An Open Platform for Smart Production: IT/OT Integration in a Smart Factory

Dan Palade[a], Charles Moller[b], Chen Li[c] and Soujanya Mantravadi[d]
Department of Materials and Production, Aalborg University, Denmark

Keywords: Industry 4.0, Smart Production, Smart Factories, Enterprise Information Systems, ERP, MES, IoT, IT/OT Integration, Vertical Integration.

Abstract: As industries are becoming increasingly digitalized, new manufacturing concepts require redesigning the information systems architecture. The Smart Production Laboratory is used as a learning factory aimed at exploring new industry 4.0 technologies and for demonstrating Smart Production solutions. The initial Smart Production Laboratory was built on a proprietary software stack. Experimenting with the information systems architecture using proprietary systems has shown to be difficult, which is why we built a complete modular open-source software stack for the Smart Production Laboratory intended to enable high-speed and low-cost development of demonstrators for research, teaching, and innovation. Therefore, the purpose of this research is to capture the development of the software stack and identify the required target architecture for the platform. This is further used for discussing potential future challenges in demonstrating new and innovative Smart Production concepts.

1 INTRODUCTION

The industry 4.0 movement has seen a vast interest from the manufacturing world as well as academia [Xu, Xu & Li]. It entails a complex transformation of the industrial environment focused on digitalization and connectedness that leads to enterprise transparency and holism. As production is being increasingly digitalized, everything inside and outside a factory is becoming instrumented, interconnected and intelligent.(Martin *et al.*, 2010)

The new technologies driven forward by the Industry 4.0 movement have challenged the manufacturing industry to transform and to develop new and innovative solutions (Kagermann, 2015). Those new solutions often require substantial changes in the information systems and the architecture of the enterprises (De Jong, Lalla-Sewgoolam and Vainberg, 2019). Planning and managing changes in the enterprise architecture is a complex and long-term endeavor, and consequently, the architecture is not designed but emerges as a consequence of legacy systems and past IT-projects (Ross and Weill, 2006).

Smart Production is a research capturing the industry 4.0 challenges from an industrial point of view, and one of the elements, smart factories, have been in the center of a number of research projects over the last few years at Aalborg University (Madsen and Møller, 2017). We have established and built a Smart Production Laboratory environment, further called Smart Lab, where we can emulate end-to-end industrial manufacturing in a scaled-down version, but with real industrial-grade technologies and systems (Nardello, Madsen and Møller, 2017).

During the research and innovation projects, a larger number of industrial demonstrators have been developed. A demonstrator uses Smart Lab as a platform to demonstrate a particular solution in a scaled-down but realistic context. A central aspect of these demonstrators is the underlying information architecture and the platform they are built on.

The objective of this paper is to build and capture the development of a modular open platform for

[a] https://orcid.org/0000-0001-6595-7215
[b] https://orcid.org/0000-0003-0251-3419
[c] https://orcid.org/0000-0001-6249-8957
[d] https://orcid.org/0000-0001-9382-8314

Palade, D., Moller, C., Li, C. and Mantravadi, S.
An Open Platform for Smart Production: IT/OT Integration in a Smart Factory.
DOI: 10.5220/0010436807070714
In *Proceedings of the 23rd International Conference on Enterprise Information Systems (ICEIS 2021) - Volume 2*, pages 707-714
ISBN: 978-989-758-509-8

smart production (OP4SP). The OP4SP is a simplified enterprise software stack built on open-source components and designed to be easily integrated with any production system. The foundation of the paper is a state-of-the-practice analysis of the enterprise systems architecture with the outset in (Li, Mantravadi and Møller, 2020), leading to formulating the high-level platform requirements. The next chanpter presents and discusses the background of the research and the concrete challenge leading to developing OP4SP, while chapter 3 present the methodology for this research. In chapter 4 we scrutinize the need for such experimental platform through the analysis of four research engagements where part of the solution was applied. This led to formulating the target architecture for the platform, where the selected components are outlined. In the last chapter, we identify the gaps and recommend further use and development of the platform.

2 BACKGROUND

In this section, we provide the background for the research and conceptualize the enterprise software stack in regard to smart production. An analysis of state-of-the-practice is presented, which drives the research objective.

2.1 The Smart Production Laboratory

In order to make sense of this complex transformation, a smart production concept covering horizontal and vertical integration, end-to-end engineering integrations, as well as customer and user interactions was created that provides a lens of clarity towards the impact of Industry 4.0 on a manufacturing company.

The Smart Factory is the concepts within the that framework. A common understanding of the term refers to a highly digitized shop floor with connected machines and devices that collect and share data through information systems. It shares features and goals with related areas such as smart home and smart city.

At our institution Smart Lab was developed in order to drive the research related to smart factories. The Smart Lab (see overview in figure 1) acts as a learning factory to enable collaborative projects between researchers, students and enterprises. It is a fully automated small production line integrating and demonstrating various Industry 4.0 concepts and technologies.

The Smart Lab is composed of several standard FESTO-CP factory transportation modules (conveyor belts), process modules like parts dispenser, drilling module, and assembly module, as well as dedicated integrated robots and mobile robot platforms. From a data perspective, everything is IP enabled. All modules have at least one PC controlling the sensors and actuators. It is integrated using an MES system, which acts as a unified system for controlling the production line. It is a proprietary solution that came from FESTO (MES4) with the procurement of the line, and incorporates a couple of ERP specific jurisdictions, like order creation and bill of materials. In the last couple of years, several projects with the scope of bringing transparency and connectedness to the Smart Lab took place, which culminated with demonstrators being presented to the industry. Through these projects, we observed that a common obstacle was to integrate the information systems and allow for shared data and interoperability within the system. To bypass this issue, we strive to create a platform that encompasses minimal required software applications to ensure streamlined order management and monitoring. For this, we will use open-source tools paired with standard protocols. The rest of the chapter will present the hierarchical model of relevant information systems and the argument for using open-source software.

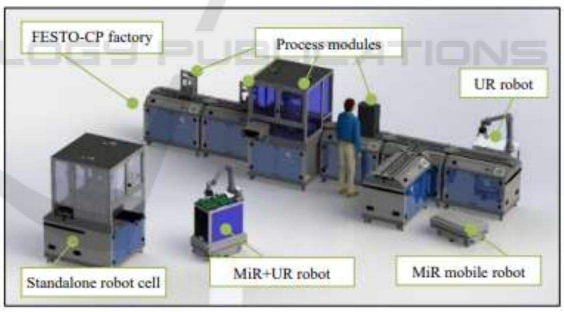

Figure 1: The representation of AAU Smart Production Laboratory (Nardello, Madsen and Møller, 2017).

2.2 Enterprise Systems

Enterprise systems are information systems directed at helping enterprises to collect, store, and distribute relevant information with the aim to support operations, decision-making, and general management. There are multiple tools characterized as enterprise systems: ERP (Enterprise Resource Planning), MES (Manufacturing Execution System), CRM (Customer Relations Management), PLM (Product Lifecycle Management), CPM (Corporate Performance Management), BA (Business

Analytics), and other (Møller, 2005). However, in a manufacturing context, the information systems do not have the same weight (in terms of importance), and there is a form of hierarchy backed by the standard protocol and architecture (ISA-95) in order to map them according to their scope.

ISA-95 firstly distinguishes between two domains: Enterprise Domain and Control Domain. Enterprise Domain refers to the strategic management of the enterprise and correlates with the ERP system. It encompasses *Level 4 Business Planning & Logistics* from PERA model. The Control Domain refers to actions within a factory wall, and encompasses *Level 3 Manufacturing Operations and Control*, which is popularly called the MES (Manufacturing Execution System) or MOM (Manufacturing Operations Management when reffering to extended functionalities) layer, and Level 2,1,0, which are also known as OT (Operations Technology).

Although ISA-95 clearly dictates boundaries between ERP and MES functionality, this view is being challenged by technology providers that extend the functionalities of their tools to incorporate the other ones. For example, the ERP is extended to include order tracking, and MES includes resource management and planning/scheduling (Franzosa, 2019). Moreover, the shift to the Cloud has the potential to disrupt the whole hierarchy. De Jong, Lalla-Sewgoolam and Vainberg (2019), outline the challenges of the transformation from presented decoupled information systems architecture towards the future of the integrated modular components. This transformation is central to most of the demonstrators in the Smart Lab, which is the reason why we didn't develop the enterprise software stack as one entity, but rather as a collection of modular systems with clear integration protocols in place which are easy to replace, extend, and deploy according to our needs.

The integration of the components found in the PERA hierarchy model is called Vertical Integration in Industry 4.0 ontology (on account of them being presented in a vertical hierarchy) and is also commonly known as IT/OT integration. In a nutshell, IT/OT integration deals with connecting the data and the processes from the manufacturing floor to the strategic level. Internet of Things (IoT) is one of the technologies enabling this integration.

2.3 Open Source

At the time of this writing, there are no less than 50 proprietary IIoT platforms; however, the proprietary solutions often rely on an ecosystem of partnership, thus making system integration difficult. However, given the heterogeneous nature of data within IoT, it is no surprise that open-source technologies, standards, and protocols may be chosen as an alternative and even preferred to proprietary IoT solutions. The drivers for choosing open-source technologies for IoT over proprietary solution are summarized here from (Kim, Lee and Jeong, 2019): (1) The cost of implementing open source IoT frameworks is low; (2) open-source code leads to open innovation, thus making operability across operating systems more probable; (3) the use of Open APIs (Application Programming Interface) is preferred, thus leading to the common gateway (backed by standard protocols) for connecting software and hardware; (4) the open-source framework usually offers a wide range of working libraries; (5) solves the problem of interoperability; (6) open-source software is more secure than proprietary software.

2.4 Research Objective

We strive to use the gained experience from building Smart Lab demonstrators to construct a generalized enterprise software stack incorporating minimal ERP, MES, and IoT functionalities, for vertically connecting information sources, to be able to explore new concepts and easily make new demonstrators for research and innovation purposes.

3 METHOD

This research is structured as a DSR (Design Science Research) approach, with the creation and evaluation of an artifact (OP4SP) at the center. The OP4SP represents a concrete technological instantiation of a full factory software stack that includes an ERP, an MES, and an IoT solution. It is created and refined in 4 design cycles, which are presented in figure 2.

The knowledge base is provided by standards, specifically ISA-95, and guides the architecture and functionalities of each level of the artifact, which ensures the rigor of the research. A study (Mantravadi *et al.*, 2020) deduced that ISA 95 structure is indeed helpful in securing IIoT interconnections in a factory. Furthermore, an open-source enterprise solution was beneficial in the implementation of virtual intelligent-assistant systems on the shop floor for operator assistance (Mantravadi, Jansson and Møller, 2020).

Moreover, the identified principles related to Industry 4.0 technology creation, also called Industry 4.0

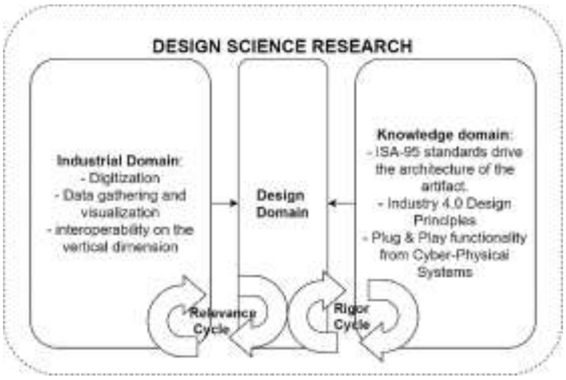

Figure 2: DSR Research Overview presenting the three domains and relevance/rigour cycles.

Application is underlined by providing a means to have industrial demonstrators built on top of the physical instantiation presented in this research. The demonstrators take place because there is interest from industrial partners. It is important to note that the artifact (enterprise software stack) and its abstraction (the platform) should be used as a means to an end, which is a concrete solution to a demonstrator project, and not as an end of itself, thus the measurement by which the artifact is assessed is by how easy it is to build industrial demonstrators around it.

There are a set of high-level requirements that drive the design and development of the platform. They are: (1) the use of open source is mandatory; (2) no hard coding necessary; (3) inclusion of ERP, MES, and IoT; (4) the architecture must be modular; (5) real-time capability is required (6) allow virtualization and information transparency.

Moreover, the design and development of the artifact is constrained by external factors: (1) the artifact should be tested at our Smart Lab, because it will be used there; (2) be easily customizable or programmable; (3) allow Plug and Play feature.

The artifact evolved because of specific needs from four previous demonstrator projects, each of them guiding the development from specific perspectives having different scopes and requirements, but still acting as a stage of iterative development. The contextualization of each demonstrator is presented in figure 3, and in the further section.

3.1 Demonstrators Scenario

The platform evolved through as a result of four demonstrators, which are presented further.

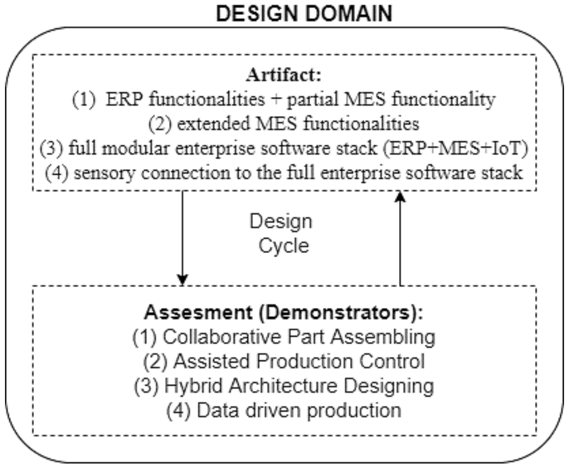

Figure 3: The Design Domain from DSR, presenting the design cycle.

1) *Collaborative Part Assembling*: In this scenario, the MES provides the instruction to the mobile robots to deliver the materials to different robot cells to assist product assembling. The production line consists of two robot cells, one mobile robot and materials (i.e., PCB). In this scenario, the MES receives the production order from the Odoo Sales (part of Odoo ERP) module and checks the mobile robot's state to see if it is available or not. After receiving the command from the MES, the mobile robot will pick up the specific PCB and deliver it to the robot cell. This task requires the MES to be able to communicate with the mobile robots through OPC UA protocol. The order information and mobile operations are set as parameters transferring between MES and mobile robots.

2) *Assisted Production Control*: The second scenario we tested relates to the task of production control. There are four pieces of equipment involved in this scenario, counting machine one, counting machine two, robot station, and manual station. This task simulates the LEGO bricks assembling process. The counting machine one and two counts two types of bricks separately and put them to the pallet according to the work order. The robot station can select the other three types of bricks for assembling. All the bricks in the pallet will be assembled at the manual station. In this task, MES helps to schedule the production, balance the workload of the equipment, and control the production process. To synchronize the order states and avoid the same order is produced at the same time, MES also introduces a synchronize mechanism to create a production sequence of the work order.

3) *Hybrid Architecture Designing*: The third scenario is focused on a hybrid architecture that provides an integration solution that introduces the IoT platform (Thingworx is chosen as the IoT platform in this case) to the traditional hierarchical model. The proposed architecture follows the Industrial standards ISA-95 and includes the key activities of different functional hierarchy layers. It defines the several interfaces to support data collection and transformation between the MES and IoT platform. The integration between MES and IoT platform is through the ISA-95 middle layer which helps to generate an industrial standard followed, standardized, and formalized data structure.

4) *Data Driven Production:* The fourth scenario is focused on creating a simple monitoring system for production lines with outdated machinery without compromising or infiltrating the legacy systems already in place. A Node-Red (simple programming tool) instantiation was installed on a Raspberry Pi, and was receiving vibration sensory data from ESP8266 microcontrollers, that were mounted on a conveyor, that would declare if a machine is functioning or idle. Moreover, a fully customizable dashboard accessible from PC would present the necessary data, which was also collected in a database for statistical purposes. The setup is modular and easily customizable with minimum programming knowledge.

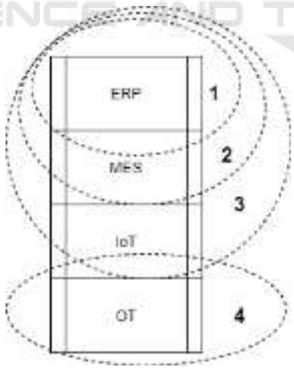

Figure 4: Levels of the hierarchical model, detailing where the demonstrators' scope correlated with the enterprise stack.

3.2 Development

Based on the knowledge acquired from these demonstrators, an architecture was proposed, and an instantiation of a platform was developed that would facilitate further demonstrators. Figure 4 presents the levels of the platform's architecture, and specifically where previous demonstrators augmented the design of it. The next chapter presents in detail the road to designing and developing the platform.

4 STAGES IN THE EVOLUTION OF THE PLATFORM

The Smart Lab is the learning factory at our research institution. It is the foundation on which new industry 4.0 concepts are tested, and artifacts designed and deployed as part of industrial demonstrators. It has a proprietary MES solution, and at procurement it had an ERP system from SAP, which was discontinued due to the inability to customize it. This is the outset from which we start our journey. The direction of our journey is top to bottom from the vertical integration perspective, and the demonstrators mirror this approach.

4.1 Design Cycles

The first step was to replace the SAP system with something that is customizable, modular, and easy to deploy. The Odoo ERP system was considered (formerly Open ERP). The community edition of Odoo ERP is open source and can be deployed both onsite and in the cloud. Odoo is structured in modules, each of which has a specific authority.

In the **(1)** ***Collaborative part assembling*** demonstrator the Odoo Sales and Odoo manufacturing modules were tested. Odoo manufacturing was customized specifically to fit the Smart Lab, and specifically this demonstrator. Through OPC-UA (OPC-Unified Architecture) the manufacturing module would check the availability of resources (in this case, mobile robots) and assign a task to them. On completion, it would receive a signal and take the next task. Through this demonstrator, we observed that Odoo fits the need of the Smart Lab and thus it was decided to use it further.

In the **(2)** ***Assisted production control*** demonstrator, we further tested the customizability of the Odoo manufacturing module by designing a production planning operation that would synchronize the order states and balance the workload of the resources used. Through this, we also tested the real-time capabilities of the system, deemed it acceptable for our purposes.

Further, in **(3)** ***Hybrid architecture designing*** demonstrator we complete the vertical integration of information systems by introducing an IIoT platform (Thingworx). The integration follows the industrial standard ISA-95 through a middle layer that supports standardized and structured data. The solution was deployed on the Cloud and represented a modular software with a digital backbone that was customizable, and quickly deployable. However, customizing the IIoT platform required a lot of hard coding and with each new use case the legacy would grow, thus bringing complexity into maintaining the platform. Thus, it was decided that Thingworx is not fully suited for our purposes, and that testing another solution is required. Although there are other open source IIoT platforms (FIWARE, Mobius, SiteWhere, Kaa, DeviceHive), we decided to test an IoT platform designed for automating your house, Home Assistant, because it has a much larger audience and is designed specifically for ease of use. In the last couple of years, Home Assistant was appreciated with grants and awards from open-source societies for its flexibility and ease of integration with smart resources and third-party software. Although it was criticized in the beginning for its file-specific integration (the use of YAML setup files), presently, it shifted to a more web-based GUI. Home Assistant was tested on the premises of the Smart Production Lab by creating a local version on a raspberry pi and connecting it to the Festo CP factory, through OPC-UA.

In **(4)** ***Data driven production*** demonstrator, we tested the possibility of using a cheap setup of vibrational sensor and ESP32 (cheap microcontroller architecture) to bring *smartness* to old machinery. An often-cited motive for the difficulty to integrate machinery into a central system (like an IoT platform) was the lack of functionality and connectivity embedded in its system. We bypassed this problem by adding inexpensive smart sensors instead that are easy to install and connect, thus completing the skeleton of vertical integration.

Finally, the platform was tested and evaluated at our facility. Our artifact, which constitutes a skeleton of a full enterprise automation stack, is able to fully control and monitor the state of the order and machinery.

4.2 Target Architecture and Workflow

The artifact is designed to correspond to the levels of functionality dictated by the ISA-95 standard. At each layer there are containers with relevant applications. Figure 5 presents an overview of the architecture.

It was decided to have a clear hierarchical model, but also to divide the functionalities in separate containers in order to be able to migrate them either to the Cloud or to the edge according to our needs and keep the distinct integration protocols in place.

The ERP layer includes Odoo Community edition, deployed locally as the MVP (minimum viable product) with *sales*, *employment*, *inventory*, *purchase*, and *accounting* modules. It is considered to deploy the enterprise edition on the Cloud in the future release. The MES layer includes another module from Odoo called *manufacturing*, which was customized according to our needs and maybe further changed to fit specific demonstrator scopes. There is also the Festo Agent, which is a python based program that acts as a control layer for the machines through OPC-UA. The IIoT layer includes an instance of Home Assistant core running add-ons like partainer, ESPHome, and Node-RED in separate containers, and a Home Assistant OS.

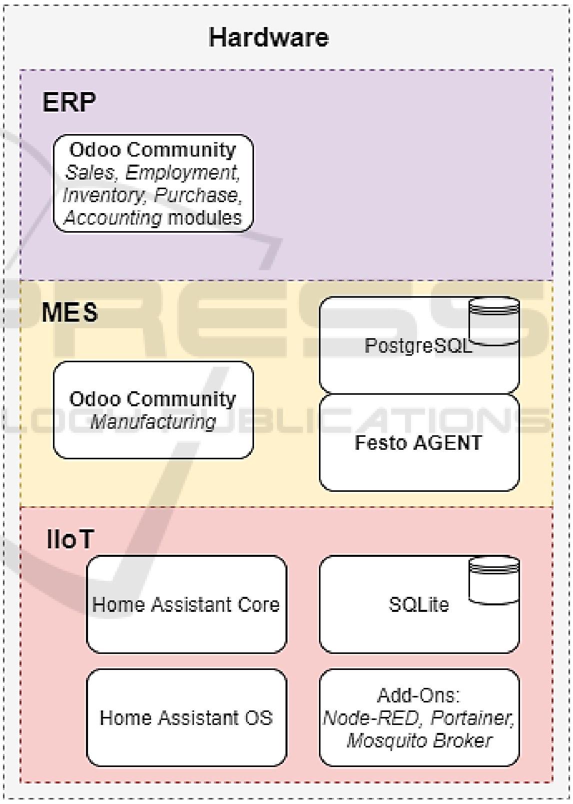

Figure 5: High Level Architecture of the enterprise software stack.

Figure 6 presents the workflow of the order, detailing the course from sales to execution. It represents a generic order flow that can be applied in any manufacturing context, thus ensuring the relevance of the research. The logical blocks (different colors) correspond with specific functionalities from ERP (Purple and Blue), MES (Yellow), and IIoT (Red) layers.

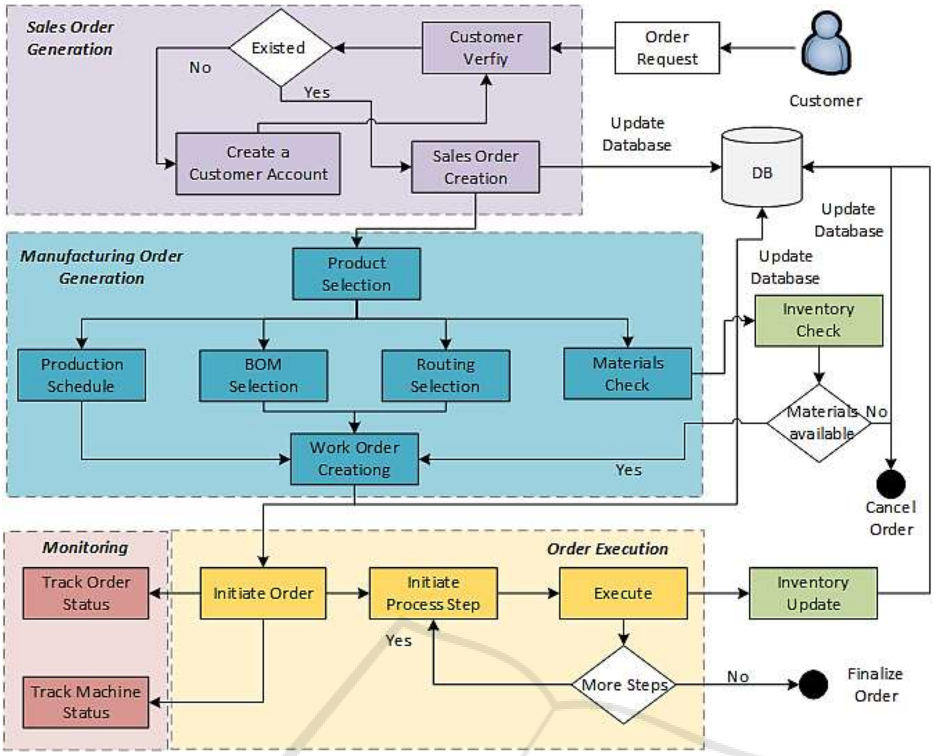

Figure 6: Generic Order Workflow model.

5 DISCUSSION

In the next couple of months, AAU plans to host several industrial demonstrators with multiple industrial partners. In this section, we will argue that the presented artifact will facilitate the creation of the demonstrators by specifically pointing out the processes that it will perform for each project. First demonstrator is titled *Mass Customization*. The outset of the project is to demonstrate the capability of a simple setup, to receive an order for a customized product (made by the customer through a configurator), sort the correct components, and package them. The resources include but are not limited to feeders with counting devices, grippers, and robots. Our artifact has a major role, specifically controlling the order management through the ERP layer, and production processes through the MES layer. The IoT will collect machine status and order data for a statistical reason and strategic decision making. The secondary scope is to demonstrate traceability and quality assurance. Second demonstrator titled *Paperless Production* is directed toward companies that are at the beginning of the digitization journey and have no or minimal gain from using information systems at their site. The scope is to demonstrate the capabilities of digital tools through the whole spectrum of the hierarchical stack; thus, our artifact will be used extensively in this demonstrator, especially for collecting data. Some of the goals are: (a) automatic capturing and storage of information from machines, devices, and employees; (b) aggregation and visualization of information for decision support; (c) automatic model-based decision; (d) reporting and publishing insights for actions. Third demonstrator titled *Predictive Maintenance* has scope is to create a base for intelligent maintenance of machines and devices through diagnostic, predictive, and prescriptive analytics. For this, a stable data collection and storage procedure should be in place, which is provided by our platform.

The OP4SP will be the facilitator for conducting these planned demonstrators and will allow for quick setup according to new requirements for each demonstrator.

6 CONCLUSIONS

In this paper we have stated that our research institution uses its facility, the Smart Lab, to create industrial demonstrators for showcasing Industry 4.0 concepts and technologies. We argue that the Smart Lab misses a digital backbone that would allow us to easily collect data and track the production. This digital backbone would help us as researchers to explore new concepts and create industrial demonstrators faster. The digital backbone entails a full enterprise automation stack (as explained in ISA – 95 standard) developed from open-source tools. The architecture includes an ERP system (Odoo ERP), a MES (MES – based on Odoo Manufacturing), and an IoT Platform (Home Assistant), which was the result of a DSR approach with 4 design cycles. Our artifact is not the final state and will continue to be refined as it will be used in the upcoming industrial demonstrators.

The presented platform fulfills almost all the requirements presented earlier. It is composed of open-source tools (1), has little hard coding involved, only in the FESTO Agent (2) , includes ERP, MES, and IoT (3), has a modular architecture through the containers that hold the programs (4), the response is close to real-time (5), the virtualization and information transparency is in place (6). Further development also seeks to fully complete the requirements (2) and (5).

The contribution of this paper includes proposed architecture of the enterprise software stack, a concrete instantiation of the platform, and the generic order workflow model.

It is also planned that the OP4SP will be used further in the context of helping small and medium sized enterprises (SMEs) by providing minimum necessary enterprise functionalities and observe their digitization journey. Moreover, the stack will facilitate research into implementation of industry 4.0 technologies, with respect to SMEs as well.

REFERENCES

Awouda, A. *et al.* (2019) 'Practical Implementation of Industry 4.0 Based on Open Access Tools and Technologies', in *IFIP Advances in Information and Communication Technology*. Springer, pp. 94–103.

Franzosa, R. (2019) *Magic Quadrant for Manufacturing Execution Systems*. Available at: https://www.gartner.com/en/documents/3970825/magic-quadrant-for-manufacturing-execution-systems (Accessed: 18 December 2020).

De Jong, E., Lalla-Sewgoolam, B. and Vainberg, G. (2019) *Unlocking the full power of automation in industrials*.

Kagermann, H. (2015) 'Change through digitization—value creation in the age of industry 4.0', in *Management of Permanent Change*. Springer Science+Business Media, pp. 23–45.

Kim, M., Lee, J. and Jeong, J. (2019) 'Open Source Based Industrial IoT Platforms for Smart Factory: Concept, Comparison and Challenges', in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Springer Verlag, pp. 105–120.

Li, C., Mantravadi, S. and Møller, C. (2020) 'AAU Open Source MES Architecture for Smart Factories - Exploiting ISA 95', *Ieee International Conference on Industrial Informatics*.

Madsen, O. and Møller, C. (2017) 'The AAU Smart Production Laboratory for Teaching and Research in Emerging Digital Manufacturing Technologies', *Procedia Manufacturing*. Elsevier B.V., 9, pp. 106–112. doi: 10.1016/j.promfg.2017.04.036.

Mantravadi, S. *et al.* (2020) 'Securing IT/OT Links for Low Power IIoT Devices: Design Considerations for Industry 4.0', *IEEE Access*, 8, pp. 200305–200321. doi: 10.1109/ACCESS.2020.3035963.

Mantravadi, S., Jansson, A. D. and Møller, C. (2020) 'User-Friendly MES Interfaces: Recommendations for an AI-Based Chatbot Assistance in Industry 4.0 Shop Floors', in Nguyen, N. T. et al. (eds) *Intelligent Information and Database Systems*. Cham: Springer International Publishing, pp. 189–201.

Martin, J. L. *et al.* (2010) 'Preface: Technologies for a Smarter Planet', *IBM Journal of Research and Development*. doi: 10.1147/JRD.2010.2051498.

Møller, C. (2005) 'ERP II: a conceptual framework for next-generation enterprise systems?', *Journal of Enterprise Information Management*. JAI Press, 18(4), pp. 483–497. Available at: https://vbn.aau.dk/da/publications/erp-ii-a-conceptual-framework-for-next-generation-enterprise-syst (Accessed: 18 December 2020).

Nardello, M. ; Madsen, O. ; and Møller, C. (2017) *The smart production laboratory A learning factory for industry 4.0 concepts*, *CEUR Workshop Proceedings*. CEUR Workshop Proceedings. Available at: http://ceur-ws.org/Vol-1898/paper13.pdf (Accessed: 27 November 2020).

Queiroz, M. M. *et al.* (2020) 'Smart production systems drivers for business process management improvement: An integrative framework', *Business Process Management Journal*. Emerald Group Holdings Ltd., 26(5), pp. 1075–1092. doi: 10.1108/BPMJ-03-2019-0134.

Ross, J. W. and Weill, D. P. (2006) *Enterprise Architecture as Strategy-Creating a Foundation for Business Execution*. Available at: https://www.researchgate.net/publication/236972734 (Accessed: 14 December 2020).

Williams, T. J. (1994) 'The Purdue enterprise reference architecture', *Computers in Industry*, 24(2–3), pp. 141–158.