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Lessons learned from system integration: A strategic synopsis

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Abstract

Learning from past experiences remains a key priority for industry and academia alike. Lessons learned are meant to facilitate this process of learning and are a well-known concept in project management, systems engineering, and knowledge management disciplines. However, given their embodied nature and presence in tacit and explicit forms, they are hard to acquire and fully realise through traditional means. This paper investigates lessons learned from system integration projects in the railway sector. System integration is an ongoing industrial challenge that is complex, multifaceted, hard to disentangle, and requires proper learning from prior experiences. By conducting an archival review and content analysis of thirty-seven documents (presented at an independent knowledge network), this paper investigates the frequency of ten key system integration patterns mentioned directly or indirectly at different interactive sessions (attended by a diverse group of stakeholders from multiple organisations). Consequently, the paper outlines five robust lessons learned to address these patterns. The underlying context of these lessons is also described to facilitate the development of appropriate approaches for their realisation. Finally, the paper discusses the implications of the presented lessons for policy making and systems performance management.

Keywords: Lessons learned; Best practices; System integration; Railways

1. Introduction

Learning from prior experiences is essential to optimise performances, continuously improve, and properly manage systems at a holistic level. The transportation sector operates in a complex environment where systems performance management requires proper learning from past experiences and open sharing of gained experiences. Challenges such as smooth integration of new technologies [1], project cost performance [2], effects of COVID19 policies on transportation system [3], and CO2 emission reduction [4] ask for an integral approach to organisational learning and systems management.

Lessons learned are recognised as a primary mode of transferring consolidated experiences and craftmanship across the transportation industry. Proper management of lessons learned has been advocated in project management [5], system engineering [6], and knowledge management [7] disciplines. Although lessons learned management faces challenges across multiples domains such as outlining key features and processes for lessons learned management [8], managing their tacit and explicit nature [9], and developing technological solutions for their incorporation in organisational processes, this paper focuses primarily on acquiring lessons learned from system integration in the transportation industry to facilitate continuous improvement. According to [10], the generic schema of organisational learning consists of a learning product (informational content), a learning process (acquiring, processing, and storing), and a learner. This paper uses this generic schema to draw lessons learned from system integration (learning product) by a structured document review (learning process) for transportation professionals busy with system integration (learner). The presented results will assist transportation organisations in advancing their system integration strategies and policy making for continuous improvement of system performance.

2. State of the art

Learning lessons is fundamental to organisational learning and continuous improvement. Academics and practitioners alike from a diverse group of disciplines have attempted to derive lessons, define their nature, develop models, artefacts, and strategies for their implementation and management. Although these disciplines may differ in their approaches towards disentangling the labyrinth of lessons learned they widely acknowledge their significance in improving current processes, achieving both long- and short-term goals, and facilitating innovation.

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Disciplines such as safety see lessons amongst others as a means of improving safety levels and preventing future incidents [11]. Project management sees lessons learned as an important knowledge topic that can be positive or negative, can provide competitive advantage [12], is critical to project success [5], and require a systematic approach and process for its implementation [13]. Similarly, knowledge management regards lessons learned as the knowledge that exists both in tacit and explicit dimensions [8], [14], is often overlooked when developing and implementing knowledge management strategies [15] and means of sharing project knowledge [7]. Furthermore, system engineering regards lessons learned as a means to improve organisational and project performance, advocates linking them to the process models used by organisations [6], and a medium for building team capabilities and solving issues [16].

This study specifically investigates the Lessons Learned from System Integration (LLSI). Traditionally system integration is part of the system development and realisation cycle and uses outputs of system definition to provide plans and criteria for combining created system elements [16]. ISO/IEC 15288:2015, a system engineering standard for system life cycle processes, defines system integration as the process that "iteratively combines implemented system elements to form complete or partial system configurations in order to build a product or service. It is used recursively for successive levels of the system hierarchy" [16]. Lessons learned from such system integration are hardly discussed in literature let alone structured approaches for their dissemination and management. This paper addresses this gap by outlining lessons learned from system integration in the railway sector as explained in the next section.

3. Methodology

The paper addresses the identified research gap by following a structured methodology for content analysis (inspired by the levels of abstraction proposed by [17]) as shown in Figure 1. It systematically analyses the content presented at different interactive sessions organised by Railforum, an independent knowledge network aimed at increasing the social and economic efficiency of rail transport hereon referred to as Knowledge Network.

First, an overview of available documents within the Knowledge Network's System Integration Knowledge Circle was obtained. Presentations, evaluation reports, and minutes of meetings of the core team were collected from the period 2017 to 2020. Documents relating to six interactive sessions were identified and collected. This was followed by a preliminary scanning of identified sixty-one documents to understand the content presented during these sessions to formulate a comprehensive content analysis strategy. In this regard, the relevance of these documents to the research themes of system integration and lessons learned was examined and frequently mentioned system integration patterns were identified. Based on the preliminary scan, ten system integration patterns were identified (as shown in Table 1) that formed the backbone of the content analysis strategy.

Frequency detection of these patterns and the extraction of lessons learned for addressing them were the core objectives of the formulated content analysis strategy. This was followed by a detailed scanning of sixty-one documents. This led to the exclusion of twenty-four documents, as they were either preparatory documents that were later used in main presentations or documents with a different focus than system integration and which dealt with issues related to the organisation of the sessions. Consequently, thirty-seven documents were carefully selected for coding. The coding was mainly aimed at identifying the frequency of outlined patterns and extracting lessons learned related to these patterns. A total of 109 codes was assigned using Atlas.ti (a qualitative data analysis software) which were further characterised into three categories, namely "System integration patterns" (ten codes, see Table 1), "Background knowledge on system integration and lessons learned" (sixty-one codes), "Lessons learned from system integration" (thirty-eight codes). Whereas the category "System integration patterns" assisted in prioritising between the outlined patterns, the category "Background knowledge on system integration and lessons learned" was used to describe the core research problem. Finally, the category "Lessons learned from system integration" was used to extract five robust lessons learned for addressing the outlined system integration patterns.

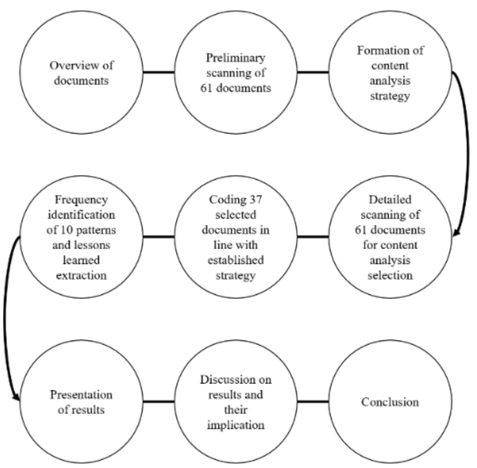

Fig. 1. The overview of followed research methodology.

4. Results and discussion

The determined frequency for identified system integration patterns is shown in Table 1.

Table 1. Frequency of outlined system integration patterns.

Pattern No.	System integration pattern	Frequency (n)
1	Subsystems are not managed in an integrated way	23
2	Nobody has an overview of the whole system and there is a need for collective wisdom	11
3	Funding is fragmented so that solutions in other parts of the system cannot be financed from other parts	9
4	Many decisions are taken using a top-down approach without involving the work floor	9
5	Problems with legislation and safety standards at the European and Dutch level	15
6	Shifting risks (due to changes in technology, policy, or regulations amongst others)	13
7	Different (development and test) life cycles of components in the system	8
8	Solutions are found or fixed too quickly without proper analysis of underlying causes	3
9	Cooperation deteriorates as soon as it gets tense	14
10	Lack of trust	5

To systematically connect the outlined system integration patterns with the derived lessons learned, a relationship map was created as shown in Figure 2. As indicated, each derived lesson was associated (based on similarity) with two patterns. A total of five lessons learned was identified after reviewing the codes in the "Lessons learned from system integration" code group.

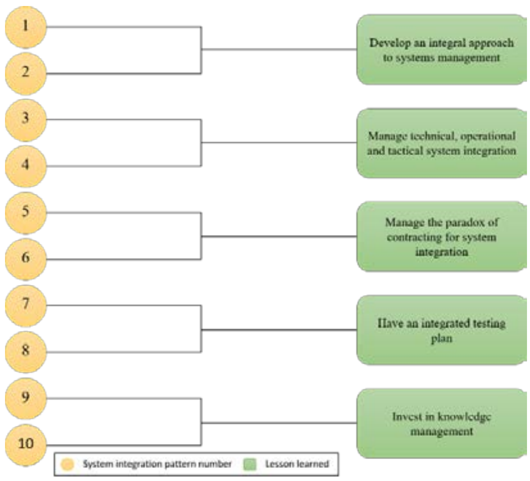

Fig. 2. Lessons learned relationship map.

4.1. Develop an integral approach to systems management

Developing an integral approach to systems management for complex system of systems (such as rail transportation), where the complexity arises not only from the systems themselves but also from the interdependencies between them, is not an easy task. In such an environment, viewing systems integration as a mere process in the systems development and realization cycle often leads to project delays and cost overruns. Instead, system integration should be approached more holistically by viewing it as part of overall systems management. The analysis revealed a number of facets that can be amongst others part of an integral approach. These include collaboration, modelling and structuring, systems management, knowledge management, and the role of policy makers, as shown in Figure 3.

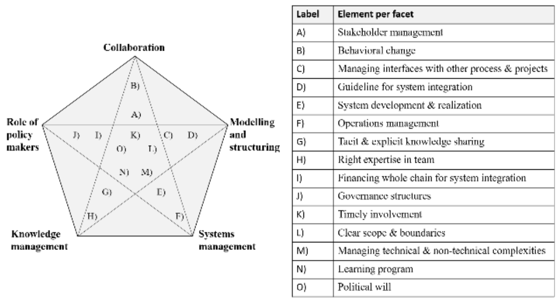

Fig. 3. Facets and elements of an integrated approach to systems management.

An integrated approach to systems management is not just about connecting technical threads, but even more about behavioural change. Collaboration at all levels within an organization, between organizations, and between the organizations and policy makers is a central element of the integrated approach. Being sensitive to intra- and inter-organizational politics and directing stakeholders accordingly can help build the relationships necessary for smooth integration. It was clear from the analysis conducted that not only more explicit guidelines for the application of system integration were desired, but also more attention to collaboration (i.e., more focus on behavioural change, among other things) across interfaces instead of the current predominant focus on structuring and modelling internal organizational processes.

A clear image, language, and conceptual framework for systems management can be achieved by developing context-specific models and structures that can serve as preconditions for building collaboration. However, **in terms of modelling it is important to realise the there is no**

one size fit all model (meaning there is no standard model that is appropriate for all situations). Participants in the Knowledge Network sessions suggested a focus on creating open models that can be tailored to different contexts rather than a single model, and on establishing appropriate links between the models developed.

Systems management includes not only systems development and realization cycles but also operational management. For the overall success of systems integration projects, it is of utmost importance to bridge the gap between the stakeholders involved in systems integration of new products and services and the end-users involved in operations management. This is traditionally done by testing products and services that have to be integrated to a certain extent in a live environment. In this regard, particular attention should be paid to the management of technical and non-technical complexities and to the development of robust approaches for contextualising established regulations and standards in organizational settings. Equally important is the ability to learn from previous experience and manage consolidated knowledge well. Participants in the Knowledge Network sessions suggested that smooth integration requires both explicit knowledge management (where a comprehensive requirements management program is developed, and specifications are harmonised) and tacit knowledge management (where consolidated lessons are properly shared and managed and a learning culture is developed to share experiences in a trustworthy and convenient manner).

Policy makers, mainly because of their financial role, play a bottleneck role in developing an integrated approach to system management. The analysis shows that separating system responsibilities in logical places is inevitable and has been legislated, but it is equally important to shape an integrated approach to managing the entire system by funding the entire system integration chain and demonstrating strong political will. There is a need to develop joint policies for the long-term development of the railroads and to establish governance structures to bridge the gap between the decision-makers and the people affected by the decisions. The analysis shows that policymakers are suggested to drive the integrability of the system by rewarding cooperation and collaboration through concessions. They also need to be involved not only in determining transportation needs but also in shaping technical services through regulation. Finally, policymakers must be aware of the implications for system users when making system choices, and the implications for project planning and control, and the relationship among organizations when making technical choices.

4.2. Manage technical, operational, and tactical system integration

System integration has traditionally been seen as the assembly of system elements into a complete system such that it meets its stated goals and results in a reliable and maintainable system [16]. The analysis revealed that the term systems integration is used in a much broader context in the rail industry. Although the term has its roots in this traditional definition, it is expanding to higher levels of operational and tactical integration. Given the interdependencies across system boundaries, various levels of system integration have been defined by the rail industry, such as all components within a single object, all objects within a subsystem, all subsystems within the transportation system concerning train track integration, and all subsystems within the transportation systems for all interfaces. In this context, the funding of the entire system integration chain by the responsible entities and the integration of the work floor into the decision-making process seem to be crucial elements.

Although it is now increasingly recognized that systems integration should be addressed as early as the design process, the costs and benefits of systems integration tend to be divided among different parties. Therefore, the authors suggest zooming out from the traditional technical view of systems integration and more toward operational and tactical systems integration which can help fill in the missing pieces in the systems integration puzzle. The analysis showed that developing specific models that can provide a holistic view of systems management help to manage the operational and tactical system integration. Similarly, while interoperability and requirements management are more meaningful for technical systems integration, awareness, behaviour change, and cultural integration are important for operational and tactical systems integration.

The authors also suggest that the goal of systems integration should not only be to combine system elements into a complete system, but also to improve system performance and promote innovation. In this regard, dividing system integration into different levels could potentially aid in defining objectives for each level. Conceptually, the **suggested tactical and operational system integration should aim to see opportunities for system integration at the whole system level and fund the complete chain of system integration**. It should also create opportunities to improve the learning capacity of the sector concerning different system integration projects through proactive knowledge sharing. The technical system, on the other hand, must ensure proper management of interfaces and pay due attention to the impact of technical solutions on the affordability and quality of overall system operation.

4.3. Manage the paradox of contracting for system integration

System integration is traditionally handled by defining specifications for different subsystems and system elements and awarding contracts to system suppliers. The terminologies “Client” and “Contractor” are commonly used in the business world for organising system integration and cooperation among them is considered necessary for smooth integration. More importantly, experiences shared in the Knowledge Network sessions revealed that the **ultimate responsibility of integration can not be outsourced**. This combined with frequent problems with legislation and safety standards (i.e., both at the national and international level) and shifting risks due to the introduction of new technologies, involvement of new subcontractors, and policy changes makes contracting for system integration quite complex. In this context, the organisation needs to actively manage the paradox of contracting for system integration as shown in Figure 4.

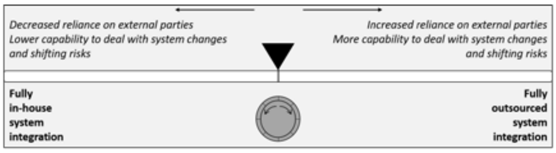

Fig. 4. The paradox of contracting system integration.

As indicated, organisations can, on the one hand, try to fully outsource system integration and, on the other hand, perform all system integration activities in-house. When system integration is fully outsourced, organisations end up with insufficient internal expertise and over-reliance on external contractors and consultants, who are often reluctant to take responsibility and remain passive in cooperation due to business interests. In contrast, when system integration is primarily done internally, organisations struggle to keep up with the pace of ongoing system changes and shifting risks (whether from technology, policy, or regulations) due to the ever-changing expertise required to address different situations.

This study highlights the need to proactively manage this paradox by investing more in co-contracting and building internal capabilities while paying close attention to what should and should not be done internally based on organisational performance goals. Similarly, the study suggests that organisations should broaden their circle of influence with the policy makers (i.e., both at the national and international level) by proactively communicating and sharing knowledge on contextual and procedural aspects of system integration.

4.4. Have an integrated testing plan

The core objectives of test operations during the system development and realisation cycle are to measure and achieve intended Key Performance Indicators (KPIs), validate project requirements, and obtain the agreed product or service. The analysis showed that a testing strategy, within the railway sector, traditionally follows a series of predefined tests, namely Factory Acceptance Test (FAT), integral FAT, integral Process and procedure Acceptance Test (iPAT), Site Acceptance Test (SAT), System Integration Test (SIT) I (part of the system), SIT II (complete system-dynamic), SIT III (processes and procedures), Integral Trial Operation (ITP), and Commercial Validation Test (CVT). These tests are performed sequentially, and the risk is expected to decrease with each successive test. In addition, the tests are ideally planned so that they do not overlap, and sufficient time is allocated for the tests to achieve acceptable exploitation starting level. However, experience in the railway sector has shown that test periods are usually carried out under extreme time pressure, with allocated test periods being shortened or several tests exceeding the allocated time, leading to several tests being carried out in parallel. It is suggested that, in addition to a timetable, **different scenarios should be developed to deal with unexpected delays**, as shown in figure 5. The study also shows that good collaboration between the client and the contractor, a good division of responsibilities in defined test protocols, and an early testing philosophy with the end-users can contribute to an integrated test plan for all components (with different development and test life cycles) of the transport system. Proper allocation of time and sensitivity to different scenarios can lead to a solution that results in fewer problems in system integration testing (i.e., both static and dynamic) in particular and testing strategy in general.

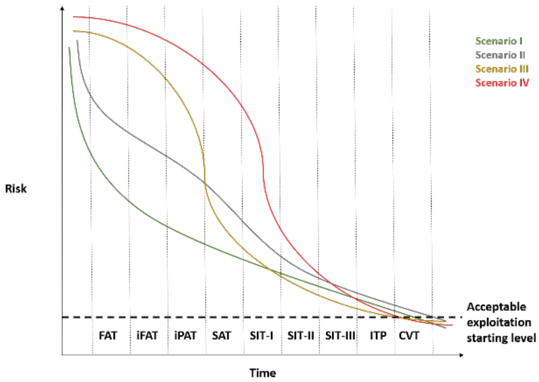

Fig. 5. Different scenarios for dealing with unexpected delays.

4.5. Invest in knowledge management

The analysis revealed that traditional knowledge management practices for systems integration (such as documentation and sharing of lessons learned reports) generally did not produce the desired learning outcomes. Rather than learning from past projects and using shared lessons, organizations often rediscovered lessons already known. It also showed that the focus on systems integration in the rail industry was mainly on the realization phase of the project, rather than paying continuous attention to it throughout the system life cycle. Deterioration of collaboration in tense situations and lack of trust point towards the need to invest in knowledge management.

From a knowledge management perspective, there is a need for a robust approach to sharing and managing lessons learned (i.e., from both technical and procedural aspects) and creating an open culture of knowledge sharing. While the **technology side of knowledge management should facilitate easy and timely access to stored information and knowledge experts**, the **non-technology side should help to create an enabling environment** where customers and contractors can readily collaborate and be motivated to share experiences and consolidated knowledge openly and reliably.

5. Conclusion

The paper provides an overview of five LLSI in the rail industry from an expert community. It shows that the term system integration is used much more widely in practice and requires not only technical root cause analyses but also attention to integrability, different levels, ownership, testing and knowledge management. Ten key system integration patterns were identified and their frequency within the six interactive sessions was examined. The results indicate that system integration is not just a technical process of combining implemented system elements but rather a philosophy where people need to closely work together with an integrated approach towards system development and realisation. The paper contributes to the academic and practical community by outlining five LLSI. These lessons lay the foundations for creating robust strategies for strategically managing systems integration. Future research may assess the validity of presented lessons within the railway and other transportation sectors.

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