Emerging Technologies in the Era of Digital Transformation: State of the Art in the Railway Sector

Dietmar Möller[1], Lukas Iffländer[2], Michael Nord[3], Patrik Krause[4], Bernd Leppla[3], Kristin Mühl[2], Nikolai Lenski[5] and Peter Czerkewski[6]

[1]*Clausthal University of Technology, Institute for Mathematics, Erzstr. 1, 38678 Clausthal-Zellerfeld, Germany*

[2]*German Centre for Rail Traffic Research (DZFS), August-Bebel-Str. 10, 01219 Dresden, Germany*

[3]*IABG mbH, Einsteinstr. 20, 85521 Ottobrunn, Germany*

[4]*3DSE Management Consultants GmbH, Seidelstr. 18a, 80335 München, Germany*

[5]*Fraunhofer AISEC, Breite Str. 12, 14199 Berlin, Germany*

[6]*Institute of Railway Technology GmbH, Carnotstr. 6, 10587 Berlin-Charlottenburg, Germany*

dietmar.moeller@tu-clausthal.de, IfflaenderL, MuehlK@dzfs.bund.de, nord, leppla@iabg.de, p.krause@3dse.de, nikolai.lenski@aisec-fraunhofer.de, pc@bahntechnik.de

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Abstract: Emerging technologies and digital transformation are essential indicators in today's industrial sectors. The railway and public transportation sectors are undergoing a substantial transformation through digitalization and emerging technologies. However, little is known about the manifold of applications in the industrial sectors and progress so far. In this study, we consider various emerging technologies and proposed use-cases. Next, using a two-step survey and a SWOTA analysis, we analyze both sector's maturity levels regarding these technologies. The analysis indicates technologies currently permeating the analyzed sectors, shows discrepancies between technology application and knowledge, and multiple issues hamper their implementation.

1 INTRODUCTION

The digital transformation transcends currently practiced roles in development and design, marketing and sales, customer services, and many other areas. In this regard, digital transformation begins and ends with enabling intelligent digital technologies in design and development. Moreover, it takes people's interaction from paper over spreadsheets and intelligent applications to digitally manage all business processes and tasks. However, digital transformation also causes a disruption (Möller, 2020).

Emerging technologies is a term used to describe technological advancements, but may also refer to the continuing development of existing technology. Against this background, the term emerging technology commonly refers to a currently developing technology available within a short period.

The railway and public transportation sectors undergo a significant transformation through digitalization and emerging technologies. However, little research on the scale of the application of emerging technologies exists. Therefore, we initiated a project to, on the one hand, evaluate the current conditions of emerging technologies and possible opportunities for their usage, and on the other hand, to fathom the reasons why the sectors do not apply seemingly promising technologies.

Against this background, we evaluated the current state of emerging technologies in the railway and public transportation sectors by applying a multi-method approach to assess, on the one hand, the everyday use of emerging technologies and, on the other hand, opportunities for their potential usage. To this end, we describe a two-stage survey comprising an online survey and an interview survey. We evaluate the replies to the surveys and analyze, e.g., contradictory answers and inconsistencies.

In the remainder of this work Section 2 describes the considered emerging technologies, accompanied by their placement inside the analyzed sectors. Next, we describe the survey method in Section 3 and evaluate the results in Section 4. Section 5 concludes the paper and gives an outlook on future work.

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2 EMERGING TECHNOLOGIES

Emerging technology is a term used to describe the continuing development of technology to expand or enable technical features or applications. We excpect such technologies' availability in the next five to ten years, such as advances in semiconductors through nanotechnology to overcome the Heisenberg uncertainty relation or advances in product design through new materials (Soares et al., 1997).

Emerging technologies are manifold. We briefly introduce these technologies that we see relevant for the studied sectors. We present the technologies in general and later place them inside the railway sector.

Artificial Intelligence (AI): Describes the ability of machines to "think" like humans. "Thinking" upon others comprises awareness of the surrounding environment and acting based on this environment.

Additive Manufacturing: Manufacturing process creating 3D objects through layered production.

Big Data and Analytics: Enables the processing of large and complex data sets that are difficult to analyze with traditional tools.

Blockchain: A directory of information cryptographically hashed and authenticated within a network of participants using cryptographic proof for secure interacion.

Cloud Computing: Provides infrastructure, application, and service resources via the Internet. In this context, cloud computing enables complex and innovative IT infrastructures to integrate into companies quickly.

Cloud Services: Represent infrastructure, platforms, software, or technology hosted by a third party and made available to potential users over the Internet, e.g., Infrastructure- (IaaS), Platform- (PaaS), Software- (SaaS), and Function-as-a-Service (FaaS).

Container: A form of secure logical process isolation on operating system level.

Fiber Optics: Technology that uses glass and plastic fibers to transmit data loss-free as light pulses over large distances or allows measurements of, e.g., vibrations in proximity to the fire.

Internet of Things (IoT): Represents a self-configuring network where sensors and actuators can be connected to the Internet. IoT can manage and monitor any number of objects.

Machine Learning (ML): A computer system with access to data to learn using different learning methods. Machine learning methods are:] Unsupervised Learning, Supervised Learning, and Reinforcement Learning.

Networks Function Virtualization (NFV): Replaces pysical network functions like routers or firewalls with virtualized network functions (VNFs).

Software Defined Network (SDN): Network architecture separating control and data planes.

Virtualization: Software-based or virtual representation of appliances.

Wireless Sensor Networks (WSN): WSN connect many sensor nodes in a communication infrastructure to monitor conditions at different locations. Connection establishment uses ad-hoc routing.

5G: Fifth generation of mobile wireless broadband technology.

The preceding introduced emerging technologies that can be used and previously used technologies and future use in various industrial sectors. Indeed, these emerging technologies are ideal for use in the railway and public transportation sectors and infrastructure.

Railway Sector Applications

The technologies we just introduced are not merely "hype technologies" in the general IT sector. Either an existing implementation or statements of intention for introduction exist for every technology. In the following, we will show at least a scientific publication or a press statement by a major stakeholder for each technology. Some applications cover multiple technologies and demonstrate their interactions.

Deutsche Bahn AG uses *Artificial Intelligence* and *Big Data Analytics* to predict train delays. To this end, (Hauck and Kliewer, 2020) employ a supervised Machine Learning model based on a neural network and achieve promising results.

Additive Manufacturing became relevant for replacement parts, especially non-safety relevant components like driver armrests. However, (Fu and Kaewunruen, 2021) note in their survey of the application in the sector that it is still in the exploratory stage. This is especially true for safety-critical components like rail track infrastructure components.

(Kuperberg et al., 2020) introduce an application for a distributed ledger (*Blockchain*) in interlocking. Instead of a central authority (e.g., the classical signal box), trains and infrastructure components (e.g., switches) interact using the decentralized information and agree on driveways and access to track segments.

The authors consider their work suitable for branch lines and a backup for regular lines.

Deutsche Bahn moved their regular IT to the *Cloud* and completed the process by 2020 (Koenen, 2020). They use a comprehensive set of available cloud technologies, including various *Cloud Computing*, *Virtualization*, *Cloud Services*, and *Container* solutions, and their multi-cloud strategy comprises the Amazon and Microsoft clouds. While the left-wing NGOs "Prellbock Altona" and "Bahn für Alle" tried to cause an outrage that "no switch could be switched" (Jung and Wolf, 2020) without this system, this is not the case. Signaling and Interlocking remain on their localized infrastructure. Especially, older mechanical and electro-mechanical interlocking systems run entirely independently of any IT infrastructure.

Fiber Optics act as monitors for railway infrastructure components. E.g., (Wheeler et al., 2019) use fiber optic sensing to measure the stress in a rail. Further experimental applications detect persons on the tracks or continuously locate trains without using axle counters. However, since these approaches are usually based on Machine Learning models, they lack proper authorization for production use.

IoT in railways comprises a more extensive set of approaches. (Brandmüller, 2022) from Deutsche Bahn introduced his passenger counter open-source tool running on an ESP32 microcontroller to count passengers based on the number of nearby Bluetooth and Wi-Fi devices and report the results via LoRaWAN. Thereby, this approach also becomes an example for *WSN*. Meanwhile, (Gbadamosi et al., 2021) identified and discussed rail asset management problems and proposed an implementation strategy for IoT-based predictive asset maintenance in the UK.

(Ruscelli et al., 2019) discuss the adaptation and introduction of *SDN* and *NFV* in railway control systems and suggest two applications: an SDN failure recovery and a secured NFV-based maintenance service. Such systems can also become a reason to introduce *NaaS*, e.g., to provide failure recovery networks.

5G will be the next standard for railway wireless communication. The 5G-based future railway mobile communication system (FRMCS) will replace the current 2G-based GSM-R. The sector decided to forego the initially proposed 4G-based LTE-R for future-proof solutions (Pierre and Christophe, 2019).

While the different technologies find application in other areas of the railway and transport sectors and are at seemingly different stages of maturity, the existence of either scientific publications or statements of intent regarding their application shows that these technologies spill over to the relevant sectors and are worthy of considering in our survey.

3 METHODS

We used two survey methods were to identify the embedment of emerging technologies in the German railway and public transportation sectors. To this end, we used a two-stage survey to determine their current market share obstacles for their introduction. We applied a quantitative online survey and a qualitative semi-structured interview method.

3.1 Online Survey

We conducted an online survey as the first part of our two-stage process. Answers refer to maturity levels in a fixed range between 0 and 5 regarding the emerging technology questioned emerging technologies. Subsequent expert interviews followed in a second step (see Section 3.2) to increase individualization.

We chose Limesurvey to realize the survey based on availability, acceptance, ease of use, and compliance with data protection requirements. The online survey consisted of two parts with specific questions on cybersecurity (not addressed in this paper) and emerging technologies. For each emerging technology mentioned in Section 2, we inquired about the know-how, the applicability, the temporal and permanent influence of adaption, and the risk. We used a linear answer scale referring to the maturity levels. In total, the survey comprised 60 questions. The question about know-how served as a filter, i.e., only technologies the participant had any knowledge of, were displayed in the following questions. Finally, we recorded demographic data on the company, such as employee numbers and turnover. In addition, the company had to map itself to the respective sub-sectors of the railway industry: (1) railway operators, (2) rail-way infrastructure manager, (3) railway energy supplier, (4) railway vehicle manufacturers and maintenance workshops, (5) railway infrastructure supplier, (6) transit authorities and public transport operators, and (7) distributors.

3.2 Interview Survey

The questionnaire of the interview survey served as a guide for the follow-up survey. The opportunity is used here to delve deeper into selected topics with open-ended questions to compensate for the disadvantage of the closed questions from the online questionnaire. For this reason, the form of the semi-structured interview (see for example (Adams and others, 2015)) was chosen. As a compromise between the large number of relevant topics that could have been deepened in such an interview and the consideration of the

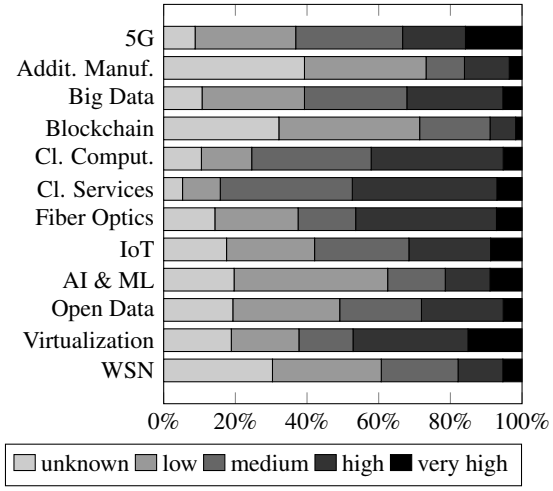

Figure 1: Knowledge about emerging technologies.

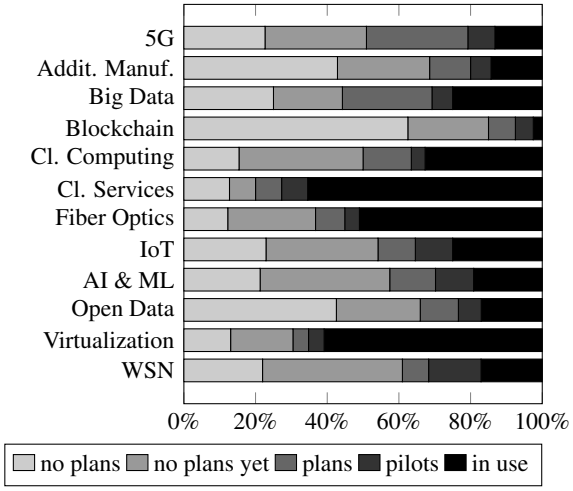

Figure 2: Usage of emerging technologies.

time of our interview participants, a total duration including welcome and farewell of about one hour was planned. Due to the pandemic situation and the physical distance to the interviewees, the interviews were conducted virtually.

Essentially, the interviews pursued three core goals: Clarifying contradictions and abnormalities, deepening specific questions regarding the degree of maturity, and identifying strengths, weaknesses, opportunities, and threats (SWOT analyses) of the cybersecurity and selected emerging technologies.

The main question for collecting data for the SWOT analysis was "why," i.e., investigating the actual cause behind the status quo, which was explored with every interview question. Questions were asked about achieving a good status and significant support factors for the strengths and opportunities. In turn, a self-assessment of existing barriers to the introduction and use of emerging technologies served to explore weaknesses (barriers as internal factors) as well as risks (in the case of external factors). The necessary measures and assistance to overcome these obstacles were also explored. Finally, data were collected for the SWOT analysis of selected emerging technologies in which the surveyed companies already showed extensive experience. To do so, the strengths, opportunities, weaknesses and threats of the affected technologies were promptly addressed.

The interview questions for each company were adapted to the results obtained from the online survey to achieve the goals described. Criteria were created to deepen the topics based on the answers to one or more questions, which were the most promising regarding the above goals. This is exemplified by the described selection of technologies a company should be asked about, based on their experience with the relevant technologies.

The interview partners were chosen based on various criteria from the participants in the online survey to find a representative subset. To this end, we covered all sectors (see Section 3.1) and adjusted the number of interviewees per sector to the relative size of each sector.

4 RESULTS

4.1 Online Survey

First, the level of knowledge about emerging technologies and their possible use in the railway sector was of significant interest. Figure 1 shows the result of the knowledge assessment regarding emerging technologies.

As shown in Figure 1, for high and very high percentages, the level of knowledge for Cloud Computing, Virtualization, and Fiber Optics is most pronounced. Emerging technologies with the lowest level of expertise represent Additive Manufacturing, Blockchain, and Wireless Sensor Networks. For assessing possible usage of emerging technologies, their gradation ranges from not planned to already in use, as shown in Figure 2.

Comparing piloting and in-use results in Figures 1 and 2, it is evident that Cloud Services, Fiber Optics, and Virtualization already are in widespread use, which shows:

Virtualization: is in advanced usage in the participating railway subsectors. It makes it easier for administrators to manage services and networks in many respects by abstracting the lower functions in the network. However, the knowledge of

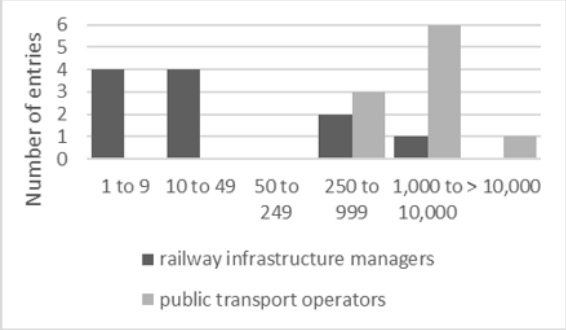

Figure 3: Maturity level in the railway sub-sectors based on categorization.

this technology is not as pronounced as the use suggests. Furthermore, virtualization in connection with SDN / NFV abstracts the lower levels of the network, offering central control without manual access to the physical network components. Consequently, one decouples oneself from the underlying technology and replaces it with easy-to-administer services. These services increasingly replace the previously required knowledge and explain the discernible difference between use and knowledge.

Cloud Services: are another technology that needs to consider in more detail. A high proportion of realization opposes a less pronounced knowledge. In the context of cloud services, the question must be asked to what extent in-depth understanding of the technology is still required. Cloud services are outsourced by the railway sub-sectors, provided via a Service Level Agreement. The railway sub-sector over-buys the loss of knowledge a service that operates these services in a kind of black box that is not transparent for the railway sub-sector. This explains why the knowledge lags behind the degree of use.

Another question arises in the survey: What role does railway sub-sector size [number of employees] play on knowledge and use of emerging technologies? Figure 3 shows the distribution of railway sub-sectors categorized as small, medium, and large $[< 50 \cdots > 10.000]$ in the railway infrastructure manager (RIM) and public transport operators (PTO). We selected these three sub-sectors out of 8 because at least ten companies from each sector took part in the online survey.

Figure 3 shows that primarily small companies took part in the RIM sub-sector, while the PTO sub-sector includes medium-sized and large companies. Therefore, both subsectors investigated the level of knowledge and usage of emerging technologies more in detail. Figure 4 shows the level of expertise in boxplots about the 12 selected emerging technologies within the RIM sub-sector.

Figure 4 shows that the levels of knowledge range between the lower threshold value / lower quartile at 0.0 “is not known” and reach a maximum of approx. 2.5 “medium,” without going into outliers. In comparison, Figure 5 shows the level of knowledge in the public transport operator’s sub-sector.

Against this background, knowledge does not always correspond to the level of commitment, e.g., using emerging technologies and the possibility of outsourcing. It should be noted; that small-sized companies fall behind both knowledge and assessment of possible usage, which can be explained by considering capacities and resources. However, it can be seen in small companies that there is a need to catch up with emerging technologies, which offers them better knowledge about them and examples of best practices.

The distribution is recognizably different here.

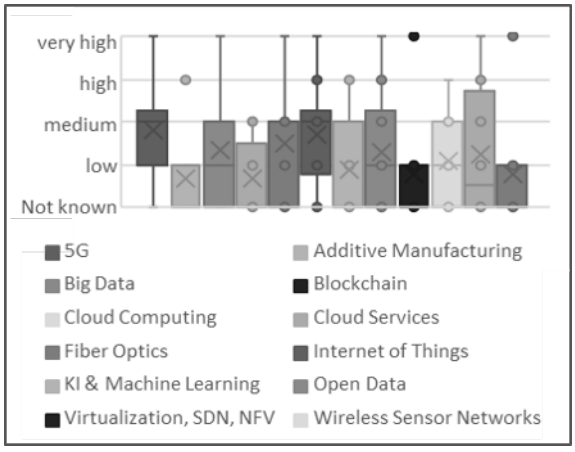

Figure 4: Knowledge in emerging technologies in the RIM sub-sector.

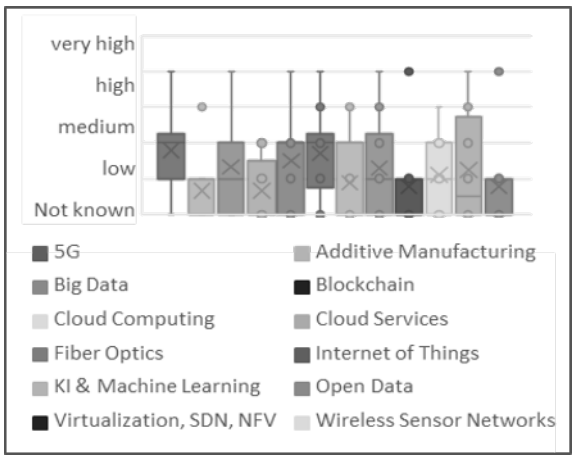

Figure 5: Knowledge in emerging technologies in the PTO sub-sector.

The values of knowledge are about one level higher than in the RIM sub-sector. Medium-sized and larger companies acquire higher expertise than smaller companies in the RIM sector. The reason is that the small companies in the RIM sub-sector cannot deal with emerging technologies. In contrast, medium-sized and large companies have more time and staff to acquire knowledge. This outcome is also a result of the online survey on emerging technologies in the overall railway sub-sectors.

A direct comparison shows that medium-sized and large-sized companies assume more application possibilities for emerging technologies or are already using them. While only two technologies are being piloted or used in the RIM sector (cloud services and virtualization), there are already 5 in the public transport sub-sector. Furthermore, It is interesting that blockchain will not play a role in the PTO sub-sector. The reason is that the small companies in the RIM sub-sector have no capacity/resources to deal with it or do not assume any value "Not intended for use" and "imaginable, but not in the planning stage"). In contrast, medium-sized and large-sized companies undergo more efforts to keep up with emerging technologies and acquire knowledge.

4.2 Interview Survey

The qualitative nature of the interview results and their semi-structured implementation makes an evaluation based on individual questions impractical. Instead. Thus, we carried out an assessment to clarify contradictions and abnormalities by deepening specific questions about selected emerging technologies and enabling data collection for a SWOT analysis.

Twenty-four companies of the 60 online survey participants agreed to participate in the interview survey. Of these twenty-four companies, 12 were selected for an in-depth discussion (criteria used see Section IV), paying attention to a representative selection of online participants. Companies that signed up for the follow-up interview but did not respond were replaced with suitable candidates. For each of the interviewed companies, an individual questionnaire was created consisting of an initial question about the motivation to participate, six to ten key questions. We depend on the company's online survey results to specify its previous answers and questions on emerging technologies in the respective railway sub-sector.

The questions concerning emerging technologies can be divided into two main directions: 1) identify reasons why emerging technologies are not used and 2) understand the level of the potential use of certain emerging technologies. While 1) can be answered with one question, 2) must be corroborated through several questions.

Due to anonymization, the data of sector "Others" and a split by interviewed participants by technologies are not displayed by sub-sectors. Some technologies are only relevant for one participant. The reason for this is that the sample we chose the participants from was limited regarding outlining results from the online survey. Therefore, only a brief overview of the number of participants by technology can be given: Regarding Additive Manufacturing, Big Data, Blockchain, Cloud Computing, Cloud Services, Fiber Optics, Internet of Things, AI/Machine Learning, Open Data and Virtualization/SDN/NFV 1 to 3 companies were interviewed. Every participant was interviewed about at least two different technologies. For 5G and Wireless Sensor Networks, no interview participant was identified. One participant was interviewed, answering the online survey that no emerging technologies were used.

The interviews lasted between one and two hours, depending on the company. The interviewers took minutes in the form of bullet points. It was striking that regardless of the technology, similar answers were given. Table 1 shows an example resulting from the interview part per question, and Table 2 shows SWOT data for each selected new technology. In the following, we will correlate the results from the interview survey with the results from the online survey.

4.3 General Findings and Limitations

As an essential issue of the research, we examined the state of the art of emerging technologies in the railway sub-sectors in the era of digital transformation. We identified outliers from the online questionnaire. This qualitative picture across all interviews provides background information on the online survey results. In this regard, the following four statements can be made about emerging technologies in the railway sector:

1. The extent of certain technologies' application varies in a broad range from not used to fully implemented – even within the same sector.
2. The general statement that emerging technologies are favorable for the company, its customers, or employees can be derived from the strengths and opportunities of emerging technologies. For example, participants see AI and Big Data as beneficial as it helps to speed up processes and identify new business models or outline business issues. In addition, it can be mentioned that certain technologies are even more beneficial when used in

Table 1: Example results from the interview survey.

Focus of Question	Answers
Reasons why emerging technologies are not used	• Railway sector is a highly conservative sector using reliable and secure (closed networks) technology • Fiber optics is not considered a new technology • Early-stage IoT research projects started
Strength and opportunities of emerging technologies	• Realize revenue potential through new business models • Create business solutions that are now technically feasible • Improve process efficiency to increase process speed or quality or to achieve cost savings • Offer new services to the customers • Make employees' daily business easier and faster
Biggest obstacles to overcome	• Convincing staff/management of advantages of emerging technologies • Convincing management that an investment beneficial • Gain basic and finally deep knowledge on emerging technologies to create use cases • Find the right staff to realize proof of concepts and to implement new solutions
Effect on employees' work and how changes can be supported	• Defensiveness towards emerging technologies as purpose technology is used for is often unclear • Lighthouse projects help to create acceptance • Involvement of key players within a company and early-stage training of employees

Table 2: SWOT Analysis of emerged Technologies.

Emerging Technologies	Strengths & Opportunities	Weakness & Threats
Additive Manufacturing	Production of parts in small quantities, e.g., for older trains, hardly any cybersecurity risks	Cost / benefit assessment, quality
Big Data	New business models, service improvement	Data acquisition, data ownership
Blockchain	Trust (traceability), efficiency	Not really arrived yet (lack of acceptance and understanding), undesirable CO2 value, inefficient
Cloud Services & Cloud Computing	Fast exchange, access, versioning (mail reduction), customer proximity, flexibility reduced efforts (outsourcing)	Lack of trust, dependency, implementation, cost
Fiber optics	High data throughput	None
Internet of things	Acquisition of data, the enabler for predictive maintenance	Gateways for cyberattacks
AI & Machine Learning	Automated image and data evaluation of / damage to components → saves money, time and it is safer	Lack of trust (in AI, possibly also in part, lack of explain ability)
Open Data	New business models, service improvement	Data acquisition, data ownership
Virtualization, SDN, NFV	Lower cost of infrastructure, flexibility, the possibility for 'digital twin'	Cost / benefit assessment, lack of use cases, lack of knowledge

a combination, e.g. Big Data, Open Data, Cloud and AI.

3. The main obstacles are the missing realization of benefits, management buy-in, and lack of money.
4. Management, employees, and customers need to be involved from the beginning while lighthouse projects prove the benefits of technology.

The main limitation of this study is the subparticipation in some subsectors, which challenges its representativeness. Cyber-security and related emerging technologies are sensitive topics that many companies are reserved for discussing, fearing revealing significant weaknesses. For example, there were no answers of interview participants representing 5G or wireless sensor networks, while other technologies were only represented by only up to three to one participant. Increasing this study's representativeness would require more interview participants or an extended questionnaire by participants.

5 CONCLUSION

Emerging technologies permeate the railway and public transport sub-sectors as part of the digital transformation. While these sub-sectors are traditionally change-resistant, they can no longer be isolated from these trends. While press releases continuously announce a new project to modernize processes, rolling stock, and infrastructures and scientific articles talk about concepts, prototypes, and demonstrators, related work on the latest technologies' embedment level falls short.

Thus, in this work, we addressed this issue. After discussing the advantages and challenges of digital transformation, we introduced several emerging technologies. We placed them inside the railway subsectors and referenced their proposed or actual application examples.

Next, we introduced our quantitative online survey and the follow-up qualitative interview survey. In the first survey, we analyzed the application of and the knowledge about technologies. Here we made several interesting findings. We found that significantly more companies use cloud services and virtualization than rate high or very high on the knowledge metric. Moreover, the commonly excited blockchain hardly receives attention and application.

The following interviews showed selected emerging technologies' strengths, weaknesses, opportunities, and threats. Common reasons for not introducing certain technologies included a lack of trust in the technology or a negative benefit-cost assessment. Major obstacles lie in convincing conservative staff or management of the opportunities and finding the right personnel to implement new approaches.

This work shows which technologies permeate the railway and transport sectors and queried the perceived strengths, weaknesses, opportunities, and threats. In future work, we intend to assess the perceived impact on cybersecurity by introducing these technologies. Furthermore, we plan to associate the affinity for emerging technologies with the cybersecurity awareness of the studied sub-sectors. Lastly, we plan to derive proposed actions for the legislative and executive bodies to improve upon the application of selected technologies.

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REFERENCES

Adams, W. C. and others (2015). Conducting semi-structured interviews. *Handbook of practical program evaluation*, 4:492–505. Publisher: Wiley Hoboken, NJ, USA.

Brandmüller, O. (2022). ESP32-Paxcounter. Publication Title: GitHub.

Fu, H. and Kaewunruen, S. (2021). State-of-the-Art Review on Additive Manufacturing Technology in Railway Infrastructure Systems. *Journal of Composites Science*, 6(1):7.

Gbadamosi, A.-Q., Oyedele, L. O., Delgado, J. M. D., Kusimo, H., Akanbi, L., Olawale, O., and Muhammed-yakubu, N. (2021). IoT for predictive assets monitoring and maintenance: An implementation strategy for the UK rail industry. *Automation in Construction*, 122:103486.

Hauck, F. and Kliewer, N. (2020). Data Analytics in Railway Operations: Using Machine Learning to Predict Train Delays. In Neufeld, J. S., Buscher, U., Lasch, R., Möst, D., and Schönberger, J., editors, *Operations Research Proceedings 2019*, pages 741–747, Cham. Springer International Publishing.

Jung, M. and Wolf, W. (2020). „Deutsche Bahn lagert komplett ihre IT aus" und „schaltet ihre eigenen Rechenzentren alle ab". Publication Title: Prellbock Altona.

Koenen, C. (2020). Die Zukunft liegt in der Cloud.

Kuperberg, M., Kindler, D., and Jeschke, S. (2020). Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control? *Ledger*, 5.

Möller, D. P. (2020). *Cybersecurity in Digital Transformation: Scope and Applications*. SpringerBriefs on Cyber Security Systems and Networks. Springer International Publishing, Cham.

Pierre, T. and Christophe, G. (2019). Railway Network Evolution Why it is urgent to wait for 5G? In *2019 IEEE 2nd 5G World Forum (5GWF)*, pages 1–6, Dresden, Germany. IEEE.

Ruscelli, A. L., Fichera, S., Paolucci, F., Giorgetti, A., Castoldi, P., and Cugini, F. (2019). Introducing Network Softwarization in Next-Generation Railway Control Systems. In *2019 6th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, pages 1–7, Cracow, Poland. IEEE.

Soares, O. D. D., da Cruz, A. M., Pereira, G. C., Soares, I. M., and Reis, A. J., editors (1997). *Innovation and Technology — Strategies and Policies*. Springer Netherlands, Dordrecht.

Wheeler, L., Take, W., Hoult, N., and Le, H. (2019). Use of fiber optic sensing to measure distributed rail strains and determine rail seat forces under a moving train. *Canadian Geotechnical Journal*, 56(1):1–13.