Implementing RAMI4.0 in Production – a multi-case study

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Abstract. The Industry 4.0 (i4.0) paradigm was conceived bearing smart machines enabling capabilities, mostly through real-time communication both between smart equipment on a shop floor and decision-aiding software at the business level. This interoperability is achieved mostly through a reference architecture specifically designed for i4.0, which is aimed at devising the information architecture with real-time capabilities. From such architectures, the Reference Architectural Model for Industrie 4.0 (RAMI 4.0) is considered the preferred approach for implementation purposes, especially within Small and Medium Enterprises (SMEs). Nevertheless, the implementation of RAMI 4.0 is surrounded with great challenges when considering the current industrial landscape, which requires retrofitting of existing equipment and the various communication needs. Through three different case studies conducted within footwear and cork industries, this research proposes a RAMI 4.0 SME implementation methodology that considers the initial stages of equipment preparation to enable smart communications and capabilities. The result is a methodological route aimed for SMEs' implementation of smart machines, based on RAMI 4.0, which considers both the technological aspects as well as the business requirements.

Keywords: RAMI4.0, SMEs, Technology Implementation Management.

1 Introduction

The premise of Industry 4.0 (i4.0) is built around the paradigm of smart machines communication through a framework that ensures a constant flow of information throughout the levels of a given company. A backbone to help devise the i4.0 information architectures is the Reference Architectural Model for Industrie 4.0 (RAMI 4.0). However, the implementation of RAMI 4.0 has been challenging, since it relies on various factors which may affect or hinder the final output, such as the current industrial landscape, as well as the multiplicity of equipment within the factory, which have different sources, diverse construction and various communication capabilities [4].

Despite broad implementation in large industries, there is a lack of methodological management when it comes to implementing i4.0-enabled machinery on Small and Medium Enterprises (SMEs). More importantly, SMEs face a lack of resources combined with precise technological maturity assessment regarding relevant solutions, as well as practical business applications [2]. A crucial aspect surrounding these obstacles is the methodological management skills, supported by the lack of standardisation and regulations for technology implementation. Based on case studies conducted in the footwear and cork industries, this research devises a methodology to help SME manufacturers into preparing industrial equipment for a RAMI4.0 architecture [3]. Such methodology is supported by cyber-physical systems designed to integrate computational & physical processes with human interactions, aimed at establishing Key Performance Indicators (KPIs), which drive the Industry 4.0 implementation process [1].

2 The Reference Architectural Model for Industrie 4.0 (RAMI 4.0)

The i4.0 paradigm has brought forth new architectural challenges, which enable a higher degree of i4.0 approaches by the organizations [5, 6, 7]. Under the Plattform Industrie 4.0 [9], RAMI 4.0 is proposed to be a guide to support the implementation of i4.0-enabled systems architectures. It is represented as a three-dimensional layer model cube which encases the most important elements of the business and i4.0 technological novelty. RAMI 4.0 proposed architecture consists on having each entity of the business represented as a component, which exposes services, functionalities and communication channels. According to Ferreira et al. [8], there are challenges that arise when designing the i4.0 architecture. The first challenge is due to the necessity of defining the required business entities: how these entities participate during the value creation process can be challenging to map and requires the perception of the real implication within the value chain network. The second challenge pertains systems integration and interoperability. Existing hierarchical architectures based on the ISA 88/95 are the most commonly found throughout the industry [10, 11, 12]. Thus, it is necessary to have a clear grasp on how to transform/integrate new systems with existing legacy systems.

The German Engineering Federation has released a Guideline for i4.0 aimed at providing guiding principles for implementing i4.0 within SMEs [13]. A scheduled process coupled with constant feedback is considered crucial for the success of the i4.0 implementation [13]. Despite having produced such guiding principles, there is a lack of implementation studies on the literature that concern i4.0 for SMEs, especially with multiple iterations and a maturity assessment done prior to the implementation process [14]. This assessment must be performed during the business definition stage, and requires a multidisciplinary team that is comprised of business model decision-makers, i4.0 component implementation experts and data analysts, since its purpose is to design a business and technological implementation framework that considers business KPIs, available data gathered from equipment sensors, and retrofitting of machinery.

3 Research Methods

The methodology used for this research consists of a literature review and multi-case study analysis aimed at proposing a RAMI 4.0 implementation methodology for SMEs. In order to achieve the above mentioned implementation methodology, an analysis of the current RAMI 4.0 literature on implementation methodology protocols and guidelines focused on SMEs was conducted, which was combined with research on innovation developments regarding i4.0 reference architectures capable of combining technological aspects with business requirements. Moreover, identification of SME-based projects with implementation of RAMI 4.0 driven architectures was carried out.

4 RAMI 4.0 SME Implementation Methodology

RAMI 4.0 implementation methodologies have widespread as industries embrace the industry 4.0 paradigm. Most of these methodologies conduct a three layer assessment, business, technology and processes definition, such as business strategy definition, KPI definition, systems modelling, technology maturity, process re-engineering, human-resource training [2, 8, 14]. Based on existing RAMI 4.0 implementation methodologies, and implementation driven case studies, a RAMI 4.0 SME implementation methodology proposal is forwarded (Figure 1), which maintains the same core objective to support. However, obstacles such as low business preparation, huge variety of existent legacy systems, and multi-disciplinary outsourced teams means that a more flexible and controlled approach during the implementation process must be taken [6, 15].

The proposed methodology provides an overall view of the process, thus enabling the identification of key agents on each step (actors, resources, and drivers), the identification of the different layers that comprise the final solutions, the design of the necessary proof of concept (PoC) to stablish a pre-solution validation, as well as the identification of obstacles and possible blocking points.

For SMEs, two types of stakeholders were identified on a RAMI 4.0 implementation project: business stakeholders, and technology & process stakeholders. Business stakeholders provide the project’s core goals, objectives and requirements under a business view perspective, sourcing and choosing the required project stakeholders, a project management to meet project goals (project timeframe, budget, and quality), and project evaluation, which oversees the successful development, integration and implementation of each considered solution. On the other hand, technology & process stakeholders are comprised of experts from fields required for the implementation process (e.g.: process, automation, communication). The intent of these stakeholders concerns the analysis, integration and implementation of technological novelty brought by i4.0 premise in the industrial production processes.

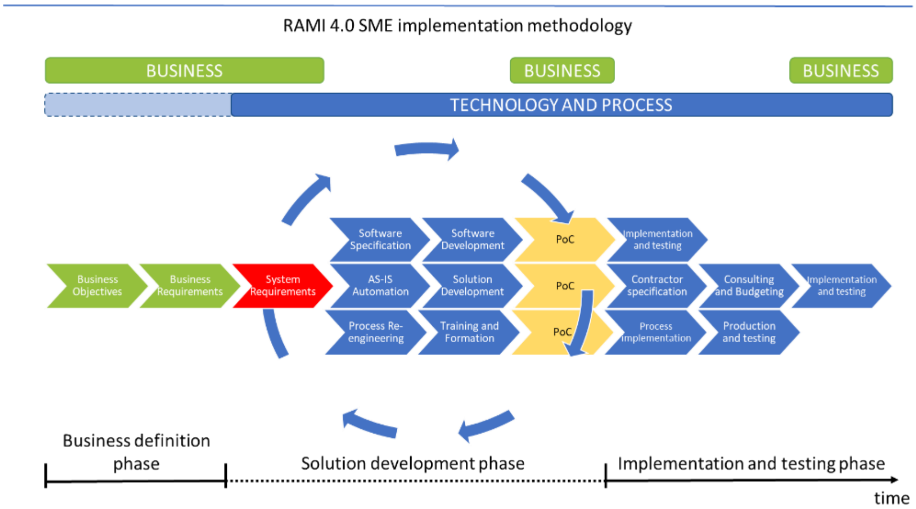

Fig. 1. RAMI 4.0 SME implementation methodology

When compared to previous methodologies, the application of PoC combined with iterative cycles during the solution development process, constitutes the main novelty of the proposed implementation methodology. In terms of approach, the methodology has three phases: business definition; solution development; and, implementation and testing. **Business definition** constitutes the baseline for the project. This phase is driven by the business expert, which embodies the business vision for the project and define the objectives and goals for the RAMI 4.0 implementation project. The choice of the stakeholders for the project, technical team and experts, should be the main objective at this stage. **Solution development** concerns the core of the methodology where the different layers of solution development take part. This phase follows an iterative cyclical approach, beginning with the system requirements definition, in which business experts discuss the business indicators and requirements with other project stakeholders. This discussion is essential as it will bring cohesion within the project with all stakeholders involved. The target of this step is to define a RAMI 4.0 architecture design adapted to the project and solutions. This step serves as a start and revision step during the iterative cycles. Having the stakeholders agreed with the system requirements, the technical development phase takes place for each required solution layer. Each layer develops a PoC of the proposed solutions, and its viability is assessed by both business and technology experts.After all solutions have been validated through a PoC and the RAMI 4.0 architecture agreed upon, the **implementation and testing** phase is initiated, where each of the proposed solutions is implemented and tested accordingly. Project management and business experts validate the final output and close the project. When considering the timeline of the project, it must be considered the length of each of the three phases that constitute this methodology. As it provides an iterative approach the solution provision can be adapted and revised in each cycle according to new information from stakeholders, avoid obstacles or solve roadblocks that could hinder, prolong or in worse scenarios, jeopardize the project timeline.

5 Multi-case study

The following three case studies applied different methodologies to implement RAMI 4.0 driven architectures. In terms of case-study typology, one case was under an industry-driven project targeting a specific industry as a whole, and the other two were business driven and performed as consulting services. A brief presentation of the Case Studies with regards to the target industry, project objectives, methodology applied and implementation stages is portrayed in Table 1.

Table 1. Presentation of the Case Studies (CS)

	CS 1	CS 2	CS 3
Industry	Footwear production	Cork transformation	Cork transformation
Project	Industry-driven implementation	Business-driven implementation	Business-driven implementation
Methodology	PoC	Waterfall	PoC and RAMI 4.0 SME Implementation
Implementation	Allowed to establish and consolidate the process on how new technology is implemented within the industry, technical and management requirement, coordination with multi-disciplinary and out-sourced teams.	I - project objectives, time frame, and budget II - business requirements and assessment of the production and support processes III - information on systems, infrastructure and automation levels IV - results from II and III sent to external automation consultant team V - implementation of the architecture proposed in IV VI - test and validation	- Outsourced experts defined the implementation project objectives and pre-determined the project length - Regular meetings to debate and check solution proposals, PoC definition and schedule industrial implementation and testing - PoC of solutions were developed for each layer of the RAMI 4.0 SME

In Case Study 1 (CS 1), a series of PoC was conducted to demonstrate the possible applications of i4.0 enabled architectures, such as RAMI 4.0, and technology in footwear SMEs. This case allowed to stablish and consolidate a general process of how i4.0 technology can be implemented. Also, it demonstrated how the implementation of RAMI 4.0 enabled architectures require parallel solution development cycles in order to tackle the different business, technological and processes layers.

Case Study 2 (CS 2) was conducted on a different company, which brought in teams experts from business and technology backgrounds to support the implementation project. However, these teams worked separately with reduced interaction and integration. The modularity concept of this methodology only had advantages on each phase separately, without an overall implementation view that incorporated both business indicators and technological capabilities. Thus, the company was not able to have feasibility and implementation feedback until the final solution was both proposed and implemented, constituting a major disadvantage since it was considered not viable for the company's initial goals.

In Case Study 3 (CS 3), teams of outsourced experts from business and technology fields were brought in since the start, contributing in defining the implementation project objectives and pre-determining the project length. Regular meetings were arranged and planned to de-bate and check solution proposals, PoC definition and schedule industrial implementation and testing. PoC of solution were developed for each implemented layer of the RAMI 4.0, such as process, automation, communication, information systems.

5.1 Discussion

The presented case studies provided inputs to understand the implementation of RAMI 4.0 enabled architectures in SME production settings. CS 1 contributed with the success of the PoC approach since it demonstrated possible implementation solutions of the various RAMI 4.0 layers. Also, this approach allowed multidisciplinary teams to work together with a global intent. CS 2 and CS 3 were similar implementation projects. However, they differ on the methodological approach taken: waterfall methodology (CS 2), and PoC with an industrial implementation objective (CS 3).

As seen in Table 2, the output in terms of qualitative parameters were more controlled and successful in CS 3 when compared with CS 2. A higher interaction among stakeholders and the development of PoC for solutions with iterative cycles provided quick gains and drove the implementation project towards its initial objectives.

Table 2. Comparison between Case Studies (CS).

Qualitative parameters	CS 1	CS 2	CS 3
Objectives	Reached	Changed	Adapted and reached
Length	Followed	Overpassed	Followed
Team participation	Start of project	Modular and scarce	Start of project
Team cohesion	Collaborative environment	Low interaction	Collaborative environment
Solution development	Iterative development	Long and unclear direction	Iterative solution, quick wins with peer validation
Solution quality	Proof of Concept (PoC)	Unclear/ undefined	PoC validated towards industrial implementation

6 Conclusions

The introduction of PoCs as a means to validate the designed i4.0 solutions, which enable scalability capabilities for widespread implementation of i4.0 componentry, is considered the major novelty of the proposed RAMi 4.0 SME implementation methodology. Furthermore, these PoCs are intended to demonstrate the integration between the different RAMI 4.0 layers: asset, integration, communication, information, functional and business.

The correct definition of the KPIs based on the business requirements, while considering technological limitations, ensures that a complete and clear implementation process is agreed upon by all stakeholders of the project, which allow for better expected outputs in terms of RAMI4.0 implementation. The correct understanding of the implementation procedure enables the experts of each solution layer to provide possible and feasible PoC solutions, thus producing the desirable outcome. Another relevant point concerns the overall alignment, where the project objectives and goals must adapt to business requirements and remain technologically feasible to the project management.

Future research on this field may apply the proposed RAMI 4.0 SME implementation methodology on other manufacturing sectors, and service-directed industries, aimed at better evaluating the extension of this implementation methodology. Furthermore, an effort to better assess i4.0 implementation costs and trade-offs with existing machinery is necessary, so that SMEs decision-makers can have better tools and more reliable information when deciding upon implementation actions.

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References

1. Barros, A. C., Simões, A. C., Toscano, C., Marques, A., Rodrigues, J. C., & Azevedo, A. (2017). Implementing Cyber-Physical Systems in Manufacturing. CIE47 Proceeding. Lisbon, Portugal.
2. Schröder, C. (2016). The Challenges of Industry 4.0 for Small and Medium-sized Enterprises. Bonn, Germany: Friedrich-Ebert-Stiftung.
3. Yin, D. R. K. (2009). Case Study Research: Design and Methods. Sage Publications (CA).

4. Wang, L., Törngren, M., Onori, M. (2015). Current status and advancement of cyber-physical systems in manufacturing. Journal of Manufacturing Systems, V. 37, Part 2, pp. 517-527, ISSN 0278-6125.
5. Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S., Reinhart, G., ... & Ueda, K. (2016). Cyber-physical systems in manufacturing. CIRP Annals, 65(2), 621-641.
6. Jbair, M., Ahmad, B., Mus' ab H, A., & Harrison, R. (2018, May). Industrial cyber physical systems: A survey for control-engineering tools. In 2018 IEEE Industrial Cyber-Physical Systems (ICPS) (pp. 270-276). IEEE.
7. Sachin S. Kamble, Angappa Gunasekaran, Rohit Sharma (2018) Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry, Computers in Industry, Volume 101, Pages 107-119, ISSN 0166-3615, https://doi.org/10.1016/j.compind.2018.06.004
8. Ferreira, F., Faria, J., Azevedo, A., & Marques, A. L. (2016, October). Industry 4.0 as enabler for effective manufacturing virtual enterprises. In Working Con-ference on Virtual Enterprises (pp. 274-285). Springer, Cham.
9. VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik. (2015). Status Report:Reference Architecture Model Industrie 4.0 (RAMI4.0) (Vol. 0).
10. Instrument Society of America (ISA). ISA-88.01 Batch Control Systems, Part 1. Models and Terminology, ISA Standards, 1995.
11. Instrument Society of America (ISA). ISA-95.01 Enterprise-control System Integra-tion, Part 1. Models and Terminology, ISA Standards, 1999.
12. SCHOLTEN, Bianca. Integrating ISA-88 and ISA-95. ISA EXPO 2007, p. 13, 2007.
13. R. Anderl, A. Picard, Y. Wang, J. Fleischer, S. Dosch, B. Klee, J. Bauer, “Guideline Industrie 4.0 - Guiding principles for the implementation of Industrie 4.0 in small and medium sized businesses,” VDMA Forum Industrie 4.0, Frankfurt, 2015.
14. Anderl, R. (2016). Industrie 4.0–Digital transformation in product engineering and production. In 21st International Seminar on High Technology-Smart Products and Smart Production. At Piracicaba (SP), Brazil.
15. Liao, Y., Deschamps, F., Loures, E. D. F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. International Journal of Production.