications, etc.) systems require a significant investment of time and money, even for the richest countries. Thus, even the smallest increase in efficiency can bring significant results. These projects (which affect the Community infrastructure) have a particularly large and long-term social impact and role in terms of social well-being. People's well-being covers joy, safety, and health [6, 7].

We examine several types of infrastructure construction projects (eg. Crossrail 2 [1-3], Navi Mumbai International Airport [4], Grand Ethiopian Renaissance Dam [5]). The main question of our study is that on the basis of which methodology the work is organised in the case of different types of construction projects, and which organising principle characterises the construction project management. The priority probe aspects cover the creation phase of the concept, preliminary feasibility studies (scope of the project), the method of setting deadlines, and preparatory work. How to reach the perfect planning of the project? Its elements can include the contract, the project milestones, information sharing, risk management, project roadmap with dependencies, project budget, work breakdown structure (listing all project deliverables and sub-deliverables), and project execution [8].

The construction industry is faced with many challenges [9]. Despite the large financial sums invested, its growth led to extremely low productivity levels when compared with other industries [10].

On the other hand, several scientific sources point to the fact that artificial intelligence technologies are being used in all industries worldwide to increase efficiency, improve productivity and reduce costs [11].

MATERIALS AND METHODS

In most cases, the data of construction projects constitute a trade secret, so we could only work from open data that can be found, for example, in the European public procurement journal. In some cases, such as the Crossrail project, more information and documents are available from open sources,. Also, a number of scientific publications have been published about The Grand Ethiopian Renaissance Dam project. We examined these references and sources during our research work.

We reviewed the announced tenders from 01/01/2022 to 30/06/2023 in connection with infrastructure constructions the submission deadline of which were no later than 30.06.2023. During this period, we found a railway construction works tender [12]. In this period, most of the existing tenders focused on airport buildings construction work [13], construction work for pipelines [14, 15], communication and power lines, highways, roads, airfields and railways [16], construction work for electricity power lines [17] and road construction works [18].

RESULTS AND DISCUSSION

Understanding and managing new risks is indispensable for investments that have significant environmental impacts or involve shaping the environment (infrastructure construction projects). Moreover, this management task must be understood in the entire lifecycle of these projects [19].

As the synthesis of the literature and open access datasets, it can be concluded that the efficiency (improved productivity and solved challenges) of construction projects should be increased especially under the conditions of modern economic insecurity and construction made over a long period [20-22]. Sha'ar et. al found ten main problems: "(1) unstable client requirements; (2) lack of proper coordination between various disciplines of the design team; (3)

awarding the contract to the lowest price regardless of the quality of service; (4) lack of skilled and experienced human resources in the design firms; (5) lack of skilled human resources at the construction site; (6) delay of dues payments; (7) lack of a specialised quality-control team; (8) lack of professional construction management; (9) delaying the approval of completed tasks; and (10) vague and deficient drawings and specifications [23]."

According to Egan [24] the construction industry is underperforming, which is manifested in low profitability, capital investment, research and development caused by delays in construction projects as a result of the high dissatisfaction from the part of the industry's customers with its overall performance.

Some research publications such as Flyvbjerg [25] and Rhodes [26] have indicated that 9 out of 10 global megaprojects experience delays, which usually lead to excessive cost overruns. Obviously, this is also a problem for smaller projects. An innovative solution to the above-mentioned problem was proposed by Egwim et al. The suggestion was to apply artificial intelligence for predicting construction project delay [11].

Dikareva et. al investigates four fields of efficiency of a project, such as budgetary efficiency, social efficiency, economic efficiency, and commercial efficiency [20]. Our research group proposes to approach the efficiency improvement question from two sides. One is the application of technological systems in project management, such as the use of AI in project management. And the other suggestion is the application of technological systems during the implementation of the infrastructural system of the managed project, that is using AI directly in the built infrastructure and subsystems.

These already mean, for example, improving efficiency with pre-construction planning [27], investing in construction technology to enhance project management, and increasing efficiency and productivity on the construction site through the training of construction teams (AI in teaching).

The project's main resource asset is information. Information is important for pre-construction planning and scoping to ensure on-time and on-budget success. For every level of the project, we need to find an understanding of the type of information necessary at each stage. We need efficient technology to collect and handle this information. The key to success is having the single version of the valid information (objectives, tasks, outputs, deadlines, and budgets) [7, 28]. In the first figure, we can see the PIM model of the Crossrail project.

We recommend using artificial intelligence to support project management techniques [11].

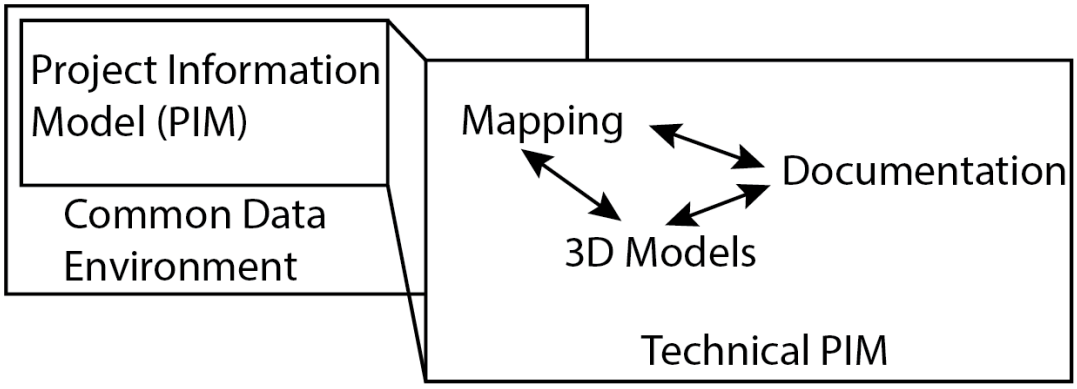


Figure 1. An example of information types on projects eg.: Crossrail PIM model [28].

Another level of information sharing in projects is collaborative decision making. Collaborative management can be a successful tool for cross-border projects involving several international actors. An example of such cooperation is the Grand Ethiopian Renaissance Dam project. In 2018, Ethiopia, Sudan, and Egypt formed a National Independent Scientific

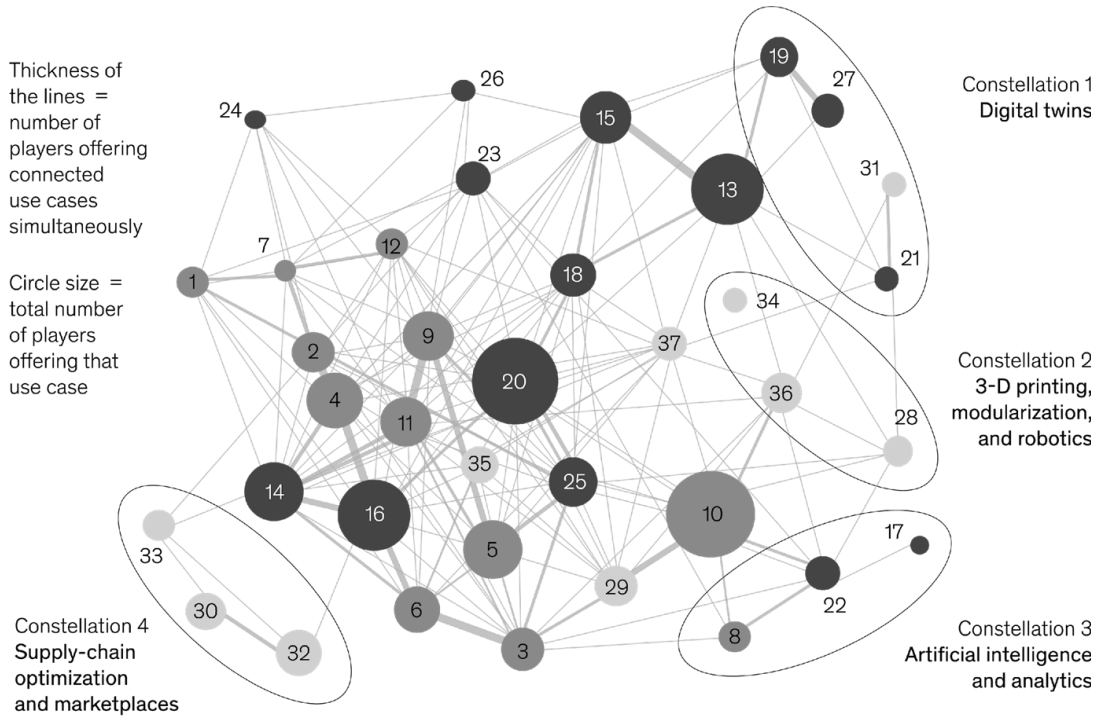
Research Group (NISRG) of researchers from the three countries [29]. The example of this project shows that in the case of an international project, project management organised on a scientific basis is particularly important. Moreover, we think that this principle could also be an important aspect in the decision making of other projects [30, 31].

By the mapping of artificial intelligence on infrastructure development project management and on the industry, Figure 2). McKinsey visualised the connections of the Global construction technology industry ecosystem. Figure 2 shows the globally used AI technology in the Construction industry [32].

For a deeper investigation, we chose one industrial sector where we have more experience. This was the railway sector [33].

Our second proposal is to build systems with artificial intelligence in infrastructural systems [34-42]. We can create a new structure which is an intelligent infrastructure.

At this time, it is not yet a widespread solution in everyday life. To accomplish this, we recommend the following roadmap for the industry.



Digital collaboration

1 Capital financing
2 Customer relationship management
3 Equipment management
4 Estimating
5 Manpower optimization
6 Materials management
7 Portfolio planning and management
8 Predictive assessment performance
9 Project scheduling
10 Real-time monitoring and control
11 Resource planning
12 Risk management

Back office

13 3-D modeling
14 Bidding process
15 Building-information modeling
16 Contract management
17 Deep learning
18 Design management
19 Design simulation
20 Document management
21 Laser scanning
22 Machine learning
23 Process simulation
24 Productivity management
27 Progress tracking and performance dashboards
26 Value engineering
27 Virtual learning

On-site execution

28 3-D printing
29 Compliance
30 Construction materials marketplace
31 Drone-enabled yard inspection
32 Equipment marketplace
33 Labor and professional marketplace
34 Off-site fabrication
35 Quality control
36 Robotics/automation
37 Testing and training

Figure 2. Global construction technology industry ecosystem [32].

Strategic Priority Step 1

Examining, updating and actualizing industry standards either based on industry-specific results or experience outside the sector.

The importance of reaching this milestone can be traced back to the fact that railway industry players place a strong emphasis on the application of standards for safety. Therefore, until these standards do not include the method of how to apply AI technology, it will certainly not spread within the railway industry.

Naturally, at the same time, the regulations characterising the industry need to be changed and clarified. In this regard, it is particularly interesting how the various railway regulations can be kept up to date.

Strategic Priority Step 2

The commitment of the manufacturers towards the awaiting application of AI technology in their products.

Is there any AI technology ready to use? Within 5 years the AI-based non-intrusive infrastructure inspection technology will reach the TRL 9 level. Also, the same status will be true for train delay prediction using Machine Learning and a little more time is needed for the predictive maintenance of railway assets to become market-ready.

Strategic Priority Step 3

Development of industry certifications flows. Since the railway industry produces a significant number of safety-critical products and systems, it is particularly important to develop the related certification requirements and methods, similarly to the aviation industry.

Strategic Priority Step 4

Additional demands are expressed in railway tenders. From the point of view of the tenderer, it is a simple question whether the industry standards include the possibility of applying AI technology. The tender will call attention to the application of the industry standards as it is usually the case. In relation to AI, there are few specific regulations which prescribe that the risks must be examined from several points of view. These categories can be seen in Figure 3.

It would be too early to talk about the mandatory use of AI technology by manufacturers. The application will gain momentum if the respective manufacturers see a significant competitive advantage in it.

These Strategic priority steps can be milestones of the Roadmap for Trustworthy Artificial Intelligence usage, especially in the Railway industry.

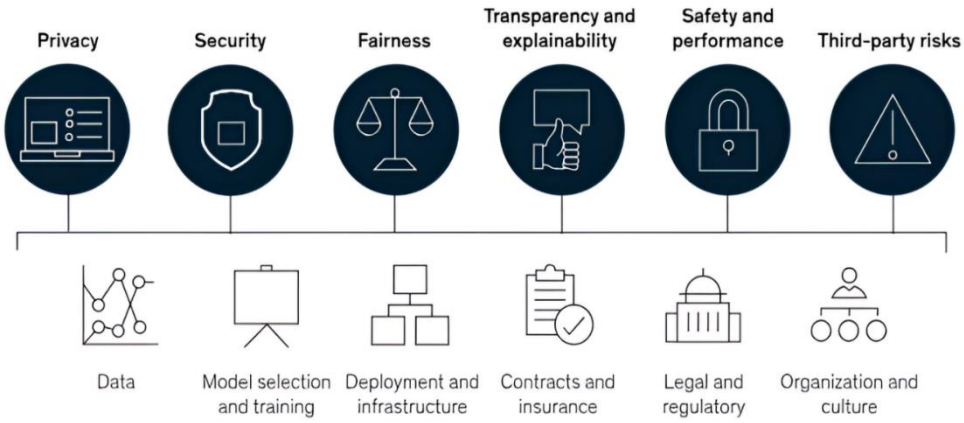


Figure 3. AI risks in global construction technology [45].

CONCLUSION

The research results show us that construction projects need to improve their efficiency. According to our research, AI can be a great tool to improve project management or on-site system operation. The barrier to AI use is its questionable trustworthiness. Therefore, the trustworthiness of AI to be used in the future is an important issue, especially in the case of its application in safety-critical systems [43]. These Trustworthy systems have to reach the ethics standard which means adequate human oversight, technical robustness and safety, privacy and data governance, transparency, diversity, non-discrimination and fairness, environmental and societal well-being and accountability [44].

In our study, we connected infrastructure construction projects to AI technology in the management field and technological field in order to improve efficiency. We can find good examples at different levels, but sectoral changes are ahead of us. To facilitate this, we outlined our proposed roadmap for the use of trustworthy artificial intelligence.

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REFERENCES

[1] Haylen, A.: *Crossrail 2.* https://researchbriefings.files.parliament.uk/documents/CBP-8481/CBP-8481.pdf, accessed 20th May 2022,

[2] Pricewaterhouse Coopers LLP.: *Crossrail 2 Funding and financing study*. https://www.pwc.co.uk/capital-projects-infrastructure/assets/crossrail-2-funding-and-financing-study.pdf, accessed 20th May 2022,

[3] TfL Board: *2023/24 TfL Budget.* https://board.tfl.gov.uk/documents/s19826/TfL%20Budget%202023-24.pdf, accessed 20th May 2023,

[4] Navi Mumbai International Airport Pvt. Ltd.: *Pre-Feasibility Report Navi.* https://environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=1cYzworudk9etY2YOWycq4F/DK+g3bAKkh9DGyenUROgSwE0GSQRsSg+28KDyHA0XH8Be2cH7sfi4SbB5FhJaYPyMOwyk9g4qfDfnzgc1M4=&FilePath=93ZZBm8LWEXfg+HAlQix2fE2t8z/pgnoBhDlYdZCxzUeqEISsDpNmaozay3MPM7v, accessed 20th May 2022,

[5] Abtew, W. and Dessu, S.B.: *Financing the Grand Ethiopian Renaissance Dam.* In: Abtew, W. and Dessu, S.B.: *The Grand Ethiopian Renaissance Dam on the Blue Nile*. Springer Geography, Springer, Cham, pp.161-169, 2019, http://dx.doi.org/10.1007/978-3-319-97094-3_11,

[6] Lin, C.; Zhao, G.; Yu, C. and Wu, Y.: *Smart City Development and Residents' Well-Being.* Sustainability **11**(3), 1-17, 2019, http://dx.doi.org/10.3390/su11030676,

[7] Bagnall, A.M., et al.: *Systematic review of community infrastructure (place and space) to boost social relations and community wellbeing: Five year refresh.* https://whatworkswellbeing.org/wp-content/uploads/2023/01/Places-and-Spaces-Review-Refresh-31-Jan-2023-final-with-logos.pdf, accessed 20th May 2023,

[8] Martins, J.: *The 6 phases of construction project management (CPM).* https://asana.com/resources/construction-project-management, accessed 20th May 2023,

[9] Qin, Y. and Ofori, G.: *Challenges of construction industries in developing countries.* Open Journal of Business and Management **4(**4), 1-13, 2000,

[10] Abioye, S.O., et. al: *Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges.*
Journal of Building Engineering **44**, No. 103299, 2021,
http://dx.doi.org/10.1016/j.jobe.2021.103299,
[11] Egwim, C.N., et al.*: Applied artificial intelligence for predicting construction projects delay.*
Machine Learning with Applications **6**, No. 100166, 2021,
http://dx.doi.org/10.1016/j.mlwa.2021.100166,
[12] Aktsiaselts Eesti Raudtee: *Railway construction works*.
https://ted.europa.eu/udl?uri=TED:NOTICE:295435-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[13] Bundesamt für Infrastruktur Umweltschutz und Dienstleistungen der Bundeswehr: *Airport buildings construction work.*
https://ted.europa.eu/udl?uri=TED:NOTICE:319032-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[14] Rail Baltic Estonia: *Construction work for gas pipelines.*
https://ted.europa.eu/udl?uri=TED:NOTICE:331133-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[15] Rail Baltic Estonia: *Construction work for gas pipelines.*
https://ted.europa.eu/udl?uri=TED:NOTICE:322528-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[16] Riigi Kaitseinvesteeringute Keskus: *Construction work for pipelines, communication and power lines, for highways, roads, airfields and railways; flatwork.*
https://ted.europa.eu/udl?uri=TED:NOTICE:331120-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[17] Elering, A.S.: *Construction work for electricity power lines.*
https://ted.europa.eu/udl?uri=TED:NOTICE:309900-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[18] Transpordiamet: *Road construction works.*
https://ted.europa.eu/udl?uri=TED:NOTICE:302071-2023:TEXT:EN:HTML&src=0, accessed 20th July 2022,
[19] Wheeler, K.G., et al.: *Understanding and managing new risks on the Nile with the Grand Ethiopian Renaissance Dam.*
Nature Communication **11**, No. 5222, 1-9, 2020,
http://dx.doi.org/10.1038/s41467-020-19089-x,
[20] Dikareva, V. and Voytolovskiy, N.: *The Efficiency and Financial Feasibility of the Underground Infrastructure Construction Assessment Methods.*
Procedia Engineering **165**, 1197-1202, 2016,
http://dx.doi.org/10.1016/j.proeng.2016.11.839,
[21] Long, N.D.; Ogunlana, S.; Quang, T. and Lam, K.C.: *Large construction projects in developing countries: a case study from Vietnam.*
International Journal of Project Management **22**, 553-561, 2004,
http://dx.doi.org/10.1016/j.ijproman.2004.03.004,
[22] Haseeb, M., et al.: *Problems of Projects and Effects of Delays in the Construction Industry of Pakistan.*
Australian Journal of Business and Management Research **1**, 41-50, 2012,
[23] Sha'ar, K.Z., et al.: *Design-construction interface problems in large building construction projects.*
International Journal of Construction Management **17**, 238-250, 2017,
http://dx.doi.org/10.1080/15623599.2016.1187248,
[24] Egan, J.: *Rethinking the Report of the Construction Task Force. Constr. Task Force.*
https://constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf, accessed 20th July 2022,

[25] Flyvbjerg, B.: *What you Should Know about Megaprojects and Why: An Overview.* Project Management Journal **45**, 6-19, 2014, http://dx.doi.org/10.1002/pmj.21409,
[26] Rhodes, C.: *Construction Industry: Statistics and policy. House Commons Libr. 1-13.* https://researchbriefings.files.parliament.uk/documents/SN01432/SN01432.pdf, accessed 20th July 2022,
[27] Togal.AI: *The Impact of Artificial Intelligence (AI) in the Preconstruction Project Stages.* https://www.togal.ai/blog/ai-in-preconstruction, accessed 20th July 2023,
[28] MacDonald, I.: *Information Handover Principles.* https://learninglegacy.crossrail.co.uk/documents/information-handover-principles, accessed 20th July 2023,
[29] Basheer, M., et. al.: *Collaborative management of the Grand Ethiopian Renaissance Dam increases economic benefits and resilience.* Nature Communication **12**, No. 5622, 2021, http://dx.doi.org/10.1038/s41467-021-25877-w,
[30] Khahro, S.H., et al.: *Delay in Decision-Making Affecting Construction Projects : A Sustainable Decision-Making Model for Mega Projects.* Sustainability **15**(7), No. 5872, 2023, http://dx.doi.org/10.3390/su15075872,
[31] Marovi, I. and Hanak, T.: *Selection of adequate site location during early stages of construction project management : A multi-criteria decision analysis approach Selection of adequate site location during early stages of construction project management : A multi-criteria decision.* IOP Conference Series: Materials Science and Engineering **251**, No. 012044, 2017, http://dx.doi.org/10.1088/1757-899X/251/1/012044,
[32] McKinsey and Company: *Rise of the platform era: The next chapter in construction technology*. https://www.mckinsey.com/industries/private-equity-and-principal-investors/our-insights/rise-of-the-platform-era-the-next-chapter-in-construction-technology, accessed 20th July 2022,
[33] RAILS Consortium: *RAILS*. https://rails-project.eu/about/advisory-board, accessed 28th July 2022,
[34] Oluleye, B.I.; Chan, D.W.M. and Antwi-Afari, P.*: Adopting Artificial Intelligence for enhancing the implementation of systemic circularity in the construction industry: A critical review.* Sustainable Production and Consumption **35**, 509-524, 2023, http://dx.doi.org/10.1016/j.spc.2022.12.002,
[35] Pappaterra, M.J.; Flammini, F.; Vittorini, V. and Bešinović, N.: *A Systematic Review of Artificial Intelligence Public Datasets for Railway Applications.* Infrastructures **6**, 136, 2021, http://dx.doi.org/10.3390/infrastructures6100136,
[36] Donato, L.D., et al.: *A Survey on Audio-Video Based Defect Detection Through Deep Learning in Railway Maintenance.* IEEE Access **10**, 65376-65400, 2022, http://dx.doi.org/10.1109/ACCESS.2022.3183102,
[37] Dirnfeld, R., et al.: *Railway Digital Twins and Artificial Intelligence: Challenges and Design Guidelines.* In: Marrone, S., et al., eds.: Dependable Computing – EDCC 2022 Workshops. Communications in Computer and Information Science **1656**. Springer, Cham, pp.102-113, 2022, http://dx.doi.org/10.1007/978-3-031-16245-9_8,
[38] Azari, M.S.; Flammini, F. and Santini, S.: *Improving Resilience in Cyber-Physical Systems based on Transfer Learning.* International Conference on Cyber Security and Resilience, IEEE, Rhodes, 2022, http://dx.doi.org/10.1109/CSR54599.2022.9850282,

[39] De Donato, L., et. al: *Towards AI-assisted digital twins for smart railways: preliminary guideline and reference architecture.*
Journal of Reliable Intelligent Environments **9**, 303-317, 2023,
http://dx.doi.org/10.1007/s40860-023-00208-6,

[40] Natarajan, R., et. al.: *Fault detection and state estimation in robotic automatic control using machine learning.*
Array **19**, No. 100298, 2023,
http://dx.doi.org/10.1016/j.array.2023.100298,

[41] Canonico, R., et al.: *Automatic Generation of Domain-Aware Control Plane Logic for Software Defined Railway Communication Networks.*
In: Margaria, T. and Steffen, B., eds: *Leveraging Applications of Formal Methods, Verification and Validation. Practice*. IsoLA, Lecture Notes in Computer Science **13704**. Springer, Cham, pp.308-320, 2022,
http://dx.doi.org/10.1007/978-3-031-19762-8_23,

[42] Besinovic, N., et. al: *Artificial Intelligence in Railway Transport: Taxonomy, Regulations, and Applications.*
IEEE Transactions on Intelligent Transportation Systems **23**(9), 14011-14024, 2022,
http://dx.doi.org/10.1109/TITS.2021.3131637,

[43] Flammini, F., et. al: *Towards Trustworthy Autonomous Systems: Taxonomies and Future Perspectives.*
IEEE Transactions on Emerging Topics in Computing, 1-13, 2022,
http://dx.doi.org/10.1109/TETC.2022.3227113,

[44] European Commission, Directorate-General for Communications Networks, Content and Technology High-Level Expert Group on AI: *The Assessment list for trustworthy artificial intelligence (ALTAI) for self assessment.*
http://dx.doi.org/10.2759/791819,

[45] McKinsey & Company: *A systematic approach to identifying and prioritizing AI risks can help organizations effectively target mitigation efforts.*
https://www.mckinsey.com/capabilities/quantumblack/our-insights/getting-to-know-and-manage-your-biggest-ai-risks, accessed 20th July 2023.