Available online at www.sciencedirect.com

ScienceDirect

IFAC Papers Online CONFERENCE PAPER ARCHIVE

IFAC PapersOnLine 55-4 (2022) 334–339

Asset Administration Shell - manufacturing processes energy optimization

Tomáš Benešl*, Václav Kaczmarczyk **, Tomáš Sýkora*, Jakub Arm ∇, Petr Dvorský∇∇, Michal Husák∇∇∇, Petr Marcoň, Zdeněk Bradáč**

Department of Control and Instrumentation, Faculty of Electrical Engineering, Brno University of Technology, Antonínská 548/1, Brno, 602 00, Czech Republic,

**Tel: +420 54114 6449; e-mail: tomas.benesl@vut.cz*

***e-mail: kaczmarczyk@vut.cz*

****e-mail: tomas.sykora2@vut.cz*

∇e-mail: jakub.arm@vut.cz

∇∇e-mail: petr.dvorsky2@vut.cz

∇∇∇e-mail: michal.husak@vut.cz

Abstract: The paper deals with the issue of Asset Administration Shell (AAS), especially from the point of view of production process optimization. From the authors' point of view, Industry 4.0 brings the main advantages especially in decentralization and thus the independence of individual production machines, which will enable greater variability of production and better response to failures. The content is a description of the parts of the AAS that are closely related to production optimization, these are active submodels for autonomous negotiation, optimization (evaluation criteria), predictive maintenance and resilience. In the case of the implementation of the mentioned submodules, a robust production solution will be implemented, which is suitable for discrete piece production with direct links to the customer, who can freely configure his product. This paper provides an overview of optimization in the use of AAS and their main functions - submodules and their possible implementation and benefits for production systems.

Keywords: Asset Administration Shell, Industry 4.0, Optimization, Horizontal integration, Predictive maintenance, Resiliency, Autonomous production

1. INTRODUCTION

Standardization is one of the primary goals of Industry 4.0, mainly due to interoperability, and thus horizontal integration at all levels of the manufacturing company as well as at all stages of the value chain. With the growing trend of agile production (agile production systems), a quick possibility of conversions to a new type of product is required. In the preparation and modernization phase, it is essential that tools in different domains can work together. To achieve such interoperability, it is necessary to have standards so that the same information can be used in more than one sector.

In the Industry 4.0 reference model (RAMI4.0), the Asset Administration Shell (AAS) is presented as the cornerstone of interoperability. Asset Administration Shell can be imagined as an extension of any device that wants to cooperate in the Industry 4.0 world. Such a device can then be called an Industry 4.0 component – ie a device enabling active data exchange within an Industry 4.0 network. AAS consists of several submodels that extend and describe its functionality, but also the functionality of the device (asset). The primary task of AAS is to interpret the functionality, information, parameters, documents, etc. of the asset in a standardized consistent form. AAS of any product, standing, etc. - generally asset, should ideally arise at the beginning of the value chain. AAS can also be used to standardize human actions, thus creating an AAS operator.

AAS functionality can be divided into two parts:

- Passive – part of AAS containing submodels for storing data related to the asset (datasheets, project documentation, 3D models, diagrams, identifiers, etc.). This is a function that does not require a communication interface. It is thus a standardized data storage structure mentioned above. This part is crucial especially at the time of product design (ie before its production) and subsequently after completion, where it is possible to store all the information from the production process of this asset.
- Active – part is the cornerstone for autonomous production management. Machine autonomy is a key pillar of the Industry 4.0 idea. However, the most efficient autonomy can only be achieved with a

10.1016/j.ifacol.2022.06.055

standard machine-to-machine communication interface, which is provided by AAS.

The optimization of the production process can be viewed from different angles. One of the possibilities is energy optimization or optimization of the production process. These are the most frequently addressed issues in production. For example, by optimizing the production process, production costs can be effectively reduced, but also the time required for production. The following can be considered as optimization of the production process:

- Production planning optimization – self-organized production = distributed production management. The consequence of the use is energy optimization and the need for production in stock.
- Resilience of production systems – lower failure rate and in case of failure it is a safe failure. Communication network resilience is an important part of Industry 4.0 horizontal integration.
- Predictive maintenance (PdM) - with the amount of data obtained during the production and creation of digitized service operations, it is possible to predict service operations more and plan them in an ideal time when the production unit is idle or during technology outages. This eliminates unwanted downtime and service operations that can be efficiently scheduled and do not interfere with the smooth running of large production units.

2. RELATED RESEARCH

Currently, standards for AAS are being developed and the idea of these standards is to implement them in real production. The ZVEI / VDI (Verein Deutscher Ingenieure) standard is relatively complex and is therefore difficult to fully implement in existing control systems, so the resulting implementations often differ. Concessions, depending on the platform implemented, can cause incompatibilities between I4.0 components. The basic and most used control system in industrial automation is PLC (Programmable Logic Controller). The authors of the article (Cavalieri, 2020) dealt with the creation of parts of AAS for PLC, and our next work on the I4.0 testbed called Self-acting bartender (Kaczmarczyk, 2018) will also deal with this direction. Another principle of AAS implementation is a server / cloud solution which, in our opinion, is only suitable for machines with an Ethernet-based interface. It would be very complicated to connect the server / cloud version of AAS using buses such as RS485, RS232, CAN etc.

Another significant disadvantage is the theoretical centralization of technology – all AASs run on the same hardware and rely on a single communication interface. This can be solved by redundancy or a similar approach. This can minimize the risk of failure, but in essence it runs counter to the decentralized approach of Industry 4.0 principles.

The ideal solution thus seems to be a full implementation in a PLC or the creation of embedded hardware, which will be part of the production machine. It would also include a suitable interface for the asset.

However, none of these ideas address, for example, where the AAS product or the AAS operator will be physically located. As part of the work on the research project Self-acting bartender, our research group will focus on solving these unknowns in the issue of AAS implementation.

3. ASSET ADMINISTRATION SHELL FOR MANUFACTURING OPTIMIZATION

This chapter details the key features of AAS. These are mainly features that help optimize the production process, which lead to higher efficiency of the entire production chain.

3.1. Distributed manufacturing process

The current principle of production using the MES (Manufacturing Execution Systems) system is very robust until the moment when the production machine fails, and it is necessary to reschedule production. The weakness of the solution using the MES system is also the centralization of the entire solution and the impossibility of modifying the production process, for example in the form of plug and play, the addition of production machines, etc.

In contrast, it is possible to use production control using autonomous production units. The basic idea of Industry 4.0 is the possibility of two-way communication between individual devices. Ideally, production planning can be distributed among separate units because each machine, software, product, operator, etc. is able to communicate with any device.

Using AAS and its submodels, it is possible to implement models for production planning, negotiation (implementation of supply, demand, orders, etc.) and other necessary submodels for the full functionality of distributed production management.

MES, as it is known today, will thus be reduced to a mere passive database containing production steps according to the customer's order. Upon receipt of the order, the MES system creates an AAS for the product and provides it with all the necessary information so that the product can "be manufactured by itself". With the use of unified communication and functional units (submodules), he is able to negotiate individual production steps on machines in production, plan transport to the workplace and possibly optimize its production in case the machine breaks down or a third-party supplier needs to be used.

In order for everything to work properly according to the current vision, it is necessary that everything follows the same standard. In our implementation for production testbed Self-acting bartender, the implementation of AAS will be as closer as possible to be compatible with the ZVEI / VDI standard.

A great benefit of distributed production management is the ability to reschedule the entire production on the fly and it is possible to optimize the production time of the product, and thus the price and potential energy costs for the production of each product. Optimization submodels can be easy for initial validation, but there is a huge opportunity for research on how to implement intelligence and planning optimization in AAS. This approach then leads to the optimization of the entire production from many perspectives.

3.2. Digital Twin

A new approach to production optimization solutions is to use virtual commissioning, often referred to as Digital Twin. As the name implies, this is a digital copy of a real device, which is used not only in development but also, for example, in putting the machine into operation.

Virtual simulation of the production cycle brings us important information not only in real time, but also in a shorter time horizon. This can be used when planning production-related logistics operations or when planning individual production machine operations. The AAS twin thus provides real AAS services in terms of simulation. AAS Digital Twin implements connectors in simulation and emulation software such as PLCSIM Advanced, SIMIT or Matlab. AAS_DT provides complete software in the loop (SiL) and can also be used as hardware in the loop (HiL) in manual mode for debugging purposes.

There are more options for connecting a virtual twin. Mechatronic Concept Design (MCD) supports up to eight external control modes. Of these options are specialized protocols for PLCSIM Advanced, SIMIT (SHM) or Matlab Simulink. The environment is additionally equipped with a universal industrial interface OPC UA / DA, TCP, UDP, or Profinet. Universal industrial interfaces are an ideal option for the HiL method. It uses this solution to control the simulation using a physical PLC.

Another possibility of using the digital twin is for the purpose of training operators, maintenance, and dispatching work. For some operations, this is the only training option, due to the hazardous environment or technology instability. For example, the use of virtual twins for the prediction of immeasurable quantities for PdM is challenging. It is also possible to test collisions that would lead to its destruction on a real device.

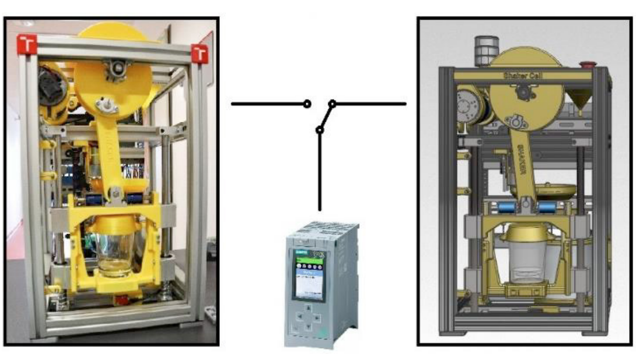

Figure 1 Implementation CPS

Figure 1 shows an example of a real machine on the left and its digital appearance on the right. This is a Shaker production cell, whose virtual image was created in the Siemens NX environment and its MCD module. This is an example of a device whose control is implemented using a virtual PLC in the program PLCSIM Advanced v4.0 for SiL concept. It is able to perform a complete simulation of the entire device without the need for its physical implementation. Communication between the PLC simulator and the virtual model in the MCD takes place via a direct connection. Other connection options are in the testing phase when it is possible to switch between real and virtual machine. Upon completion, the virtual twin could be a valid part of the machine connected via an OPC UA server with a physical PLC (Hardware in Loop Method).

3.3. Predictive maintenance requirements

Maintenance is an important function in terms of production optimization, which is the ability to prevent unplanned downtime in production. In terms of practical possibilities, two approaches to maintenance are used today:

- Preventive maintenance (PM) - the disadvantage of preventive service and life cycle planning is the premature termination of parts of the production facility that still have residual production capacity. It is also necessary to maintain stocks of spare parts.
- Predictive maintenance (PdM) - uses all production capacity of the equipment or part of the equipment. By measuring the current state of health of the facility, can be predict when the cut-off score limit for the fault condition will be exceeded. Thanks to this, It is able to plan the maintenance of a fault that has not yet occurred or reduce the capacity requirements for the equipment and delay the shutdown. Flexibility can be used in this direction to optimally cover the production capacity of unexpected demands.

The combination of PM & PdM is a more difficult option in terms of implementing maintenance planning, but it is in demand. State-of-the-art in the field of predictive maintenance does not yet include a diverse range of equipment in the industry, and therefore in some cases it has to rely on preventive maintenance. This is a multicriteria optimization problem with many variables, but also parameter constants.

Vendor-oriented architecture

Vertical integration provides us with a direct link between elements that do not exist in normal production. It is, for example, the link between the maintained equipment and the maintenance worker, which is protected by already superior intelligence such as enterprise resource planning (ERP). The staff in the AAS network is packaged in its own AAS and acts as a unit that provides a maintenance service. They provide maintenance in the form of production capacity, which the equipment orders.
Data for PdM (acquisition, storage, reduction)
For low-cost technologies with higher failure rates, it is advantageous to obtain run to failure data. The service life of such components is extended to the maximum usable life cycle.
Implementing a predictive model in AAS raises questions that needs to be answered.

- Where the implementation of the PdM model is located in the AAS device or separately as a service
- Acquisition of data from sensors and where to place historical data? They don't fit on lightAAS.
- Service intervention changes the predictive model, which must toggle or ignore the original remein useful live (RuL) estimate.

The solution is not to store any data, just to rethink the model. However, this radical step is quite risky due to the retroactive reconstruction of operating conditions, for example when dealing with a batch defect. Historical data is stored in AAS batches, but there may not be all the machine operating data that PdM works with. In the limited function of AAS, which is implemented on a PLC with limited memory, there is another possibility to use a cloud solution as a service for "lightAAS". Light AAS provides only the most necessary functions associated with the execution of production implemented on the edge, the remaining functions of the asset are located for the cloud solution. In the article (Cavalieri, 2021) the authors use PdM fragmented into so-called "logical blocks". Examples of such a block are data acquisition functions, RUL predictor or scheduling functions. However, in our case, these functions will have to be divided into groups executable on the OT and IT side.

Maintenance Decision-making

As already mentioned, the response to the performed maintenance is production capacity and quality of production. The optimal balance between quality and quantity in production has been addressed for a long time. Optimization algorithms exist; however, the implementation of such systems is demanding on the overall understanding of the technology, i.e., it is not transferable between different types of production. Therefore, we chose the knowledge of human experts for our concept and tried to implement it into a multicriteria expert system. We consider this step to be state-of-the-art in the field of maintenance optimization.

3.4. System resiliency

Resilience as such should guarantee fault avoidance and fault tolerance of a given technical system and can be divided into different domains such as information, structural and time domain, as well as into individual attributes such as robustness, integrity (safety and security), recoverability, reconfigurability, testability, adaptability, evolvability and reliability. (Castano, 2015)

In general, the implementation of the principles of the resilient system should predominantly lead to better performance, reliability and security of the system itself, therefore even within the AAS.

Based on the general RAMI4.0 model (Schweichhart, 2016), subject to the horizontal line "life-cycle and value stream", within design/development it is necessary to always include requirements not only for the functionality of a system but also requirements for individual attributes of resilience.

Based on previous, it is not appropriate to implement methods to increase the resilience into the system retrospectively and artificially as ADD-ONs. This approach can bring extra cost, extra complexity and inefficient mitigation actions. Therefore the requirements for increasing the resilience of the system must be included at the beginning of the design. (Hosseini, 2021)

Consider that AAS can be internally divided into active and passive parts (Active and passive AAS), while the active part can be further divided into individual sub-models that manage and functionality of certain areas/parts of AAS (safety and security sub-module), then these principles described in (Hosseini, 2021) can therefore be applied to most of the resilience attributes. Thus, it is possible to incorporate attributes of resilience within the AAS as individual sub-modules (in the active part of the AAS), which provide the required management of each attribute within AAS. However, it is always necessary to think about whether such an implementation will bring the desired results in terms of increasing the resilience of the AAS or will only complicate the AAS unnecessarily.

The concrete implementation of individual resilience attributes in AAS also depends on whether it is a simple AAS, where the asset is a technical device or a human AAS, where the asset is a human being. (Hosseini, 2021)

4. IMPLEMENTATION

The following chapter discusses the possibilities of AAS implementation, both in terms of the standard and structure (models/submodels) of AAS, and in terms of the communication protocol / interface used.

4.1. Standards

Because of the principles stipulated by the Industry 4.0, standards have to be used in the whole life-cycle of any component. This fact is eligible for a production and even for an AAS creation. Nowadays, many standards have been released, thus, only crucial parts will be discussed.

The structure of the AAS is defined by the meta-model presented in (Bader, 2020). The structure consists of head and body. The body comprises types, dictionary, submodels. The submodels contains instances of parameters, methods, and events describing a functionality.

Because of many nationalities have different customs, unit definitions, naming conventions, and taxonomies, a standard need to be followed. So far, there is standard IEC 61360 that defines the dictionary schema and may be used to define vocabularies. The standard (IEC 61360-4) also presents a dictionary (IEC CDD, 2021) for use in the field of electro-engineering and related domains. Based on the standard, other dictionaries can be defined, such as eCl@ss accessible in (ECLASS, 2021).

The dictionaries provide only the description of the properties and metadata in the standardized way comprising the naming convention and taxonomy, which can be used by submodel creation; even though, it is not enough to fully describe the component features, especially the relationships among properties.

When an I4.0 component is created using AAS, it is usually connected with others to share data and implement a function. The standard is also applicable in the interaction between these components. (Details of the Asset Administration Shell, 2020) already defines the interaction protocol, but still a complete standard comprising the message definition is missing.

From our scrutiny, any standard defining the location and runtime framework of AAS is missing. There are some options such as execute on a server to use the computational power to its full extent. Another option rests in the implementation of the AAS into the PLC to comply with the distributive pillar of the I4.0 concept; on the other hand, it will always lack some features and be limited by the hardware platform. So far, the AAS is based on the OPC UA technology, the OPC UA standard could be considered as the general framework for the AAS creation if the explicit mapping between AAS and OPC UA is finally defined by some standard.

4.2. Communication

As already mentioned, it is very suitable to use OPC UA or MQTT protocols for the actual communication of individual devices or their asset administration shell components. Each is suitable for a different use.

OPC UA is, unlike the original OPC specification based on Microsoft's COM / DCOM technologies, a technology based on the commonly used communication standards TCP / IP, HTTP, SOAP and others. OPC UA is therefore cross-platform, with the fact that it can also be used by third-party manufacturers in their facilities. Unlike the original OPC protocols, which had separate access to data (OPC DA), alarms (OPC AE) and historical data (OPC HDA), OPC UA does not define these specific approaches, but only the format of the transmitted messages. Communication here is based on data transfer via a client-server connection. The protocol specifies the structure of the data provided, the methods of authentication, and secure access to the data. Because OPC UA is defined as SOA (Service Oriented Architecture), services are defined within the server that the client can query, and the server always responds with the appropriate response. Communication within the OPC UA is always implemented via a secure channel.

The MQTT protocol is a standardized protocol that allows very simple transmission of a limited amount of data over a common TCP / IP Internet network. The protocol is based on the transmission of messages through a central server - a broker, which acts as a "journalist" receiving messages from the message provider and sending messages to their recipients. It follows from the above that the communication model used is, unlike OPC UA, of the "Publisher - Subscriber" type. One broker can have many different news providers and many readers connected, and only pass on to those readers the news that each reader has subscribed to. Due to the modular architecture of the entire solution, it is possible for one device to be both a message provider and a recipient of (other) messages. Within the MQTT protocol, the transmitted messages are sorted into topics. Each message belongs to exactly one topic, while the topics are defined directly by the message generator - Publisher. The subscriber must then know in advance the name of the topic he wants to subscribe to. The subscriber does not have to know the communication address of the publisher, he only needs the communication address of the broker. MQTT offers the possibility of encrypted transmission via SSL / TLS protocol as well as the possibility of authentication with client certificates, which is the highest possible level of communication security.

The MQTT protocol is very suitable for use in devices with limited computing power. It is also suitable for limited communication bandwidth due to data economy. The big disadvantage of the MQTT protocol compared to OPC UA is its centralization in the form of a single network broker. In the event of its failure or unavailability, the entire MQTT solution immediately becomes unusable.

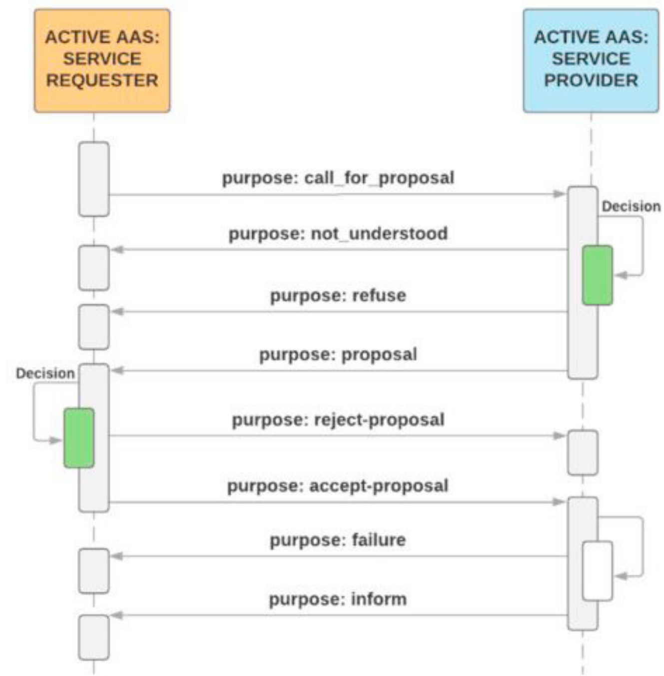

Figure 2 Negotiation flow diagram (Belyaev, 2019)

4.3. Communication principles

Due to the distribution of the decision-making process, it is the basic principle of negotiation. The negotiation algorithm is described by one of the basic AAS submodels. Figure 2 shows a UML sequence diagram of the negotiation process. The principle of the function is similar to the standard process between the customer and the supplier, where the demand is first created and the most suitable one is selected from the received orders. On the service provider side, a time slot is reserved for production.

At the moment, however, it is necessary to treat a large number of limit states that may occur - the service requester (product) does not respond, it is possible to reallocate the time slot for production; service provider does not respond - production on other machines is requested again. However, the validity of the reservation must be checked periodically on both sides, which is very demanding on the amount of communication with a higher number of products in the production cycle.

5. EVALUATION CRITERIA

Not only during the negotiation process - i.e., the attempt to allocate production equipment, but also within the entire production process, it must be possible to quantify the efficiency with which the process takes place at different levels of the hierarchy. In other words, there is a need to calculate some of the known Key Performance Indicators, which are standardized within the ISO 22400 standard and are currently implemented within the production management systems (MES). There is also standardization for these systems, which is a well-known international standard ANSI-ISA 95 defining the so-called manufacturing operation management (MOM) - a set of models (functional, data, communication) and recommendations for creating MES. If the manufacturer follows this standard, a system (MES, level 3) is created that guarantees interoperability with subsequent systems, whether enterprise resource planning systems (ERP, level 4) or with the domain of technological process management.

Introduce of the term KPI for calculating efficiency, everyone is reminded of one of the most well-known indicators - Overall Equipment Efficiency (OEE), which is used to evaluate the efficiency of one device in terms of availability, performance, and quality. The calculation of this indicator can be interesting within each component of the Asset Administration Shell. The value of OEE can be used in the process of negotiating production resources. By obtaining this value from multiple parallel sources, the AAS of the product can decide which of the sources to allocate. Note that OEE will not be the only indicator that will be key to the product's AAS in such a case. This will also consider, for example, the current length of the registration queue of a particular resource (in other words, the time he will have to spend in the queue) as well as other indicators.

Another problem is the determination of the so-called Overall Factory Effectiveness. This indicator evaluates the complete production process and can be deployed both on a specific production line and on a company-wide level. OFE calculation includes relationships and interactions between devices and processes and divides them into four groups - series, parallel, assembly, expansion. These groups of subsystems can be used to model the entire production operation.

CONCLUSIONS

As part of the research on I4.0, our research group has created a testbed self-employed bartender, on which we try to gradually test most of the principles and approach of I4.0. the testbed is made largely by additive production and a CPS is created for each autonomous cell (production machine).

The next step is to implement a decentralized production principle, which necessitates the implementation of AAS for Siemens S7-1200 PLCs. As this is a low-end PLC from Siemens, it will be necessary to optimize the implementation so that it is interoperable with standard AAS and at the same time it can be implemented in a PLC. The testing will also include finding out the parameters of individual communication protocols and their comparison and applicability to the given use case.

In the case of AAS functionality, the last step will be to optimize the production process, primarily using the evaluation criteria described in Chapter 5.

The result of the effort will be not only a functional prototype of the I4.0 production platform, but also a comparison of the advantages and potential disadvantages of this approach compared to the current I4.0 approach.

ACKNOWLEDGEMENT

The completion of this paper was made possible by the grants:

No. FEKT-S-20-6205 - "Research in Automation, Cybernetics and Artificial Intelligence within Industry 4.0";

No. FV40196 - "Research and development of the monitoring beds for immobile persons from the perspective of the risks of bedsores - decubitus";

No. FV 40247 - "Cooperative robotic platforms for automotive and industrial applications";

No. FW03010100 - "Research and development of detection and monitoring of people with dense coverage in shopping centers in order to optimize shopping flows and, in the event of crises and epidemics, access control to these areas".

REFERENCES

Castano, V. a. (2015). *Resilient computer system design.* Springer.

Hosseini, A. M. (2021). Towards adding safety and security properties to the Industry 4.0 Asset Administration Shell. *2021 17th IEEE International Conference on Factory Communication Systems (WFCS), 41--44.* IEEE. doi:10.1109/WFCS46889.2021.9483606

Schweichhart, K. (2016). Reference architectural model industrie 4.0 (rami 4.0). *An Introduction. Available online: https://www. plattform-i40. de I*, 40.

Cavalieri, S., & Salafia, M. G. (2020). Asset Administration Shell for PLC Representation Based on IEC 61131–3. IEEE Access, 8, 142606–142621. https://doi.org/10.1109/ACCESS.2020.3013890

Kaczmarczyk, V. et al., 2018. An Industry 4.0 Testbed (Self-Acting Barman): Principles and Design. IFAC-PapersOnLine, 51(6), pp.263-270. Available at: https://linkinghub.elsevier.com/retrieve/pii/S2405896318309108.

Belyaev, Alexander & Diedrich, Christian. (2019). Specification "Demonstrator I4.0-Language" v2.0.

Cavalieri, S., & Salafia, M. (2021). Predictive Maintenance Model based on Asset Administration Shell. 2(Iceis), 681–688. https://doi.org/10.5220/0010389306810688

Bader, S., Barnstedt, E., Bedenbender, H., Billman, M., Boss, B., & Braunmandl, A. (2020). Details of the Asset Administration Shell Part 1 - The exchange of information between partners in the value chain of Industrie 4.0. Plattform Industrie 4.0, 0, 473. https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/Details-of-the-Asset-Administration-Shell-Part1.html

German Electrical and Electronic Manufacturers' Association. (2017). Examples of the Asset Administration Shell for Industrie 4.0 Components-Basic Part Continuing Development of the Reference Model for Industrie 4.0 Components. April. www.zvei.org