Digital Twin and AAS in the Industry 4.0 Framework

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Abstract. The paper goes out from the state of the art in the area of Industry 4.0 initiative of the most developed countries. There are also discussed reasons of Industry 4.0 development and implementation into existing still developed technologies. According to the last development, the term digital twin became a very often-used word. Authors explain differences in the content of the digital twin and recommend to use for the Industry 4.0 area the more appropriate and precise specified term – the Asset Administration Shell (AAS). Next parts of the contribution therefore deal with the Asset Administration Shell (AAS) in details to enable engineers, technicians and informatics from the praxis much more simple introduction in the Industry 4.0 problems and their solution. There is introduced and explained the structure of the AAS, the model and sub-models architecture, parameters and features in the contribution.

1. Introduction
The contribution deals with Industry 4.0 (I4.0) as with a phenomenon, with its properties and procedures of its solution and implementation. Authors introduce readers in the state of the art after some years of the I4.0 initiative has been started in the most developed countries. Authors catch attention on what has been already done and how to utilize these outputs from the research and development for implementation for practical use. They point out also on the importance of standardization in each step of the value chain of industrial production systems, they present a list of them, and show an outlook of the next standards. One part of the contribution deals with a comprehensive list of requirements, which led to the specification of the most important idea and the most important component – the Asset Administration Shell – the electronic rucksack or digital twin of components in the I4.0 smart production systems. As it has been told in many forums by different opportunities, the I4.0 phenomenon is something like the 4th Industrial revolution. But as has been also said, the I4.0 is more then revolution a rapid and complex evolution of existing automation and automated production with sometimes still a significant level of robotics, complex automation, global communication, digitization, standardization, and openness. The existing industrial production, which can be titled as production in the intention of the Industry 3.0, still shows attributes, which are a challenge and respectable steps towards the creation of a higher type of organization, architecture, and realization of industrial production and even next social aspects of human activities. It can lead to too optimistic evaluation (self-evaluation) of managements of firms, that they already implemented I4.0 principles into their production systems. However, in the most case, there is missing a lot of very important features, characterizing the really I4.0 ideas, principles and technologies. For example, the digitization is used for many years, but not
systematically. Authors are the opinion, that only systemically utilized digitalization can grow into the Industry 4.0 world period.

The truth is, that still many features of existing Industry 3.0 (I3.0) production support a statement that we are on the boarder towards a new, higher level of industrial production, tell the 4th industrial revolution. This statement is supported by following phenomenaes.

Accelerated chain from idea via research, development, and realization of a new product, next a high value of digitization of information from production, next utilization of this digitized information in the control infrastructure of machines, production lines and technological processes. In addition, the high level of intelligence in process instrumentation, control, and monitoring systems, in MES and ERP systems supports the chance of a possibility of transformation existing production systems from the I3.0 to the I4.0 world. Also digitization of all attributes of physical components, marketing methods and procedures and technical and technological development periods, big data flow in the production process, storing and processing of measurement and control values in the cloud supports idea of the coming Industry 4.0 period. This opinion is supported as well as by activities of standardization organizations in highly developed countries to standardize interfaces, communication protocols, production procedures, requirements on the functional safety and security of the all value chain play a significant role.

One of the most promising phenomenon of this historical period, which still influences significantly all the human society is Internet. Internet influences the production processes - the Internet of things (IoT) and the Industrial Internet of things (IIoT) represent the highest development phenomenon horizontal and vertical integration for Industry 4.0 purposes.

Authors are the opinion, that still the slow progress in the implementation of I4.0 principles is caused by non-systematic digitization, non-optimal data acquisition and data processing and low level of application of standards, an unwillingness of specialists in control, measurement and informatics to apply still existing standards and in missing some of needed standards. It appears particularly in communication subsystem, in communication interfaces and protocols. On the other hand the I4.0, its popularity, broaden up, much work which already has been done during last years, and due to competences of many standardization working groups, mutually cooperated across Germany, France, Italy, but also with support and cooperation with the USA, China, Japan bring and open an excellence opportunity and challenge in technical development, that was not possible still 5-7 years ago. I4.0 activities bring the following opportunities:

- An opportunity for unified communication in the all control pyramid.
- Communication by a unified communication protocol from the shop to the highest levels of the office floors of the all value chain.
- Interconnection of all activities in the value chain of industrial production thanks to unified interfaces of HW as well as SW interfaces, protocols, production procedures, production documentation, quality control, safety, and security.
- A significantly higher degree of cooperation among producers and consumers.
- Support of the informatics branch in research, development, standardization, and implementation of unified real-time communication not only in time-critical production processes but also inside the all value chain.
- Acceleration of the activities design – development – production, increasing of digitization and the use of it, decreasing of redundancy in data acquisition processes.

These opportunities will be utilized only, when following preconditions will be to provided systematically and in a standardized way:

- Solid, systematic and standardized digitalization of information from the all value chain.
- Virtualization of production, process modeling in a virtual environment and after tuning all the process to transmit optimized control algorithms into the physical production, output quality checking, marketing and service.
- A higher level of the horizontal integration of the all value chain.
- Intelligence until the component of the production.
- Creation of a standardized architecture of a digital twin of physical components (machines, components of machines), components of a transport system, supermarkets, control SW, technical documentation, product, and market documentation.
- Production components will be designed, developed and implemented as the Industry 4.0 components, specified by the ZVEI, VDE/VDI, and cooperating organizations [1], [2], [5], [8].

The contribution goal is to help technical experts from praxis to understand the importance of the I4.0 component model and to win skills in working with it. This I4.0 component model is described in the next chapter. The official term of the production component is the "I4.0 component" and its electronic form is oft titled “the digital twin”.

2. Digital twin alias Asset Administration Shell (AAS)

The term digital twin was for the first time used by NASA (National Agency of Space and Aeronautics of the U.S.A.) for approximately 60 years to name an electronic version of the physical model of physical comics systems (space shifts, and other systems to fly in the space. Such a very precious mathematical description and consequently very precise digital realization (digital twin) enables monitoring, control and maintenance of the American space system on very long cosmic distances. Because of similar functionality and an appropriate and with the most important element of the I4.0 activity, the Asset Administration Shell – the electronic rucksack is the AAS oft in the last time named digital twin. It was seen also during the last Hannover Fair that the term digital twin very oft used the title. However, in the sense of the NASA, the digital twin is a virtual representation, an embodiment of an asset of any type, material or non-material – including everything from power turbines to services and maintenance. The digital twin is described by the structure and behavior of connected "things" generating real-time data [3].

In comparison, the asset administration Shell (AAS) is the crucial item in the all I4.0 idea. It creates an interface between the physical and virtual production steps. AAS is a virtual digital and active representation of an I4.0 component in the I4.0 system [2]. Any component of production in the I4.0 environment has to have an administrative shell [2].

Fig. 1 shows the structure and connection of the physical thing and the administration shell (AS). The component of the I4.0 is a unity of an asset and the electronic model – the corresponding AS.

The co-author of this contribution lived such a misunderstanding of term digital twin during one oral presentation of one tutor by a tutorial in the ZVEI Forum I4.0 in this April in Hannover. The tutor needed several digital twins for one I4.0 component, but from the AAS definition would be fully acceptable and recommended only one AAS with several sub-models.

Much wrong is, that from commercial reasons, the term digital twin is used also for the 3D model, e.g. of a production unit, machine, or car, including simulation. This interpretation is currently state of the art and used by a broad industrial community. However, the 3D model is an I3.0 technology only [3].

Maybe, that existing digital twins in the commercial interpretation will step by step grow to cover all useful information which is relevant across the lifetime of the related asset, from the initial idea to the engineering, logistics, operation, maintenance, reuse, and destruction. They could become a future digital twin that will contain a simulation model, the 3D model, a lot of other properties, historical data, handbooks, installation guidelines, property function blocks, interlockings, state models, alarms, event definition, etc. On the other hand – a static asset will not include in its digital twin any simulation model [3].

In this context, the term AAS is for purposes of the I4.0 more appropriate title then the term digital twin. Therefore authors emphatically recommend to preferably use the term AAS in the I4.0
environment. How great is the difference between the AAS and a pure digital twin in the commercial interpretation can be seen from the following chapters, dealing with the structure of the AAS.

3. Asset Administration Shell Advanced Topic
Much work has been done by working groups of the ZVEI, VDI/VDE, BITCOM exactly in the structure and its components in the Asset Administrative Shell specification. A very comprehensive material of the detail of the AAS was prepared for publication at the end of 2018.

This material is a result of the new situation in Europe. The initial I4.0 idea of the German state institutions ZVEI, VDI/VDE, BITCOM, and some private companies and organizations became newly a larger European background when it has been started initiatives to keep up and improve three the most developed industrial European countries in the manufacturing industry. Alliance Industrie du Future in France, Platform Industrie 4.0 in Germany and Piano Industria 4.0 in Italy have agreed to join forces working on a shared action plan towards internationalization as an end to end digital continuity and global standardization are of crucial importance for a digitized economy [4].

Let us explain more comprehensively, because of high importance, the term AAS:
- The I4.0 component is the combination of the asset and its logical representation, the AAS.
- The AAS is the standardized digital representation of the asset, cornerstone of the interoperability between the applications managing the manufacturing systems.
- The AAS may be the logical representation of a simple component, a machine or a plant at any level of the equipment hierarchy.
- From the manufacturer point of view, the asset is a product. The manufacturer manages different types that have a history with different versions. In parallel, he produces instances of these different types and versions.
- The manufacturer provides the standardized digital representation to his customers, creating both an AAS for the asset type and for asset instance. The system designers, the asset users, the applications, the processes and the asset itself update the information of AAS during the life of the asset until its disposal [4].

**Figure 1.** AAS Structure in details (inspired by [4,8]).

Figure 1 shows the AAS structure associated with some specific use cases and much more specifies the contents of the AAS towards the body’s part, hence towards submodels.
What is a submodel? Submodels represent different aspects of an asset. Possible aspects and therefore a possible submodel could be: Identification, Communication, Engineering, Configuration, Safety, Security, Lifecycle status, Energy Efficiency, Condition Monitoring, etc.

Each submodel contains a structured quantity of properties that can refer to data and functions. Properties can be specified in accordance with the standard IEC 61360, but data and functions can be specified in various formats [4]. The following example stemming from the project RACAS shows how a specific communication process (bidding process or "interaction pattern") is directed towards the domain-specific submodels in the AAS, Fig. 1 [8]. The bidding between two assets in an industrial production line with 3D printers is described in the top of Fig. 2: an asset (e.g. semi-finished product) asks another asset (3D printer) situated in the production line, if its capacity, functionality, availability are able to provide the specified operation (printing on the semi-finished product of its dimensions <150x200x50 mm from material PLA by filament density 50 % printing operation in color RAL1003, a quality 0.2 mm taking time shorter than 4 hours.

![Administration Shell example, 3D printer](image)

**Figure 2.** Bidding process directed towards the specific submodels of the AAS.

For such purposes, there have to be implemented in the AAS of the 3D printer at least two submodels ("Manufacturing process" submodel with parameters of the printer such as MPP053 work-piece dimension, MPP068 processing time and, and. There should be also implemented the second submodel the "3D printing" with parameters of the printing – PSP021 material, PSP034 filament density, PSP041 filament color.

This example recovers a principle of decentralized control in the I4.0 environment. The I4.0 components of the I4.0 production would control self their live cycle by negotiation with other I4.0 components. By this way, many problems with fronts in narrow places in production processes will be solved dynamically without a central control system. This architecture also enables more rapid and more flexible reaction of production processes in malfunction of machines, production lines, control systems, transport system and other parts of enterprises technologies.

An important pre-condition for such a production process is, that each I.0 component will be equipped by its standardized AAS.

### 4. Requirements regarding the AAS

The structure, properties, content of submodels, parameters and other features the AAS have been specified, developed and implemented into the AAS on requirements which have been collected, sorted and specified in detail by working groups of ZVEI, VDI/VDE, GMA, and others and will be openly published in the 2019 year. Contribution contains a proposal of them.

Requirements regarding the AAS sorted into three groups:
1. General requirements (R#1 – R#5)
2. Requirements regarding identifiers (R#6 - R#7)
3. Requirements regarding the AAS self (R#8 – R#22)

Particularly, the Requirements regarding the AAS self have significantly influenced the existing model of the AAS [8,9]. All requirements are listed in the following summary [4].

**Requirement # 1**
The AS shall accept properties from different technical domains in mutually distinct submodels that can be version-controlled and maintained independently of each other.

**Requirement # 2**
The AS should be capable of including properties from a wide range of technical domains and of identify which domain they derive from.

**Requirement # 3**
For finding definitions within each relevant technical domain, different procedural models should be allowed that respectively meet the requirements of standards, consortium specifications, and manufacturer specifications sets.

**Requirement # 4**
Different ASs in respect of an asset must be capable of referencing each other. In particular, elements of an AS should be able to play the role of a “copy” of the corresponding components from another AS. E.g., one or more assets can be portrayed in an AS - mechanical axis, motor, servo amplifier, and additional assets constitute an “encapsulate-capable” Smart Manufacturing Component. The ASs of several individual assets that a manufacturer brings into the market individually is consolidated into one AS, if this manufacturer also sells a whole axis system.

**Requirement # 5**
Individual ASs should, while retaining their structure, be combined into an overall AS

**Requirement # 6**
Identification of assets, ASs, properties, and relationships shall be achieved using a limited set of identifiers (IRDI, URI, and GUID), providing as far as possible offer global uniqueness.

**Requirement # 7**
The AS should allow retrieval of alternative identifiers such as a GS1 and GTIN identifier in return to asset ID (referencing).

**Requirement # 8**
The AS consists of header and body, see Fig. 1.

**Requirement # 9**
The header contains information about the identification, Fig. 1. The header contains minimal information about identification. It uniquely identifies the AS. This identification can therefore also serve as a root entry point for an application programming interface (API) to browse for information and functionalities. The header contains also the identification of one or multiple assets that are described by the AS. The header also indicates if these assets are asset types or asset instances.

**Requirement # 10**
The body contains information about the respective asset(s). The body contains information about the asset(s) and describes functionalities that are associated with the asset(s) or the AS. The information can concern asset type(s) and/ or asset instance(s). Thus, the body serves as the actual carrier of information and functionality.

**Requirement # 11**
The information and functionality in the AS are accessible by means of a standardized application programming interface (API).
Requirement # 12
The Administration Shell has a unique ID.

Requirement # 13
The asset has a unique ID. It should be ensured that the link between assets and ASs does not break, even if they are saved in digital repositories or saved in a manner that spans all value-added partners.

Requirement # 14
An industrial facility is also an asset; it has an AS and is accessible by means of ID. The concepts of the AS shall be applicable on all hierarchy levels of an industrial facility, such as factories/plants, production lines, stations, controls and field devices.

Requirement # 15
Types and instances must be identified as such. ASs can be formulated for both types and instances of assets. It must be possible to differentiate between these. Ideally, an information relationship will also be established between component producers and the system integrator that, where required, allows updated developments regarding asset types to be communicated to the system integrator and conversely feedback to be transmitted to the component producer about the component use.

Requirement # 16
The AS can include references to other ASs or Smart Manufacturing information. For the cross-linking of information to knowledge, it is important that this can also take place on an over-arching basis. Thus, for example, a component can model the dependencies on other components or can contain a circuit diagram, which refers to other components.

Requirement # 17
Additional properties, e.g. manufacturer specific must be possible. The Smart Manufacturing component can only meet future requirements if, in addition to the information content stipulated by standards, consortia and manufacturer properties can also be quickly agreed and processed. The AS should, therefore, support this consortia and proprietary information content and, associated accordingly, necessary collaboration processes.

Requirement # 18
A reliable minimum number of properties must be defined for each AS. ASs shall be a reliable source of information to other ASs or other systems. To do so, it shall be possible to define for each asset class a minimum set of properties and value statements that can be relied upon. The following requirements are applicable to the properties of an AS; the properties are structured by submodels. Standardized submodels types can require the presence of properties in submodel instances.

Requirement # 19
The properties and other elements of information in the AS must be suitable for types and instances. ASs can be formulated for both types and instances of assets; thus, properties need to be able to describe particularities of on asset type and, maybe, in addition, the asset instance. An AS of an asset instance shall also feature the properties of the AS of the respective asset type, as long as these properties were not overridden. NOTE: This can for example also mean, that the descriptions of an asset type are extended over the lifetime or, for an asset instance, properties are added, amended or deleted depending on (maintenance) activities of the respective asset.

Requirement # 20
There must be a capability of hierarchical and countable structuring of the properties. The volume of properties to be organized is rather large and it is anticipated that it will steadily increase in the progress of Smart Manufacturing. This means that these quantities should remain manageable for humans and machines. It is thus necessary to be able to organize properties using combinations of structures and arrays.
Requirement # 21
Properties shall be able to reference other properties, even in other ASs. Properties referring to other properties allow expressing dependencies on values contained in other ASs. In addition, knowledge can be modeled by interrelating two properties by a predicated relationship.

Requirement # 22
Properties must be able to reference the information and functions of the AS. The structure of submodels and properties serves as a clearly defined “table of contents” for all information and functions within the AS. Properties are of uniform structure, they are standardized and they are thus providing a very stable source of information. Complex data (digital models) and functions, on the other hand, can have a large variance and can be very complex in structure. Therefore, properties shall be able to refer to these complex data and functions in order to provide an anchor point for these entities in the above "table of contents". NOTE: This concept relies on an extended understanding of an IEC 61360 property concept.

5. Conclusion
Contribution deals with the most important term of the Industry 4.0 theory and application – the AAS. This fundamental term has been already specified in details and can create a reliable basis for the realization of not only I4.0 case studies and test beds, but for the real design, development and implementation of I4.0 principles in reality of factories of the future. Authors repeat terminology and associate technical as well as theoretical basis of the I4.0 idea based on the AAS.

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