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Strategic Decisions in Production and Operations Management (Locomotive Retrofit Case Study)

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1. Introduction

1.1. Strategic Management in Production and Operations: Railway Industry Use Case (Locomotive Retrofit Projects)

Strategic management is pivotal within production and operations, especially in sectors like the railway industry where the complexity and scale of projects such as locomotive retrofits with European Train Control System (ETCS) [1] installations demand meticulous planning and execution. This form of management is crucial for aligning operational efficiency and safety with broader organizational goals through systematic planning, monitoring, analysis, and assessment.

Retrofit projects in the railway industry, aimed at upgrading locomotives to enhance their performance, efficiency, and compliance with new standards, are quintessential examples of strategic management at work. These projects not only demand a careful allocation of resources but also necessitate optimal logistics and resource management, particularly when components must be shipped internationally and installed on-site. The effective management of these elements ensures that the retrofitting processes are both streamlined and cost-efficient.

Moreover, strategic management within these projects supports competitive advantage. It enables organizations to meet and exceed updated safety and operational standards, such as those imposed by ETCS, and to do so in a manner that improves service reliability and speed. Additionally, the role of strategic management in mitigating risks associated with overhauling critical transport infrastructure cannot be understated. Comprehensive risk assessments are undertaken to prevent operational downtime and ensure safety during and post-retrofit, aligning with environmental standards and corporate social responsibility goals [14].

Adaptability and change management are also critical, as the railway industry frequently encounters new technological advancements. Strategic management supports the integration of the latest technologies and methodologies in retrofit projects, ensuring quick adaptation to new regulations and market demands.

Overall, the strategic management framework, including tools like Porter's Value Chain Analysis [1][12], aids in pinpointing operations that directly enhance efficiency and effectiveness. For instance, in retrofitting projects, this could involve the streamlined logistics for delivering ETCS components or optimized installation schedules that minimize locomotive downtime, crucial for maintaining robust railway operations.

Theoretical Underpinnings: Frameworks like Porter's Value Chain Analysis [2] are crucial for identifying value-adding activities in retrofit projects. This analysis helps pinpoint operations that directly enhance efficiency and effectiveness, such as streamlined logistics for the delivery of ETCS components or optimized schedules for installation that minimize downtime for locomotives.

Project Specifics: For example, in retrofitting projects, logistical coordination involves the international shipment of ETCS components from manufacturers, often in Germany, to operational sites, like Egypt. Strategic management here includes designing an optimal logistics strategy that considers cost, timeliness, and risk factors. Installation and quality assurance stages require precise management to ensure that the retrofit meets both operational standards and safety regulations.

The ETCS Project case study for this paper is retrofitting 100 locomotives of the Egyptian National Railways in order to get them ready for operations with the standard ETCS system and that includes lots of strategic planning, logistics, risk management and operational tasks that should be planned in order to have a reliable schedule and to not impact the daily activities of the railway operator at the same time.

European Train Control System (ETCS): ETCS is an essential component of the European Rail Traffic Management System (ERTMS) that standardizes railway signaling equipment and procedures to ensure interoperability across national borders within Europe. It improves railway safety and efficiency by automating train protection and allowing trains to run at higher speeds with closer intervals. ETCS levels range from Level 1, which provides basic features, to Level 3, which offers full automation of train operations[3].

Vehicle Retrofitting: In the railway industry, vehicle retrofitting refers to the process of upgrading existing locomotives or rolling stock with new technology or features. This often includes the installation of advanced systems like ETCS, modern safety equipment, or energy-efficient components. Retrofitting aims to extend the operational life of the fleet, enhance performance, and ensure compliance with current regulations.

European Railway Agency (ERA): The European Railway Agency (ERA) is responsible for facilitating the interoperability of rail systems within the European Union. It sets common safety rules and technical standards, such as those related to ETCS, to ensure that railway systems across different countries can operate seamlessly and safely together [4][5].

Thus, the process start with lots of documentation analysis to the locomotives, workshops and trackside as well, and in order to get the locomotives installed, commissioned, tested and integrated in the needed time.

Fig.1 shows the American locomotive Wabtec ES30 Aci under preparations in one the Egyptian National Railway tracks for the start of the site survey activities and installation preparations as initial steps before the installation starting, the surveys include vehicle investigation in its systems, body, underframe, and roof for the antenna installations.

Figure 1 Wabtec ES30 Aci under preparations for retrofitting at ENR

2. Locomotive Retrofit Projects: A Strategic Overview

2.1. Overview of Retrofit Projects in the Rail Industry

Retrofitting in the rail industry involves updating and modernizing existing locomotives and rail equipment to enhance performance, safety, and efficiency. The primary goal is to extend the operational lifespan of the fleet, incorporate new technologies, and comply with updated industry standards and regulations. These projects are critical for maintaining the competitiveness and sustainability of rail services.

2.2. Case Study Introduction: Siemens Mobility's Retrofit Projects

This section introduces a case study focused on Siemens Mobility's retrofit projects in Egypt [5], highlighting the strategic role these initiatives play within the company. Siemens Mobility has been a frontrunner in providing comprehensive retrofit solutions to global rail operators, aiming to upgrade their fleets with the latest in rail technology, including ETCS (European Train Control System) systems, which significantly improve the safety and efficiency of rail operations.

2.3. Strategic Decisions in Retrofit Projects

Retrofit projects require a series of strategic decisions that influence their success and alignment with broader business objectives. These decisions include:

- **Technology Selection**: Choosing the right technologies to incorporate, such as ETCS for enhanced train control and safety features.
- **Supplier and Partner Selection**: Determining which suppliers and partners can best meet the project's needs for components and systems, considering factors like reliability, cost, and technological compatibility.
- **Project Scope and Scale**: Deciding the extent of the retrofitting process, including which components of the locomotive are outdated and need replacement or upgrading.
- **Budget Allocation**: Allocating the budget effectively to cover all necessary expenses while ensuring the project remains financially viable.
- **Timeline and Scheduling**: Setting realistic timelines for project completion to minimize downtime and disruption in rail services.
- **Regulatory Compliance**: Ensuring all retrofit upgrades comply with national and international railway safety and performance standards.
- **Stakeholder Engagement**: Engaging with all stakeholders, including train operators, maintenance crews, and regulatory bodies, to ensure the project meets operational needs and compliance requirements.

These strategic decisions are crucial for the successful planning and implementation of retrofit projects in the rail industry. They require careful consideration of technical, economic, and regulatory factors to ensure that the retrofitted locomotives meet current demands and future expectations.

3. Operational Strategies in Retrofit Projects

3.1. Project Management Approaches

Effective project management is vital in locomotive retrofit projects to ensure that upgrades are delivered on time, within budget, and to the required quality standards. Key approaches include:

- **Agile Project Management**: This method is particularly beneficial for retrofit projects that involve complex systems like ETCS, where requirements can evolve based on emerging technologies and regulatory changes. Agile allows for flexibility and iterative testing of components before full-scale implementation.
- **Lean Project Management**: Focuses on maximizing value by eliminating waste throughout the retrofit process. This can involve streamlining supply chains, optimizing logistics, and reducing downtime during installation.
- **PRINCE2 (Projects in Controlled Environments)**: Offers a structured approach that can be tailored to the specific needs of retrofit projects, providing frameworks for managing risk, quality, and stakeholder engagement effectively.

3.2. Risk Management

Identifying and mitigating risks is crucial in retrofit projects to prevent cost overruns, delays, and failure to meet regulatory standards. Key aspects include:

- **Risk Assessment**: Conducting comprehensive risk assessments during the planning phase to identify potential issues with technology integration, supplier reliability, and project timelines.

- **Mitigation Strategies**: Developing specific actions to mitigate identified risks, such as establishing strong agreements with suppliers, incorporating buffer times into project schedules, and employing robust testing and validation processes for new systems.
- **Continuous Monitoring**: Regularly reviewing and adjusting risk management strategies throughout the project lifecycle to respond to new challenges and ensure the project remains on track.

3.3. Quality Control and Standards

Maintaining high quality standards is essential to ensure the safety and reliability of retrofitted locomotives. Important considerations include:

- **Quality Assurance (QA) Processes**: Implementing comprehensive QA processes to check the quality of both incoming materials and finished installations. This includes regular audits and inspections throughout the retrofitting process.
- **Compliance with Industry Standards**: Ensuring all retrofit activities comply with national and international standards, such as those set by the European Railway Agency for ETCS systems.
- **Certification and Testing**: Conducting thorough testing and certification processes to verify that retrofitted systems meet all operational requirements. This could involve simulated environment tests and field trials to ensure systems perform as expected in real-world scenarios.

4. Case Study Analysis: Locomotive Retrofit Projects

4.1. Description of Retrofit Activities

Retrofit activities in the rail industry typically involve the integration of advanced technologies into existing locomotive fleets to enhance performance, efficiency, and compliance with newer standards. For example, retrofitting older locomotives with ETCS (European Train Control System) not only improves safety by enabling automatic train protection but also increases interoperability across European rail networks. Specific tasks might include the installation of onboard ETCS components, upgrading signal systems, and software enhancements. Each retrofit project may vary in complexity depending on the age and condition of the locomotive, the systems being installed, and the operational requirements of the rail network.

1) **Integration of New Technologies**: Installing new hardware like control units or communication systems that interface with ETCS.
2) **System Upgrades**: Updating software to handle new functionalities and ensure compatibility with existing onboard systems.
3) **Testing and Validation**: Conducting extensive field tests to validate the functionality and reliability of retrofitted systems under operational conditions.

4.1.1. Integration of New Technologies

The integration of new technologies such as control units, communication systems, and ETCS (European Train Control System) components is a complex process that involves multiple operational challenges. The installation of new hardware requires careful planning and precision to ensure compatibility with the existing systems of the locomotive.

- **Hardware Installation**: This includes fitting advanced control units that interface directly with ETCS, requiring technical expertise to integrate seamlessly with older locomotive architectures. These control units manage communication between the train and trackside equipment, essential for the ETCS functionality.
- **Communication Systems**: Installing upgraded communication systems involves not just physical installation but also ensuring they meet the specific frequency and protocol requirements of the rail network. This ensures that the locomotive can communicate effectively with central control rooms and other trains.
- **Interoperability Concerns**: New technologies must be tested to ensure they work harmoniously with different systems across international borders, especially in Europe where trains often cross several countries. The same applies for compatibility with TSI standards [6][9].

There are many standards to be considered for such retrofit activities for rolling stock included in Table.1 below:

Table 1 Standards needed for rolling stock activities

Nr.	TSI References	Date
(EU) 1302/2014	Lokomotiven und Personenwagen (LOC&PAS)	18.11.2014
(EU) 2020/387	Änderung der TSI -LOC&PAS-	09.03.2020
(EU) 1302/2014	3. Berichtigung der Lokomotiven und Personenwagen (LOC&PAS)	19.04.2016
(EU) 1302/2014	2. Berichtigung der Lokomotiven und Personenwagen (LOC&PAS)	22.12.2015
(EU) 1302/2014	1. Berichtigung der Lokomotiven und Personenwagen (LOC&PAS)	16.01.2015
(EU) 2018/868	Änderung der Lokomotiven und Personenwagen (LOC&PAS)	13.06.2018
(EU) 1303/2014	Sicherheit in Eisenbahntunneln (SRT)	18.11.2014
(EU) 2016/912	Berichtigung der Sicherheit in Eisenbahntunneln (SRT)	09.06.2016
(EU) 2019/776	Änderung der Lokomotiven und Personenwagen (LOC&PAS) und Sicherheit in Eisenbahntunneln (SRT)	16.05.2019
(EU) 1300/2014	Zugänglichkeit für Menschen mit Behinderung und Menschen mit eingeschränkter Mobilität (PRM)	18.11.2014

(EU) 2019/772	Änderung der Zugänglichkeit für Menschen mit Behinderung und Menschen mit eingeschränkter Mobilität (PRM)	16.05.2019
(EU) 1304/2014	Fahrzeuge - Lärm (NOI)	26.11.2014
(EU) 2019/774	Änderung der Fahrzeuge - Lärm (NOI)	16.05.2019
(EU) 2023/1694	Änderung der Lokomotiven und Personenwagen (LOC&PAS) und der Fahrzeuge-Güterwagen (WAG) und der Fahrzeuge-Lärm (NOI)	10.08.2023

4.1.2. System Upgrades

Upgrading the software systems of locomotives involves enhancing existing functionalities and ensuring new systems are fully compatible with current operations. This process must consider both the technical and operational aspects of railway management.

- **Software Enhancements**: Updating the software to manage new functionalities such as real-time data logging and automatic train operation. This includes integrating software that can interpret and respond to ETCS signaling.
- **Compatibility Testing**: Ensuring the new software works with existing onboard systems, which may be decades old. This involves extensive coding and testing phases to avoid disruptions in train operations.
- **Regulatory Compliance**: All software upgrades must comply with international railway standards, such as TSI (Technical Specifications for Interoperability) and specific national regulations. Compliance ensures that retrofit projects meet safety and performance criteria set by regulatory bodies.

There are wide range of versions for each system and the decision making for system version selection could impact the overall strategy as well as overall operations.

4.1.3. Testing and Validation

Testing and validation are critical to ensuring the reliability and functionality of retrofitted systems. This phase must be meticulously planned to cover all conceivable operational scenarios the locomotive might encounter.

- **Field Testing**: Conducting on-track tests to validate the performance of retrofitted systems under various operational conditions. This includes speed tests, distance measurement accuracy, braking behavior, and response to ETCS commands.
- **Simulation Tests**: Before field tests, simulations are run to predict potential issues and assess the locomotive's responses in a controlled environment. This helps in fine-tuning systems before they are deployed in real-world conditions.
- **Certification**: Post-testing, the retrofitted locomotives must undergo certification processes to verify that they meet all relevant safety and performance standards. This often involves third-party verification by certified bodies to ensure unbiased assessment.

4.2. Strategic Impact of Retrofit Decisions

The strategic decisions made during the locomotive retrofit projects significantly shape the operational capabilities, safety, and service life of rail vehicles. In the context of retrofitting older locomotives with systems like the European Train Control System (ETCS), these decisions are not merely operational but strategic, influencing long-term asset management and operational readiness.

Cost-Effectiveness

Strategic retrofitting decisions often pivot on the analysis of the return on investment (ROI) compared to purchasing new equipment. Retrofitting with ETCS can substantially extend the useful life of existing locomotives, offering a cost-effective solution compared to the high capital expenditure of new units. The decision to retrofit or replace involves detailed cost-benefit analyses considering not only the immediate financial outlay but also long-term savings in maintenance, improved efficiency, and reduced downtime.

- **Long-term financial planning**: Integrating a detailed projection of the lifecycle costs of retrofit projects versus new acquisitions.
- **Operational cost reduction**: Retrofit projects can lead to operational cost reductions by enhancing fuel efficiency, reducing the need for frequent repairs, and leveraging modern technology to minimize breakdowns.

Regulatory Compliance

Ensuring compliance with current transportation standards and regulations is paramount. Strategic decisions in retrofit projects must align with international safety standards, environmental regulations, and interoperability requirements as mandated by bodies such as the European Union Agency for Railways. Compliance not only impacts the technical aspects of the retrofit but also the project's scheduling, budgeting, and execution strategies.

- **Adherence to safety standards**: Implementing ETCS components requires compliance with specific technical specifications for interoperability (TSI) standards.
- **Environmental regulations**: Meeting environmental standards by incorporating energy-efficient and low-emission technologies during the retrofit process.

Enhanced Performance

The strategic impact of retrofitting extends to the enhancement of locomotive performance. By upgrading to ETCS, locomotives benefit from increased reliability, safety, and efficiency. These improvements are critical for operators looking to enhance service offerings, increase train speeds safely, and reduce headways between trains on busy rail corridors.

- **Reliability and safety improvements**: Upgraded systems provide more reliable service with enhanced safety features, reducing the risk of accidents and operational failures.

- **Operational efficiency**: Advanced control and monitoring systems can optimize routes and speed, directly improving operational efficiency and punctuality.
- **Project Examples and Application**

To illustrate these strategic impacts, specific examples from ongoing or completed retrofit projects can be discussed. For instance, detailing a project where older models of locomotives were retrofitted with the latest ETCS level, explaining the decision-making process, challenges encountered, and the outcomes achieved:

- **Project Scope and Scale**: Discussing the extent of retrofitting, including specific subsystems upgraded, and the rationale behind these choices.
- **Technology Integration**: Highlighting the integration of new technologies and the complexities involved in ensuring system compatibility and interoperability.
- **Stakeholder Engagement**: Outlining how operators, maintenance teams, and regulatory bodies were involved in the decision-making process to ensure the project met all operational needs and compliance requirements.

4.3. Lessons Learned from Locomotive Retrofit Projects

4.3.1. Project Management Enhancements

Streamlined Project Execution: Learning from past projects, project management methodologies can be refined to streamline workflow, improve coordination between teams, and enhance communication channels. For example, implementing advanced project management software to provide real-time updates and track project milestones can significantly reduce delays and improve execution efficiency.

Resource Allocation: Based on historical data, better forecasting models can be developed to optimize resource allocation, ensuring that manpower and materials are available when needed, thereby reducing downtime and costs.

4.3.2. Risk Management Evolution

Proactive Risk Assessment: Leveraging data from previous retrofit projects to develop a robust risk assessment framework that identifies potential pitfalls early in the project lifecycle. This could include more rigorous testing of retrofit components and early engagement with regulatory bodies to ensure compliance with all applicable standards.

Adaptive Risk Mitigation Strategies: Creating flexible risk management plans that can quickly adapt to unforeseen challenges, such as supply chain disruptions or unexpected technical issues. This adaptability ensures that projects remain on track despite external pressures.

4.3.3. Incorporating Comprehensive Feedback Mechanisms

- **Operator and Maintenance Feedback**: Systematically incorporating feedback from operators and maintenance staff to enhance the usability and functionality of retrofitted equipment. This could involve regular post-retrofit reviews and the establishment of feedback loops that inform continuous improvement in retrofit designs.

- **Customer Satisfaction Surveys**: Conducting detailed surveys and feedback sessions with end-users to understand the real-world effectiveness of retrofit upgrades, focusing on areas such as performance improvements, ease of use, and maintenance requirements.

4.3.4. Development of Best Practices

- **Standardization of Procedures**: From the accumulated experiences, develop standardized retrofit procedures that ensure consistency and quality across all projects. This could include standardized training programs for technicians and operators that focus on the specifics of newly installed systems and technologies.
- **Innovation in Retrofit Technologies**: Encouraging a culture of innovation within the project team to explore new technologies and methodologies that could further enhance retrofit outcomes. For instance, exploring the use of AI and machine learning to predict equipment failures before they occur, thereby reducing maintenance costs and extending the equipment's operational life.

4.3.5. Strategic Decision Making

Cost-Benefit Analysis: Regularly conducting cost-benefit analyses to determine the financial viability of retrofit projects. This includes assessing the long-term savings associated with extended asset life versus the upfront costs of retrofitting.

Regulatory Compliance and Sustainability: Ensuring all retrofit projects not only comply with current regulations but also contribute to sustainability goals. This may involve incorporating environmentally friendly materials and practices into the retrofit process.

5. Operational and Strategic Review for Short-Term and Long-Term Goals

This section delves into the strategic management processes utilized in locomotive retrofit projects, focusing on both the short-term operational targets and long-term strategic objectives. The emphasis is on how these targets align with broader business goals, ensuring that the operational activities support sustained strategic growth and adaptation in the railway industry.

Short-Term Operational Targets

Short-term targets primarily focus on the immediate milestones that need to be achieved during the retrofitting process. These include:

1. **Project Initialization and Planning:**

    - **Objective:** Establish a clear project scope, timelines, and resource allocation.
    - **Action:** Conduct initial assessments, finalize project charters, and secure necessary approvals and funding.

2. **Component Sourcing and Logistics:**

    - **Objective:** Ensure timely procurement and transportation of retrofit components such as ETCS systems.
    - **Action:** Strengthen partnerships with suppliers, optimize supply chain operations, and implement robust logistics management practices to handle international shipments effectively.

3. **Installation and Testing:**

    - **Objective:** Achieve successful installation of retrofit components and conduct comprehensive testing.
    - **Action:** Schedule and execute installation phases with minimal disruption to ongoing operations, followed by rigorous testing to ensure system compatibility and performance.

4. **Quality Control and Compliance:**

    - **Objective:** Maintain high standards of quality and ensure compliance with international railway safety and operational standards.
    - **Action:** Implement continuous monitoring and auditing of retrofit processes, adherence to TSI standards, and regular engagement with regulatory bodies.

Long-Term Strategic Targets

Long-term strategic targets focus on the overarching goals that the retrofit projects aim to achieve over a more extended period. These include:

1. **Enhanced Operational Efficiency and Safety:**

    - **Objective:** Improve the operational efficiency and safety standards of the retrofitted locomotives.
    - **Action:** Leverage advanced technologies such as ETCS to enhance the reliability, speed, and safety of railway operations.

2. **Sustainability and Innovation:**

    - **Objective:** Promote sustainable practices and continuous innovation within retrofit projects.
    - **Action:** Focus on eco-friendly retrofit solutions, recycling old components, and exploring new technologies that could further improve the environmental footprint.

3. **Market Competitiveness and Expansion:**

    - **Objective:** Strengthen market position and explore new opportunities for expansion.
    - **Action:** Utilize the improved capabilities of retrofitted locomotives to expand service offerings and enter new markets, thus enhancing overall competitiveness.

4. **Stakeholder Engagement and Corporate Governance:**

    - **Objective:** Enhance stakeholder engagement and corporate governance structures.
    - **Action:** Foster transparent communication and collaborative decision-making processes with all stakeholders, including employees, customers, and regulators.

6. Summary

This paper examines strategic management within the context of locomotive retrofit projects in the railway industry, with a focus on operational and strategic insights gained from these complex undertakings. Central to the analysis is the deployment of the European Train Control System (ETCS) in retrofit operations aimed at upgrading the performance, safety, and efficiency of older locomotives. This strategic initiative not only extends the operational life of railway fleets but also aligns with updated safety and efficiency standards crucial for maintaining competitiveness and sustainability in the sector.

The paper begins by detailing the fundamentals of strategic management in production and operations, emphasizing the importance of strategic planning, risk management, sustainability, and adaptability. Specific project examples, notably Siemens Mobility's retrofit projects, illustrate the practical application of these principles. The discussion elaborates on the logistics involved in these projects, such as the international shipment of ETCS components and the meticulous planning required for on-site installations.

Further sections delve into the operational strategies deployed in these retrofit projects, including project management approaches and the critical role of risk management and quality control in ensuring the success of retrofit initiatives. The paper also provides an analysis of the strategic impacts of retrofit decisions, discussing the cost-effectiveness, regulatory compliance, and performance enhancements achieved through strategic retrofitting.

The final sections synthesize lessons learned from past projects, highlighting improvements in project management, risk mitigation, and the integration of feedback mechanisms. These lessons foster the development of best practices that not only reduce costs and minimize operational disruptions but also enhance the overall effectiveness of retrofit projects.

By integrating theoretical frameworks with practical examples and real-world applications, this paper presents a comprehensive view of strategic management's role in enhancing the operational and strategic capabilities of the railway industry through retrofit projects.

References

[1] Porter, M.E. (1985) *Competitive Advantage: Creating and Sustaining Superior Performance*. New York: Free Press.

[2] European Railway Agency (2023) *Technical Specifications for Interoperability*. Online: https://www.era.europa.eu/domains/technical-specifications-interoperability_en, date of use: 30.01.2025

[3] Siemens Mobility (2024) *Siemens Mobility Retrofit Projects*.

[4] European Union Agency for Railways (2024) *European Train Control System (ETCS) Specifications*. Online: https://www.era.europa.eu/domains/infrastructure/european-rail-traffic-management-system-ertms_en , date of use: 30.01.2025

[5] AfDB (2023) *Egypt - National Railways Modernization Project (ENRMP) - Environmental and Social Impact Assessment Report*.

[6] Eisenbahn-Cert (2023) *Technical Specifications for Interoperability (TSI) LOC&PAS*.

[7] Ghosh, S., Saeed, K. and Thompson, G. (2020) *Strategic Planning for Operational Efficiency in Railways*. *International Journal of Rail Transport*, 8(3), pp.213–229. DOI: 10.1080/23249935.2020.1788901.

[8] Raghuvanshi, A. and Rao, P.S. (2019) *Emerging Technologies in Railway Safety: The Role of ETCS in Risk Mitigation*. *Journal of Transportation Safety and Security*, 11(4), pp.400–414. DOI: 10.1080/19439962.2018.1542920.

[9] UIC (2024) *Railway Retrofitting Practices: Best Practices for ETCS Deployment*.

[10] Coyle, J.J., Langley, C.J., Novack, R.A. and Gibson, B.J. (2016) *Supply Chain Management: A Logistics Perspective*. 10th edn. Boston: Cengage Learning.

[11] Kerzner, H. (2013). Project Management: A Systems Approach to Planning, Scheduling, and Controlling. John Wiley & Sons.

[12] European Union Agency for Railways. (2020). ETCS – European Train Control System: A Guide for Business. Online: https://www.era.europa.eu/domains/technical-specifications-interoperability_en, date of use: 30.01.2025

[13] Pachl, J. (2018). Railway Operation and Control. VTD Rail Publishing.

[14] Nash, A., Schümperlin, O., & Weidmann, U. (Eds.). (2016). Railway Management and Engineering: Fourth Edition. Ashgate.