A Pilot Study of Industry 4.0 Asset Interoperability Challenges in an Industry 4.0 Laboratory

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Abstract - **System integration is a crucial concept in the Industry 4.0 (I4.0) vision, where information processes supporting flexible production are digital. System integration paves the way for leveraging the Industrial Internet of Things, big data analysis, simulation, cloud computing, and augmented reality. The first step towards system integration is to examine the assets (machine software) ability to exchange information in an I4.0 setting. This paper aims to analyze challenges for asset interoperability by conducting asset integration in the University I4.0 laboratory (I4.0 lab). Conducting asset integration has been a part of building an Information Backbone (IB) as a minimum viable product in the I4.0 lab. An IB is a software infrastructure that involves integrating into various assets, e.g., warehouse, transport, and robotic systems, and providing communication among them. The pilot study reveals that the maturity of assets interoperability readiness are at very different levels, e.g. missing external interfaces, poor documentation, and varying technologies. These challenges need to be further addressed to collect architectural requirements for system integration, and establish a common vocabulary and understanding of I4.0 concepts.**

Keywords - **Information Processing and Engineering, Industry 4.0, Challenges, Asset interoperability, System Integration, Software infrastructure, Flexible Robots, IIoT**

I. INTRODUCTION

The industry is currently entering the fourth industrial (I4.0) revolution, where new opportunities are introduced through Industrial Internet of Things (IIoT), big data analysis, simulation, cloud computing, augmented reality, and communication technology infrastructure [24,10]. The report "*Winning The Industry 4.0 Race*" [1] recommends raising awareness of the technologies and helping the industry adopt the technologies through demonstration centers. Leading software platform providers, technology vendors, and end-users [4,2,23,7,9,11] raise the need for increased awareness and use of the technologies to achieve seamless vertical and horizontal integration [1].

A. Industry 4.0

In [22], I4.0 is defined as a new level of organization and control over the entire value chain of the life cycle of products that is geared towards increasingly individualized customer requirements. In [1], I4.0 is defined as linking machines, products, processes, and systems together in real-time. Both definitions emphasize the need for digitalization and integration within the company and the entire supply chain, and the ability to handle changing requirements in an unpredictable environment in flexible production. In the I4.0 paradigm interaction between devices and components can be visualized as a social network that transcends the boundaries in the traditional hierarchical automation pyramid [12]. Fig. 1 shows the shift from a hierarchical to a network oriented flow of information.

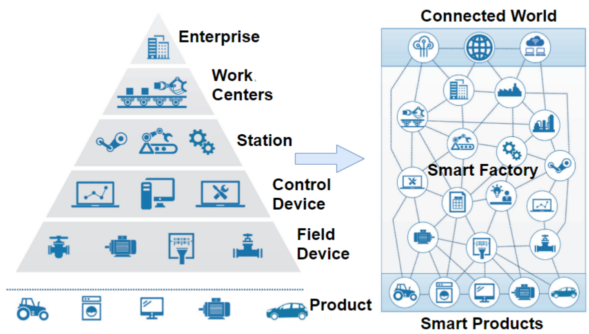

Fig. 1 The traditional hierarchical automation pyramid and the I4.0 network constructed model [14].

Interoperability is not seen as critical in the hierarchical automation pyramid [8]. In comparison, in a network construction, the interoperability of I4.0 assets is crucial in achieving the potential of I4.0. Different assets need to be investigated for interoperability and the use of different software technologies [6]. An asset in this context refers to the software that controls the physical machine, e.g., warehouse systems, transport systems, and production cells, and interoperability refers to how two or more systems exchange meaningful information [3]. In [25] barriers to interoperability in control systems means that communication between systems can be challenged by obstacles such as connectivity readiness. This imposes the need for more knowledge about assets interoperability.

B. Industry 4.0 drivers

Industry 4.0 is characterized by drivers who are fundamental for realizing the potential of I4.0 [1]. A description of six drivers follows, which rely on information processing and interoperability on multiple

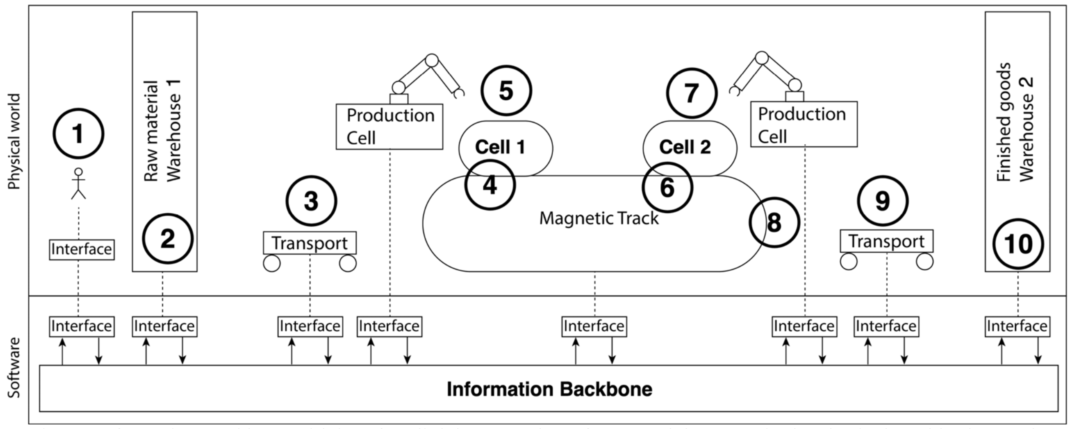

Fig. 2. Information Backbone with interface link between the software and the assets in the physical world. The numbers represent the production sequence in the experiment.

levels in manufacturing.

IIoT. New opportunities arise from using sensor data in an industrial context that supports production efficiency, e.g. in the planning and control of machines, inventory management, and tracking of products [22]. In I4.0, IIoT is defined as industrial products such as components and machines connected to the internet to optimize production [16]. The definition states that all production systems are accessible connected "things", improving production efficiency and big data analysis.

Big data analysis. The amount of data is expected to increase exponentially due to a growing number of sensors that capture data from the physical environment [17]. In [16], big data is defined as large volumes of high velocity, complex and variable data requiring advanced techniques to enable the capture, storage, distribution, management, and analysis of the information. The definition states that a vast amount of data will be generated that needs to be stored and analyzed to support a variety of decision-making applications, e.g., simulation or machine learning.

Simulation. Simulation is a way to mirror the physical world in a virtual world, thereby gaining a deeper understanding of the dynamics of the system [22]. In [18], simulation is defined as the imitation of the operation of a real-world process or system over time, allowing insight into complex systems where concepts can be validated, without disrupting the running system. The definition states that simulation allows testing of manufacturing processes and configurations to optimize downtime and production errors without implementing it on the real system.

Cloud computing. Computing resources will have a central role with the increased need for data sharing and the need for low response times. Cloud is a technology offering computing resources on demand. It is an alternative for those companies that do not want or can afford to run their hosting. NIST (National Institute of Standards and Technology) defines the cloud as resource pooling with rapid elasticity and measured service, on-demand self-service, and broad network access [19]. The definition states that the cloud is a flexible computing resource, capable of serving both small and large manufacturing needs.

Augmented Reality. There will be a growing need for guidance or assistance without being physically present to solve tasks. In I4.0, AR is defined as digitally processed reality with digitally added artificial objects within the scene, that opens new possibilities for solving tasks [16]. The definition states that by merging real world objects with an overlay of virtual objects in the same view, new opportunities open within the industrial environment and manufacturing field. It makes it possible to get interactively 3D support, enhancing human performances e.g., in maintenance work.

II. PROBLEM AND METHODLOGY

The drivers have a significant impact on realizing the potential of I4.0. The university has invested in an I4.0 lab with state-of-the-art equipment to support experimenting and knowledge sharing regarding the challenges of adopting the potential of I4.0 in a production environment. The I4.0 lab sets requirements for system integration to achieve interconnection between assets and the surrounding software systems, which has a fundamental impact on information processing in a heterogeneous environment to exploit the potential of I4.0 drivers.

Currently, more examination of asset interoperability is needed to facilitate effective communication between systems and move towards the goal of a flexible production process supported and enabled by the drivers. In order to analyze the feasibility of effective system integration, the following question is proposed: *What are the interoperability challenges the I4.0 pilot study reveals?*

To accommodate technical and organizational learning, industry collaboration, and knowledge building an agile approach has driven the workflow. Through three one-month iterations the requirements for the asset's interfaces and communication have been analyzed.

By conducting a pilot study, a preliminary study is carried out to get valuable insight into how assets in an

I4.0 lab exchange meaningful information. The pilot study evaluates an I4.0 case and experiences with asset interface information leading to interoperability challenges. The study is carried out in approximately three months before a full-scale information backbone (IB) project.

The following sections are structured as follows. Section II presents related work and shortcomings, followed by section III, introducing the I4.0 case which focuses on the interoperability of the examined assets. Section IV presents asset interoperability challenges, followed by a discussion in section V.

III. RELATED WORK

The Reference Architectural Model Industrie 4.0 (RAMI4.0) [5] proposes a high level model that combines the hierarchy levels from ISA-95 [5] with Life Cycle Value streams and relate them to layers from the asset level to the business level to provide a framework for understanding I4.0 [8]. RAMI4.0 propose a generic approach but lack recommendations on how to realize the architectures.

The Asset Administrative Shell (AAS) is a shell surrounding an asset, enabling communication with a digital representation of a component connected in a network. The AAS contains an internal interface to the asset, an external interface, and various submodels representing the asset functionality [13]. The AAS proposes a structure for building interoperable components with a set of functionality and information models. Nevertheless, for the/an AAS to be successful, it should be investigated whether the asset is ready to digitally communicate with its outside world.

OPC Unified Architecture (OPC-UA) is an industrial standard for exchanging information in a client-server architecture, ranging from simple data acquisition to sophisticated monitoring, control, and analysis. OPC-UA requires a more or less complicated data model on the server [20,21]. However, it is a standard which should be considered as a mean to exchange information between assets and the IB.

IV. I4.0 CASE

The University is investing 140 million DKK in a new I4.0 lab, which constitutes 800 m^2 with state-of-the-art flexible robots and automation solutions from leading technology vendors. The University I4.0 lab is a strategic initiative that targets the support of research, industry collaboration, innovation, and education in the newest I4.0 technologies. Furthermore, the lab is a demonstration window for industries working to adapt I4.0 technologies into their production. The lab is currently in its initiating phase, where an infrastructure of hardware and software is built, and experience gained with the different assets [15].

The experiment requirement was to gain experience with the asset interoperability and technologies in the University I4.0 lab, in an interdisciplinary collaboration project. The aim is to interlink all needed operations of the assets, i.e. warehouses, material transport systems, and robot assembly cells, to fulfill a customer order. The project focuses on a minimum viable product (MVP), which should, among other things, facilitate knowledge of asset interoperability. The product to be produced in the setup is a simple drone. Fig. 2 shows the interfaces between the assets and IB, connecting all operations, handling the communication to the different assets and controlling the demo sequence. The demo production sequence in the experiment is as follows:

1. User order arrives at ERP
2. Warehouse 1 (WH1) prepares the parts for the order
3. AGV transports parts to the magnetic track
4. Magnetic track (MT) transports the parts to the cell 1
5. Production cell 1 executes a first assembly step
6. MT transports the parts to the cell 2
7. Production cell 2 executes a second assembly step
8. MT transports the product to the AGV
9. AGV transports the product to warehouse
10. Warehouse 2 (WH2) puts the product into storage

The ERP (Enterprise resource planning) is where the customer order arrives. The ERP manages raw material inventory, production capacity, and it generates a production order. Both warehouses are an automated storage unit with effective order picking. The AGV (Automated guided vehicle), consists of an autonomous mobile robot with a robot arm. It can load and unload objects and transport objects from one place to another place. The magnetic track is a high-speed transport system with precision positioning. It has exchangeable shuttles (transport devices), which are attached magnetically to the track. An object is mounted on the shuttles, in this case, a fixture to hold parts for the drone. The production cell contains two collaborative robot arms capable of carrying out a specific task. In this case, the cell performs partial drone assembly. The production cell (PC) is highly configurable, depending on the task it performs.

V. RESULTS

An analysis of the case and the experiences obtained while gathering information about interfaces, yielded the following challenges.

V. *Challenges*

Table I summarizes the possibilities for integration of each asset, and the results express the maturity level of interoperability, ranging from having a functioning external interface to having no options for external communication. The experiences gained from the preliminary case study indicates that the documentation describing the integration process of external software systems varies a lot from asset to asset. The documentation quality and thoroughness from some vendors is either poorly described or not described in enough detail to be useful, while other vendors may lack documentation about integration entirely. The implication from these findings sets current technical barriers for integrating all assets.

TABLE I
ASSET INTEROPERABILITY OVERVIEW

Interoperability		WH1	AGV	MT	PC	WH2
	Integration documentation	✓				✓
	External interface	✓				✓
	External interface under development		✓	✓	✓	
	Internal interface	✓	✓	✓	✓	✓

TABLE II
MATURITY OF INTEGRATION DOCUMENTATION

Maturity		WH1	AGV	MT	PC	WH2
	Training/Courses			✓	✓	
	Simulated development integration environment					
	Best practices of code integration					
	Concrete code examples					
	Pseudo code examples	✓				✓
	Overview of interface methods	✓				✓
	Design diagrams	✓				✓

Table II illustrates varying levels of documentation, ranging from basic design diagrams to practical training and courses. The maturity level expresses the practical usefulness of information, where more descriptive documentation helps to better understand and design the software that integrates the functionality of an asset. The figure highlights that assets often lack mature documentation and learning methods and reflect the current standards within the industry. The integration process tied to Warehouse 1 may prove to be further challenged by the fact that the control software is outsourced to a third-party software developer, which provides an extra layer of complexity to coordinate changes and adjustments to the existing software system. One implication of immature documentation is the risk of not realizing a reliable and robust integration and potentially affecting essential non-functional requirements.

Table III illustrates various technology standards used to communicate with the different assets, ranging from web services (Simple Object Access Protocol (SOAP) and REST) to OPC-UA and MQTT. The agreed communication protocol indicates an external asset interface, while the alternative communication protocol indicates that an alternative method is available. In some instances, technology vendors might have an established system running on legacy software technologies, making it harder to migrate from an older to a newer and supported technology standard, which is an additional challenge in standardizing technologies. The implication of this heterogeneity of applied technology standards demonstrates the need for interoperability within a range of technology standards.

TABLE III
DEVELOPMENT AND MATURITY OF COMMUNICATION PROTOCOLS

	WH1	AGV	MT	PC	WH2
Alternative comm. protocol			**REST, MQTT**	**REST, OPC UA**	
Communication protocol	**SOAP**	**REST**	**OPC-UA**	**Socket**	**File/TCP**
Development	**External**	**Internal**	**Internal**	**Internal**	**Internal**

The results reveal a low level of documentation supporting the integration process of assets and the need for increased awareness around the documentation process regarding the interoperability of the assets.

VI. DISCUSSION

Conducting a pilot study around an I4.0 case and asset interoperability seems to be worth the effort since it reveals fundamental challenges that need to be explicitly addressed further with respect to missing external interfaces, insufficient or vague documentation, and communication technologies, before the system integration phase. Analyzing asset interoperability is challenging due to different levels of knowledge, priorities, and interest in the setup and the laboratory, among the involved partners. However, the first steps have been taken to establish an ecosystem between researchers, software platform providers, technology vendors, and end-users that will benefit from the collaboration and the laboratory. It is our impression that all the investigated assets are state-of-the-art automation and robotics, and they can be configured through a graphical internal vendor interface with the required configuration to carry out a task. However, there seems to be a gap from being individually configured through an internal interface to communicate digitally through a network constructed model, where new systems are built around existing systems. Data streams between assets and the IB need to be exploited to help close this gap in order to leverage the potential of information processing such as monitoring, control, optimization, and machine learning applications. Furthermore, to facilitate the development of streamlined system integration, standardization of communication technologies, such as OPC-UA, needs to be achieved through common reference models, e.g., AAS, which supports the vision proposed by RAMI 4.0.

VII. CONCLUSION

A pilot study has been conducted, consisting of a MVP case, analysis and a discussion. The study identifies fundamental asset interoperability challenges concerning the maturity and interoperability readiness of the assets, which is currently at an immature level in order to implement interconnectivity through a network-constructed communications model. The challenges indicate an apparent lack of understanding of the necessity of asset interoperability in an I4.0 context, and therefore system integration is currently not possible. However, the pilot study has contributed to an understanding that communication technologies are under development, which helps facilitate the vision of full interoperability between assets and indicates the feasibility of interoperability in the project's upcoming phases. The next step will be to establish integration requirements between the assets and the IB in close relation to common reference models and technology standards and evolving the software architecture of the IB infrastructure to support the I4.0 vision. The requirements will be developed in close collaboration with technology vendors. Furthermore, future work should focus on strengthening the I4.0 lab's ecosystem and the prevalence and understanding of I4.0 concepts in the industry.

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