

IT/OT lifecycle alignment for reliable railway assets

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Digitized railway assets increasingly integrate information technology (IT) with operational technology (OT), enabling applications such as remote monitoring and predictive maintenance. However, IT systems typically have shorter life cycles than physical assets and are often managed separately, leading to lifecycle misalignment, higher costs, and reduced availability. This study examines how the Dutch railway operator NS can align IT and OT lifecycles to enhance operational performance. Using Design Science Research Methodology and co-design workshops with industry professionals, we supported and evaluated three initiatives that complement the ISO 55000 asset management framework: the IT/OT Aspect Plan, Baseline Planning, and the Integrated Design Team. These initiatives aim to improve planning transparency and foster collaboration across IT, OT, and asset management domains. Validation through stakeholder feedback confirmed their perceived value while identifying areas for improvement, such as creating a more dynamic visualization and adding risk indicators. This study highlights the need to strengthen collaboration and cross-domain relationships between IT and asset management teams, as doing so is essential for bridging organizational silos and achieving integrated lifecycle planning. Future research will focus on developing an interactive planning tool and testing the framework in other asset-intensive sectors.

Keywords: IT/OT convergence, Asset Management, Lifecycle alignment, ISO 55000, design science research, cross-domain collaboration, Railway

1 Introduction

1.1 General Context and Problem

The convergence of information technology (IT) and operational technology (OT) with physical assets is transforming asset management practices across asset-intensive industries, including transportation, energy, and manufacturing. This integration enables real-time monitoring, predictive maintenance, and enhanced control over physical assets, offering significant opportunities to improve operational efficiency and asset performance (Haider 2015; Ehie and Chilton 2020).

While IT/OT convergence promises efficiency and innovation, it also introduces challenges that extend beyond technology. Moving from isolated systems to integrated cyber-physical environments creates both technical and organizational complexities, requiring companies to rethink processes, governance, and workforce capabilities to adapt to these new environments (Villar-Fidalgo et al. 2018). This complexity is further amplified as original equipment manufacturers (OEMs) transition from product suppliers to asset managers, embedding service-oriented business models into their offerings (European Commission 2011). These shifts challenge traditional lifecycle management approaches and demand new strategies for aligning IT and OT domains.

One of the most pressing issues is the misalignment between the life cycles of IT, OT, and the physical asset itself, see Fig. 1. While physical assets often have lifespans measured in decades, IT and OT components evolve on much shorter cycles, requiring frequent updates and replacements (Barry 2023; Kok et al. 2023). Life-cycle mismatches are especially problematic when long-life physical assets contain shorter-

lifespan IT and OT components (Bradley and Guerrero 2008). These misalignments are often aggravated by organizational silos, in which IT departments typically manage digital systems and asset management teams oversee physical assets (Amadi-Echendu et al. 2010; Barry 2023).

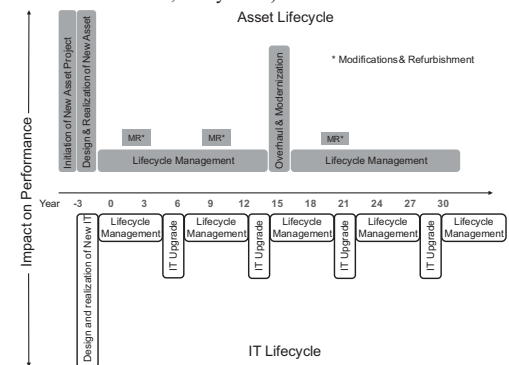


Fig. 1: Typical differences between the life-cycles of IT and the physical asset that IT is part of, adapted from Van Dongen (2015)

IT/OT lifecycle misalignment, amplified by organizational silos, drives fragmented decision-making, inflates lifecycle costs, and introduces planning inefficiencies that collectively erode asset performance. These effects become visible in day-to-day operations, where disjointed asset management practices often lead to fragmented decision-making, creating operational bottlenecks and hindering effective planning

(Maletič et al. 2020). Misalignment also distorts financial transparency: fragmented lifecycle cost accounting inflates total ownership costs and steers organizations towards suboptimal long-term choices (Haanstra and Braaksma 2018). Compounding these challenges, integration gaps between project management and asset management, mirroring the separation often seen between IT and OT, undermine reliability and sustainability over time (Lazo et al. 2024). Collectively, these dynamics illustrate how lifecycle misalignment and organizational silos degrade performance and increase costs, reinforcing the need for integrated IT/OT lifecycle management strategies.

Existing frameworks, such as ISO 55000 and ITIL, provide valuable guidance within their respective domains but fall short of addressing the hybrid nature and lifecycle differences inherent to IT/OT convergence. As they tend to treat IT and physical asset management separately (Howard 2012; NEN 2014; Helstrom et al. 2024). By comparison, alignment-oriented frameworks, such as those proposed by Erguido et al. (2022), primarily focus on product-service systems and do not resolve lifecycle misalignments arising from IT/OT convergence. Furthermore, reviews reveal an overemphasis on maintenance phases at the expense of planning, acquisition, and disposal activities (Alquraidi and Awad 2024). Collectively, these gaps underscore the need for holistic, lifecycle-spanning frameworks to guide integrated IT/OT-converged asset management decisions.

1.2 Case Study Context: Dutch Railway Sector

The railway sector is undergoing rapid digitalization, introducing advanced IT solutions into traditionally OT-driven environments (European Commission 2011; Poliński and Ochociński 2020; Gago 2021). This digital transformation brings initiatives such as driver-controlled operation (Office of Rail and Road 2025) and the implementation of remote software updates (Siemens Mobility 2025), which rely on seamless integration of IT and OT systems. However, misalignment across their lifecycles can lead to operational disruptions, as recent incidents on trains have shown (treinreiziger.nl 2021; NOS Nieuws 2023).

A key challenge arises from the differing lifecycle durations of these components: while rolling stock typically remains in service for 30–40 years, onboard IT systems require updates every few years, or, in the case of software, even monthly. Additionally, developing a new type of rolling stock can take around five years, meaning IT components are often outdated by the time the train enters service (Lellouche 2025).

Unlike physical components such as bearings or pumps, which degrade over time through wear and cause visible defects, software does not degrade physically. Instead, software failures arise from mechanisms such as bugs or configuration errors, which often manifest less visibly than hardware faults (van Vliet 2008). Despite this difference, software failures can have a significant impact on system performance and safety (Taylor 2020a, 2020b).

At the Dutch railway operator NS, ongoing digitalization creates a need for closer collaboration between departments that have traditionally operated separately. The asset management team is responsible for rolling stock, while the digitalization department manages onboard IT systems. Bridging this organizational separation by enhancing cooperation between these departments can lead to more reliable performance and smoother operations.

1.3 Research Aim and Contribution

Building upon our earlier work that examined the social impacts of IT/OT convergence through serious gaming and the technical impacts during design with the RIAMS matrix (Kok et al. 2024, 2025), this paper presents an intervention that combines these social and technical perspectives.

Research Question: *How can IT and OT life-cycle alignment opportunities be identified within their combined life cycles to improve overall performance and minimize total life-cycle costs?*

2 Methodology

This study adopts the Design Science Research Methodology (DSRM) in combination with co-design principles to address the challenge of IT/OT lifecycle misalignment in digitized railway assets. DSRM provides a structured process for developing and evaluating artefacts that solve real-world problems (Peffers et al. 2007), while co-design ensures active stakeholder involvement in the design process (Sanders and Stappers 2008). Fig. 2 illustrates the research methodology framework and its alignment with the steps described below.

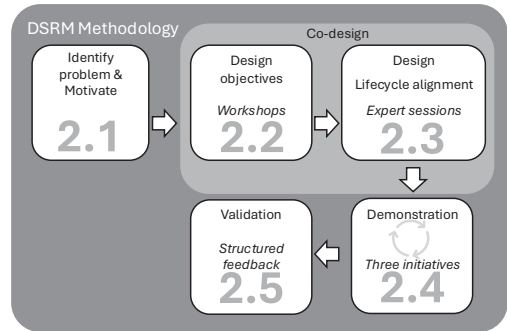


Fig. 2: Research methodology framework, adapted from Peffers et al. (2007) and Sanders and Stappers (2008)

2.1 Identify the problem and motivate

IT/OT convergence in asset-intensive industries creates opportunities for improved performance but also introduces lifecycle misalignment between rapidly evolving digital components and long-lived physical assets. This misalignment, intensified by organizational silos, results in fragmented decisions and higher lifecycle costs. Addressing this problem is essential because existing standards and frameworks do not provide integrated guidance for managing these hybrid lifecycles.

2.2 Design objectives

To define objectives for lifecycle alignment, two co-design workshops were organized with professionals from industry, primarily IT/OT project managers and IT architects.

- Workshop 1: Introduced the problem using a plenary presentation and a serious game (Kok et al. 2024), followed by brainstorming using Post-it notes. Results were digitized and clustered by the principal researcher.
- Workshop 2: Discussed these clusters in a plenary session to refine objectives.

Workshop design

The workshop was organized to facilitate discussions and gather qualitative data. Facilitation was guided by the first author of this study, using a combination of methods to encourage participant engagement. For an overview of the workshop details, see Table 1. The participants were a mix of IT/OT project managers and IT architects. Data collected during the workshop were recorded through note-taking and subsequently transcribed and analyzed in a spreadsheet.

Workshop	Participants	Duration	Methods
1	8	3 hours	Serious game, brainstorming, Post-it clustering
2	5	2 hours	Plenary discussion

Table 1: Overview of workshop participants, duration, and methods used

2.3 Design

Building on workshop insights, we subsequently held expert meetings to translate high-level objectives into actionable initiatives (Ruitenburt et al. 2014). These initiatives were then mapped against NS's ISO 55000-based asset management framework to ensure alignment with existing processes.

The resulting IT/OT lifecycle alignment is an integrated framework composed of several existing but previously disconnected initiatives. These initiatives, which expand the scope of NS's ISO 55000 asset management system, were combined and coordinated through this research to enhance lifecycle alignment across IT and OT domains. This integration forms the core of the proposed lifecycle alignment, enabling better collaboration and alignment within the operational context of NS.

2.4 Demonstration

The proposed IT/OT lifecycle alignment, as developed in the design phase by integrating multiple initiatives, was demonstrated within NS through three selected initiatives: the IT/OT Aspect Plan, Baseline Planning, and the Integrated Design Team (IDT).

Iterative refinement occurred through ongoing collaboration and regular meetings with stakeholders to address practical challenges and optimize implementation. The primary focus was on embedding the initiatives within NS's operational context and ensuring alignment with design objectives and the ISO 55000 asset management framework.

2.5 Validation

Validation focused on assessing the usability and perceived value of the baseline planning visualization, as well as the overall lifecycle alignment. Semi-structured feedback sessions were conducted with five key stakeholders from both IT and OT domains, including engineering, software, asset strategy,

and project management. The feedback focused on three different aspects:

- Clarity and effectiveness of the visualization
- Ability to identify alignment opportunities through these tools
- The support provided for informed decision-making

Data from these sessions were collected and analyzed to draw conclusions about the practical value of lifecycle alignment and areas for improvement.

3 Results

3.1 Problem analysis outcome

During the two workshops, professionals highlighted the key challenges and considerations for aligning asset life cycles. Based on their insights, we formulated the following design objectives to guide decision-making and responsibility allocation.

3.2 Design objectives

- Design objective 1 (DO1): What does the combined life cycle look like regarding asset life-cycle planning?
- Design objective 2 (DO2): How can we decide when life-cycle alignment between IT and OT is desired?
- Design objective 3 (DO3): Who is responsible for which part of these combined life cycles?

3.3 Design

The expert meetings have identified three key initiatives within the company to gain insight into developments in the IT domain. These three initiatives are:

- The IT/OT aspect plan
- A baseline planning
- The creation of an integral design team

To understand how the initiatives integrate within NS's ISO 55000 asset management system, we map them against existing documentation. Focusing on the physical asset and its planning, Fig. 3 illustrates how the proposed documents (highlighted in orange) complement the current ISO 55000-based documentation at NS.

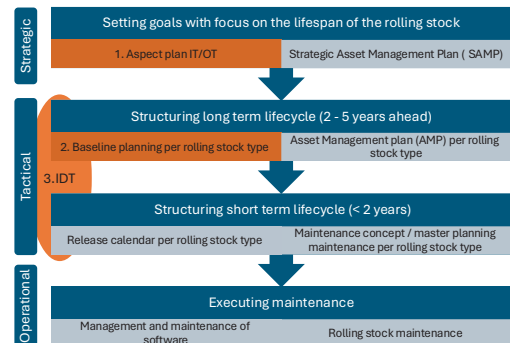


Fig. 3: Overview of the current and newly proposed documents relating to asset management within the Dutch railways. The initiatives in orange are proposed to help plan IT changes more effectively.

The first initiative, the IT/OT aspect plan, is a new effort updated annually to provide asset management teams with a roadmap for IT and OT developments over the next 2 to 10 years. IT/OT professionals have drafted this plan.

The second initiative is baseline planning. This plan covers not only upcoming IT changes but also system changes, such as the phase-out of GSM-R, for each rolling stock type. By bundling IT and OT plans, this approach helps identify opportunities for life-cycle alignment. The next step is to further implement these alignment opportunities across the various asset management plans.

The third initiative is the Integrated Design Team (IDT), which decides whether, when, and how IT is integrated into the trains. This team operates separately from both the asset management and IT feature teams, although the asset manager oversees the IDT and the asset management teams. To promote mutual understanding, there is intentional overlap among the three teams. Fig. 4 illustrates this overlap, highlighting opportunities for improved coordination. Currently, the asset manager is the only member participating in both the IDT and the asset management team. The lead engineer is part of the IDT to ensure proper integration of IT systems into the trains. In addition, the IT/OT aspect manager and the software desk engineer maintain regular contact to keep both teams aligned.

IT Domain	Asset domain		
	IT Feature Team	Integral IT/OT Design Team	Asset Management Team
Asset Manager	-	Standard	Standard
IT/OT Aspect Manager	Optional	Standard	Optional
Lead Engineer	-	Standard	Optional
Software desk engineer	Optional	Optional	Standard
Reliability Engineer	-	Optional	Standard
Other AM roles	-	-	Standard
Product Owner	Standard	Optional	-
Other IT roles	Standard	-	-

Fig. 4: Overview of the IT, integral IT/OT design team, and physical asset management teams. Standard: Permanent team member, Optional: Optional team member -: Not part of this team;

3.4 Demonstration

The proposed IT/OT lifecycle alignment was demonstrated within NS through three initiatives: (1) IT/OT Aspect Plan, (2) Baseline Planning, and (3) Integrated Design Team (IDT).

3.4.1 Implementation of Initiatives

- (i) IT/OT Aspect Plan: Provided a long-term roadmap for IT and OT developments, improving visibility of upcoming changes. The outcomes of this initiative are being integrated into the annual asset management plan for each rolling stock type, ensuring IT/OT developments are explicitly considered in lifecycle planning.
- (ii) Baseline Planning: Introduced an integrated schedule combining IT, OT, and physical asset lifecycle events, enabling identification of alignment opportunities.
- (iii) Integrated Design Team (IDT): Established a cross-functional team to coordinate IT/OT and physical changes, fostering joint decision-making.

Two initiatives, the IT/OT Aspect Plan and the IDT, have been finalized for use within the company, while the Baseline Planning remains under development.

To visualize the impact of alignment, Fig. 5 compares baseline planning before and after applying lifecycle alignment, showing IT, OT, and combined changes for an anonymized train series. This visualization served as the basis for

stakeholder discussions on interdependencies and alignment opportunities.

3.4.2 Key Insights from Implementation

The implementation of the identified initiatives revealed several factors that influence IT/OT lifecycle alignment. The IT/OT Aspect Plan provided a clear basis for managing converged assets and, when integrated into the annual asset management plan, improved traceability of upcoming changes. Multi-annual release planning emerged as another success factor; by integrating IT, OT, and physical asset planning data over a five-year horizon, alignment opportunities can be identified early. Aligning IT hardware upgrades with physical asset revisions was found to be logical. However, these timeframes do not always align with IT product lifecycles, given revision cycles of up to 2 years. Preparatory measures, such as pre-installing cabling and other components during revisions, were identified as practical mitigations to improve flexibility and reduce downtime. Finally, cross-team collaboration emerged as a cornerstone for successful alignment. Existing arrangements, such as the asset manager’s dual role in both the IDT and asset management teams, and regular coordination between the IT/OT aspect manager and software desk engineer, provide a strong foundation for integration, while expanding these roles offers further potential. These insights will guide future refinements of the initiatives and provide strategic direction for embedding lifecycle alignment within the organization.

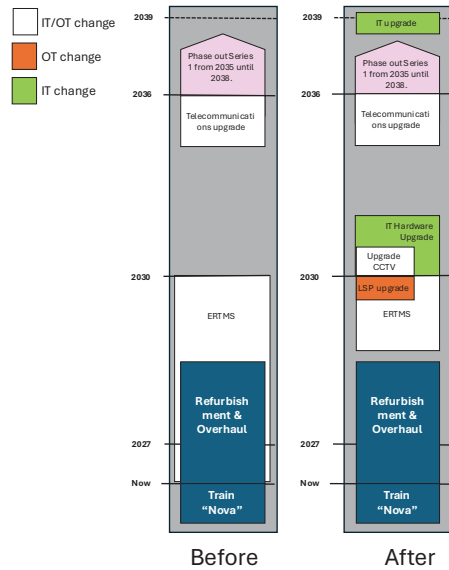


Fig. 5: Baseline planning with IT, OT, and IT/OT changes before and after lifecycle alignment was applied, adapted from Schouten (2025).

3.5 Validation

To evaluate how well the proposed lifecycle alignment meets the design objectives (DO1–DO3), the five key stakeholders reviewed the baseline planning with IT, OT, and IT/OT

changes before and after lifecycle alignment (Fig. 5). The review results are summarized below:

DO1: The integrated visualization provided a combined view of the IT/OT asset life cycle, enabling stakeholders to identify cross-domain dependencies and reduce siloed decision-making.

DO2: Stakeholders confirmed that baseline planning aided early detection of conflicts and clustering opportunities, helping inform decisions on when alignment is beneficial, thereby demonstrating the lifecycle alignment's practical value in promoting proactive coordination.

DO3: Only partially achieved, as responsibility for each change is not visually represented, even though IT, OT, and physical changes are visible. This limitation indicates that while technical alignment is supported, organizational clarity requires further refinement.

Table 2 summarizes the limitations identified during the review and proposed improvements, several of which aim to strengthen alignment with DO1 and DO2. A revised prototype incorporating these improvements is under development to better support iterative planning and decision-making.

Design objective	Identified Limitation	Proposed Improvement
DO1	Visualization is static and does not reflect iterative planning.	Develop an interactive version to support iterative updates.
DO1	Missing start and end dates for projects.	Include timelines with start and end dates.
DO2	Lack of indicators for cost, complexity, and risk.	Use block size to represent risk or cost.
DO2	Project status is not visually represented.	Apply color coding and a legend to indicate project status.
DO3	Responsibility for each change is not visually represented.	No suggestions were made for improving this objective.

Table 2: Identified limitations and proposed improvements

4 Discussion

This study demonstrates that identified initiatives, such as the IT/OT Aspect Plan, Baseline Planning, and Integrated Design Teams, can provide a foundation for aligning IT and OT lifecycles within railway asset management. While these initiatives improved visibility and enabled early identification of conflicts, several organizational and technical challenges remain.

4.1 Interpretation of Findings

The IT/OT Aspect Plan offers a structured roadmap for managing converged assets; however, its development is primarily led by IT/OT aspect managers. While asset management teams provide input, they do not perceive themselves as co-owners of these aspects. This limited sense of ownership may constrain cross-domain alignment. Increasing shared responsibility by involving asset management teams more actively in drafting and decision-making could strengthen collaboration and ensure that lifecycle considerations across IT, OT, and physical assets are fully integrated.

The observed benefits of baseline planning confirm its potential as a success factor for IT/OT integration. Aligning planning horizons of 5 years or more and synchronizing IT upgrades with physical asset revisions can reduce risks and the need for last-minute changes. However, misalignment between IT product lifecycles and long physical revision periods introduces complexity. Preparatory measures, such as installing cabling and other components during overhauls, can increase flexibility and minimize downtime.

Despite these technical advances, organizational integration remains a critical area for improvement. Current arrangements provide a foundation for collaboration, yet expanding formal overlap among IT, OT, and asset management teams offers significant potential to strengthen integration. This observation aligns with prior research on cultural barriers in railway organizations (Jakubeit 2023), underscoring the need for proactive strategies to foster collaboration. By fostering better relationships between teams, organizations can reduce risks associated with fragmentation and unlock additional benefits from IT/OT lifecycle alignment.

To address these gaps, adjustments to team composition and governance structures are recommended. The IT/OT aspect manager could act as a liaison across all three domains, while embedding lead engineers within asset management teams may enhance technical oversight and trust. For Integrated Design Teams, a rotating attendance system for IT product owners could broaden engagement without inflating meeting sizes. These measures aim to balance inclusivity with efficiency, fostering collaboration essential for managing converged assets.

The discussion on IDT composition raises broader questions about optimal team overlap and decision-making authority. Should design authority be centralized to coordinate IT/OT integration, or remain asset-specific to preserve domain expertise? Hybrid approaches, such as alternating team focus between IT and physical priorities, may offer a pragmatic balance, but require further empirical testing. Addressing these areas will not only strengthen empirical evidence but also guide organizations toward more integrated and resilient lifecycle management practices.

4.2 Limitations and Future Research

While this study involved a small sample size (four to five participants) and primarily qualitative validation measures, it provides an important exploratory foundation for IT/OT lifecycle alignment research. Future research can build on these findings by incorporating quantitative metrics to provide a more rigorous assessment of alignment outcomes. Additionally, exploring innovative organizational models for IT/OT convergence, particularly those that balance cross-team membership and governance structures, offers significant potential to enhance collaboration without compromising efficiency. Addressing these areas will not only strengthen empirical evidence but also guide organizations toward more integrated and resilient lifecycle management practices.

4.3 Theoretical & Practical Implications

Theoretically, this study underscores the importance of embedding IT/OT integration within ISO 55000 frameworks and highlights gaps in research on organizational structures for managing digitized assets. In practice, the three initiatives provide structured approaches to improve the planning and coordination of IT/OT changes within asset management systems, enabling better lifecycle alignment and risk reduction.

5 Conclusion

This study addressed the challenge of aligning the life cycles of digitized railway assets, where IT, OT, and physical components are increasingly interconnected but often misaligned. Using Design Science Research Methodology and co-design sessions with industry professionals, we supported the implementation and refinement of three initiatives, the IT/OT Aspect Plan, Baseline Planning, and Integrated Design Team, that extend the ISO 55000 asset management framework to better integrate IT/OT lifecycles.

Our contribution focused on facilitating discussions, providing feedback, and monitoring progress to assess how these initiatives improve lifecycle alignment and collaboration. Validation through stakeholder feedback confirmed their perceived value: the IT/OT Aspect Plan enhanced visibility of planned changes, Baseline Planning enabled clustering of lifecycle events, and the Integrated Design Team fostered joint decision-making. Specifically, the baseline planning with IT, OT, and IT/OT changes provided a combined view of the IT/OT asset lifecycle, enabling stakeholders to identify cross-domain dependencies and reduce siloed decision-making. Stakeholders also confirmed that this visualization aided early detection of conflicts and clustering opportunities, helping inform decisions on when alignment is beneficial. These mechanisms collectively strengthen cooperation among IT, OT, and asset management teams, which is essential for effectively managing converged assets.

Theoretically, this study emphasizes the importance of strengthening collaboration and cross-domain relationships between IT and asset management teams to overcome organizational silos and to enable integrated lifecycle planning. Practically, it structures mechanisms for managing IT/OT-converged assets and reducing lifecycle misalignment. Future research will focus on developing an interactive planning tool and testing the framework in other asset-intensive industries to generalize its applicability.

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References

- Alquraidi, Alya, and Mahmoud Awad. 2024. "Physical Asset Management for Critical Utilities— A Systematic Literature Review." *IEEE Access* 12: 90644–59. <https://doi.org/10.1109/ACCESS.2024.3421335>.
- Amadi-Echendu, Joe E., Kerry Brown, Roger Willett, and Joseph Mathew, eds. 2010. *Definitions, Concepts and Scope of Engineering Asset Management*. Vol. 1. Engineering Asset Management Review. Springer London. <https://doi.org/10.1007/978-1-84996-178-3>.
- Barry, Don M. 2023. *Asset Management Excellence: Optimizing Equipment Life-Cycle Decisions*. 3rd ed. CRC Press. <https://doi.org/10.1201/9781032679600>.
- Bradley, James R., and Héctor H. Guerrero. 2008. "Product Design for Life-Cycle Mismatch." *Production and Operations Management* 17 (5): 497–512. <https://doi.org/10.3401/poms.1080.0056>.
- Ehie, Ike C., and Michael A. Chilton. 2020. "Understanding the Influence of IT/OT Convergence on the Adoption of Internet of Things (IoT) in Manufacturing Organizations: An Empirical Investigation." *Computers in Industry* 115 (February): 103166. <https://doi.org/10.1016/j.compind.2019.103166>.
- Erguido, Asier, Adolfo Crespo Márquez, Eduardo Castellano, Ajith Kumar Parlikad, and Juan Izquierdo. 2022. "Asset Management Framework and Tools for Facing Challenges in the Adoption of Product-Service Systems." *IEEE Transactions on Engineering Management* 69 (6): 2693–706. <https://doi.org/10.1109/TEM.2019.2951438>.
- European Commission. 2011. *Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System*. No. 52011DC0144. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144>.
- Gago, Stanislaw. 2021. "ICT for Rail Transport in Poland." *Problemy Kolejnictwa - Railway Reports* 65 (190): 75–84. <https://doi.org/10.36137/1901e>.
- Haanstra, W., and A. J. J. Braaksma. 2018. "Life Cycle Costing in Physical Asset Management: A Multiple Case Study." February 23, 12. <https://research.utwente.nl/en/publications/life-cycle-costing-in-physical-asset-management-a-multiple-case-s/>.
- Haider, Abrar. 2015. "Asset Lifecycle Data Governance Framework." In *Proceedings of the 7th World Congress on Engineering Asset Management (WCEAM 2012)*, edited by Woo Bang Lee, Byeongkuen Choi, Lin Ma, and Joseph Mathew. Lecture Notes in Mechanical Engineering. Springer International Publishing. https://doi.org/10.1007/978-3-319-06966-1_27.
- Helstrom, Brian, Ron Green, and Brian Helstrom. 2024. "Information Technology Asset Management." In *Asset Management Excellence*, 3rd ed. CRC Press.
- Howard, Dave. 2012. *IT Release Management: A Hands-on Guide*. 1st edition. CRC Press.
- Jakubeit, Nina. 2023. *Coordinated Inter-Organizational Decision-Making: Dealing with Project Complexity in the Dutch Railway Context*. University of Twente.
- Kok, Arno, Alberto Martinetti, and Jan Braaksma. 2023. "RAMS Never Dies! Applying the Approach to IT/OT Converged Systems." *Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)*, September 3, 3181–87. https://doi.org/10.3850/978-981-18-8071-1_P286-cd.
- Kok, Arno, Alberto Martinetti, Ferry Verrijzer, and Jan Braaksma. 2025. "RAMS Is Not Enough! The Design of a Software Integration Risk Analysis Matrix (SIRAM) for Assessing the Impact of Software Integration on Physical System Performance." *Proceedings of the 35th European Safety and Reliability Conference (ESREL2025) and the 33rd Society for Risk Analysis Europe Conference (SRA-E 2025)*, June 15, 1224–31. https://doi.org/10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P1355-cd.
- Kok, Arno, Jan-jaap Moerman, Willem Haanstra, Alberto Martinetti, and Jan Braaksma. 2024. "A Serious Maintenance Management Game for Decision-Making on Digitized Railway Assets." *Procedia CIRP* 122 (June): 1–6. <https://doi.org/10.1016/j.procir.2024.01.001>.
- Lazo, Andrea Gonzales, Mustafa Selçuk Çidik, and Simon Addyman. 2024. "Perspectives on Project Management and Asset Management Integration: A Systematic Review." In *Proceedings of the 40th Annual ARCOM Conference*, edited by C. Thomson and C. J. Neilson, vols. 423–432. Association of Researchers in Construction Management. <https://discovery.ucl.ac.uk/id/eprint/10201438/1/f8eb5bde7225798ffbe7212cde80f334.pdf>.
- Lellouche, Nicolas. 2025. "Le nouveau métro à Paris (MF19) fait un choix bizarre pour ses ports USB." *Numerama*, February 17. <https://www.numerama.com/vroom/1906255-le-nouveau-metro-a-paris-mf19-fait-un-choix-bizarre-pour-ses-ports-usb.html>.
- Maletič, Damjan, Matjaž Maletič, Basim Al-Najjar, and Boštjan Gomišček. 2020. "An Analysis of Physical Asset Management Core Practices and Their Influence on Operational Performance." *Sustainability* 12 (21): 21. <https://doi.org/10.3390/su12219097>.
- NEN. 2014. *NEN-EN 55000 - Asset Management - Overview, Principles and Terminology*. NEN-EN 55000. Delft, February. <https://connect.nen.nl/Standard/Detail/193078?compId=16755&collectionId=0>.
- NOS Nieuws. 2023. "Nog steeds veel vertraging bij nieuwe intercity's ondanks verbeteringen." October 6.

- <https://nos.nl/artikel/2493064-nog-steeds-veel-vertraging-bij-nieuwe-intercity-s-ondanks-verbeteringen>.
- Office of Rail and Road. 2025. "Driver Controlled Operation (DCO) | Office of Rail and Road." <https://www.orr.gov.uk/guidance-compliance/rail/health-safety/strategy/driver-controlled-operation-dco>.
- Peffer, Ken, Tuure Tuunanen, Marcus A. Rothenberger, and Samir Chatterjee. 2007. "A Design Science Research Methodology for Information Systems Research." *Journal of Management Information Systems* 24 (3): 45–77. <https://doi.org/10.2753/MIS0742-1222240302>.
- Poliński, Janusz, and Krzysztof Ochociński. 2020. "Digitization in Rail Transport." *Problemy Kolejnictwa - Railway Reports* 64 (188): 137–48. <https://doi.org/10.36137/1885E>.
- Ruitenburt, R. J. (Richard), A. J. J. Braaksma, and L. A. M. van Dongen. 2014. "A Multidisciplinary, Expert-Based Approach for the Identification of Lifetime Impacts in Asset Life Cycle Management." *Procedia CIRP* 22: 204–12. <https://doi.org/10.1016/j.procir.2014.07.007>.
- Sanders, Elizabeth B. N., and Pieter Jan Stappers. 2008. "Co-Creation and the New Landscapes of Design." *CoDesign* 4 (1): 5–18. <https://doi.org/10.1080/15710880701875068>.
- Schouten, Oscar. 2025. "NS - IT/OT-Planning Nova Series - 2e Iteratie, Bevindingen En Adviezen." Internal document.
- Siemens Mobility. 2025. "Remote Software Updates." Mobility-portfolio-detail. Siemens. <https://www.mobility.siemens.com/global/en/portfolio/digital-solutions-software/digital-train-solutions/remote-software-update.html>.
- Taylor, Emma, host. 2020a. *When Software Goes Wrong - The Need for Culture Change - The Rail Safety and Standards Board Podcast*. Episode 10. The Rail Safety and Standards Board Podcast. December 15. 22:01. <https://www.buzzsprout.com/925129/episodes/6856771-when-software-goes-wrong-part-2>.
- Taylor, Emma, host. 2020b. *When Software Goes Wrong—Digital Asset Integrity on the Railway - The Rail Safety and Standards Board Podcast*. Episode 6. The Rail Safety and Standards Board Podcast. October 28. 20:46. <https://www.buzzsprout.com/925129/episodes/6106243>.
- treinreiziger.nl. 2021. "ICNG kampt met softwareproblemen: nieuwe treinen later in reizigersdienst." *Treinreiziger.nl*, June 30. <https://www.treinreiziger.nl/icng-kampt-met-softwareproblemen-nieuwe-treinen-later-in-reizigersdienst/>.
- Van Dongen, Leo. 2015. "Asset Management: A Maintenance Engineer's View." *International Journal of Performability Engineering* 11 (2): 181–97.
- Villar-Fidalgo, L., A. Crespo Márquez, V. González Prida, A. De la Fuente, P. Martínez-Galán, and A. Guillén. 2018. "Cyber Physical Systems Implementation for Asset Management Improvement: A Framework for the Transition." In *Safety and Reliability - Safe Societies in a Changing World*, 1st ed., edited by Stein Haugen, Anne Barros, Coen van Gulijk, Trond Kongsvik, and Jan Erik Vinnem. CRC Press. <https://doi.org/10.1201/9781351174664>.
- Vliet, Hans van. 2008. *Software Engineering: Principles and Practice*. 3rd ed. John Wiley & Sons.