The Industry 4.0 Journey: Start the Learning Journey with the Reference Architecture Model Industry 4.0

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Abstract. The wave of the fourth industrial revolution (Industry 4.0) is breaking on manufacturing companies. In manufacturing, one of the buzzwords of the moment is "Smart production". Smart production involves manufacturing equipment with many sensors that can generate and transmit large amounts of data. Data and information from manufacturing operations are however not used by most manufacturing companies and this impedes organizational learning. To address this problem, the authors applied in a Smart Production Laboratory the International Electrotechnical Commission (IEC) Reference Architecture Model Industry 4.0 (RAMI4.0) standard for Smart production. The instantiation contributed to organizational learning in the laboratory by collecting and sharing up-to-date information concerning manufacturing equipment.

Keywords: Digital Manufacturing, RAMI4.0, Enterprise Architecture.

1. Introduction

"The fundamental purpose of Industry 4.0 is to facilitate cooperation and collaboration between technical objects" [1]. The novelty introduced by Industry 4.0 is the communication capability of new products and new production equipment. German public and private institutions developed the Reference Architecture Model Industry 4.0 (RAMI4.0) that provides a common vocabulary and structure to describe Smart Production (Industry 4.0 components). In March 2017, the International Electrotechnical Commission (IEC) adopted RAMI4.0 as a Publicly Available Specification for Smart manufacturing (IEC PAS 63088:2017).

From informal interviews, the authors acknowledged that Danish manufacturing companies are underutilizing the Industry 4.0 components. In fact, the data and information of manufacturing operations generated is stored but it is not shared or used in the organization. This impedes organizational learning to take place preventing the organization to improve their manufacturing operations.

Organizational learning is intended as "the process by which new knowledge or insights are developed by a firm" [2]. It is divided in four consecutive sub processes:

information acquisition, information dissemination, shared interpretation, and development of organizational memory [5]. From the authors' understanding, most of the Danish manufacturing companies fail at the information dissemination, therefore blocking the organizational learning process. The goal of this project is to enable information dissemination in the organization and therefore allow the organizational learning process to progress by applying a standard framework. The authors chose RAMI4.0 because of its importance in the manufacturing industry. The research questions are:

1. How does an instantiation of the RAMI4.0 contribute to organizational learning?
2. How does an instantiation of the RAMI4.0 contribute to the information dissemination sub process?

To assess these research questions, the authors conducted a project where they modelled the Smart Production Laboratory ("Lab" in the remaining of the paper) at Aalborg University using the RAMI4.0. The Lab includes fully automated conveyor belt modules with mounted on top manufacturing equipment. In addition to contributing to organizational learning, the authors are presenting in this project the first instantiation of RAMI4.0. At the time of writing, to the authors' knowledge no application of the RAMI4.0 was published in journals or conference proceedings. Therefore, this paper is the first to demonstrate RAMI4.0 application. Related work includes, Langmann et al. with [3] and who have modelled a manufacturing equipment as an Industry 4.0 component, and Pauker et al. with [4] who propose an approach for information model design in Industry 4.0.

Applying a design science based research methodology, the authors developed the instantiation and the preliminary results of its application show that RAMI4.0 contributes to organizational learning by collecting all the knowledge related to manufacturing equipment and by providing up-to-date and exhaustive information related to it.

This paper continues with a description of the RAMI4.0 and organizational learning literature. Subsequently, the authors present the Lab where they applied RAMI4.0. Following, the methodology and the artefacts sections. The paper concludes presenting the results and a discussion.

2. Literature

2.1. Reference Architecture Model Industry 4.0

RAMI4.0 [1] provides a structure for describing different aspects of an asset. An asset is defined as an "object which has a value for an organization" [1], which therefore not only means physically tangible objects, but also intangible objects such as ideas, archives and software. An asset is not necessarily an I4.0 component: "only if it is an entity, has at least passive communication capability and has been equipped with an 'administration shell' does an asset become an I4.0 component" [1]. One of the goals of RAMI4.0 is to facilitate the understanding of an asset by analysing it using three dimensions: (1) architecture axis, (2) life cycle and value stream, and (3) hierarchy levels. The goal is to reduce the complexity of analysis of an asset to more manageable sections and at the same time provide a holistic view of it. Due to space constraints, the presentation will focus more on the first dimension because of its relevance for designing the models. More information related to the other two dimensions is available in the standard [1].

First, the architecture axis dimension structures the asset's properties and functions specifying its relation to the different aspects. In the RAMI4.0 these aspects are organized in six layers [1]:

- The business layer describes the commercial view of an asset and it includes:
  - Organizational boundary conditions (such as order commissioning and general ordering conditions), monetary conditions (price, availability of resources, discounts), legal and regulatory conditions;
  - Business models, business processes, service orchestration and their relationship.
- The functional layer describes the logical and technical functions of an asset by:
  - providing a digital description of its functions and a platform for horizontal integration among assets' functions;
  - models with runtime data of processes, functions and applications.
- The information layer describes the data related to the technical functionality of an asset. These data are divided between:
  - non-real-time data, like execution rules, data integration rules, and interfaces for structured data transmission;
  - real-time data, such as production data and events that impact the functional layer.
- The communication layer describes "the access to information and functions of a connected asset by other assets" [1]. This layer specifies "which data is used, where it is used and when it is distributed" [1]. Communication between assets requires the use of a uniform data format among the different assets combined with a "data publishing services" to make the data available. The publishing service is a core concept of Service-Oriented Architecture (SOA).
- The integration layer documents the relation from the physical world to the information world, changes in the physical world need to be represented in the information world. It includes the infrastructure (e.g. field buses, RFID and QR codes) necessary to implement a function, as well as the properties and process-related functions required to use an asset in the intended way.
- The asset layer digitally represents physical assets, for example production equipment or product part. For every asset represented in this layer there must be a virtual representation in the above layers. Among the physical assets, this layer includes the digital interface with humans and the relationship to elements in the integration layer.

The second dimension, the life cycle and value stream dimension is concerned with the asset's general information and its individual information. The general information relate to the asset's characteristics that are common to all types of that asset (e.g. product part ID). The individual information relate to the properties of an individual instance of that type of asset (e.g. product serial number).

The third dimension, the hierarchy levels relate to the factory physical location or level of analysis. Starting from the lower levels, the product and field device levels represent the elements involved with performing the manufacturing activity. Extending the scope, the control device, station, work centres and enterprise levels identify the asset's location with an increasing abstraction level. The connected world level is the most extended level and it describes the relationship between assets in different enterprises (or companies).

RAMI4.0 describes "a reference architecture model in the form of a cubic layer model, which shows technical objects (assets) in the form of layers, and allows them to be described, tracked over their entire lifetime (or "vita") and assigned to technical and/or organizational hierarchies" [1]. It also describes "the structure and function of Industry 4.0 components as essential parts of the virtual representation of assets" [1].

2.2. Organizational learning

At its basic level, organizational learning is "the process by which new knowledge or insights are developed by a firm" [2]. In organizational learning literature, this process is generally perceived as four sub processes [5]: information acquisition, information dissemination, shared interpretation, and development of organizational memory.

First, the information acquisition process allows organizations to actively look for and gather useable information [2]. For this sub process there are three distinct sources [5]: direct experience, experience of others, and organization's own memory mechanisms. Once information is acquired by organizations, through the information dissemination process it is "distributed to those individuals who need it in order for the learning process to be effective" [2]. After the information is disseminated, consensus as to the meaning of the information evolves in the organization [2]. This process, known as the shared interpretation process, refers to the presence of consensus among organizational members with regard to the meaning of information [5]. Finally, the organizational memory process "refers to the amount of stored information or experience an organization has about a particular phenomenon" [6]. This last process provides first "a foundation for change through generative learning processes, and second, it can have a significant impact on the learning process by influencing the type of information that is sought and the manner in which the information is analysed" [5].

To the authors knowledge, the contribution of reference or architectural models has not been researched in the organizational learning field. Through the application of RAMI4.0 the authors intend to demonstrate possible contribution to organizational learning.

3. Methodology

The goal of this project was to develop an instance of the RAMI4.0, and assess its contribution to organizational learning. To the authors, applying design-science research methodology for information systems [7] is the most appropriate choice because it "focuses on the creation and evaluation of innovative IT artefacts that enable organizations to address important information related tasks" [7]. The four main steps of this project were [8]: problem identification, definition of objectives of the artefact, design and development of the artefact, and demonstration of the artefact. Due to time constrains, the authors did not perform a formal evaluation of the solution but they demonstrated its contribution to the organizational learning field. The project involved the Lab manager because of his unique knowledge on the Lab activities.

3.1. Problem identification

To identify the specific research problem, the first author interviewed the manager to understand the challenges and problems affecting people doing research at the Lab.

Based on the interview, the authors focused on two problems experienced also by Danish manufacturing companies related to the information dissemination sub-process. The first one is the lack of shared access to information about the production line (e.g. modules errors). This problem is related to the information dissemination process because the information generated by the modules of the production line is accessible only locally through the Manufacturing Execution System (MES).

The second problem involves the new knowledge created by the students and researchers – in the form of tutorials, student reports, guidelines and so on – which is either not shared or is shared during biweekly student meetings. As the manager explained, "the only way somebody would know that it [the documentation] exists is by coming to this biweekly meeting where hopefully they [a student group] can say *we plan to do something like this* and he [a student from another group] can say *I actually did it [I will send you my last semester report]*". This problem also relates to the information dissemination process because information is disseminated in an unstructured way.

3.2. Definition of the objectives of the artefact

The problems were addressed with two solutions, included in the artefact, to distinguish between dissemination of automated information versus dissemination of human generated information. To address the first problem, solution 1 should enable the communication of information generated autonomously by the production systems (e.g. error information) to those individuals who need it (e.g. Lab manager). To address the second problem, solution 2 should enable the communication of human generated information (e.g. tutorials made by a student) to those individuals who need it (e.g. student group).

3.3. Design and development of the artefact

The authors designed the artefact modelling the Lab applying the RAMI4.0 based on the standard specifications [1] summarized above. QualiWare Enterprise Architecture Platform [9] was used since it provides an extensive set of modelling features that facilitate the modelling of the different elements in the Lab. When modelling, the authors adopted both top-down and bottom-up approaches [10]. These approaches are used in SOA modelling so that high-level business aspects are modelled while capturing also the low-level aspects, and the relation between the high- and low-level elements [10]. The top-down approach consisted in modelling first the business and functional layers of the RAMI4.0. In the bottom-up approach, the authors modelled in order the asset, integration and communication layers. Alternating the two approaches, the authors completed the models required to apply the RAMI4.0.

3.4. Smart Production Laboratory

This project involved Aalborg University's Smart Production Laboratory. This research facility includes a fully automated small production line (fig. 1a) integrating and demonstrating various Industry 4.0 concepts and technologies. The elements relevant for this project are the FESTOs CP factory and the process modules. The FESTO CP factory are transportation modules (linear conveyor belts) that form a small modular and expandable factory with Industry 4.0 technologies. These modules are connected to the MES, the system managing the production process, and to a data storing cloud platform. On top of the linear conveyor belt there are the process modules, for example drilling module, inspection module, and assembly module. These modules are performing the manufacturing activities on the products.

The Lab produces a simplified mobile phone (see fig 1b) that is transported by the conveyor belt using a carrier (see fig 1c). This phone is composed of four parts: back-cover, top-cover, circuit board, and fuses.

Due to time constraints, among the different production activities in the Lab, the authors focused on the back-cover drilling activity.

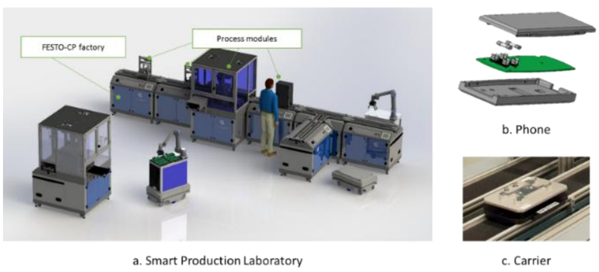

Fig. 1. Overview of the Smart Production Lab

3.5. Demonstration of the artefact

Continuing with the design-science methodology [8], the authors investigated whether the artefact contributed to the whole organizational learning process and to solve the two problems related to the information dissemination sub process. In a second meeting with the manager, the first author presented the instantiation of the RAMI4.0 of the Lab. All the models and solutions created were shown to the manager. Afterwards, the first author interviewed the manager using an interview guide with open-ended questions. It was divided into five sections: one for each of the four sub processes of organizational learning and a final one about the organizational learning process. For assessing the success of the artefact, the authors analysed the interview transcript identifying relevant quotes from the manager.

At the time of writing, the authors completed one iteration of the design research methodology. The artefact designed is presented in the next section.

4. Artefact

The authors developed as artefact an instantiation of the RAMI4.0. For each layer of RAMI4.0, the authors designed at least one model of the layer's architecture which connected to the life cycle and value stream as well as to hierarchical elements. Based on these models, the authors developed specific features for the two solutions. The first solution focused on the development of the functionalities in the QualiWare platform required to include close to real-time production data from the MES in the models. The second solution used existing functionalities of the platform to link external documents to the models.

4.1. Application of RAMI4.0 at Aalborg University Smart Production Lab

This subsection starts with a description of the models created for each layer of the RAMI4.0. It concludes with a more detailed presentation of the process model that was key for solving the two problems. A better version of the figures is available at https://coe.qualiware.com/lab/.

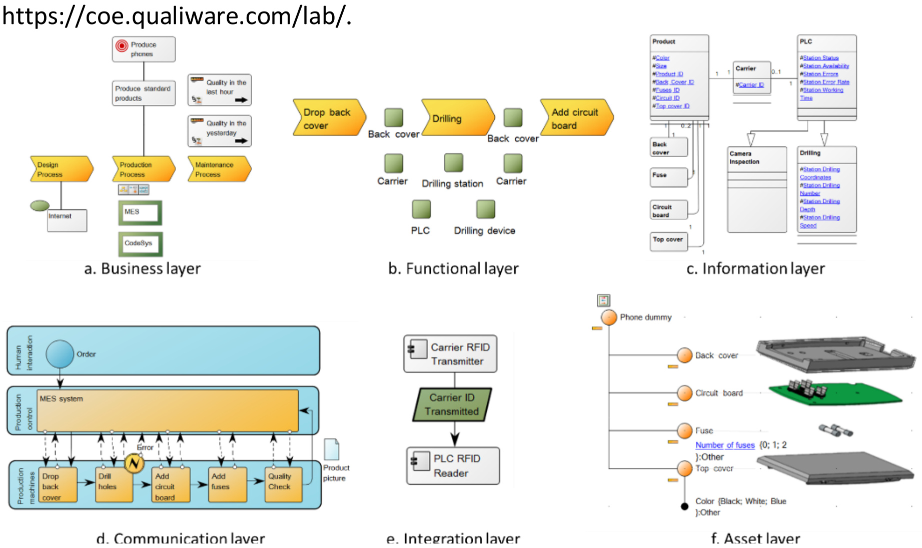

Fig. 2. Overview of the models in the layers

The information related to the *business layer* (fig. 2a) of the RAMI4.0 is represented in the strategic model. Starting from the top it includes: business goals of producing phones, linked to the capability of producing standard phones, also linked to the production process for producing phones. Information pertaining to the *functional layer* (fig. 2b) is represented in the process model. It includes the flow of activities, the equipment and the product parts required to produce a phone. The *information layer* (fig. 2c) focuses on the data related to assets. A data model diagram represented for each physical asset – back-cover, product, carrier, plc, drilling equipment – its parameters and attributes in individual classes. The content of the *communication layer* (fig. 2d) presents in the application model. Within the context of the drilling process, the application model describes the interaction between the MES system and the PLC application of the drilling station, and the message flow. Continuing with the *integration layer* (fig. 2e), the physical interaction between the carrier and the PLC is documented through the infrastructure and communication model. Finally, information about the *asset layer* (fig. 2f) is presented in the product model. The first model presents the production line equipment, while the second one describes the phone and its parts.

The process model includes the flow of activities, equipment and product parts required to produce a phone. Focusing on the drilling activity, one back-cover on a carrier is the input for the activity that produces as output the back-cover with holes on a carrier. This activity is performed at the drilling station, which is composed of one FESTO PLC and one drilling device. This model distinguishes between life cycle and value stream dimensions. What was described above refers to general activity of drilling, while specific drilling data from the equipment in the lab is available in tables in QualiWare Platform that are accessible by clicking on the drilling activity box (fig. 3).

4.2. Solution 1 – Autonomously generated information

The first solution focused on the drilling activity and it required the creation of three new elements in the QualiWare platform that involved an integration with the MES: one table with the last ten errors (fig. 3d), one table with the last 10 products manufactured (fig. 3c), a modified version of the production process model (fig. 3b). The tables contained partly invented and partly simulated data. For the last ten errors, the error table presented the Error ID (e.g. emergency stop button being pressed or loss of connection between the module and the MES system), the last product ID elaborated by the module and the time stamp. For the last ten parts produced by the module, the production table showed the order number, the product ID, the time stamp, when the activity started and ended (the last two columns are not represented in the figure due to space constrains). The production process model was modified by highlighting in red the activity with a problem and the equipment that generated the problem.

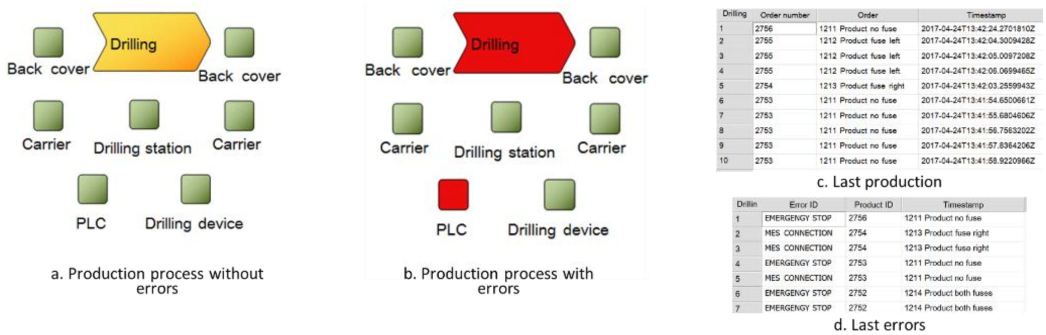

Fig. 3. Drilling activity in the process model

All these models were linked to the drilling activity in the production process model. At the moment of writing, QualiWare and the authors are still working on autonomously update this model.

4.3. Solution 2 – Human generated information

Solution two involved the creation of links between the drilling activity in the process model and external resources. The links, Uniform Resource Locator (URL), pointed to: an online video (fig. 4a) demonstrating how the drilling module operates, a student report in stored in the university project database (fig. 4b), and a document with guidelines (fig. 4c) available on a shared document platform.

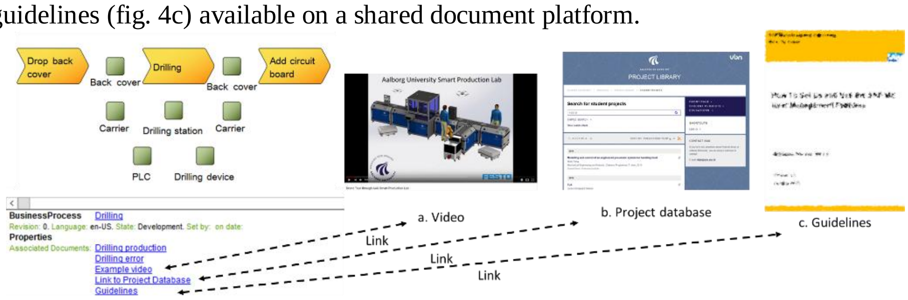

Fig. 4. External resources linked to the model

5. Results

The goal of this paper was to identify how an instantiation of RAMI4.0 contributes to organizational learning and to the information dissemination sub-process. RAMI4.0 contributed to the overall organizational learning process by helping the Lab manager to “keep track of how things are connected, [… and] figuring out what exactly is that I’m looking for.” In addition, the instantiation “is also a very nice way of communication to other people, new people, […] how it [the production line] works”. The models “provide the linking, the association between a certain student project, or video […] and a certain resource.” RAMI4.0 “is effectively a way of collecting all the knowledge we have about the system [production line].” It contributes to organizational learning “by providing me [manager] with up to date information, and all the relevant information.”

Solution 1 contributed to the information dissemination process enabling the manager to “resolve the errors much faster because probably here [in the models] I can see what is making the error and what is the cause of the error”.

Solution 2 contributed to information dissemination “when training new people this [RAMI4.0 instantiation] is a very valuable way. […] It gives an overview what is actually the process of it [production process].” In addition, it allows researchers to “know something about how I am supposed to use this one [the drilling module], what I can do, what I can’t do”. The link feature in solution 2 “is exactly how we could disseminate some of the information to them [students working in the Lab]. By simply providing them with easy access to the information”.

6. Discussion & Conclusion

In this paper, the authors presented an instantiation of the RAMI4.0 to demonstrate its contribution to organizational learning. Through this instantiation at the Lab at Aalborg University, the authors demonstrated that reference models contribute to the information disseminations sub-process. The solutions allowed to share autonomously and human generated information (e.g. respectively machine errors and equipment guidelines). Reference models contributed to organizational learning by collecting relevant knowledge about a specific context (e.g. manufacturing equipment) and providing it when need it. In addition, reference models facilitated the explanation of how the production line works.

The two major limitations of this project are to have implemented the reference architecture model in a research laboratory and not in an industrial context, and to do not have fully automated the integration with the MES system. As next step, the authors plan to apply RAMI4.0 in manufacturing companies to make industrial demonstrators.

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