

A survey framework for setting an Augmented Reality (AR) roadmap in rolling stock organizations

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Abstract

In anticipation of Industry 4.0's significant impact on future maintenance systems, Augmented Reality (AR) emerges as a key technology. Even though AR has proven to be mature and applicable in maintenance practices, its practical implementation and challenges faced by organizations remain understudied. The integration of AR into organizational systems poses a crucial challenge, necessitating novel maintenance strategies, interdepartmental collaboration, and clearly defined goals. This research addresses the impact of AR on organizations, emphasizing the need for organizational readiness and adaption in maintenance processes, AR technology adoption, and IT infrastructure integration. This research demonstrates the development of an AR roadmap for rolling stock organizations through the application of a comprehensive survey framework. The study is based on a dual-pronged approach, incorporating a maturity and readiness assessment to ascertain the current state of AR adoption and organizational readiness. The survey framework systematically evaluates critical aspects such as existing technology infrastructure, operator skills, challenges faced, and desired organizational outcomes. The survey findings contribute to developing a tailored AR roadmap that addresses the specific needs and challenges of rolling stock maintenance operations. This research aims to enhance AR integration in rolling stock organizations and provides a practical guide for effective implementation.

Keywords: Augmented reality; rolling stock maintenance; roadmap; survey framework

1. Introduction

Extended Reality (XR), comprising Augmented Reality (AR) enhancing real-world environments with digital overlays, Mixed Reality (MR) seamlessly integrating virtual elements with the physical world, and Virtual Reality (VR) immersing users in entirely virtual environments, transforms industries by merging physical and digital realms for enhanced user experiences and productivity. AR stands out as a pivotal technology in the realm of Industry 4.0 concepts, serving as a primary driver for the advancement of such concepts within the industry, as acknowledged by the European Union [1]. AR has reached a state of maturity, demonstrating its effectiveness and innovation in design, maintenance, and manufacturing applications [2]. AR allows for the simulation, assistance, and enhancement of machines and their maintenance processes before actual implementation. The integration of AR into human-machine interfaces has empowered operators to manipulate components with lifelike hand gestures, providing a more realistic interaction experience, accompanied by tactile feedback [3]. Although academic research on AR is growing exponentially, evidence of AR implementation in practice is still

scarce. Moreover, the challenges organizations face when implementing AR seem to be even less addressed [4]. Extracting challenges in AR implementation is a complex process because complex organisations such as rolling stock never operate isolated. Therefore, the environmental context extends the AR implementation to external players [5], such as competitors e.g. to thrive in challenging environments, government e.g. for regulations and standards, and external partners e.g. for external collaboration and support. Engaging in collaboration with external stakeholders can facilitate the implementation of technology by promoting knowledge management and embraceability.

To digitise Europe's railways, it is required for each country to establish a realistic target state and define a joint roadmap for the rail sector in their country [6]. When it comes to the essentials of digitization of rolling stock operations, different stakeholders have conflicting interests and priorities. All companies in the railway industry want to avoid double investments and financial disadvantages as early adopters. Therefore, research into AR implementation in one European country can benefit others by aligning their strategies and refining their system and user requirements. To address the

challenges identified in the digitization of rolling stock operations, this study stresses the need for rolling stock organizations to develop an AR roadmap identifying the key factors for successful AR implementation.

Existing models for assessing the current readiness and maturity of AR technology adoption demonstrate limitations in road mapping, the absence of tailoring the needs of different industries, and ineffectively capturing the dynamic nature of the organization. The prevailing literature review highlights a predominant trend where the maturity and readiness models provide a holistic view of an organization as a singular system concerning ideal Industry 4.0 characteristics [7]. However, a crucial gap emerges in the lack of specialized models tailored to the specific Industry 4.0 technologies, phases of the maintenance process or individual maintenance departments. There is a need for a structured set of guidelines to conduct surveys and assess the readiness and maturity of AR technology adoption in rolling stock organizations. Therefore, the current study aims to fill this gap by proposing a survey framework, specifically oriented towards AR road mapping by including measurement dimensions for the evaluation of organizational capabilities and preparedness for AR integration.

The survey framework employed in this study serves as a systematic tool for evaluating the current readiness and maturity of AR technology adoption for rolling stock organizations. It involves a structured approach to collecting both quantitative and qualitative data, ensuring a comprehensive understanding of the organizational landscape and paving the way for the strategic development of an AR roadmap. The framework encompasses various dimensions such as leadership, strategy, maintenance operations, general operations, culture, people, governance, and technology, enabling a thorough assessment to inform the development of an AR roadmap.

The followed methodology is given in section 2. The AR adoption analysis is described in section 3. Section 4 outlines the AR roadmap development approach, while section 5 details the methodology for assessing the current maturity state and readiness. Section 6 discusses the results and proposes the AR roadmap for rolling stock organizations. Section 7 concludes the paper and outlines future research.

2. Methodology

The paper addresses the identified research gap by following Becker's step-by-step process for developing a survey framework for organizational AR roadmap development [8]. Following Becker's methodology, a literature review, expert interviews, conceptual modelling, and validations as well as

testing of the new survey framework for AR roadmap in the field was performed (see Figure 1). The first steps of the study involved conducting a literature review of existing survey frameworks, current situation assessment, e.g. evaluating the existing state of AR implementation and usage within a rolling stock organization, and detailing criterion assessment requirements, e.g. specifying the criteria and factors essential for the successful development and implementation of an AR roadmap. Based on the aforementioned criterion, the survey is constructed consisting of both an online questionnaire and semi-structured interviews. Complementing the online questionnaire with semi-structured interviews offers a more holistic and nuanced understanding of developing an AR roadmap by providing a richer dataset incorporating both qualitative and quantitative insights.

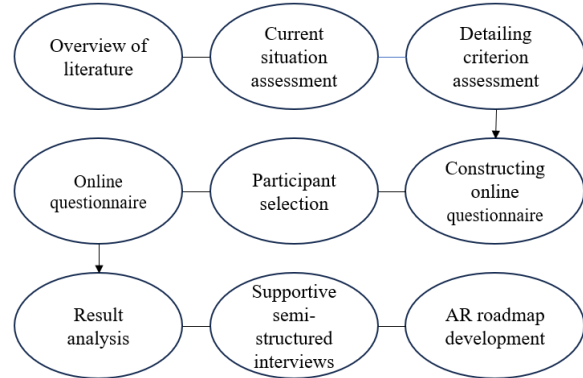


Fig. 1. Methodology overview.

The survey framework for AR roadmap development is tested and validated in the Dutch railway organization NS. In total, 11 employees specialized in innovations, management, and maintenance were interviewed. These participants, with an average of 10 years of experience in their respective fields, are selected for the study because of their maintenance, management, innovation, and XR background. In addition, they are selected because they are exclusively and actively involved in new AR projects for the rolling stock organization. Furthermore, the online questionnaire was also distributed among these 11 experts. The questionnaire took approximately 10 minutes, whereas the semi-structured interview takes about 60-90 minutes. The semi-structured interview is recorded and fully transcribed, data is processed in ATLAS.ti [9], coded and categorized in the different criterion assessment groups to complement the online questionnaire results.

3. AR adoption analysis

In the context of AR technology adoption, a maturity model helps organizations evaluate and improve the incorporation of AR in their operations,

while a readiness assessment gauges their preparedness for adopting specific technologies. Combining these tools offers insights into an organization's current state and its capability to embrace new technologies. The maturity model and readiness assessment can help support rolling stock organizations to evaluate their current state in terms of AR adoption, including assessing existing processes, technology infrastructure, operator skills, and overall organizational readiness for AR implementation. Current maturity models lack specificity and comprehensive coverage for the nuanced aspects of AR technology within organizational contexts [10]. A survey framework is considered suitable, as it allows for tailored, context-specific insights, addressing the limitations of existing models and providing a nuanced understanding of AR readiness and maturity [11].

In the broader context, the related work describes instances of road mapping associated with Industry 4.0 concepts. As Digital Twin (DT) becomes a major milestone in many sectors, related work focuses on creating a maturity and readiness model by creating a self-assessment tool to include technology infrastructure investments, senior management support, skilled/trained employees, and readiness of the sector [12]. The self-assessment tool is an expeditious survey for airline organizations to examine the DT trajectory of organizational adaptation, however, it still lacks the positioning of DT in organizations. Many models exist which can be used to implement AR solutions and applications of Building Information Modelling (BIM) in the construction industry [13]. The majority of the studies focus on BIM-AR integration and focus on the information models application level but still require adopting BIM-AR in organizational processes. The majority of AR-based maintenance roadmaps focus on defining tools required for creating an AR application, defining and handling virtual objects, and implementing marker recognition [10]. However, the relations between the AR technology configuration and the organizational implementation are seldom addressed.

4. Developing the AR roadmap

The development of the AR roadmap is based on a robust and comprehensive approach, incorporating a well-structured methodology ensuring a holistic process, as illustrated in Figure 2. The steps in the figure are gathered based on the recognition that a thorough assessment of the current state, envisioning future possibilities, and synthesizing these insights into actionable guidelines are crucial for successful AR integration in rolling stock maintenance. Additionally, defining application scenarios and identifying research challenges helps tailor solutions

to specific needs, prioritize implementation efforts, and address potential obstacles, ultimately driving innovation and improvement in maintenance practices. The current state evaluation involves a thorough explanation of existing rolling stock maintenance processes, technology infrastructure, operator skills, and organizational readiness. This assessment serves as the foundational step for building future state evaluations and determining the requirements essential for designing an AR roadmap.

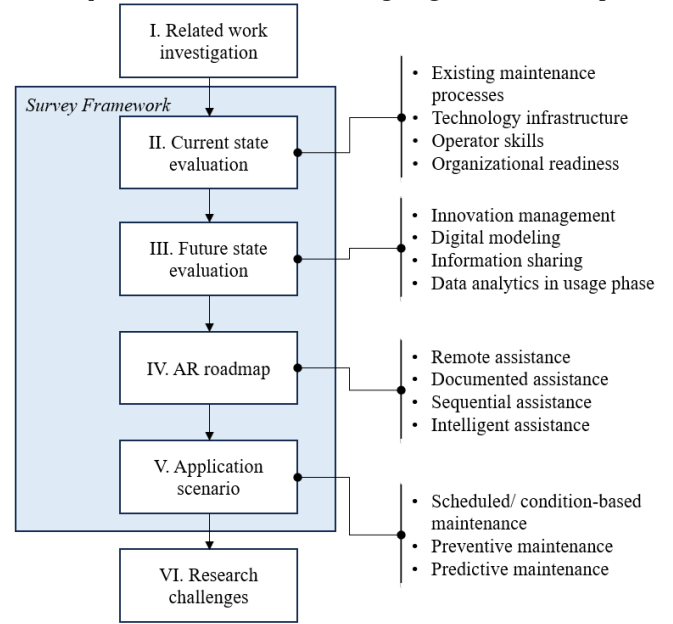


Fig. 2. Development of the AR roadmap.

In examining maintenance processes, the focus is on understanding the intricacies of current procedures and assessing the efficiency of fault diagnosis and troubleshooting. The evaluation of technology infrastructure aims to gauge the existing system's compatibility with AR integration and its ability to support real-time data processing. Operator skills are a critical aspect, with a focus on assessing the proficiency of maintenance technicians in utilizing AR tools and interpreting augmented information. Organizational readiness involves understanding the cultural and structural aspects that influence the successful implementation of AR in maintenance operations. The future state evaluation shifts towards innovation management, digital modelling, information sharing, and data analytics during the usage phase. This forward-looking assessment considers how AR can be leveraged to enhance innovation practices, create digital models for troubleshooting, facilitate information sharing among stakeholders, and harness data analytics for predictive maintenance.

To gradually and systematically implement AR in rolling stock maintenance operations, four distinct levels of applications are defined in this work: (1) remote assistance, e.g. technicians receive guidance

and instructions in real-time from experts or centralized support, (2) documented assistance, e.g. digital overlay of maintenance instructions and schematics onto the physical equipment, (3) sequential assistance, e.g. step-by-step interactive overlay of execution of tasks, and (4) intelligent assistance, e.g. integration of Artificial Intelligence (AI) and Machine Learning (ML) to analyse, predict failures and provide proactive maintenance recommendations.

The AR roadmap is versatile and can be applied across various maintenance strategies, including scheduled/ condition-based maintenance, preventive maintenance, and predictive maintenance. In each maintenance scenario, the AR roadmap adapts to the specific needs of the organization. By combining insights from the survey framework, the AR roadmap design can be tailored to address the specific challenges and opportunities present in the rolling stock industry.

5. Survey framework

The survey framework serves as a foundational step in the development of an AR roadmap, offering a systematic approach to evaluate the current state of AR maintenance technology adoption in rolling stock organizations. The survey framework consists of two main components: a detailed criterion assessment and a combination of online questionnaires and semi-structured interviews.

5.1. Detailing criterion assessment

This study comprises 8 maturity dimensions for developing an AR roadmap, focusing on strategy, leadership, culture, governance, people, general operations, maintenance operations, and technology. The maturity dimensions and criterion assessment are derived from existing Industry 4.0 models, as adopted from [14]. Figure 3 presents an overview of all maturity dimensions with their corresponding criterion assessments.

5.2. Constructing an online questionnaire

In designing the questionnaire, content validity is crucial to ensure that the scale items accurately represent the intended domains or concepts [15]. This involves gathering expert opinions to validate the alignment between the maturity dimensions and criterion assessment. The online questionnaire, comprising 31 questions, was developed and distributed to all 11 experts. The 5-point Likert scale is adopted to record the responses for each statement. Here, '1' represents completely disagree, whereas '5' represents completely agree. Table 1 presents examples of the online questionnaire statements. In

this example, the maturity dimensions of culture, technology, and general operations are combined.

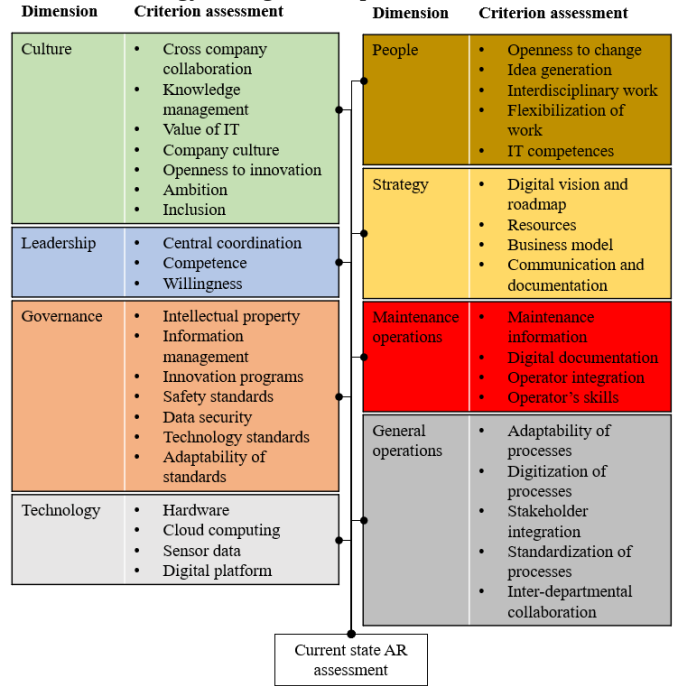


Fig. 3. AR criterion assessment overview, adopted from [14].

Table 1. Online questionnaire example statements.

Sample statements	Response on a 5-point Likert scale				
The organization supports knowledge-sharing, enables open innovation and cross-company collaboration	1	2	3	4	5
The organization actively assesses both the AR product development phase and implementation phase	1	2	3	4	5

The current AR criterion assessment of each maturity dimension results from calculating the weighted average of all criterion assessments within its related dimension. The weighting factor is assumed to be equally distributed as 1 to not influence the study with preset weighting factors.

5.3. Supportive semi-structured interviews

To improve rigour, a mixed-method approach was used to support the triangulation of data by cross-validating the findings. Sample semi-structured interview questions as presented in Table 2 were asked from the experts to support the understanding and evaluation of the current AR implementation strategy. The information retrieved from the interviews was used to produce a complete AR roadmap. Maintenance scenarios were applied to provide a set of structured views of future conditions against which decisions could be made for an AR roadmap. This helped to improve the robustness of activities proposed by the roadmap, so

they were adaptable and relevant to various future conditions.

Table 2. Semi-structured interview examples.

Sample question
To what extent does the organization's business model align with the use of AR for rolling stock maintenance?
- What is the current maintenance business model?
- What changes are required for AR implementation?

6. Results and discussion

The survey results indicate that the rolling stock organization holds an overall maturity score of 2.9 on a 1 to 5 scale. This score suggests opportunities for improvement, signalling that the organization might need to bolster its capabilities to fully leverage the advantages of AR in maintenance (Figure 4). Moreover, results indicate room for improvement in the maturity dimensions of governance (maturity score 2.6), general operations (maturity score 2.7), maintenance operations and leadership (maturity score 2.8), and culture (maturity score 2.9).

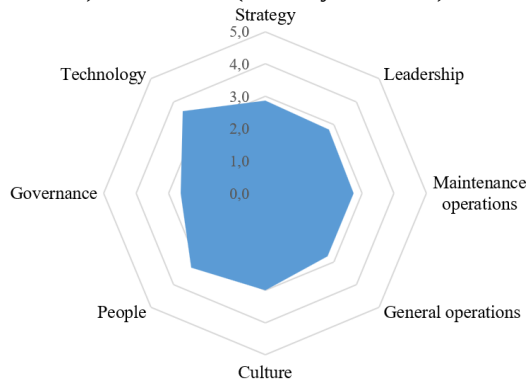


Fig. 4. Radar chart results of the online questionnaire.

The semi-structured interviews revealed that the low maturity score of governance is caused by a need for more structured governance practices, emphasizing the importance of standardization and regulation in AR implementation. The participants identify the organization as bureaucratic, with processes that are difficult to change and require high-level maintenance support. Operations follow departmental procedures, and inter-departmental collaboration is optimal. The participants state that current maintenance operations are supported with tablets and online documentation, however, historical maintenance data is not consistently up-to-date and accessible. Knowledge is dispersed leading to additional challenges in capturing relevant information and implementing accurate AR solutions. The organization has high innovation ambitions, although motivating employees can be challenging. Showing the AR technology potential

and sharing knowledge are identified as key support mechanisms. Difficulties are faced in the IT infrastructure for AR usage and integration.

6.1. Current AR technology adoption strategy NS

The Dutch railway organization NS aims to initiate a pilot Sequential Augmented Reality Assist (SARA) project, aiming to address rolling stock system failures through AR solutions. The successful launch of such a project necessitates the formulation of an AR technology adoption strategy. Insights from the semi-structured interviews reveal that NS requires a structured approach, coupled with an exploration of initial requirements. This is essential for achieving strategic objectives in utilizing AR for rolling stock maintenance.

Optimizing (internal) communication through dedicated AR teams and sharing knowledge emerges as a critical factor supporting the adoption of this technology. The solution outline entails identifying stakeholders, road mapping the future and defining a technology blueprint, including all implementation requirements. Ongoing iterative evaluations are required and essential to ascertain progress toward the defined goals. However, the adoption of AR technology depends on addressing organizational impediments such as restrictions and adherence to governmental rules and regulations.

6.2. AR roadmap for rolling stock organizations

The following are generalizable AR roadmap features, based on the survey framework, for rolling stock organizations looking to implement AR in their maintenance strategies are as follows:

- Comprehensive AR roadmap (strategy dimension): develop a comprehensive, accessible, and applicable AR roadmap that spans across the entire organization.
- Dedicated AR teams and inter-departmental collaboration (strategy, general operations, culture, and people dimensions): establish dedicated teams or platforms specifically focused on AR-related work to drive AR initiatives and innovations, fostering expertise in the domain.
- Centralized documentation (strategy, maintenance, and general operation dimensions): implement centralized online knowledge management platforms for maintenance and operational documentation to streamline information retrieval and sharing.
- Leadership knowledge enhancement (leadership, people, and culture dimension): enhance leadership's understanding of AR to facilitate effective communication and knowledge management by providing necessary resources and guidance.

- Data accessibility and real-time monitoring improvement (maintenance and general operation dimensions): improve the availability of real-time monitoring data and ensure historical maintenance data is up-to-date and accessible.
- Process flexibility (maintenance and general operation, technology, and culture dimensions): invest in overcoming IT challenges to ensure seamless integration of AR technologies by addressing bureaucratic processes and promoting work flexibility.
- Adaptation of AR standards (governance dimension): develop and adapt new AR-related standards in areas such as cybersecurity, safety, intellectual property, and privacy.
- Pilot program implementation (technology dimension): develop and implement pilot programs to test and refine AR technologies in real-world scenarios.

7. Conclusion

This study offers valuable insights for implementing AR and a practical survey framework for crafting an AR roadmap tailored to the rolling stock organization's challenges. The study presents a validated survey framework, incorporating online questionnaires and semi-structured interviews, to assess organizational readiness and maturity in rolling stock organizations. The framework evaluates capabilities across eight dimensions: strategy, leadership, culture, governance, people, general operations, maintenance operations, and technology. Utilizing the survey framework, we propose a generalizable AR roadmap that aims to facilitate effective AR implementation, enhance maintenance operations and advance Industry 4.0 concepts in the railway sector. In terms of limitations, the study sample size is relatively small. A larger and more diverse sample could enhance the study's generalisability and provide a broader understanding of AR adoption in rolling stock organisations. In addition, the assessment criterion and maturity dimensions do not cover all aspects of AR adoption. Consequently, future research should consider incorporating diverse case studies from various industries, employing a more extensive sample size, and expanding the spectrum of evaluated dimensions.

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