

Disentangling large scale technological projects: Learning from ERTMS roll-out case study in the Netherlands

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ABSTRACT

To avoid project delays and cost overruns, it is crucial that organisations' knowledge base on project management is expanded and that experiences in large-scale projects are more widely shared through effective management of lessons learned. However, the management of lessons learned from large scale projects remains a scientific and practical challenge. In addition to their multi-stakeholder setting, the natural loss of experienced knowledge through retirement and the presence of lessons in both tacit and explicit form make their management quite complex. This paper investigates the shortcomings in the current lessons learned management process and contributes to the literature by presenting a formal process for extracting and managing lessons learned from large scale projects. It does this by conducting a case study on the deployment of the European Traffic Management System (ERTMS) in the Netherlands. A nuanced five-step methodological approach is presented, whereby twenty-four structured interviews are conducted with key stakeholders from the Dutch railway sector. The interview data is analysed using the content analysis method and the results are then validated by three independent assessors. To ensure rigour and quality of gathered results, the interrater reliability is determined by calculating Gwet's AC1 coefficients. The paper provides an overview of the key lessons learned from the deployment of ERTMS in the Netherlands and sets out fourteen principles for effective systems management of ERTMS. Finally, the paper also offers six recommendations for policymakers related to their role, such as appointing an independent system integrator, and five recommendations for railways organisations on organisational learning and system integration. The results can be used both to facilitate communication for better decision-making and to develop strategies for effective management of lessons learned.

1. Introduction

While numerous technology introduction and upgrade projects are transforming railway operations, these projects are complex and prone to delays and cost overruns (Bakhshi, Ireland, & Gorod, 2016; Nguyen, Nguyen, Le-Hoai, & Dang, 2015). Additionally, a workforce with experience of such projects is being lost because of retirement. These combined problems pose a grave danger, as the lessons learned in handling complex, technological large-scale transport projects will be lost. Consequently, the future implementation of such projects will lead to the repetition of familiar mistakes, with their accompanying delays and cost overruns. However, learning from such projects is further complicated since it involves both tacit and explicit knowledge and therefore requires nuanced approaches for their management (Biresselioglu, Demirbag Kaplan, & Yilmaz, 2018; Haddad, Sanders, & Tewkesbury,

2020; Kasvi, Vartiainen, & Hailikari, 2003). Finally, complex technological projects typically involve multiple stakeholders; therefore, knowledge management, especially for tacit knowledge, is a complicated, multifaceted task (Guzman, 2009; Koskinen, Pihlanto, & Vanharanta, 2003; Nonaka & von Krogh, 2009; Reich, Gemino, & Sauer, 2014; van der Hoorn & Whitty, 2019).

An understanding of the current state of lessons-learned management is paramount in order to properly manage the lessons learned from large-scale projects and ensure organisational learning. The prior research on lessons learned indicates their limited future application despite identification and categorisation (McClory, Read, and Labib, 2017). According to the organisational learning theory of Argyris and Schön (1996), the general scheme of organisational learning comprises of: a learning product, a learning process, and a learner. Determining which of these is responsible for the limited future application of lessons

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learned is essential for improving the knowledge management of lessons learned in particular and largescale projects in general, which is instrumental for project performance and policy-making (Flyvbjerg, 2014; Reich et al., 2014).

This paper contributes to the debate on how to manage the lessons learned from large-scale projects by presenting a formal process for their extraction and management in the railway sector. It draws on the experience gained from a large-scale infrastructure development project in the Dutch railway sector, namely, the European Rail Traffic Management System (ERTMS). The ERTMS is a new railway traffic management system that builds on the basics of the signalling system. The European Commission plans to equip 30–40% of core network corridors with the ERTMS by 2023 (European Commission, 2017). In the Netherlands, the ERTMS was first deployed in the early 2000s on the Betuweroute (from Rotterdam to Germany). Additionally, a pilot project was carried out in 2012–2015 on the Amsterdam-Utrecht route prior to the current national deployment programme. Recent years have seen a long chain of knowledge development, sharing and application for the implementation of ERTMS and investigating the approach to managing the lessons learned for such implementations can benefit future similar efforts.

This paper conducts a case study on one of the busiest railway corridors in the Netherlands. It first identifies the key stakeholders involved in the ERTMS rollout in the Netherlands and then conducts a series of carefully structured interviews with the key individuals involved. To understand the underlying context and outline the main research challenge of this study, archival documents were reviewed on the ERTMS implementation as was the literature on project management, system engineering, transportation research, knowledge management, and organisational learning. Emphasis was placed on the underlying context for and cultural constraints that influence learning. Finally, the paper presents a formal process for extracting and managing the lessons learned from both large-scale projects and from their application. The findings of this paper can help to develop appropriate strategies for managing the lessons learned from ERTMS and for the timely and efficient deployment of similar large-scale projects.

The rest of the paper is structured such that Section 2 overviews the current state of the lessons-learned management, its importance for the ERTMS and the research challenge addressed in this study. Section 3 offers comprehensive and detailed insights into the research methodology. Section 4 summarises the background information on the ERTMS case study chosen and establishes its focus. The findings are described in Section 5 and discussed in more detail in Section 6. This discussion is followed in Section 7 by explicit recommendations for both policy-makers and railway organisations, as well as the identification of future research areas. Finally, Section 8 presents the research conclusions.

2. State of the art

In this section, the authors first outline the state of lessons-learned management. Then, the theoretical basis for managing lessons learned for large-scale projects such as the ERTMS is presented. Finally, the research challenge addressed in this study is offered. This structure positions this research within the ongoing debate on the management of lessons learned from large-scale projects within the railway sector.

2.1. State of the lessons-learned management

Lessons learned are an emerging research topic in the project management, knowledge management, and organisational-learning research communities. Secchi, Ciaschi, and Spence (1999) defined lessons learned as “knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Successes are also considered sources of lessons learned. A lesson must be significant in that it has a real or

assumed impact on operations; valid in that is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result”. Effectively managing lessons learned requires the involvement of the appropriate stakeholders, the provision of management support and the sharing of knowledge in both codified and uncoded ways (Jugdev, 2012). As previously noted, the organisational learning theory of Argyris and Schön (1996) consists of a learning product, a learning process, and a learner. In the context of lessons learned, the learning product would be any new lessons acquired through experience or the existing lessons absorbed from others in the organisation. Similarly, the learning process would include the acquisition, processing, storing, sharing and utilisation of the lessons learned, and the learners would be the organisation members who are directly or indirectly affected by the lesson learned.

Prior research on lessons learned has shown that despite their identification and categorisation, their future application frequently appears limited (McClory, Read, & Labib, 2017). Moreover, Williams (2008) noted that the transfer of lessons learned from the project team to the organisation is one of the least successful aspects of learning. Likewise, Liebowitz (2008) highlighted that the lessons-learned process is a critical item that is too often overlooked when developing and implementing knowledge-management strategies. This finding implies that, based on Argyris and Schön (1996), lessons-learned research faces challenges in the learning process, which is herein referred to as the lessons-learned management process.

The lessons-learned management process aims to capture “the result and experiences from successes, failures, and near-misses, and absorb them into the organizational structure for future use” (McClory et al., 2017, p. 1322). A number of barriers to implementing lessons learned have been identified in recent decades, such as a lack of clear guidelines, incentives, and purpose and an awareness of added value (Carrillo, Ruikar, & Fuller, 2013; Hartmann & Dorée, 2015; Love, Teo, Davidson, Cumming, & Morrison, 2016). In a cross-case analysis for improving lessons-learned processes, Wiewiora and Murphy (2015) stated that by introducing an easily accessible, intelligible, and user-friendly storage space for lessons learned, they can be catalogued according to themes. In doing so, a clear action plan can be developed thereby improving their future use. However, having a single, easily accessible database for lessons learned and a unified action plan are major challenges in large-scale transportation projects that are often spread across multiple organisations with diverse interests. Moreover, the proper cataloguing of lessons learned requires not only well-documented explicit lessons but also the conversion of consolidated tacit knowledge, where possible, into explicit forms through externalisation (Nonaka, 1994). However, views are controversial on the management of tacit knowledge through digital means alone in terms of feasibility and effectiveness (Al-Qdah & Salim, 2013). This situation implies that due consideration should be given not only to the technological but also to the cultural, procedural, and social aspects of the proper management of lessons learned (Duffield & Whitty, 2015). Therefore, an adequate approach to the lessons-learned management process should address both the explicit and tacit dimensions of consolidated lessons (i.e., the learning product). Abbas, Martinetti, Rajabalinejad, Frunt, and van Dongen (2020) in their LEAF framework emphasised the fostering of four key features—(L) *learnability*,¹ (E) *embraceability*,² (A) *applicability*,³ and (F) *findability*⁴—for

¹ Learnability here is defined as the ease with which one learns from a particular lesson or shared knowledge.

² Embraceability here is defined as the degree of acceptance and the use of lessons learned at the individual and organisational levels.

³ Applicability here is defined as the ease with which a shared lesson is applied in a particular context.

⁴ Findability here is defined as the ease of finding desired knowledge in the available knowledge sharing platforms.

managing both the explicit and tacit dimensions of lessons learned (for more on the LEAF framework, please see Abbas et al. (2020)).

Since both the explicit and tacit dimensions for proper lessons-learned management are important, in this paper we use the LEAF framework to investigate the degree to which the lessons learned from a large-scale technological project in the railway industry were implemented. In addition, the paper aims to capture key knowledge for the better management of lessons learned and catalogues the captured knowledge into both the key themes, as suggested by Wiewiora and Murphy (2015), and into principles to improve the current lessons-learned processes.

2.2. Importance of the lessons-learned management for the ERTMS

Large-scale projects, as noted by Hetemi et al. (2021, p.295), “typically involve multi-organizations and deliver a substantial physical infrastructure or a complex product with a lifecycle that can extend for decades and across industries”. Examples of such projects include high-speed rail lines, airports, seaports, etc. (Flyvbjerg, 2014). The ERTMS is a prime example of a large-scale project in the railway sector. With multiple parties involved and large financial investments from the European Union, national governments, and private bodies, it is an ongoing large-scale infrastructure development and upgrade project in Europe.

The introduction of the ERTMS, in addition to interoperability, promises benefits in terms of safety, capacity, and efficiency (Smith, Majumdar, & Ochieng, 2012). However, it has faced several technological, operational, and procedural issues across Europe (Smith et al., 2012; van Dongen, Frunt, & Rajabalinejad, 2019). Sweden experienced project delays (Alexandersson & Rigas, 2013; Zasiadko, 2020), and long before the recent outbreak of the COVID-19 pandemic, Bekkers (2008) showed that the timely full-scale deployment of the ERTMS was difficult to justify and subject to economic and safety scrutiny. Required new specifications have led to a “wait-and-see” climate around the ERTMS, and proactive management and a wider sharing of experiences are needed (Laroche & Guihéry, 2013).

These two factors in large-scale projects such as the ERTMS require attention to several aspects. First, the effective management of project complexity is needed to reduce the risk of unscheduled delays and overspending (Bjorvatn & Wald, 2018). In this regard, Chapman's (2016) six elements of complexity for rail transportation projects—finance, context, management, site, task, and delivery—are highly relevant for effectively managing ERTMS complexity. Second, the wider sharing of experience requires the establishment of a formal lessons-learned system. Such a system increases the retention of project management competence (Ekrot, Kock, & Gemünden, 2016) and facilitates knowledge transformation among the project team members, which can help to avoid both delays and cost overruns, as highlighted by Bjorvatn and Wald (2018). However, Aerts, Doods, and Haezendonck (2017) stated that much of the project management knowledge in large-scale infrastructure development projects remains tacit, and little attention is given to explicitly expanding its base.

A key remaining challenge is the development of a comprehensive approach to manage the lessons learned from the ERTMS. In principle, this approach should be relatively straightforward, given the safety-centric nature of the entire railway system and the common goal of improving its interoperability across Europe through the ERTMS. However, Pellegrini and Rodriguez (2013) highlighted the substantial separation remaining between conventional rail transportation systems in Europe. This separation of transport services from infrastructure management based on European Union Council Directive 91/440 was intended to facilitate the future development and efficient operation of railway systems (Council of the European Communities, 1991). Instead, it has led to divergent and often conflicting goals among railway organisations. For instance, Montero and Finger (2020) pointed to the lack of incentives for infrastructure managers to increase freight transport, as

track access charges are lower for freight transport than they are for passenger services. This situation implies that railway organisations, due to business interests, are reluctant to openly share critical knowledge and lack incentives to share experiences at the sector level. However, human behaviour is vital for the safe and efficient operation of railways (European Commission, 2018), and human and organisational factors must be integrated for a sound railway safety management system (European union agency for railways, 2018). Therefore, adequately managing lessons learned from large-scale projects such as the ERTMS is indispensable.

2.3. Research challenge

Little attention has been paid to explicitly expanding the existing organisational project management knowledge base for large-scale infrastructure development projects (Aerts, Doods, & Haezendonck, 2017). Moreover, experiences need to be more widely shared for the ERTMS (Laroche & Guihéry, 2013) to help avoid project delays and cost overruns (Bjorvatn & Wald, 2018). Therefore, this paper explores the means of better managing the lessons learned from the ERTMS than at present by conducting a case study. In doing so, the authors use the LEAF framework of Abbas et al. (2020) to capture key knowledge on implementing and improving the ERTMS lessons-learned management.

3. Methodology

The study followed a stepwise methodological approach to address the research challenge. Fig. 1 shows the five main defined steps—design of the study and the criteria for case selection, data collection, data analysis and results validation—to examine the research challenge comprehensively. Specific tasks and outputs were described for each step to clarify its contribution in addressing the research challenge. The authors drew on the literature to properly perform each task to ensure the overall quality and reliability of the research. A detailed account of each of the five methodological steps is provided next.

3.1. Design of the study

Proper lessons-learned management requires attention to both the explicit and tacit dimensions of consolidated lessons. The organisational project management knowledge base must be explicitly expanded (Aerts et al., 2017), and experiences need to be more broadly shared for large-scale projects such as the ERTMS (Laroche & Guihéry, 2013). Therefore, the study required the formulation of specific research questions that could dissect various aspects of the lessons learned and provide in-depth knowledge about the implementation and improvement of their management in the context of the ERTMS. To formulate the research questions, the authors used the LEAF approach because of its development and prior use in the railway sector (Abbas et al., 2020). The LEAF approach emphasises the proactive fostering of the four features—learnability, embraceability, applicability, and findability—to improve the lessons-learned management.

In this study, the authors used these four features to formulate seven research questions for ERTMS-specific cases. Given the interviewees' possible lack of familiarity with the terms, the first research question focussed on documenting the interviewees' understanding of these four features and their relevance for the lessons-learned management of the ERTMS. Second, because the aim is to capture key knowledge about implementing the lessons learned, three research questions inspired by LEAF features were formulated to study the learnings from the lessons-learned implementation of an ERTMS-specific case. These questions focussed on asking the interviewees to identify the lessons learned from that case, determine their degree of implementation, and outline the barriers to and enablers for knowledge-sharing. Finally, three research questions inspired by LEAF features were formulated to gain knowledge about the improvements needed in the lessons-learned management.

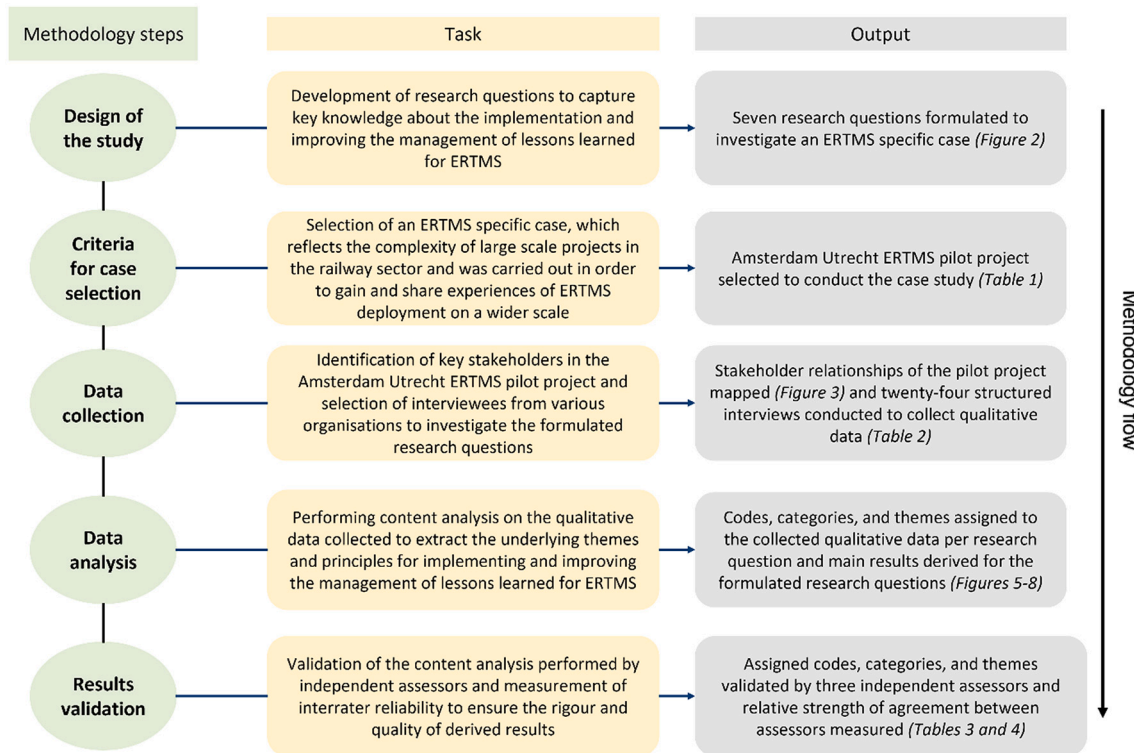


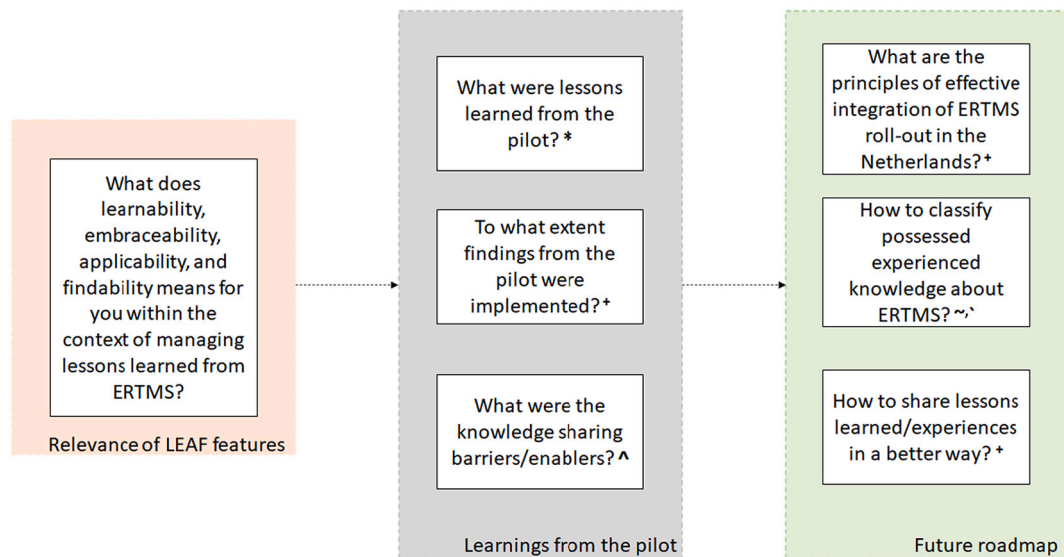
Fig. 1. Methodological overview.

These research questions focussed on identifying the principles for effective ERTMS deployment, deriving ways to classify experiential knowledge and determining better knowledge-sharing practices for managing the lessons learned from the ERTMS. An overview of the seven research questions with the described research focus points is shown in Fig. 2.

3.2. Criteria for case selection

The proactive management of large-scale projects such as the ERTMS

requires that project complexity be effectively managed to reduce the risk of unscheduled delays and overspending (Bjorvatn & Wald, 2018). To ensure that an appropriate ERTMS case is selected for investigating the formulated research questions, a comprehensive criterion is needed that can capture the complexity of rail transport projects. For the ERTMS case selection, the authors opted for the six dimensions of complexity proposed by Chapman (2016) because they specifically emphasise the examination of project complexity for railway megaprojects. These dimensions revealed by Chapman (2016) are finance, context, management, site, task, and delivery. A detailed account of the characteristics of



Connection with: Learnability *, Embraceability ^, Applicability ~, Findability ` , All LEAF features*

Fig. 2. Research questions.

these complexity dimensions present in the candidate ERTMS case is given in Table 1. The candidate ERTMS case is the Amsterdam Utrecht pilot project, which was established at the end of 2011 by the Ministry of Infrastructure and Water Management, ProRail (the principal infrastructure manager in the Netherlands) and the Dutch Railways (the principal railway undertaking in the Netherlands). The project's purpose was to gain operational experience with the ERTMS and to contribute to the broader ERTMS deployment strategy.

As shown in Table 1, the Amsterdam Utrecht pilot project (hereafter, pilot project) possessed characteristics for each complexity dimension highlighted by Chapman (2016). Thus, its complexity made it a suitable candidate for investigating the formulated research questions. Hence, it was chosen for the case study. A further description of the pilot project can be found in Section 4.

3.3. Data collection

Comprehensive data collection for the formulated research questions requires a clear understanding of the key stakeholders involved in the pilot project. To identify them, a simplified stakeholder relationship map was designed for the pilot project, as shown in Fig. 3.

As indicated in Fig. 3, different stakeholder categories were (directly or indirectly) involved in the pilot project, such as policy-makers, railway undertakings, suppliers, engineering consultancies and infrastructure managers. Experts from different organisations from these stakeholder categories were involved in the pilot project by its management team under the umbrella of the ERTMS Programme Board. To adequately select interviewees for the case study, the author selected at least one interviewee from all relevant stakeholder categories that were directly or indirectly involved in the pilot project. Moreover, since the members of each organisation had been carefully selected by the pilot project's management team, the authors considered them to be experts and suitable candidates for conducting the case study. Consequently, twenty-four experts from different organisations and stakeholder categories were interviewed to investigate the formulated research questions, as shown in Table 2. Individuals from the stakeholder categories of passengers/taxpayers and legislators were not interviewed due to the specific sectoral focus of the research questions and the difficulty of accessing the relevant experts.

3.4. Data analysis

A comprehensive data analysis is required to extract underlying themes and principles. In this study, the authors used a content analysis because it allowed for an easy analysis of the qualitative interview text (Erlingsson & Brysiewicz, 2017) and because of its prior use in transportation research (Jiang & Wu, 2019). A content analysis is defined as a “[s]ystematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding” (Stemler, 2001, p.1). Hermann (2008) emphasised that the choices and assumptions made in a content analysis should be guided by the research questions. These choices include the choice of materials used (reports, open-ended interviews, etc.), the nature of the content analysis (qualitative vs. quantitative), the determination of the unit of analysis (words, sentences, whole documents, etc.), coding rules and procedures, the way to contextualise information, and the way to determine the reliability and validity of the analysis (Hermann, 2008).

In this study, the interviews provided structured qualitative response data to the formulated research questions. Thus, a qualitative content analysis with response data per research question as the unit of analysis was an appropriate choice for this study. In addition, the corresponding author used the coding terms (code, category, and theme) specified by Erlingsson and Brysiewicz (2017) to code and contextualise the collected responses. Doing so allowed for easy coding replication due to the standardised process of moving from a lower (codes) to a higher (categories and themes) level of abstraction. Furthermore, these terms

Table 1

Complexity of the candidate case based on the six complexity dimensions of Chapman (2016).

Complexity dimensions	Characteristics of the complexity dimension in the candidate ERTMS case based on Chapman (2016)	Description of the characteristics for the candidate case: Amsterdam Utrecht pilot project
Finance	Limitation on total spending with controls on payment amounts	In 2010, the Dutch House of Representatives made €37.5 million available to, among others, gain experience with the ERTMS on the Amsterdam-Utrecht route. After incorporating various activities from the Netherlands Railways and ProRail, a joint budget was consolidated of €33.79 million (Program Direction ERTMS, 2015). The financial complexity increased during the pilot project, because initially the cash flow to the Netherlands Railways was intended to compensate for their expenditures and that to ProRail was intended to compensate for both ProRail's expenditures and the deployment of other (freight) transport operators whom they were to contract. Ultimately, however, the procurement system of the Netherlands Railways was used to contract these parties, which led to considerable financial complexity.
Context	Cultural and legal	During the pilot project, the parties involved were expected to gain operational experience in running passenger and freight trains with the ERTMS and to acquire and record critical knowledge, which could help in the transition to the national implementation of the ERTMS in the Netherlands. However, given the cultural differences and legal compliance issues, it was challenging to create a neutral environment in which all parties were willing to share their data with the pilot project team. For example, the data from a trainset series that operated on both Dutch and German territory had to be split by a trusted party and required much consultation before it could be shared with the pilot project team.
Management	Organisational structure in terms of horizontal differentiation	The pilot project management team coordinated with a number of organisations in the railway sector—such as ProRail, Netherlands Railways, freight operators and maintenance and service companies—to achieve the desired goals. For example, the project team worked with the relevant members of different organisations to establish learning points while they were still on the payroll of their parent organisation. Thus,

(continued on next page)

Table 1 (continued)

Complexity dimensions	Characteristics of the complexity dimension in the candidate ERTMS case based on Chapman (2016)	Description of the characteristics for the candidate case: Amsterdam Utrecht pilot project
Site	Extent of connections to existing infrastructure	while the pilot project team management could have relevant members establish learning points, doing so had limited influence on the participating organisations to ensure that the lessons learned were applied in a timely and effective manner in the various organisational processes. To improve the public-transport accessibility between Amsterdam and Utrecht, in 1995, the number of railway lines between the two cities was doubled. This decision was implemented in 2000 and in 2003, it was decided that the tracks would be built with two train safety systems: NS'54/ATB and the ERTMS Level 2. The double track between Amsterdam and Utrecht was completed with NS'54 in 2007 and with ERTMS Level 2 in 2011. Thus, during the pilot project implementation, the site consisted of two safety systems, which created additional operational and site complexity. As a result, for the pilot project, only the ERTMS-equipped trains ran under ERTMS Level 2 on the Amsterdam-Utrecht route.
Task	Technological characteristics, such as experience with technology and the adoption of new technology, and information characteristics, such as sharing information across organisation boundaries	The overall objective of the pilot project was to contribute to the wider ERTMS deployment strategy. In the pilot project, key railway organisations were introduced to the new ERTMS technology and the needed changes were realised in their organisational processes to implement the ERTMS. A database containing large amounts of relevant information on the pilot project (e.g., project evaluations, (field) research reports) was set up and shared in a closed environment with the relevant organisations. This situation implied that although the pilot project tried to share information and lessons across organisational boundaries, the participating organisations were responsible for incorporating the shared insights, which was not a trivial task.
Delivery	Project schedule urgency	The pilot project was originally planned for 2013 and was brought forward to the summer of 2012 due to the urgency of the decision-making bodies to schedule the project. This move made it difficult for other involved organisations to ready all the assets, such as the rolling stock and infrastructure, in time for the pilot project.

have been used in previous knowledge management research (Tur-yahikayo, Pillay, & Muhenda, 2021). Consequently, the responses to each research question were first reviewed and assigned codes based on their condensed meaning. These assigned codes were then clustered into different categories responding to each research question. Finally, the categories were further clustered into predominant themes to make their underlying meaning explicit and obtain an in-depth understanding of the collected responses. A detailed overview of the content analysis can be found in the attached codebook as supplementary material to this paper. Finally, the results were thoroughly validated by three assessors who performed an independent validation of the content analysis to ensure rigour and quality and to determine the reliability and validity of the derived results. The validation of the results is presented in the next section.

3.5. Results validation

Three assessors were carefully chosen to independently validate the content analysis. The first assessor had over 30 years of working experience within the Dutch railway sector and was a former member of both the Amsterdam Utrecht pilot project and the ERTMS program direction of the Netherlands. The second assessor had over 15 years of working experience in the Dutch railway sector and was a member of the ERTMS program direction (at the time of the study). Both assessors were chosen to obtain expert opinions on the assigned codes, categories, and themes from the subject matter perspective. The third assessor (also the third author of this article) was chosen because of his previous publishing experience in conducting content analyses and his psychology background to gain additional insights into the consistency of the content analysis.

The results were validated in four parts, where first, all codes and categories assigned to the collected responses to the question about the relevance of the LEAF features for the ERTMS (as shown in Fig. 2) were shared with the assessors. The assessors independently recorded whether they agreed or disagreed with the assigned codes and categories from the perspectives of the contents and the consistency of the coding. A discussion session was then organised with the assessors to address any questions about the assessment process. The same procedure was followed for the second and third parts, i.e., the learnings from the pilot and the future roadmap, as shown in Fig. 2. After all assigned codes and categories for the three mentioned parts were validated, the assessors were asked to validate the assigned themes per category. A codebook consisting of all the derived themes with their corresponding categories and codes was shared with the assessors to facilitate the theme validation. The complete codebook with all assigned codes, categories, and themes is available in the attached supplementary material of this paper. A discussion session was also organised to answer any questions that the assessors may have had on the theme validation. The assessment of the content analysis took approximately seven weeks, during which the assessors independently recorded their agreements and disagreements with the assigned categorisation.

Table 3 shows the agreements and disagreements expressed by the three assessors on the assigned codes, categories, and themes. In situations in which the assessors disagreed with the assigned categorisation, they either disagreed with the content or found it irrelevant to the context. Alternatively, they simply could not understand the relationship between the assigned categorisation and the particular context. Based on the assessment, a percentage agreement was observed of 90.9% for codes, 82.5% for categories, and 94.5% for themes, as shown in Appendix A (i.e., reported value of pa).

To assess intercoder reliability and correct for agreements between assessors due to chance, several indices have been identified in the literature (Feng, 2015; McHugh, 2012; O'Connor & Joffe, 2020). Since the content analysis consisted of three assessors, and a high extent of agreement was found between them, the authors chose Gwet's AC1 index to measure intercoder reliability, as recommended by Feng (2015)

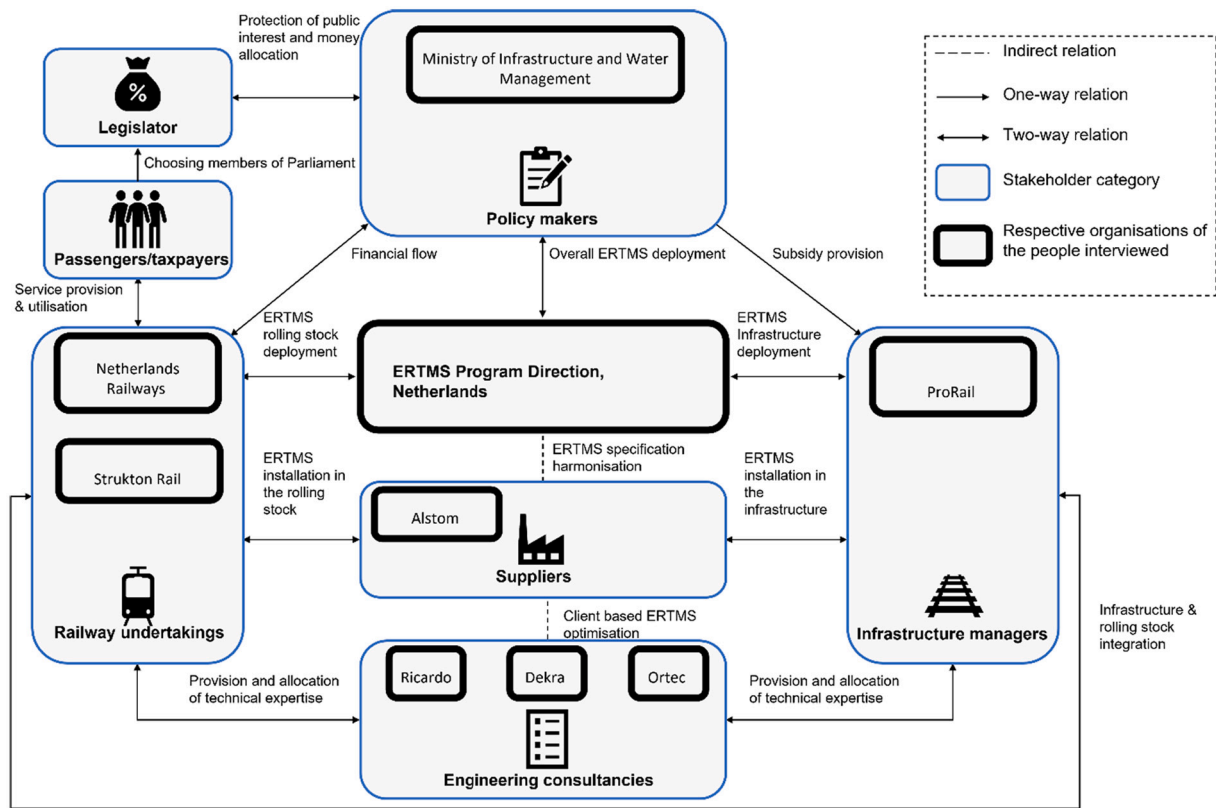


Fig. 3. Stakeholder relationship map of the pilot case.

Table 2

Overview of people interviewed per stakeholder category.

Stakeholder category	Number of people interviewed
Railway undertaking	7
Infrastructure manager	3
ERTMS program direction	4
Ministry of infrastructure and water management	3
Engineering consultancies	5
Suppliers	2

Table 3

Number of assessor agreements and disagreements on the content analysis.

Level of abstraction validation	Assessor 1		Assessor 2		Assessor 3		Total
	NoAs ^a	NoDs ^b	NoAs	NoDs	NoAs	NoDs	
Codes	136+	11+	146+	1+	142+	5+	514
	174+	21+	186+	9+	189+	6+	
	161 =	11 =	169	3 =	161	11 =	
	471	43	= 501	13	= 492	22	
Categories (per code)	132+	15+	121+	26+	144+	3+	514
	155+	40+	170+	25+	189+	6+	
	144 =	28 =	157	15 =	161	11 =	
	431	83	= 448	66	= 494	20	
Themes (per category)	11+	0+	11+	0+	11+	0+	61
	26+	0+	25+	1+	26+	0+	
	23 =	1 = 1	23 =	1 = 2	22 =	2 = 2	
	60		59		59		

NoAs/NoDs for each assessor by level of abstraction presented as: NoAs/NoDs (Relevance of the LEAF features)+NoAs/NoDs(Learnings from the pilot)+NoAs/NoDs(Future roadmap)=Total NoAs/NoDs.

^a Number of Agreements (NoAs).

^b Number of Disagreements (NoDs).

& Gwet (2008) for such situations. This choice was appropriate in comparison with the Kappa index, given the Kappa paradox, namely, a high percentage of agreement but a low Kappa value (Falotico & Quatto, 2015; Feinstein & Cicchetti, 1990) and the lesser affectability of the index by the marginal probability (Wongpakaran, Wongpakaran, Wedding, & Gwet, 2013).

The magnitude of the calculated AC1 coefficients was interpreted using the benchmark scale of Landis and Koch (1977) and by incorporating guidelines for retaining the agreement strength, established by Gwet (2014). A detailed overview of the AC1 calculation and benchmarking is given in Appendix A. Table 4 presents the calculated AC1 values and the determined strength of agreement between the assessors across the assigned codes, categories, and themes.

As indicated, there was “almost perfect” agreement between the assessors on the assigned codes and themes and “substantial” agreement on the categories. Thus, the rigour and quality of the content analysis is demonstrated. This finding imparts confidence to the derived results but also outlines a way to validate qualitative results for large-scale rail transportation projects.

4. Case study: Amsterdam Utrecht ERTMS pilot project

This section provides background information on the pilot project and outlines the focus of the case study in line with the presented methodology.

4.1. Background information

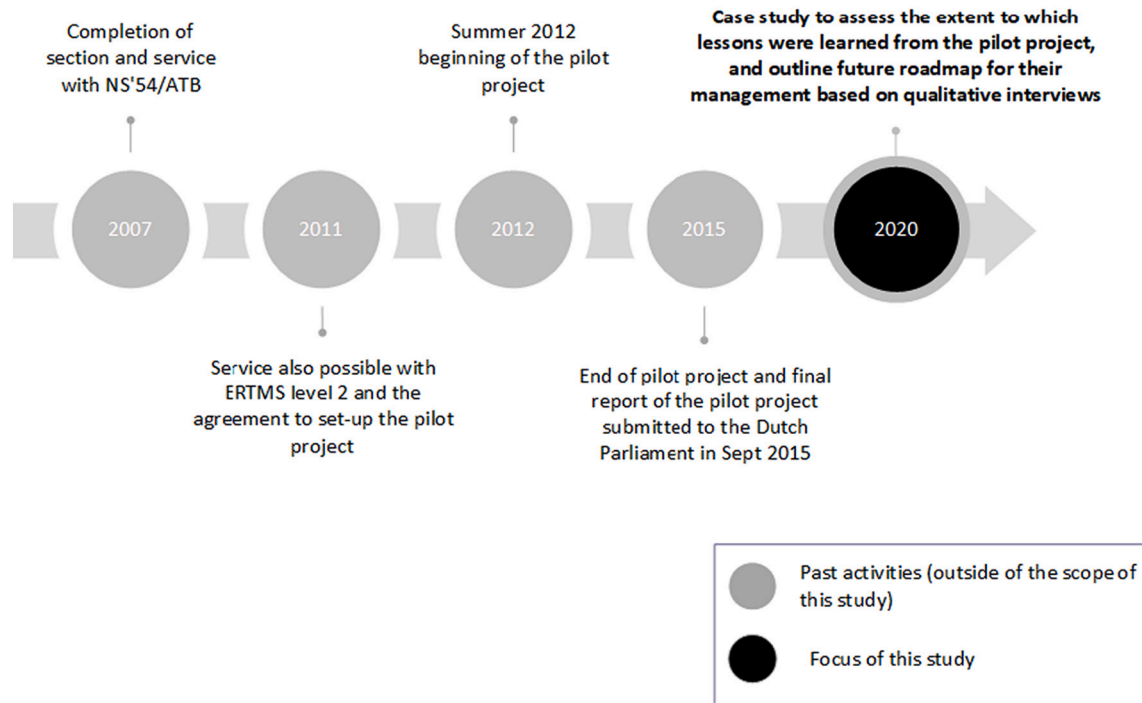
As described in Table 1, to improve rail accessibility, it was decided in 1995 to upgrade the track between Amsterdam and Utrecht. Furthermore, it was decided as early as 2003 to equip the track with two train safety systems, namely, NS'54/ATB and ERTMS Level 2, in preparation for future ERTMS train operations. Fig. 4 shows that the service with the NS'54/ATB safety system started in 2007, but the track only

Table 4

Relative strength of agreement.

Interrater reliability	Gwet's AC1 value			The relative strength of agreement between assessors		
	Codes	Categories	Themes	Codes	Categories	Themes
Among all three assessors	0.899	0.782	0.942	"Almost perfect"	"Substantial"	"Almost perfect"

Amsterdam-Utrecht ERTMS deployment timeline

**Fig. 4.** ERTMS deployment timeline on the Amsterdam-Utrecht track.

became available for ERTMS Level 2 operations in 2011. The main challenge at that time was the limited experience with ERTMS operations of key railway organisations in the Netherlands. To address this challenge, at the end of 2011, the Dutch Ministry of Infrastructure and Water Management, in collaboration with Netherlands Railways and ProRail, commissioned a pilot project on the Amsterdam-Utrecht railway section. Its key objective was to contribute to the broader national ERTMS implementation strategy, and it officially began in the summer of 2012.

During the pilot project, in addition to different types of locomotives for freight transport, ten sprinter trainsets and eleven high-speed passenger trainsets were made available to test ERTMS operations. Experts from various stakeholder categories participated in the pilot project, as shown in Fig. 4. The pilot project examined topics such as safety, train technology, capacity, human behaviour, work pressure, and user processes. The main learnings from the pilot project related to the preparation of the necessary assets, examples of which follow:

1. the modification and admission of the rolling stock (freight locomotives and passenger trainsets) for use on the ERTMS Amsterdam-Utrecht track,
2. the development of the ERTMS training program (including training simulators) for train drivers and dispatchers,

3. the development of an official ERTMS examination system for ERTMS licensing (which was non-existent prior to the pilot),
4. the operational training of the train drivers, and
5. the development of a (neutral) environment in which all parties were willing to share their data with the pilot organisation.

The pilot project was officially completed in 2015, and the main findings were presented to the Dutch Parliament in the form of an abstract report in September 2015 (see Programmadirectie ERTMS 2015) and stored in a database. The database was managed in a closed environment where interested parties could request permission to access the findings.

4.2. Case study focus

The case study focussed on assessing the extent to which lessons had been learned from the pilot project and on outlining a roadmap for their management based on the results from the qualitative interviews, as shown in Fig. 4.

The case study was conducted from January to December 2020, when 24 structured interviews were held with people from different stakeholder categories to investigate the seven research questions presented in Fig. 2. The case study findings contribute to the broader ERTMS implementation strategy by providing valuable insight into the

improvements needed in managing the lessons learned from the ERTMS and outlining key principles for its effective knowledge-driven deployment.

5. Findings

A holistic overview of the themes that emerged from the data analysis is presented in Fig. 5.

Themes were identified for each of the three research focus points: the relevance of LEAF features, the learnings from the pilot and the future roadmap. A combined understanding of the themes is essential to better manage the ERTMS lessons learned and its effective rollout. To facilitate this understanding, the following three subsections provide a detailed account of each theme for all three research focus points. These subsections outline the corresponding categories for each theme and briefly elaborate their condensed meaning based on the responses collected for the respective research questions in the qualitative interviews.

5.1. Relevance of LEAF features

Four themes were identified in this subsection, as shown in Fig. 5. To clarify the contribution of the investigation into the relevance of the LEAF features to the ERTMS, the corresponding categories of each theme, shown in Fig. 6, are described in detail in the following subsections. These shared findings can help to promote the ERTMS lessons-learned management.

5.1.1. Learnability principles

This theme comprised twenty codes classified into two categories. The codes refer to the extracted meanings of the collected responses from the interviews for the respective research question. The first category highlighted the need to focus on objective operational implementation facts rather than subjective opinions, success factors (e.g., best practices), and operational integration (i.e., the smooth introduction of new technologies in operations) to facilitate the lessons learned. The second category claimed that since people learn in different ways,

alternative learning methods should be provided to organisational members.

5.1.2. Embraceability principles

This theme was composed of fifty-one codes that were further classified into four categories, as demonstrated in Fig. 6. The codes on individual aspects stressed addressing intrinsic issues, e.g., building trust and motivation and being sensitive to the needs and fears of individuals in the organisation. Organisational aspects asked for raising awareness on the significance of the lessons learned (both good and bad), addressing commercial aspects of knowledge-sharing, providing organisational support, supporting the development of knowledge-sharing, and formalising knowledge-sharing to improve the embraceability of lessons learned. Similarly, cultural aspects highlighted factors such as organisational politics, operational pressure, and the poor utilisation of prior lessons learned as key barriers to the lessons-learned embraceability. The interviewees suggested working on organisational culture integration, such as safety culture integration, across the entire railway sector to build embraceability. Finally, some of the key best practices for improving the lessons-learned embraceability included an open knowledge-sharing culture for technical data-sharing across organisations, taking ownership, focussing both on the technological and social aspects of knowledge management, and having proper stakeholder management.

5.1.3. Applicability principles

This theme was composed of thirty-five codes that were further classified into three categories, as shown in Fig. 6. The first category highlights contextual complexities that make knowledge applicability difficult. These include human-machine interaction design, different stakeholders' interests, and the difference between work as imagined and work as done collectively. The interviewees argued that determining knowledge applicability for social knowledge such as workforce relationships was more complex than determining technical knowledge. Similarly, in terms of domains requiring knowledge applicability realisation, the interviewees mentioned as key knowledge domains ERTMS Technical Specifications for Interoperability (TSIs), human factors,

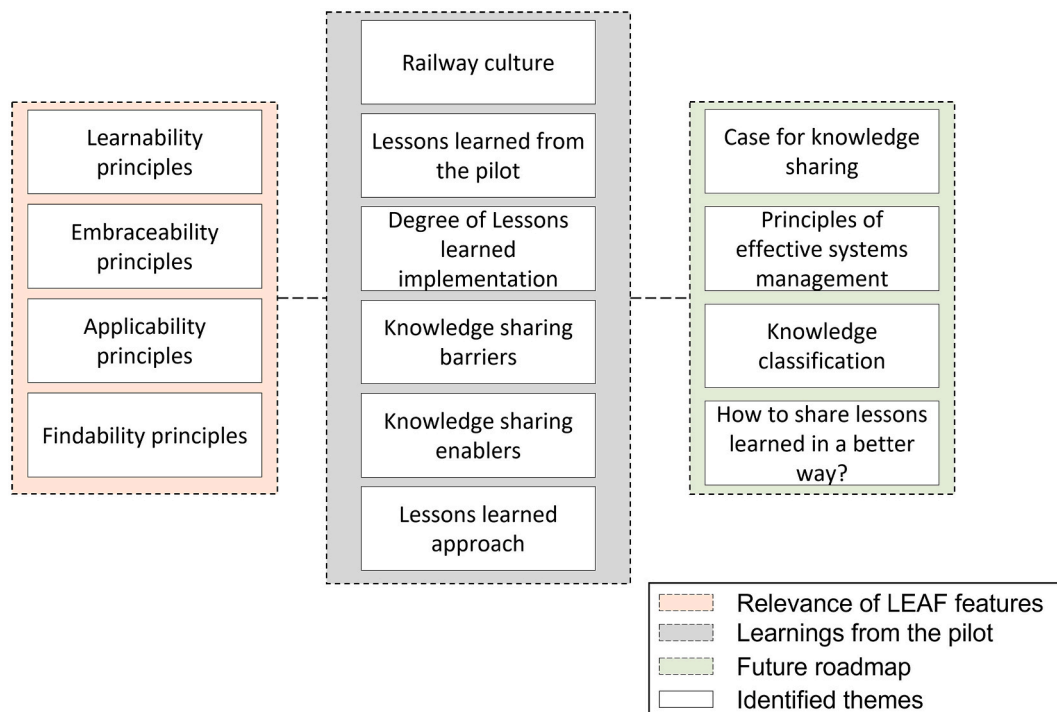


Fig. 5. An overview of the themes constructed from the interviews.

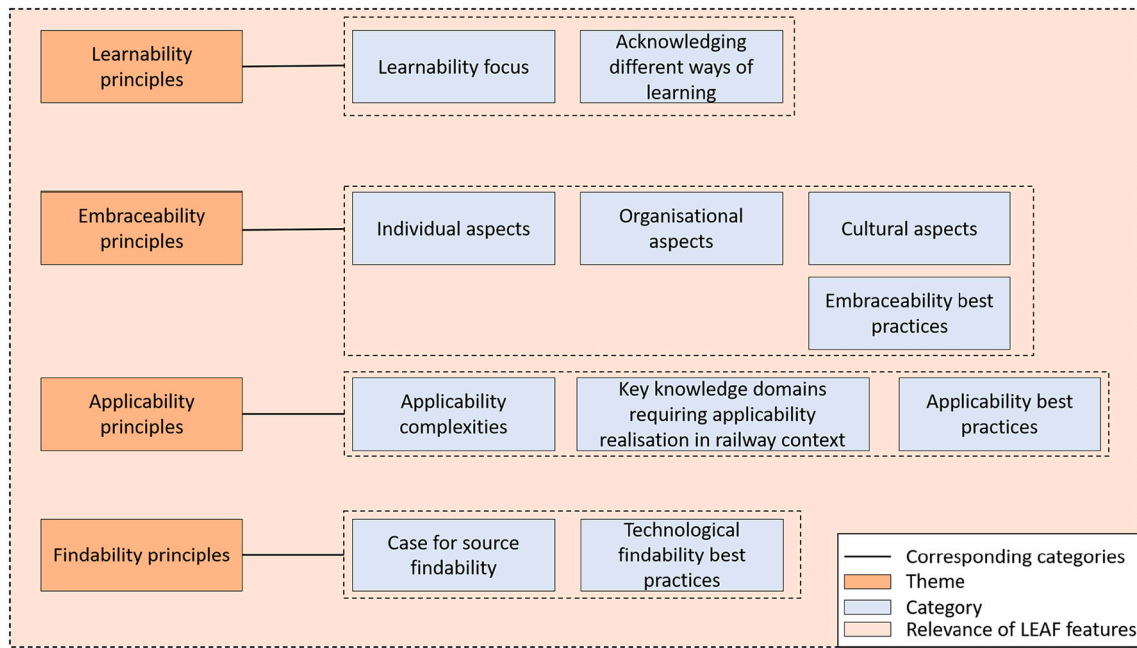


Fig. 6. Categories per theme for the research focus point relevance of the LEAF features.

rolling stock, maintenance, and user processes. Last, some of the key best practices for improving the lessons-learned applicability included the harmonisation of user manuals; proper descriptions of context, roles, and responsibilities; and the building of communities of practice.

5.1.4. Findability principles

The theme consisted of eleven codes and two categories, as displayed in Fig. 6. The first category highlighted the importance of facilitating informal knowledge-sharing for tacit knowledge transfer. Furthermore, it acknowledged that not everything could be documented, although the interviewees lacked consensus on the best way to transfer it. In comparison, the second category stressed ensuring the easy traceability of centrally stored documents and the maintenance of a fact book for key

knowledge domains.

5.2. Learnings from the pilot

In this subsection, six themes were identified, as shown in Fig. 5. Here, we clarify the contribution of the investigation into the learnings from the pilot project. We do so by describing in detail the corresponding categories of each theme, shown in Fig. 7, in the following subsections. These shared findings can help to understand the prevailing railway culture, the key lessons learned in the pilot project and the barriers and enablers for implementing them in the railway sector. Moreover, the findings shed light on the approach needed to better implement the lessons learned.

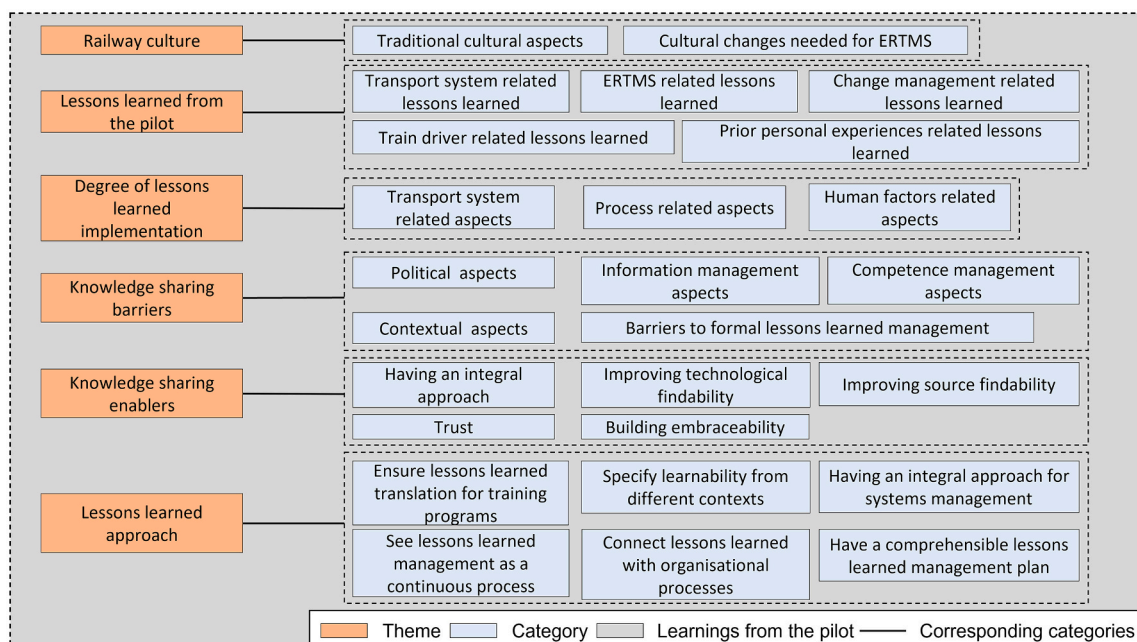


Fig. 7. Categories per theme for the research focus point learnings from the pilot.

5.2.1. Railway culture

This theme comprised two categories, as displayed in Fig. 7. Eighteen codes were assigned to this theme, twelve related to “traditional cultural aspects” and six related to “cultural changes needed for the ERTMS”. The codes in the first category stressed the underlying cultural issues as management sticking to traditional methods of working, the different business models of involved organisations, and an overarching organisational mindset of maintaining traditional safety methods. This mindset ultimately led to problems such as standstill trains (i.e., malfunction during regular train operation), increased complexity in coordinating interorganisational knowledge-sharing, and difficulties learning among organisations. For the second category, the different roles of implementation organisation and system integrator were ascribed to ProRail. This situation hindered cooperation between the involved parties in the ERTMS project. The interviewees stated that, when answers to technical questions seemed to diverge, organisational politics played a key role in decision-making.

5.2.2. Lessons learned from the pilot

This theme comprised five categories, as shown in Fig. 7. Each of these categories is discussed in turn.

5.2.2.1. Transport system-related lessons learned. Sixteen codes were assigned to this category. The codes consisted of important lessons learned, such as the need to have an integral approach for the railway sector, in which the roles and responsibilities of each involved individual are clearly defined. Similarly, the importance was highlighted of having an independent system integrator, at the entire railway system level, who can make decisions in the best interest of the system and who has a holistic overview of the needs of the entire sector. The interviewees also stressed having a coherent certification approach for all key stakeholders in the sector and properly implementing quality system and system-engineering practices to ensure the smooth integration of large-scale technological projects (the benefits of implementing system engineering to project governance and performance have been highlighted by Locatelli, Mancini, & Romano, 2014).

5.2.2.2. ERTMS-related lessons learned. Nine codes were assigned to this category, which highlighted the ambiguities (i.e., predominant focus on best-case scenarios) in the ERTMS TSIs and technical compatibility issues in the installation of European train control systems. For instance, the interviewees pointed out the lack of harmonisation in guard time-setting at both the national and international levels due to open points in ERTMS TSIs, which resulted in different recovery mechanism problems and train standstills.

5.2.2.3. Train driver-related lessons learned. This category comprised five codes that stressed having a practical approach to training, designing technical systems with a human-centred approach, and ensuring that drivers preserved their route knowledge. The interviewees stated that the driver's willingness and openness to use designed information technology (IT) systems, aimed at providing information during train operations, was of critical importance in ensuring successful ERTMS operations.

5.2.2.4. Change management-related lessons learned. Eleven codes were assigned to this category. These codes comprised the lessons learned related to intangible aspects, such as raising awareness of the effects of a system change and building an open and collaborative culture, and tangible aspects, such as reducing variability in the technical system and incorporating product improvement (through new developments) instead of product replacement in the contract.

5.2.2.5. Prior personal experiences-related lessons learned. Twelve codes were assigned to this category, which mainly consisted of the lessons

learned by the interviewees from experiences prior to and identified in the pilot case. These included intangible aspects, such as having the right people on the team and taking responsibility instead of delegating it, and tangible aspects such as preparing for early failures (as explained by Ohring (1995) for the bathtub curve) and performing in-house maintenance for technical systems.

5.2.3. Degree of lessons learned implementation

This theme comprised twenty-nine codes relating to the implementation degree in three categories, as outlined in Fig. 7. Regarding the transport system, items reported were the development of a user process-monitoring system and an operational knowledge centre for the ERTMS, incorporation of the lessons learned in the national programme, and development of ATB-STM (train safety system) requirements. In comparison, on the process front, mixed opinions were reported related to the extent to which the pilot case was a good representation of a “real world” rail operations scenario. Some of the interviewees appreciated the large-scale testing and the robustness of the tests conducted in the pilot study. Meanwhile, others were critical of dual signalling, conferencing speed-only operations (i.e., driving at a speed lower than normal operations) and the comparatively small number of train drivers involved. The interviewees reported that the pilot study focussed more on tangible technical aspects and less on intangible cultural aspects. Political and commercial factors were reported to have hindered the lessons-learned implementation. Last, in terms of the human (and organisational) factors perspective(s), the interviewees stressed the need to have both bottom-up and top-down approaches in project execution. Moreover, they acknowledged the experience gained by train drivers in the pilot study, adding that it played a critical role in issue management (as defined by Heath (2002)) and technical product innovations.

5.2.4. Knowledge-sharing barriers

Thirty-six codes were assigned to this theme, which was subsequently classified into five categories, as shown in Fig. 7. Regarding the first category on barriers to formal knowledge management, loyalty to an organisation and loyalty to the higher goal of the integrated transport system were sometimes in conflict. This situation led to knowledge-hoarding, insufficient description of the context, contracts being seen as rigid and non-negotiable, and unusable lessons-learned reports (because of, e.g., irrelevant or incomprehensible knowledge). Similarly, key barriers from an information management standpoint were lack of awareness, accessibility, and structure as well as difficulty in finding desired documents on available knowledge-sharing platforms.

Regarding competence management, key knowledge-sharing barriers were difficulty finding subject matter experts, lack of knowledge of the overall transport system, and the knowledge-hoarding of existing inventions. Key barriers reported from a political standpoint were the “not invented here” syndrome, sector segregation, and organisational politics. Finally, contextual barriers were highlighted such as market protection, legal compliance, vulnerability to change, and protection of public interests from unnecessary media attention.

5.2.5. Knowledge-sharing enablers

As indicated in Fig. 7, twenty-seven codes were assigned to the theme of knowledge-sharing enablers, which were further classified into five categories. The analysis indicated that trust was needed not only in people but also in systems, especially in a situation in which the parties were deeply interdependent upon one another. Similarly reported were the improvement of technological findability (i.e., ease of finding the desired knowledge on the available knowledge-sharing platform) through enablers such as having user-friendly IT systems, improved structure, and context description. Source findability (i.e., the ease of finding subject matter experts) enablers were also identified such as open communication, geometrical proximity (i.e., physical distance or organisational hierarchy relationship), and facilitating closer work between the design engineers and train drivers for the complex subject.

Regarding having an integral approach, key knowledge-sharing enablers were seen as using proper tools and having an independent, empowered, and free political influence system integrator. Last, the interviewees reported that the lessons-learned embraceability (i.e., degree of knowledge acceptance and use at the individual and organisational level) could be built by having a clear goal, providing the right resources and leadership, and ensuring proper knowledge applicability for problem solving.

5.2.6. Lessons-learned approach

This theme comprised six categories and thirty-one codes, as outlined in Fig. 7. A key example provided for specifying learnability (i.e., the ease with which one learns from a particular lesson) was the development of an operational knowledge platform. This tactic provided operational knowledge to the ERTMS-implementing organisations (i.e., railway undertakings and infrastructure manager). Moreover, training programs needed to be more realistic than the current simulator training was and held more frequently. The interviewees stated that the lessons-learned approach could be substantially improved by specifying what others could learn from a certain lesson, describing the underlying context, establishing new procedures based on the lessons learned, and learning from things that went right. Similarly, an integral approach for systems management could be guaranteed by the parallel introduction of rolling stock and infrastructure and an integral approach to system safety, capacity and maintainability. The interviewees stressed the need to see lessons-learned management as a continuous and iterative process. Also reported were the need to move away from the “silo mentality” and use past experiences to ensure the continuous improvement of the lessons learned.

The interviewees also stressed having a master specification program and reference architecture backed by proper management support to facilitate the incorporation of new lessons learned into existing organisational processes. Finally, necessary prerequisites for improving the current approaches to lessons learned included having a comprehensive plan that pays due attention to the perception of lessons learned, establishing a fact book (i.e., a living document that can be used to obtain consensus on factual matters concerning the ERTMS), and having a policy for sharing critical knowledge in an interorganisational setting.

5.3. Future roadmap

In this subsection, four themes were identified, as shown in Fig. 5. This study aims to clarify the contribution of the investigation into the future roadmap for the management of ERTMS lessons. To do so, the corresponding categories of each theme, shown in Fig. 8, are described in detail in the following subsections. These collective findings make a case for the effective knowledge-sharing of the ERTMS lessons learned. Furthermore, they outline ways to classify practical knowledge about ERTMS deployment and the best practices and principles for effective ERTMS management.

5.3.1. Case for knowledge-sharing

This theme comprised thirty codes that were further classified into four categories, as indicated in Fig. 8. The first category stressed the need for tacit knowledge management in the railway sector to ensure system performance optimisation. The second category encompassed codes that acknowledge the practical relevance of LEAF features and stated that the LEAF approach could facilitate knowledge development. The third category outlined the factors that influence the lessons-learned sustainability. Specifically, the perceived relevance of the lessons learned, instituting a pull instead of a push approach to knowledge-sharing and having communities of practice for proper lessons-learned utilisation. Last, a key argument for knowledge-sharing in the railway sector was sensitivity towards contextual complexities such as the knowledge management of large-scale multi-organisational technological projects.

5.3.2. Principles of effective systems management

Eighty-two codes were assigned to this theme and subsequently classified into fourteen categories, as outlined in Fig. 8. The essence of each of these categories is presented below.

5.3.2.1. Optimising lessons-learned management. This category encompassed codes from submitting change requests for ERTMS TSIs to harmonising the lessons learned at the national and international levels. The interviewees also stressed the provision of knowledge-sharing

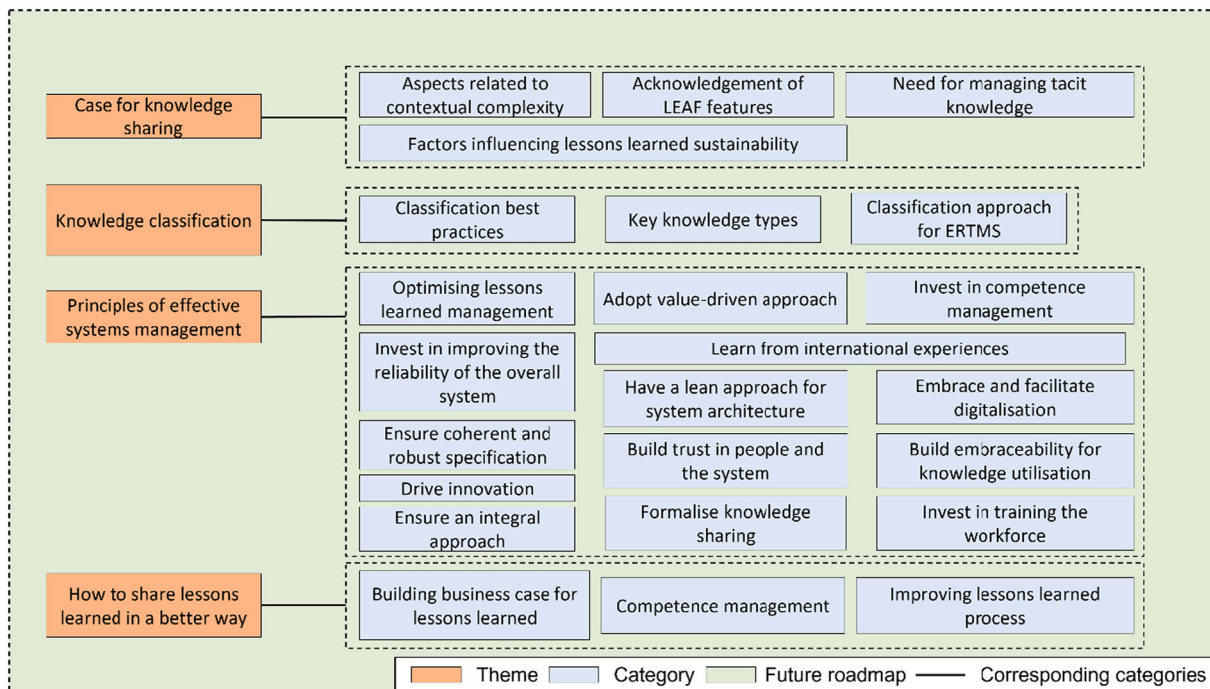


Fig. 8. Categories per theme for the research focus point future roadmap.

platforms on which people can easily interact and share the lessons learned.

5.3.2.2. Adopt value-driven approach. This category consists of codes that stressed adopting a societal value-based case perspective instead of a business case perspective. The interviewees argued that instead of working in a “silo mentality”, having an open culture and making decisions that bring value to the entire society were needed to cope with ongoing changes in the railway sector. Similarly, they advocated for the relaxation of jurisdictional boundaries to facilitate knowledge-sharing and suggested that the railway undertaking should focus more on the functional aspects while creativity relating to technical aspects should be left to suppliers.

5.3.2.3. Invest in competence management. The codes in this category highlighted the high dependency relating to personnel within the railway sector and stressed the need to invest in competence management. The interviewees noticed that traditionally the railway system had remained relatively stable from a technology standpoint and that the recent pace in technological innovations asked for robust competence management approaches.

5.3.2.4. Invest in improving the reliability of the overall system. This category stated that key emergent properties in the railway sector—such as punctuality, capacity, and reliability—required investment in terms of running experiments and determining heuristics (without compromising overall system safety). Therefore, it is important to invest in simulations and to test programs to improve the reliability of the entire system.

5.3.2.5. Learn from international experiences. Considering the focus on the interoperability of European railways, the interviewees stressed the need to learn from the international experiences of ERTMS deployment. They highlighted the need to make all efforts to ensure that no hurdles impeded railway operations between European countries, which means that not only trains but also train drivers can drive freely across countries.

5.3.2.6. Ensure coherent and robust specification. This category advocates for having coherent specifications, especially at interfaces, to ensure proper integration at the system level. Moreover, the category suggests contracting the whole chain of system deployment projects instead of undertaking this task piecemeal.

5.3.2.7. Have a lean approach for system architecture. The interviewees stressed the need to have a “lean approach” towards system architecture by centralising control and reducing the variation in infrastructure construction. They asked for special attention to be paid to the potential mismatch between organisational structures and technical systems and redundancy against the possible discontinuation of technical parts.

5.3.2.8. Embrace and facilitate digitalisation. This category advocated for speeding safety processes to cope with ongoing digitalisation in the railway sector. The interviewees argued for learning from system-engineering practices in the IT sector.

5.3.2.9. Drive innovation. This category advocated for a shift in mindset so issues could be addressed with a focus on finding opportunities for innovation rather than on minimising risks. Furthermore, it stressed making room for innovation in the railway industry by providing incentives and the right kind of management support.

5.3.2.10. Ensure an integral approach. This category acknowledged the contribution of system-engineering tools in having an integral approach for the installation of technical equipment in the railway sector and

stressed the need for having an independent system integrator at the entire railway system level. The interviewees noted that safety was the core of the railway sector and asked for cost and functionality decisions to be made in the best interests of the entire system. They claimed focussing both on short- and long-term goals (which are typically in conflict) could guarantee the integration of the entire railway system.

5.3.2.11. Build trust in people and the system. This category highlighted the need to build trust in people and systems by incorporating trust-based mechanisms in technical systems and by creating an open knowledge-sharing culture. The interviewees stated that trust was a keyword for integration and a prerequisite for ensuring proper system performance management.

5.3.2.12. Build embraceability for knowledge utilisation. The interviewees noted that although they had robust lessons available (i.e., factual lessons learned), they were not always properly utilised. They stressed the need to build organisational embraceability for knowledge utilisation by proper management support, to have shared values, and to work collaboratively towards a unified goal.

5.3.2.13. Invest in training the workforce. This category stated that further efforts are needed in training and educating the workforce to properly manage any ongoing system changes. The interviewees cautioned against potential resource capacity issues, such as a limited number of technical experts for large-scale technological projects such as the ERTMS. They advocated having comprehensive training programs for operational integration.

5.3.2.14. Formalise knowledge-sharing. This category stressed the need to formalise knowledge-sharing by incorporating it into organisational processes. The interviewees suggested introducing a knowledge-sharing plan at project initiation similar to a safety plan. They also argued that knowledge-sharing was successful when the recipient of any appropriate knowledge could describe it accurately in their own words.

5.3.3. Knowledge classification

This theme is composed of thirty-seven codes that were further classified into three categories, as demonstrated in Fig. 8. The knowledge types identified for the railway sector were professional, relational, technical, human, functional, procedural, transitional, tactical, and strategic. Similarly, prominent best practices of knowledge classification were identified as maintaining a fact book, managing the configuration, providing background information, using technical readiness levels, building a matrix with transport system architecture and organisational key performance indicators (KPIs), having operational processes and principles, and continuously monitoring developed contextual categories. Last, the interviewees suggested that the functional and procedural domains were more important for primary users, as defined by the [International Standards Organization \(ISO\) \(2011\)](#); technical and procedural domains, for secondary users; and goals, for tertiary users of the ERTMS.

5.3.4. How to share lessons learned in a better way

Fifty-two codes were assigned to this theme, which was further classified into three categories. The first category on competence management asked for the organisational members to build competencies in the knowledge-sharing of the lessons learned. It stressed creating and disseminating success (and non-success) stories, appointing knowledge ambassadors, and having an interactive development program for the lessons learned. The second category argued for building a strong business case for lessons learned and stated that cost and reliability were KPIs that would benefit the most from the proper management of lessons learned. It also argued for making the impact of the lessons learned clear for overall railway operations and devising robust data-sharing policies

for interorganisational projects. Finally, improvements were suggested for optimising lessons-learned management such as rewarding knowledge-sharing, making tangible and robust work packets, clarifying the responsibilities of knowledge seekers and providers, and building a knowledge-sharing culture.

6. Discussion

The paper responds to the call for a wider sharing of the experiences relating to the ERTMS (Laroche & Guihéry, 2013). Furthermore, it extends the existing knowledge base on organisational project management for large-scale projects by providing an overview of the activities needed to properly manage the lessons learned for such projects. Following a five-step methodology, the paper identifies both the current shortcomings and the improvements required to manage the lessons learned from large-scale infrastructure development projects. These findings emphasise that lessons-learned management is not simply about storing explicit lessons in databases but is also about managing the valuable lessons at the cultural, organisational, and operational levels.

The investigation concerning the relevance of LEAF features shows that promoting the learnability of the ERTMS lessons learned requires identifying the success factors for operational integration, disseminating the facts about operational implementation and furthermore offering alternative learning methods to involved organisational members. Building trust in people and systems, formalising knowledge-sharing and integrating organisational cultures have all been identified as the key means of improving the embraceability of shared lessons. The necessary means of clarifying the applicability of shared lessons include harmonising the ERTMS user manuals and building communities of practice for knowledge-sharing. To improve findability, more informal knowledge-sharing can transfer tacit knowledge, and an ERTMS fact book should be established. The insights on the LEAF features not only help to better manage the ERTMS lessons learned, but also enable further developments of the LEAF theory.

When the learnings from the pilot project are considered, the findings indicate that the prevailing culture of preference for traditional ways of working, different roles and responsibilities, and organisational politics make it difficult for the organisations involved in the implementation of the ERTMS to learn from each other. The lessons learned from the pilot project point to the need for an integral approach to systems management and underline the importance of having an independent, empowered and competent entity to play the role of a system integrator. Furthermore, reducing technical system variability, harmonising system settings and performing in-house maintenance have been identified as essential for effective ERTMS operations. Regarding the implementation of the shared lessons from the pilot project, the investigation shows that, while the shared lessons have led to significant technical changes in the system, changes in the procedural and human (and organisational) factor domains are slower. The study showed that the pilot project focussed more on the technical aspects of the ERTMS and less on the cultural and organisational aspects. The barriers to knowledge-sharing—such as organisational politics, sectoral segregation, insufficient description of the context and knowledge-hoarding—may have exacerbated the less-focussed application of the lessons learned in the cultural and organisational domains. Similarly, the enablers for knowledge-sharing, such as having a clear goal and providing the right resources and leadership, may help to improve the utilisation of shared lessons. In terms of the improvements needed in the current lessons-learned process, the study suggests developing an operational knowledge platform for sharing the ERTMS lessons and having a policy for sharing critical ERTMS information and knowledge.

Future suggestions are that the perceived lessons-learned relevance should be improved for a timely and effective deployment of the ERTMS and that the LEAF features are useful in knowledge development. Moreover, the fourteen outlined principles of effective systems management lay the foundations for policy-making and the performance

monitoring of organisational learning in practice. For example, the operational integration of the ERTMS can be improved by adopting a societal value-based approach, investing in competence management, embracing digitalisation and having comprehensive training programmes. Additionally, the reliability of the overall system can be enhanced by: centralising system control, focussing on short- and long-term goals, establishing heuristics, building trust in people and systems and learning from international experiences. The paper also highlights that key practical knowledge from the ERTMS can be classified into different domains, such as technical, human and relational. Moreover, it suggests that for these domains, general principles, success stories and operational facts need to be developed for the effective dissemination of lessons learned.

Finally, given the wide range of topics discussed, Gwet's AC1 values demonstrate the consistency, rigour and quality of the content analysis. They provide both confidence in the findings and an opportunity to assess the interpretation of the results. The major study limitation lies in its predominant focus on the Dutch railway context. The study could be further validated by including ERTMS deployment cases from other European countries and by investigating the applicability of the presented methodology to different organisational environments. Additionally, each participant was interviewed once, and the study could be improved by, for example, conducting a follow-up study in which each participant was interviewed twice within an appropriate period of time.

7. Implications for managerial practice and future research

The present study has several key implications for managerial practice and future research. The authors formulated six recommendations for policy-makers and five for railway organisations. These suggestions are intended to promote the lessons-learned management for large-scale development projects such as the ERTMS and are shown in Fig. 9. These recommendations were derived after reviewing the findings in Section 5 and were aimed at helping railway professionals change the current course of their lessons-learned management.

First, the authors recommend that policy-makers appoint an independent, empowered and competent entity to act as a system integrator for the smooth deployment of the ERTMS. Specifically, the authors envision the system integrator as consisting of a team of technical experts acting as principal advisors to policy-makers at the sector level rather than a legal entity. In particular, the system integrator should incentivise and promote cooperation between railway organisations and advise policy-makers on decisions that are in the best interest of the entire railway sector. This system integrator should be responsible for setting up a fact book for the ERTMS with a “living document” approach, which can be used and co-managed by key railway organisations. Additionally, the fact book should be used as a reference by policy-makers and railway organisations to facilitate communication and obtain consensus for better collective decision-making than at present. To encourage members of railway organisations to collaborate openly across organisational boundaries and to embrace the ongoing changes in their working methods as a result of ERTMS deployment, the third recommendation suggests policy-makers adopt a societal value-based approach by working closely with railway organisations. This suggestion also aligns with wider societal aspirations—such as sustainability, equity, and access values—and will help to create ownership of the ERTMS across organisational boundaries. The fourth recommendation stresses the need to integrate the currently diverse organisational cultures. Given the adverse effects of sector segregation and organisational politics on organisational learning, the system integrator must culturally integrate at the national level. The authors also advocate defining and balancing short- and long-term goals by approaching projects based on their completion time and outlining the relationships across projects for the timely and effective deployment of the ERTMS. Finally, the authors recommend that policy-makers develop an interactive learning program for lessons learned through the independent system integrator. This

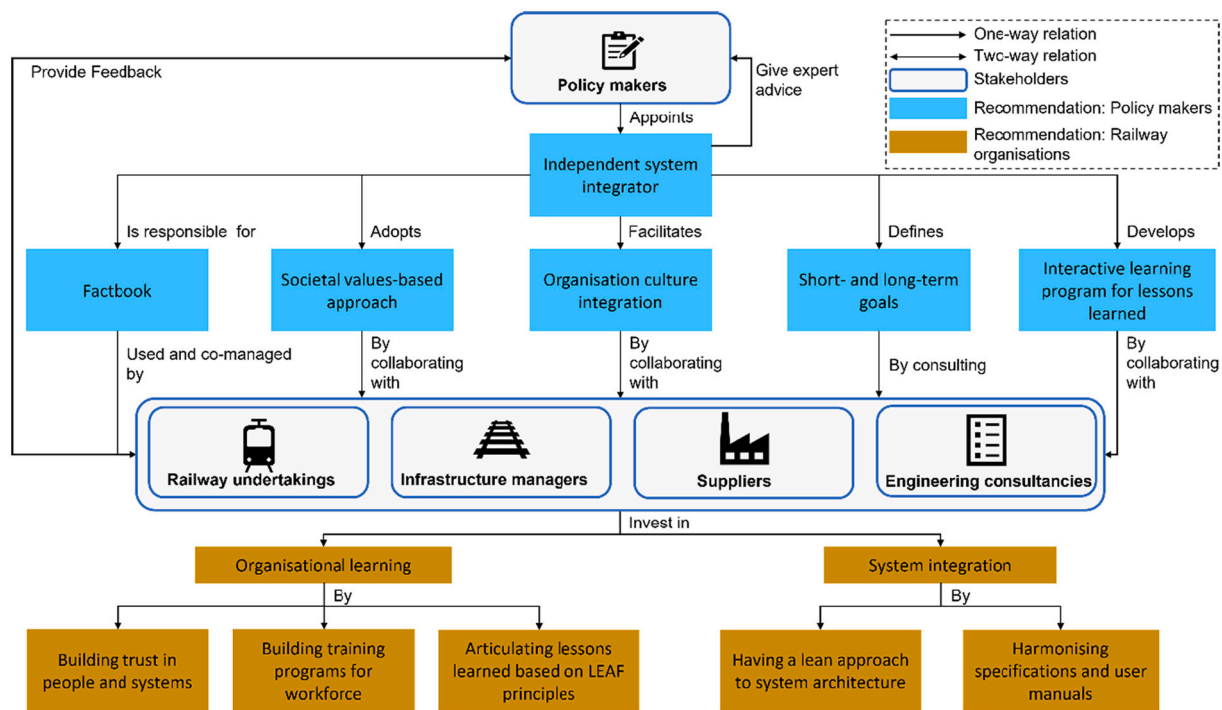


Fig. 9. Recommendations for policy-makers and railway organisations.

suggestion is recommended for coping with ongoing technological transformations in the sector and eliciting articulable tacit knowledge, see for example (Dampney, Busch, & Richards, 2002) for subsets of tacit knowledge that are articulable. To obtain feedback and a holistic overview of the sector needs, the authors also suggest a feedback loop among railway organisations and policy-makers, as shown in Fig. 9.

Five recommendations are proposed for railway organisations, three of which focus on organisational learning and two, on system integration, as shown in Fig. 9. The authors recommend investing in organisational learning in part by building trust in people and systems. This task can be done by developing trust-based consensus mechanisms and embedding them in organisational processes and systems. Likewise, the building of robust training programs for the workforce to train them for ongoing changes can immensely increase the level of organisational learning. Additionally, articulating the lessons learned based on the LEAF principles can not only assist in the further development of the organisational body of knowledge but also facilitate organisational learning.

Two recommendations were formulated to support complex system integration-related activities. The authors recommend that railway organisations have a lean approach for system architecture by centralising system control to speed system upgrades. Similarly, we stress the need to harmonise specifications and user manuals by closely collaborating with the system integrator to ensure smooth operational integration.

There are two key areas for future research. The first is to further investigate the relationship between the lessons-learned management and traditional organisational and project KPIs (especially cost and reliability). In this study, several participants reported that optimising the lessons-learned management could reduce costs and improve system reliability, which makes the subject a good candidate for further research. Second, researchers from other countries and industries are encouraged to validate the determined principles of effective systems management and the adequacy of the LEAF approach to optimise the lessons-learned in their domain specific contexts in order to enhance the research generalisation.

8. Conclusion

In complex, technological large-scale transport projects, it is relatively easy to lose the lessons learned with major cost and efficiency implications for future such projects. What complicates learning from such projects is that both tacit and explicit knowledge must be captured, a far from easy task for the former. Current methods of lessons learned have their shortcomings and as a consequence, this paper provides a formal process for lessons-learned extraction and management for large-scale projects in the railway sector. The process is a nuanced five-step methodological approach, in which the case study was chosen based on predefined criteria. Afterwards, structured interviews were held to collect data on the lessons learned from the chosen case and to determine a future roadmap for lessons-learned management. These interviews were held with the key stakeholders involved in the chosen case, who were identified by mapping the relationships between stakeholders. A detailed data analysis was then carried out using the content analysis method to compile the results. These results were then rigorously validated by first having them examined by independent assessors and then measuring the interrater reliability to determine the relative strength of agreement between the assessors on the content analysis.

The case study on one of the busiest railway corridors in the Netherlands revealed numerous shortcomings and necessary improvements in the current approach to the ERTMS lessons-learned management. For instance, it showed that the current railway culture hindered the railway organisations involved in the ERTMS implementation from learning from each other. Moreover, the incorporation of changes concerning procedures and human (and organisational) factors remains limited, whereas the culture facilitates the incorporation of technical changes. An important lesson learned from the study is the need for an integral approach to the ERTMS systems management and the need for an appointment of an independent, empowered, and competent system integrator. The barriers to knowledge-sharing point to difficulties in organisational learning and reinforce the need to promote the enablers of knowledge-sharing. The proposed improvements to enhance the learning processes, such as the establishment of an operational knowledge platform and the formulation of a policy for critical knowledge-

sharing, are of utmost importance for the timely and efficient deployment of large-scale projects such as the ERTMS.

For the future, the study formulates fourteen principles of effective systems management that can be used as input for the development of an integral approach to systems management and policy-making for the ERTMS. Moreover, the study provides six recommendations to policy-makers and five to railway organisations. These recommendations can facilitate communication for better decision-making and assist in the development of appropriate strategies for the ERTMS lessons-learned management. In conclusion, the study offers a formal process for lessons-learned management and disentangles their management for organisations undergoing the labyrinth of large-scale project implementations.

CRediT authorship contribution statement

Yawar Abbas: Writing – original draft, Conceptualization, Methodology, Investigation, Validation, Formal analysis, Visualization. **Alberto Martinetti:** Writing – review & editing, Visualization, Methodology. **Robert Houghton:** Validation, Formal analysis. **Arnab**

Majumdar: Writing – review & editing, Visualization, Methodology.

Declaration of Competing Interest

None.

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Appendix A

R studio code for calculation AC1 coefficients. R studio packages used DescTools and irrCAC (<https://cran.r-project.org/web/packages/irrCAC/irrCAC.pdf>).

Codes

```
> show(CodesAssessorstab)
# A tibble: 514 x 3
  CVA1 CVA2 CVA3
  <dbl> <dbl> <dbl>
1     1     1     1
2     1     1     1
3     1     1     1
4     1     1     1
5     1     1     1
6     1     1     1
7     0     0     1
8     0     1     1
9     1     1     1
10    1     1     1
# ... with 504 more rows
> gwet.ac1.raw(CodesAssessorstab)
$est
  coeff.name      pa      pe coeff.val coeff.se      conf.int p.value      w.name
1      AC1 0.9092088 0.09488326  0.89969  0.01227 (0.876,0.924)      0 unweighted

$weights
  [,1] [,2]
[1,]   1   0
[2,]   0   1

$categories
[1] 0 1

> landis.koch.bf(0.89969, 0.01227)
      Landis-Koch CumProb
(0.8 to 1)  Almost Perfect      1
(0.6 to 0.8) Substantial      1
(0.4 to 0.6)  Moderate      1
(0.2 to 0.4)   Fair      1
(0 to 0.2)    Slight      1
(-1 to 0)     Poor      1
Categories
```

```
> show(CategoriesAssessorstab)
# A tibble: 514 x 3
  CGVA1 CGVA2 CGVA3
  <dbl> <dbl> <dbl>
1     0     0     1
2     1     1     1
3     1     1     1
4     1     1     1
5     1     0     1
6     1     0     1
7     0     0     1
8     0     0     1
9     1     1     1
10    1     1     1
# ... with 504 more rows
> gwet.ac1.raw(CategoriesAssessorstab)
$est
  coeff.name      pa      pe coeff.val coeff.se      conf.int p.value      w.name
1      AC1 0.8249027 0.1941589  0.78271  0.01952 (0.744,0.821)      0 unweighted

$weights
  [,1] [,2]
[1,]   1   0
[2,]   0   1

$categories
[1] 0 1

> landis.koch.bf(0.78271, 0.01952)
      Landis-Koch CumProb
(0.8 to 1)  Almost Perfect 0.18787
(0.6 to 0.8) Substantial      1
(0.4 to 0.6)  Moderate      1
(0.2 to 0.4)   Fair      1
(0 to 0.2)    Slight      1
(-1 to 0)     Poor      1
Themes
```

```

> show(ThemesAssessorstab)
# A tibble: 61 x 3
  TA1 TA2 TA3
  <dbl> <dbl> <dbl>
1     1     1     1
2     1     1     1
3     1     1     1
4     1     1     1
5     1     1     1
6     1     1     1
7     1     1     1
8     1     1     1
9     1     1     1
10    1     1     1
# ... with 51 more rows
> gwet.ac1.raw(ThemesAssessorstab)
$est
  coeff.name      pa      pe coeff.val coeff.se   conf.int p.value      w.name
1      AC1 0.9453552 0.05315178  0.94229  0.02629 (0.89,0.995)      0 unweighted

$weights
  [,1] [,2]
[1,]   1   0
[2,]   0   1

$categories
[1] 0 1
> landis.koch.bf(0.94229, 0.02629)
Landis-Koch CumProb
(0.8 to 1)      Almost Perfect      1
(0.6 to 0.8)    Substantial          1
(0.4 to 0.6)    Moderate             1
(0.2 to 0.4)    Fair                 1
(0 to 0.2)     Slight                1
(-1 to 0)      Poor                  1

```

. (continued).

Appendix B. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.rtbm.2022.100856>.

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