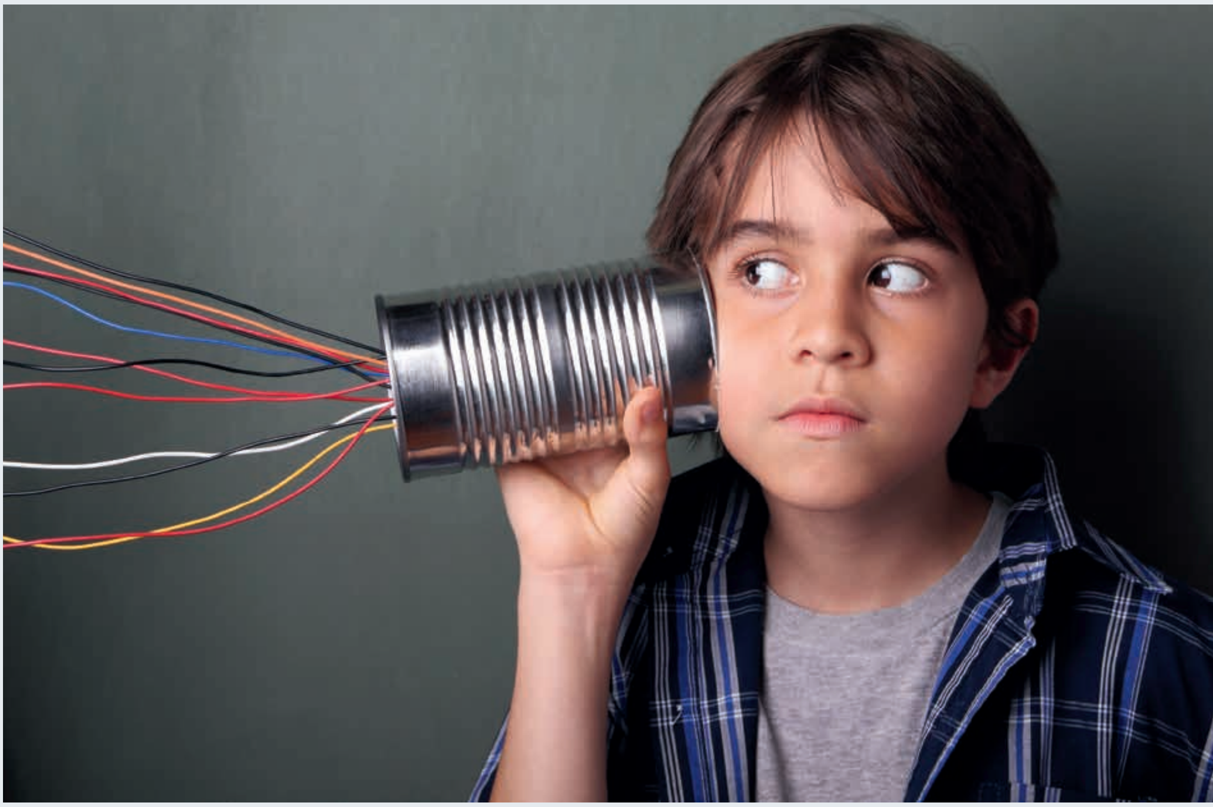
Industrie 4.0 Communication Guideline

Based on OPC UA



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VDMA Machine Information Interoperability

Editorial

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Innovations, solution competence and top quality are central characteristics of the German-European mechanical engineering industry. The current digital transformation is about integrating information and internet technologies into products and factories and generating added value from the data obtained. The German-European mechanical and plant engineering industry plays a key role as a constant driver of innovation. As a supplier and user, it integrates the latest technology into products, processes and its own production. At the same time, its products are the source of data for efficiency gains and new data-driven business models.

An important basis and at the same time a central challenge for the successful implementation of the digital transformation is the exchange of data across manufacturers and the standardisation of their content. This can be achieved by by defining standardised interfaces.

In mechanical and plant engineering, the IEC standard "Open Platform Communications Unified Architecture" (OPC UA) has established itself for this purpose. This is an open, secure, scalable communication architecture. OPC UA enables the manufacturer-independent networking of production in mechanical and plant engineering, as well as its customer industries.

In addition, OPC UA Companion Specifications, in which the semantics of the interface data are standardised, define an industry-specific and cross-industry vocabulary. A uniform language simplifies the implementation of use cases such as intelligent condition monitoring or predictive maintenance and thus supports the realisation of sustainable, efficient production.

Since 2017, the VDMA has focused its activities on the development of a uniform vocabulary in the form of OPC UA Companion Specifications, providing important orientation for the mechanical and plant engineering sector. Against this background, the new edition of the VDMA guide "Industrie 4.0 Communication with OPC UA" is a practice-oriented tool. It shows steps that contribute to the successful introduction of both OPC UA and the OPC UA Companion Specifications in products, processes and production.

Special thanks go to Prof. Dr. Oliver Niggemann and Prof. Dr.-Ing. Jürgen Jasperneite from the Fraunhofer Application Center Industrial Automation (IOSB-INA) for the scientific preparation of the VDMA guideline. In addition, it is important to thank the participating VDMA members for their commitment.

The VDMA guideline "Industrie 4.0 Communication Guideline Based on OPC UA" is thus also an example of the excellent cooperation and networking of the German machine and plant manufacturers.

We wish you all an interesting and inspiring reading.

Andreas Faath

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VDMA, Chairman of OPC UA for Machinery

Industrie 4.0 Communication Guideline Based on OPC UA Guidance for German small and medium sized companies

Prof. Dr.-Ing. Jürgen Jasperneite

The plant and mechanical engineering industry and manufacturing companies are currently experiencing a wave of innovations, both through technology and data-driven business models. For example, new methods such as predictive maintenance or self-optimization are introduced and standard IT systems as well as Big Data Platforms become part of automation systems. This will enable new business models based on data-driven services.

These approaches are based on standardized and consistent exchange of information across all layers of automation systems. Without standardization, analyzing information remains a tedious task and no automatic optimization of plants or further shortening of ramp up and retrofit phases seems possible.
The IEC Standard Open Platform Communications Unified Architecture (OPC UA) is a promising approach for the implementation of this consistent information exchange. For this reason, OPC UA is a major candidate for a future standard in Industrie 4.0. The goal of this guideline is to introduce features of OPC UA and possible migration strategies.

It should be added that OPC UA is not just another standard for real-time communication in automation. Instead, OPC UA establishes an additional communication channel between islands that were separated until now. The main task of OPC UA will be the transmission of information for new services in Industrie 4.0 rather than replacing existing protocols.

For this reason, it certainly makes no sense to wait for explicit requests from customers for OPC UA, since OPC UA is only a tool for the implementation of new customer scenarios. Especially plant and machine builders should take into account that many of these scenarios can only be implemented based on a vendor-independent and interoperable exchange of information. Additionally, integration effort should be reasonable. OPC UA has been designed with these requirements in mind. Previous projects conducted by Fraunhofer IOSB-INA were able to show that OPC UA's resource consumption is highly scalable. Therefore, sensors and field devices with resource constraints also can be equipped with appropriate functionality.

In addition to OPC UA's base functionality, implementations should focus on the usage and development of information models. Information models provide information about a plant or machine in a standardized manner, including not only the data, but also metadata, e.g. data source, quality, and interconnections. The effort for the integration of automation systems and the connection to data analytics and optimization tools can only be reduced by means of information models. These information models can be designed by each company individually. However, an agreement on standardized models for a certain branch is beneficial to all participants. Various branch-specific information models are already being standardized.

OPC UA offers an opportunity for the rapid implementation of new customer requirements and new value-added services for the machine and plant engineering industry, producers and equipment manufacturers. Especially medium-sized companies get the opportunity to open up new markets and to develop new products quickly and efficiently.

We hope to encourage companies to take this path.

Prof. Dr.-Ing. Jürgen Jasperneite
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Management Summary

Companies from the machine and plant building industry and operators are currently confronted with abstract concepts about Industrie 4.0. These concepts promise high efficiency and flexibility but lack concrete recommendations for action. Today, companies use a variety of industrial communication solutions with the associated effort for integration. Why do companies need additional Industrie 4.0 communication?

Industrie 4.0 communication does not refer to yet another industrial communication solution for real-time process and control data. It complements the existing solutions and is based on fundamental new concepts, such as service-oriented architecture (SOA) and information models for the description of devices and their capabilities. SOA allows components, machines, and systems to be more flexible because they are not configured and programmed for a specific production task, but rather offer their capabilities as services. Component services can be orchestrated into more abstract machine and equipment services.

Industrie 4.0 communication simplifies the integration of components, machines and plants.

Industrie 4.0 communication simplifies the integration of components, machines and plants and enables increases in efficiency based on simple connections to condition monitoring and optimization systems. These connections do not depend on existing fieldbus or real-time communication systems. In addition, the use case Plug & Work allows for a more flexible commissioning and retrofitting of machines, plants and factories. This feature saves time and costs.

The open standard Open Platform Communications Unified Architecture (OPC UA) is specified in IEC 62541 [1] and fulfills all requirements to Industrie 4.0 communication. OPC UA becomes increasingly established in the machine and plant building industry.

Industrie 4.0 communication based on OPC UA can be implemented step by step.

First Migration Step

Industrie 4.0 communication based on OPC UA can be implemented step by step. Basic prerequisite for Industrie 4.0 communication based on OPC UA is a network based on the Internet Protocol (IP). If an IP based network exists, OPC UA can be used as a uniform interface for accessing information from machines of various manufacturers. For example, condition monitoring systems can access information from machines via Industrie 4.0 communication. In a first step, relevant parameters for monitoring a machine or system are manually integrated into the condition monitoring system. This reduces the integration and maintenance effort of many different communication solutions to just one.

Second Migration Step

In a next migration step, the use case Plug & Work is made possible by using standardized information models, so called Companion Specifications for OPC UA. The core functionality of machines and plants from different vendors is modeled equally to enable identical integration and usage of these machines. This interoperability is demanded by more and more operators from the machine and plant construction industry, but also in the customer sectors, for example in the automotive or process industry.

Many component manufacturers, machine and plant builders have already moved towards Industrie 4.0 communication. The consequence is the creation and use of companion specifications. Many information models already exist for various areas of mechanical engineering. The specification "OPC UA for Machinery" is particularly worth mentioning here, as it can be used throughout the entire machinery and plant engineering sector. Through its use, added value can be achieved quickly, for example by evaluating the current status for an overall plant efficiency calculation.

Third Migration Step

In a third migration step, an extended information model can contain functionality that should not be standardized. This way, also in Industrie 4.0 machines and systems will differ in terms of performance and efficiency. It is not intended to standardize all aspects of machines and systems. Expertise of machine and plant builders, e.g. functions for the optimization of their machines, can be granularly protected by role-based authorization in OPC UA.

Fitting Boundary Conditions

The Federal Office for Information Security (BSI) confirms that Industrie 4.0 communication can be implemented in a secure way using OPC UA. [2]

Industrie 4.0 communication is not an abstract future concept. It already exists with OPC UA.

Of course, Industrie 4.0 communication based on OPC UA fits into the Reference Architecture Model for Industrie 4.0 (RAMI4.0) from the German organization Plattform Industrie 4.0 (**https://www.plattform-i40.de**). Industrie 4.0 communication based on OPC UA is not only found on the communication layer, but also on the information layer where OPC UA's information models are located.

Industrie 4.0 communication is not an abstract future concept. It already exists with OPC UA. Machine and plant building industries must face the future challenges coming more and more from the IT and software business. Terms such as IP-based network, information model, and SOA will belong in machine and plant builders' vocabulary in the future.

Introduction and Objectives

This guideline is intended for companies of the machine and plant building industries and their operators. In addition to the continuous goal of optimizing overall plant efficiency, operators today face challenges like customer involvement in the production process and individualized production.

Connecting machines and systems to services for increasing overall plant efficiency, such as condition monitoring and functions for system optimization, today involves a high configuration effort. In addition, an individualized production requires much more flexibility and interoperability, which can only be implemented with high effort when using the established communication technologies.

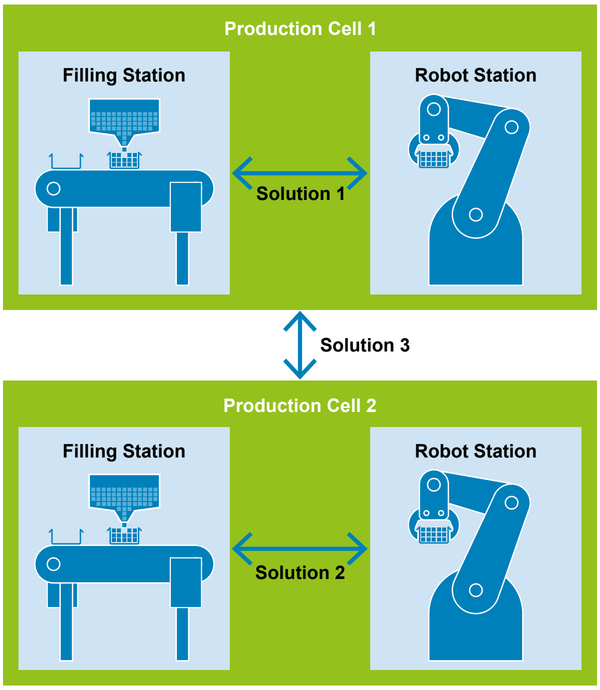

Figure 1: State of the art of industrial communication

An example for the state of the art of industrial communication is depicted in figure 1: Two production cells use different communication solutions 1 and 2. For cross-cell communication a third solution is used. Integration of these different interfaces requires high implementation time and is error-prone.

Industrie 4.0 Communication is based on Standardized Service-Oriented Architecture

For this reason, operators demand standardized, robust, IT-secure, cross-cellular Industrie 4.0 communication for the machine and plant building industries. Basically, Industrie 4.0 communication differs from previous communication technologies in the sense that it is based on standardized service-oriented architecture (SOA) and the transmission of self-describing information. Unlike today's communication, device and capability descriptions are transferred. The self-description reduces configuration effort and supports quick understanding of information.

The self-description reduces configuration effort and supports quick understanding of information.

OPC UA fulfills Requirements

The open standard OPC Unified Architecture (OPC UA) specified in IEC 62541 [1] meets these requirements. It is increasingly establishing itself for Industrie 4.0 communication in the machine and plant building industries. With OPC UA, device and capability descriptions can be created in the form of information models. Industry specific information models can be standardized as OPC UA Companion Specifications.

Guideline supports Vendors and Users

This guideline is intended to be used by machine and plant builders, as well as operators for the implementation of Industrie 4.0 communication. On the one hand, companies today face the challenges mentioned before. On the other hand, they are confronted with abstract concepts for Industrie 4.0. This guideline tries to close this gap.

The following chapter introduces use cases for Industrie 4.0 communication. Subsequently, the OPC UA toolbox for Industrie 4.0 communication is introduced, which is used for the implementation of migration steps and introduction of the use cases. This is followed by the presentation of an OPC UA Companion Specification using the OPC UA for Machine Tools specification as an example. Finally, the connection to the Reference Architecture Model Industrie 4.0 (RAMI 4.0) is explained.

Requirements

This chapter introduces requirements from operators, machine and plant builders for Industrie 4.0 communication. The requirements form the basis for the migration strategy introduced in this guideline.

The information model is a key concept and the foundation for Industrie 4.0 communication. It describes the structure of the data and provides it with semantics. It can be used both by humans and by devices. The information model consists of a network of different objects that can represent user data, as well as meta- and runtime-information. Thus, the information model might include device information, process variables, and machine capabilities. Other devices or users can read and interpret these objects. In addition to read or write access, methods can be used in order to trigger actions, e.g. to “power on” a machine. Additionally, it is possible to be notified of any changes by means of events.

The information model is a central basis for Industrie 4.0.

Requirement
„IT Security“

Industrie 4.0 communication must be secure. Using IT security mechanisms, information can be protected against unauthorized access or manipulation, thus protecting copyright and preventing damage. During the development of an information model, it is possible to limit the amount of information, so that only information required for interoperability is exchanged. Different access rights can be granted to different users in order to define which information they can read and write. Minimum requirements for IT security are described in the VDMA Guideline “Industrie 4.0 Security - Recommendations for Action for Medium-Sized Enterprises” [3].

Requirement
„Support people“

A key requirement for Industrie 4.0 communication is the reduction of the complexity that is present today. This complexity leads to high costs for commissioning and rebuilding of systems. Supporting people through a uniform interface for production systems is elementary.

Requirement
„Operate and rebuild factories efficiently“

The status quo in the operator’s factory does not allow for simple increases in overall plant efficiency while at the same time implementing a production of individual goods. Operators require a simpler integration of plants and machines into systems for monitoring (condition monitoring) and optimization through concepts such as Plug & Work. Today, this is associated with a lot of effort.

Requirement
„Integrate machines into the plant in a simple way“

Machines and systems have many different interfaces, which is the main reason for their manual integration into plants. Plant builders demand machines with uniform interfaces and information models.

Requirement
„Structured information access on machines and production cells“

Machines and production cells do not provide their information in a uniform structure. Plant builders demand a uniform communication between machines and cells.

Requirement
„Access services and data from control and field devices in a secure and interoperable way“

The integration of components, such as control and field devices, into machines involves a lot of effort today. The devices contain different information models and communication technologies, which often do not take IT security into account. Engineers request components that offer services via uniform, secure interfaces.

Use Cases

This chapter defines use cases for Industrie 4.0 communication. Considering the requirements from the last section, these applications form the core of the migration strategy for Industrie 4.0 communication.

Use Case 1: „Condition Monitoring“

Machine building companies can use features of Industrie 4.0 communication in order to monitor the condition of their machines (data analytics, condition monitoring). For this, they have standardized access to a variety of information based on current data, e.g. energy consumption, ambient temperature, process values or order status. Additionally, they can provide all available information to (mobile) devices of their customers. This already simplifies maintenance and adjustments of the machine. Thus, overall plant efficiency can be increased.

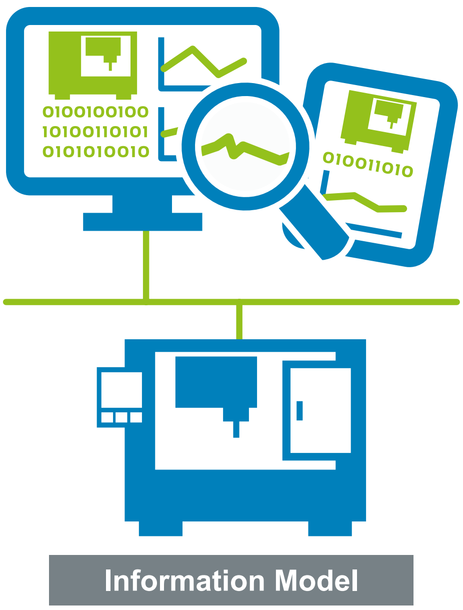

Figure 2: Condition monitoring

Example „Condition Monitoring“:
Available process information can be used by data analytics tools to extract behavioral models, which can be compared to real operation. Such models support the detection of deviations due to faulty operation or incipient errors. These data analytics tools and functions use the standardized fieldbus-independent Industrie 4.0 communication to get all required inputs and to forward feedback.

Use Case 2: „Plug & Work“

Industrie 4.0 communication increases the interoperability of machines and systems. In particular, configuration effort can be reduced by means of Plug & Work mechanisms for automatic configuration. This technology concept supports integration of new devices into networks of field devices, control systems, condition monitoring and optimization systems so that they are automatically integrated into the existing system design. For this purpose, a standardized information description is necessary to enable devices to understand each other.

Industrie 4.0 communication is based on a uniform communication interface.

Today, different manufacturers refer to the same information differently. Therefore, despite a uniform communication interface the integration of this information into higher-level systems is time-consuming. Figure 3 illustrates this with an example: The production system shown contains two machines and higher-level systems for production control, monitoring and optimization. The machines use different information models

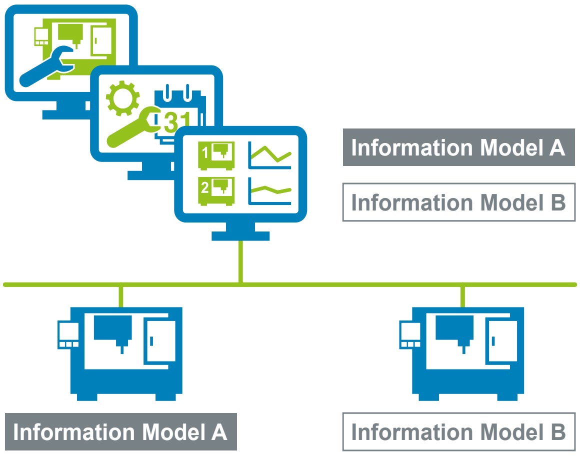

Figure 3: Uniform communication interface

A and B. In order to integrate the machines, higher-level systems must know both information models. If the information model for the machines is standardized, only one information model must be known in higher-level systems. This is shown in figure 4.

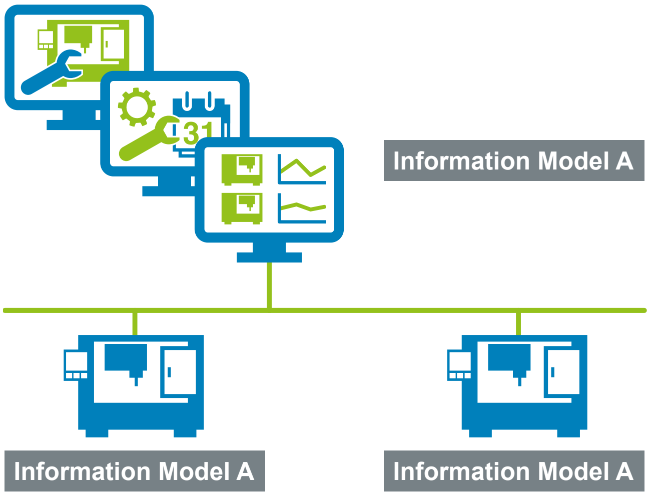

Figure 4: Uniform communication interface and uniform information model

Industrie 4.0 communication does not just start on the machine level. The individual components of a machine, i.e. the controller and field devices, can participate in Industrie 4.0 communication as well. Industrie 4.0 communication facilitates machine-building companies to easily integrate these components into their machines. Thus, for example an energy-measuring device can be integrated into a machine, which afterwards provides standardized measurement values.

Use Case 3: „Optimization“

In a next migration step energy or cycle time can be optimized. Process values for an energy-optimized machine control can be easily integrated via Industrie 4.0 communication. Data analytics functions can for example learn the characteristic energy consumption of components, machines and process steps, and from this determine parameters for optimized operation.

Example „Optimization of a high-bay storage“:
An automated high-bay storage uses several controls and storage and retrieval vehicles. Power spikes occur, which cause high costs and lead to disturbances. The control signals of the drives and the energy measurement values have to be analyzed by data analytics software. It is necessary to access information on controllers and energy meters from different manufacturers. The implementation of this information access is associated with a lot of effort today. This integration can be significantly simplified with Industrie 4.0 communication. Once the information is available, a data analysis method can analyze the energy consumption in the high-bay warehouse and calculate optimized control parameters. The calculated trajectory is transmitted to the vehicle, which carries out the necessary movements.

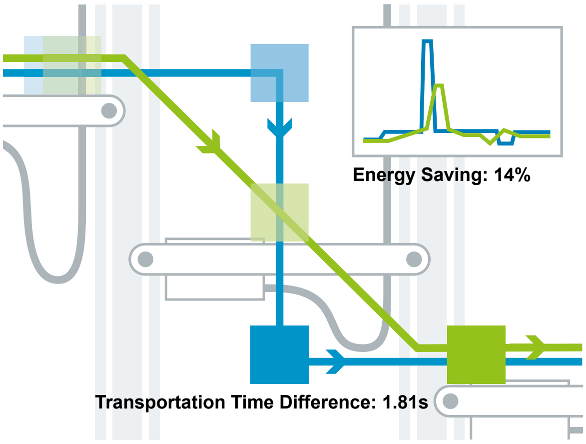

Figure 5: Energy optimization of a high-bay storage

Example „Optimization of the generation of compressed air“:
A machine requires compressed air, which is provided by a compressor. The machine includes components that predict their energy consumption for the next few minutes and communicate via Industrie 4.0 communication. The compressor uses this information to check whether it can meet the demand or whether a reserve device has to be switched on. In return, the compressor reports when it reaches its power limit. Thus, the production can be adapted to the available compressed air. A standardized communication can thus enable an optimized interaction of the networked components without additional configuration effort.

Vision: Factory-To-Factory Communication

In the vision of Industrie 4.0, communication does not end at factory level. The application scenario “Order-Driven Production” from the Plattform Industrie 4.0 depicted in figure 6 is based on the interaction of factories in order to adapt production capabilities and capacities to rapidly changing market and order conditions. A standardized Industrie 4.0 communication allows automated scheduling, distribution and control of orders including all required production steps and production resources. Individual process modules can thus be combined more flexibly than before and their specific abilities can be used [4]. As shown in figure 6, Industrie 4.0 communication for this application scenario can use a cloud.

Industrie 4.0 communication also involves the customer in development and production. In the simplest case the customer gets transparency. In further steps the customer gets active design possibilities, which he only had in earlier phases before production. This results in new possibilities for increasing customer satisfaction and additional services. Above all, customer loyalty can be increased.

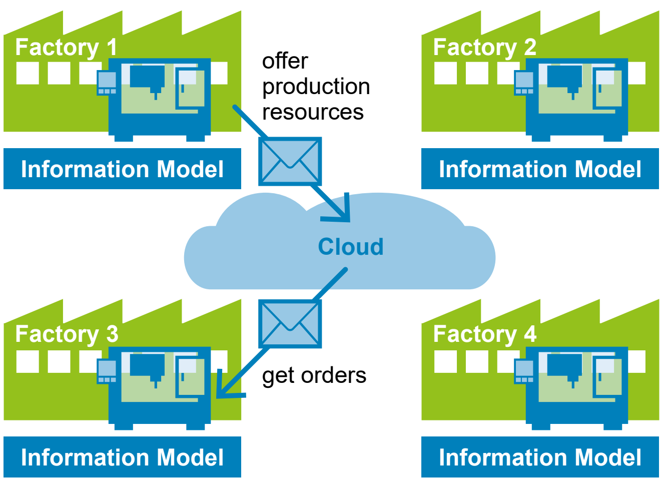

Figure 6: Factory-to-Factory Communication in the application scenario “Order-driven Production“

The Toolbox OPC UA for Industrie 4.0 Communication

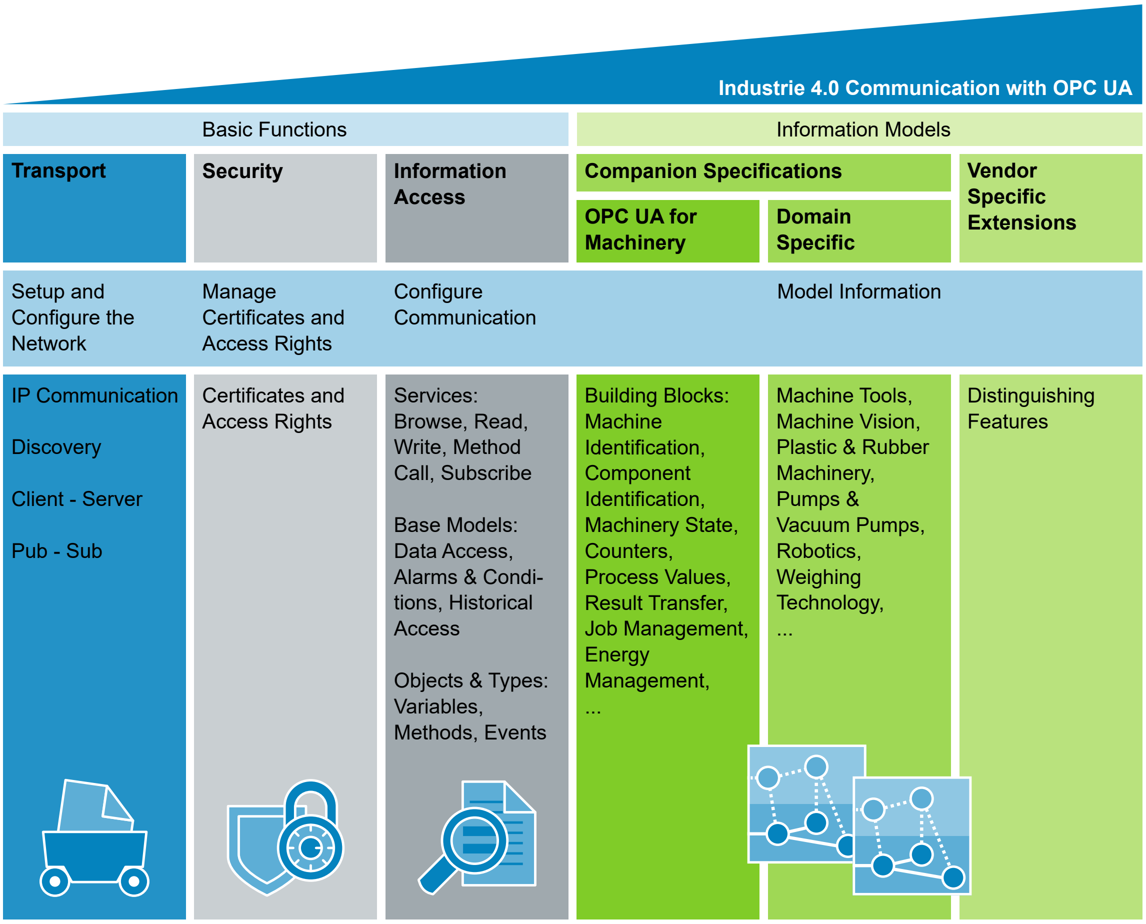

Figure 7: The toolbox OPC UA for Industrie 4.0 communication

The OPC UA toolbox is shown in Figure 7 and contains both the basic functionalities and the information models required for Industrie 4.0 communication.

The transport, security and information access are described in detail on the left-hand side. The cross-domain OPC UA for Machinery specification, the domain-specific Companion Specifications and the manufacturer-specific extensions are presented on the right-hand side.

The degree of fulfilment of Industrie 4.0 communication increases here from left to right. However, no column should be skipped.

OPC UA is a SOA and enables standardized information exchange of machine data, e.g. device descriptions, measured values, parameters and control variables. OPC UA does not replace the deterministic communication within machines, but allows uniform communication between plants, machines and components from different manufacturers. OPC UA is the successor to the classic OPC variant and extends it by standardized transport protocols, such as Web services, security mechanisms, and the ability to describe information semantically in an information model. This technology is actively managed and further developed by an industrial consortium called OPC Foundation.

The elements of the toolbox OPC UA are described in detail below.

Transport

The transport layer implements information access using various communication mechanisms and protocols based almost exclusively on the Internet Protocol (IP). OPC UA therefore requires a network infrastructure that enables IP communication. OPC UA is compatible to IPv4 and IPv6. In the future, OPC UA will support deterministic communication via Time-Sensitive Networking (TSN).

Currently, OPC UA is based on the communication patterns client-server and publish-subscribe shown in figure 8. OPC UA applications can use both types of communication in parallel. An OPC UA application can be a server, client, publisher, and subscriber at the same time. The discovery functionality makes it possible to find OPC UA servers and their functionalities.

The client-server communication implements a direct data exchange between the client and the server, in which the receipt of a message is confirmed. The publish-subscribe communication type is suitable for indirect data exchange in which the sender and receiver do not have to know each other and do not have to be active at the same time. Publish-subscribe is suitable for scenarios where a large number of senders communicate with one receiver (e.g. condition monitoring and optimization services in the cloud) or scenarios where one sender communicates with many receivers. In the latter scenario, a machine tool could provide material throughput and energy measurements that can be used by different services in the company (e.g. visualisation, MES or energy balancing).

The transport layer enables communication with different protocols such as TCP, HTTPS, UDP or MQTT with client-server and publish-subscribe. These are applicable across all levels from the field to the cloud.

Security

Security is a key element of OPC UA and has been taken into account from the very beginning. Security mechanisms cover the transport layer, the information access and the discovery mechanism. The security mechanisms require the administration of certificates and access rights. Certificates enable the authentication of OPC UA applications in order to prove their identity. Certificates can be managed either for each OPC UA application, or by means of a company-wide public-key infrastructure (PKI).

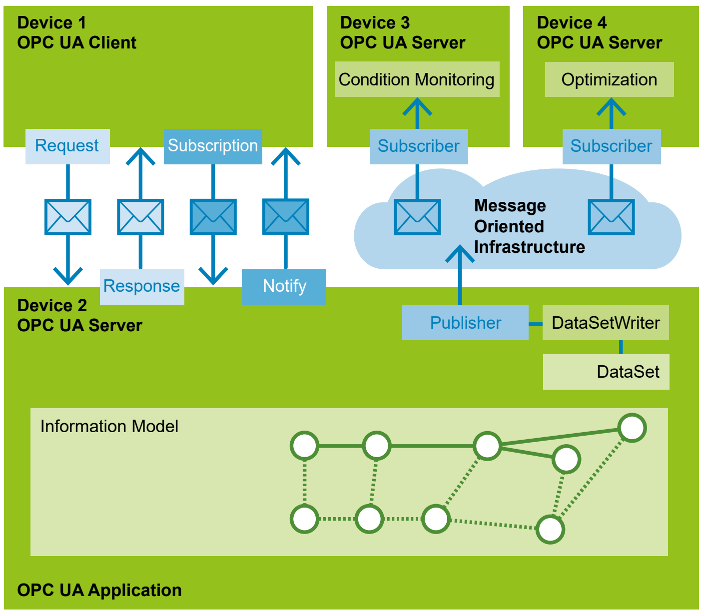

Figure 8: OPC UA Communication

A PKI can issue, distribute, and test certificates. The Certificate Authority (CA) can be used to issue company-wide certificates. The Federal Office for Information Security (BSI) confirms that OPC UA can be used to implement IT-secure Industrie 4.0 communication [2]. The VDMA guideline Industrie 4.0-Security provides detailed information for the secure implementation of Industrie 4.0 technologies [3].

Information Access

Information access includes method calls to read and write variables and to observe events.

Example:
A machine provides information for identification and energy consumption (variables), on the machine status (events) and offers the execution of jobs (methods).

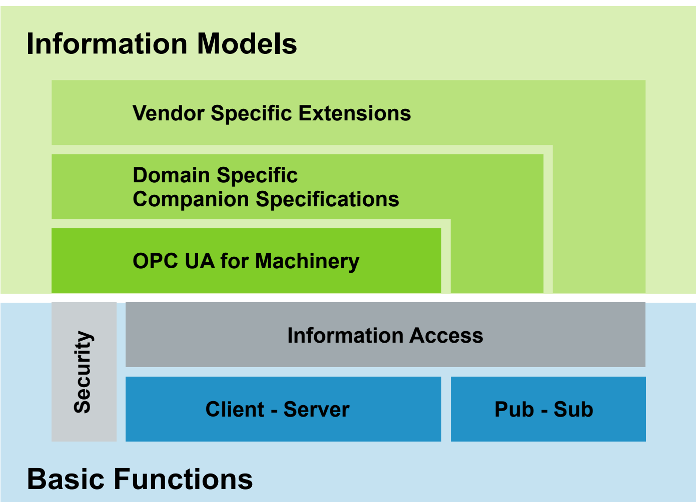

Figure 9: Logical layers of OPC UA

Companion Specification and Extended Information Model

An information model is a network of nodes and relationships between these nodes. The nodes may represent different complex objects with different characteristics, e.g. devices, machines and plants. In OPC UA, objects can contain variables, methods and events.

The OPC UA information model can represent arbitrary hierarchies. In addition, there are types and instances of nodes. Nodes can be standardized with types. This enables information access independent of specific node instances. For example, a type “machine tool” can be standardised that contains all universally applicable variables, state machines and events of a machine tool. The types and instances of this “machine tool” type are both part of the information model. Thus, an OPC UA application is able to understand any complex node without having to know them beforehand.

Example:
A manufacturer A and a manufacturer B implement the same type of machine tool. The two implementations are two different instances. Information access can be made uniformly via the type for both manufacturers A and B. A manufacturer-specific information access is not necessary. This means that applications can be developed independently of devices, machines and plants. For example, a machine tool can have a variable “Current feed” as well as a state machine “Current machine state” and an event “Next maintenance”.

The OPC UA for Machinery information model is the basis for companion specifications and extended information models.

Figure 9 maps the previously described elements of the toolbox into logical layers of the OPC UA specification. Information models are made available via the previously described information access. OPC UA applications can provide information models as servers or publishers and use them as clients or subscribers. The transport layer level describes the technical realization of the information access level while the discovery level describes possibilities to list OPC UA servers. OPC UA servers are used on devices, such as field devices, controllers, desktop computers, or IT servers.

Figure 9 shows three categories of OPC UA information models: The cross-sector specification OPC UA for Machinery, the domain-specific Companion Specifications and the manufacturer-specific extended information models.

The information model OPC UA for Machinery (OPC 40001) is the base specification for the entire machinery and plant engineering sector. The contained information can be used equally in the different sectors and thus ensures cross-domain interoperability. The contents are divided into building blocks and can be used as required. They fulfil specific use cases such as identifying machines or components, presenting the status of the machine or managing machine orders. Table 1 lists some Companion Specifications already published in the field of mechanical and plant engineering. Due to the large number of Companion Specifications from different sectors, this is only an excerpt.

Figure 10 shows an example of how OPC UA for Machinery can be used in various domains and combined with domain-specific Companion Specifications.

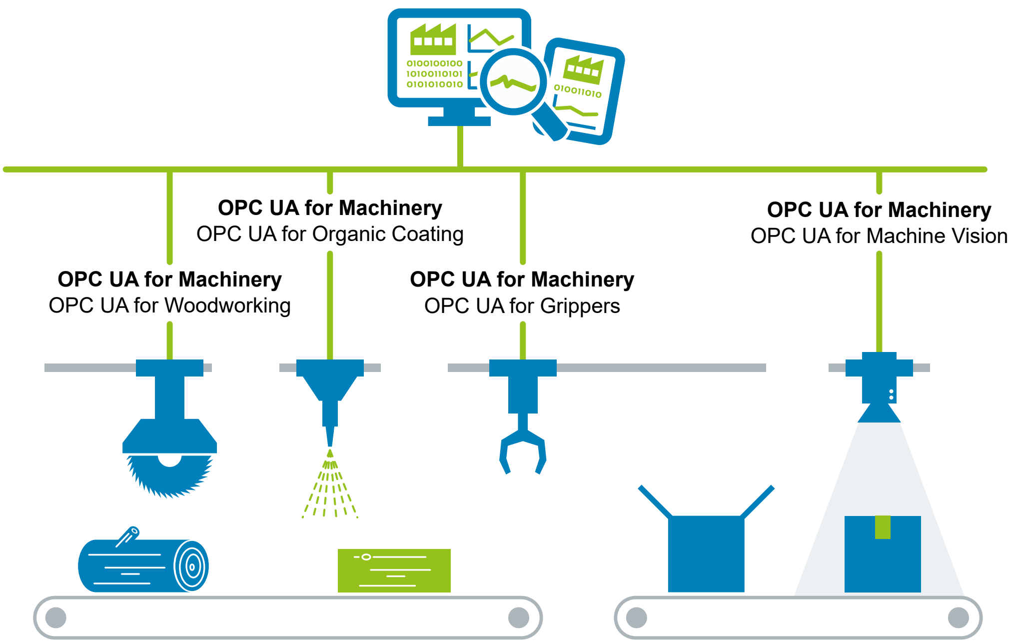

Figure 10: The universal application of OPC UA for Machinery

Companion Specification	Description
OPC 40001: OPC UA for Machinery	Basic specification for mechanical and plant engineering. Use cases are described in building blocks which can be used by other specifications or in individual implementations.
OPC 40010: OPC UA for Robotics	Companion Specification for the complete representation of any robot type. The standard can be used to connect to higher-level control and evaluation systems.
OPC 40020: OPC UA for Cranes and Hoists	Companion Specification for crane systems consisting of hoists, their controls and peripherals. Designed for high compatibility with the Robotics Companion Specification.
OPC 40077 – 40086: OPC UA for Plastics and Rubber Machinery	Companion Specifications for various machines in plastics and rubber processing. These can be used, for example, for the description of extrusion lines or for the connection of injection moulding machines.
OPC 40100: OPC UA for Machine Vision	Companion Specification for the integration of a machine vision system into its process environment. The standard both creates new interfaces and replaces existing ones.
OPC 40200: OPC UA for Weighing Technology	Companion Specification for the representation of weighing systems. It includes the manufacturer-independent modelling of a wide range of weighing system types, for example from vehicle scales to laboratory scales.
OPC 40210: OPC UA for Geometric Measuring Systems	Various measuring systems, for example coordinate and multi-point measuring systems, are covered in the Companion Specification independently of the manufacturer.
OPC 40223: OPC UA for Pumps and Vacuum Pumps	Companion Specification for modelling pump systems. The aim is to monitor and optimise pump operation using standardised modelled identification and process indicators.
OPC 40250: OPC UA for Compressed Air Systems	Companion Specification for compressed air systems with their components. The focus is the vertical integration of compressed air systems into higher-level manufacturing systems.
OPC 40301: OPC UA for Flat Glass Processing	This Companion Specification describes the interface between a flat glass processing/ assembly machine and Manufacturing Execution Systems (MES) or Enterprise Resource Planning (ERP) for data exchange.
OPC 40400: OPC UA for Powertrain	Companion Specification for powertrains and transmission elements divided into several parts with a focus on I4.0 applications. Part 1 deals with the use case of asset management.
OPC 40444: OPC UA for Textile Testing Devices	Specifies a manufacturer-independent information model of testing devices for fibres and yarns. The goal is the easy integration of different types of textile testing equipment into MES and other IT systems.
OPC 40451: OPC UA for Tightening Systems	This Companion Specification describes an interoperable interface of joining systems and components. Use cases are asset management, condition monitoring and representation of joining results.
OPC 40501: OPC UA for Machine Tools	Companion Specification for the creation of a manufacturer- and technology-independent interface for machine tools for machine monitoring and overview of processing orders.
OPC 40502: OPC UA for Computerized Numerical Control (CNC) Systems	Companion Specification for the definition of an OPC UA information model for the connection and data exchange with Computerized Numerical Control (CNC) systems.
OPC 40550: OPC UA for Woodworking Machines	This Companion Specification for woodworking machines is based on eleven use cases and describes vertical communication between a machine and MES/ERP systems.
OPC 40560 – 40569: OPC UA for Mining	Companion specification for mining, divided into sub-documents. Describes the information model structure of mining machines, equipment, systems and services, as well as their use cases.
OPC 40600: OPC UA for Weihenstephan Standards	The Companion Specification Weihenstephaner Standards describes a generic OPC UA information model for the WS domains Pack, Food, Bake, Brew and Sweets for food and packaging machines.
OPC 40740: OPC UA for Process Air Extraction and Filtration Systems	Companion Specification for Process Air Extraction and Filtration Systems (PAEFS). Describes an information model for the manufacturer-independent horizontal and vertical communication of PAEFS.

Table 1: Overview of some selected Companion Specifications of the mechanical and plant engineering industry
Further Companion Specifications can be found on the VDMA website (https://www.vdma.org/catalogs).

Migration Strategy for Industrie 4.0 Communication

Industrie 4.0 communication does not have to be implemented in one step. The implementation can be divided into reasonable parts. This section presents implementation and migration examples for the use cases defined before.

The implementation is based on the previously defined requirements for Industrie 4.0 communication as well as the functionalities of the toolbox OPC UA from the previous section. Figure 11 shows condition monitoring as the first step towards Industrie 4.0 communication.

Industrie 4.0 communication does not have to be implemented in one step.

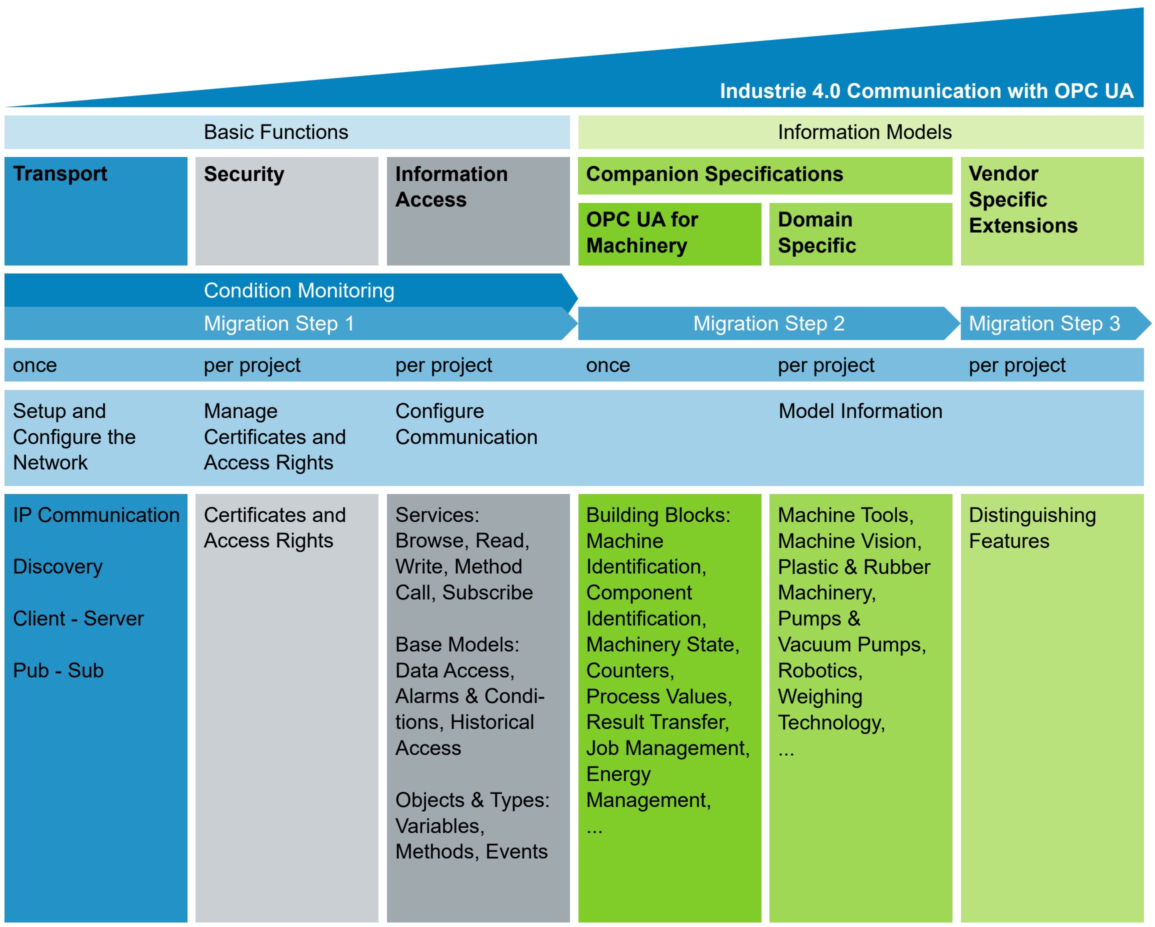

Figure 11: Condition monitoring as the first step towards Industrie 4.0 communication

Figure11 depicts condition monitoring as the first step towards Industrie 4.0 communication. The ordinate in figure 10 shows the requirements for Industrie 4.0 communication and the abscissa represents functionalities of the toolbox OPC UA.

Migration Step 1: Information Access

In a first step, OPC UA is used as a uniform communication interface for information access. Variables provided by machines and plants can be found and manually subscribed to.

For example, machine builders can implement the use case condition monitoring based on these variables. This reduces downtime. The use case scenario already provides a clear benefit for the end user and is assigned to requirements and modules of the toolbox OPC UA in figure 11.

Variables provided by machines and plants can be found and manually subscribed to.

Figure 11 presents technical prerequisites that have to be met before information access can be implemented. This is where the setup and configuration of an IP-based network comes first. For example, this network can be based on Ethernet or wireless technologies, such as Wifi or 5G mobile radio. The network infrastructure and configuration must be set up only once.

The setup and configuration of an IP-based network comes first.

A local discovery server (LDS) allows the discovery of an OPC UA server that is executed for example on a machine or in a plant. On the server side, the LDS usually does not require any additional configuration. OPC UA clients, e.g. from MES or other machines, use it in order to find available servers and to discover their available security options. The OPC UA client can establish a connection to the server based on these information.

Later, a company-wide administration of certificates, a so-called Certificate Authority (CA), might be useful.

With regard to IT security, access rights must be configured and certificates must be managed for each project. Certificates are needed to verify the identity of OPC UA applications (authentication). OPC UA applications have to trust each other in order to establish secure connections between them. In a first step, certificates can be setup manually. Later, a company-wide administration of certificates, a so-called Certificate Authority (CA), might be useful.

From now on, OPC UA applications can communicate securely via OPC UA's SOA. The user can browse the base models introduced before, read and write variables, call methods and subscribe to events. Communication between systems such as ERP, MES and PLC can be configured manually. For example, a PLC can cyclically transmit an energy measurement value to an MES.

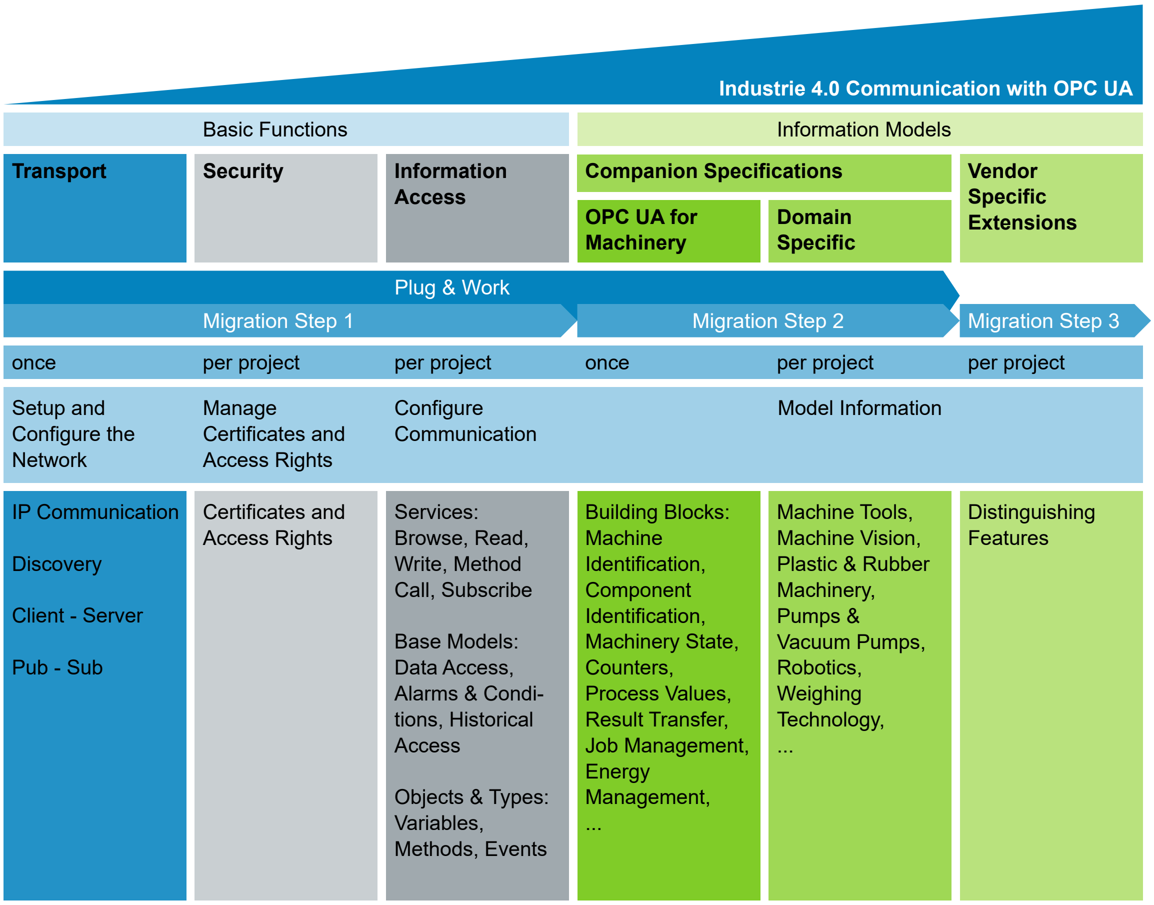

Figure 12: Plug & Work based on Companion Specifications

Migration Step 2: Companion Specification

In the first migration step, the OPC UA toolbox was used by a machine builder or end user to implement information access. In the second migration step, it is now necessary to provide for the description of the information through a standardised information model. This is done through the use of so-called Companion Specifications.

In the field of mechanical and plant engineering, Companion Specifications are created under the umbrella of the VDMA together with the companies relevant to the industry and the OPC Foundation. All Companion Specifications are being administered by the OPC Foundation.

The VDMA brings together the interests of its members and develops Companion Specifications together with the OPC Foundation.

The use of Companion Specifications increases interoperability and enables the Plug & Work use case shown in Figure 12. During commissioning and retrofitting, system integrators and automation engineers typically adapt control programs manually, for which they usually rely on manuals, data sheets and informally recorded information that varies from manufacturer to manufacturer. In the future, machine and plant builders will use the Companion Specifications to enable the exchange of information across manufacturers. A new machine can thus be integrated into a plant more easily, since standardised information is available from different manufacturers in the same way. In this way, components, machines and plants can be easily integrated into systems of the end user, such as MES. The principle is similar to the well-known USB interface.

Companion Specifications enable the Plug & Work use case.

For implementation, it should first be checked whether a Companion Specification already exists for the corresponding machine or device type. This is an information model standardised by an industry committee. Numerous standards have already been created, for example the Companion Specifications for machine tools, robots and scales. Table 1 lists further Companion Specifications in the OPC UA toolbox. The Companion Specifications for machinery and plant engineering use the OPC UA for Machinery specification as a basis. Depending on requirements, the domain-specific Companion Specifications inherit corresponding functionalities from OPC UA for Machinery.

OPC UA for Machinery forms the basis for Companion Specifications for mechanical and plant engineering.

Example:
The Companion Specification OPC UA for Machine Tools [6], which is presented in detail later in this guide, specifies information for machine tools. In addition to many other parameters, the status of machines and tools is standardised there by information models. This means that uniform KPI evaluations can be carried out on machines from different manufacturers without having to coordinate the interface and the interpretation of the data with each manufacturer individually. This facilitates the increase in overall plant efficiency and the integration into MES and ERP systems.

If there is not yet a Companion Specification for the addressed machine or component, it should be checked whether the creation of such a standardisation can be carried out with the corresponding market competitors. This is where the VDMA provides support. With the help of such a domain-specific standard, it can be ensured that the desired functional spectrum is fully covered. Alternatively, OPC UA for Machinery can also be used on its own to implement the cross-industry functionalities provided there.

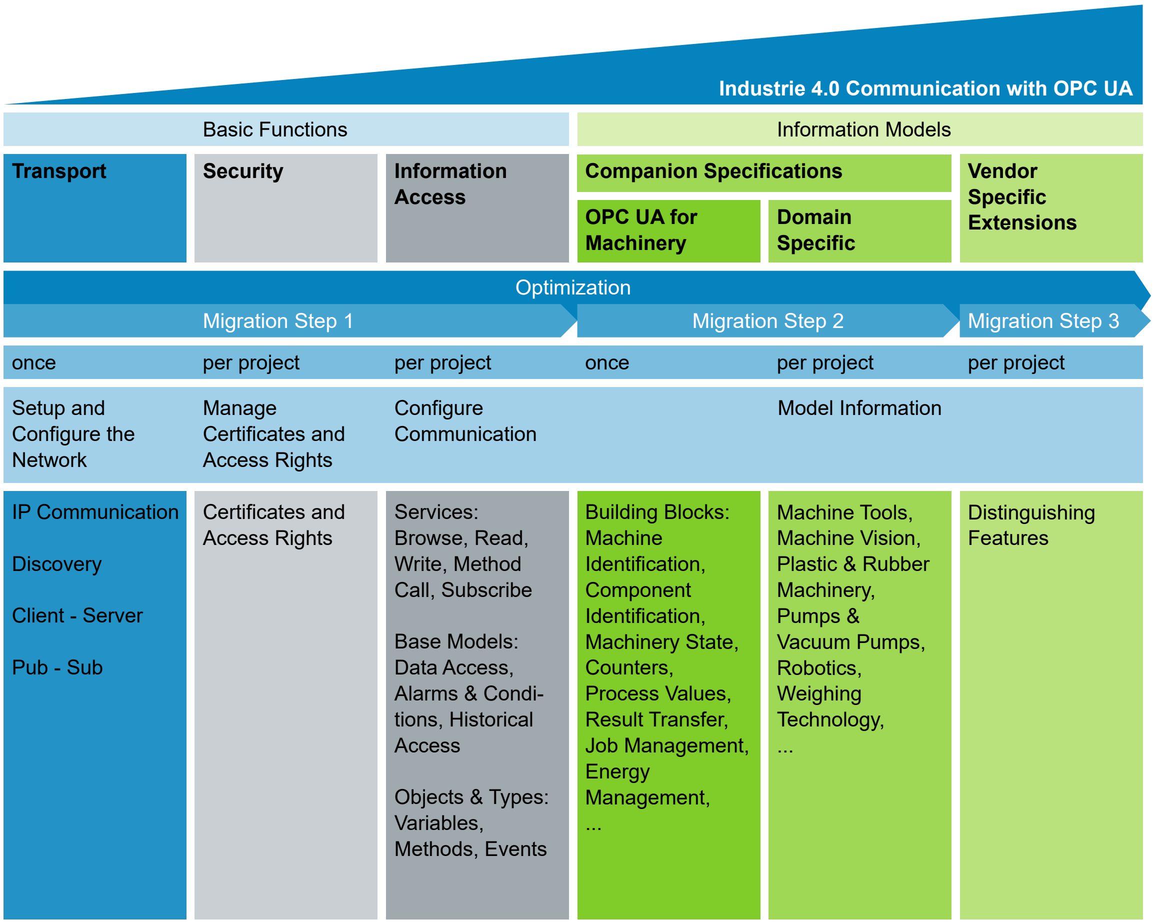

Figure 13: Optimization based on extended information models

Migration Step 3: Extended Information Model

An OPC UA server can contain multiple information models. In addition to several Companion specifications, these can also be manufacturer-specific extensions. Apart from standardized information models and a manufacturer-independent basic set of information, there can also be differentiation characteristics for Industrie 4.0 communication.

Differentiating characteristics can exist for Industrie 4.0 communication.

For example, machines can offer functions such as energy or cycle time optimization. These functions can be based on experience and proprietary knowledge of the manufacturers, which should not be standardized. The extended information model only includes information that the manufacturer would like to offer explicitly. In an OPC UA information model, information can be explicitly protected against unauthorized access.

As indicated on the right side of figure 13, Industrie 4.0 communication is still under development. Implementing future applications will require further migration steps.

Implementation-oriented Challenges

Implementation options for Industrie 4.0 Communication based on OPC UA

The open standard OPC UA can be obtained free of charge. This applies to the specifications as well as to example implementations in different programming languages. However, it should be noted that OPC UA implementations can differ in functionality. One can use the profiles listed in Table 2 in order to classify OPC UA implementations with regard to supported functionalities. For example, some implementations support IT security mechanisms (UA-Security) and methods.

The sample implementation from the OPC Foundation is provided free of charge and can be used in order to evaluate the technology. This implementation makes no claim to completeness or product maturity. To use it in one's own use case- specific solutions is therefore associated with increased efforts.

Numerous companies provide commercial support for the implementation of OPC UA. Offers range from trainings, workshops, consulting, and support to professionally maintained and product-tested tool kits. Toolkits abstract functionalities via simple interfaces and offer a suitable starting point for inexperienced users. Toolkits can be tested by the OPC Foundation and their conformity to the specification can be certified (conformance tests). The use of development and toolkits can entail license costs.

OPC UA implementations can differ in functionality.

OPC UA Profile (FullFeatured)	
Nano Embedded Device Server Profile	Limited functionality only for the smallest devices, e.g. sensors and actuators. Only one connection, but without UA security, no subscriptions and no method calls possible.
Micro Embedded Device Server Profile	Restricted functionality, at least two parallel connections, additional subscriptions and data monitoring, but no UA security and no method calls.
Embedded UA Server Profile	Basic functionalities of OPC UA are available plus UA security and method calls.
Standard UA Server Profile	Includes all functionalities for secure information access including UA security. No alarms and no history. PC based servers should support at least this profile.

Table 2: OPC UA Profiles (FullFeatured)

Develop Companion Specifications actively

The internationally composed working groups bring together manufacturers, users and other stakeholders such as cloud providers or integrators to drive Industrie 4.0 communication for the respective industry. Active participation in the definition of Companion Specifications offers those involved an early insight into new trends and enhancements in addition to the opportunity to contribute their own needs to the standardisation. The final drafts of the specifications are made available to the public for comment.

The promotion and implementation is supported by umati.

Cooperation with research partners

In the implementation initiative called umati, companies and institutions come together to jointly promote the practical use of OPC UA Companion Specifications. In addition to the community and implementation support, a demonstrator in the form of an open dashboard is available. Furthermore, umati supports the worldwide promotion of OPC UA Companion Specifications as the leading standard for interoperability with a strong brand name.

Further information is available at umati.org

Check list

This section should help machine and plant builders, as well as operators, to identify the next steps towards Industrie 4.0 Communication. The following questions should point out necessary competences. One should be able to answer the following questions with “yes”.

Machine builder’s view

Prepare migration step 1

- ☑ Do software systems and devices comprise an OPC UA server and / or client?
- ☑ Is it possible to use OPC UA and real-time protocols in parallel in the machines?

Carry out migration step 1 in a secure fashion

- ☑ Does the architecture of machines include concepts for information security, e.g. the management of certificates?
- ☑ Do roles and rights exist for machines?

Use migration step 1

- ☑ Can OPC UA be used to access information from components?
- ☑ Is OPC UA supported by components of machines?

Work together in migration step 2

- ☑ Are Companion Specifications being standardized together in order to enable Plug & Work functionality for customers?
- ☑ Does Know-how with regard to object-oriented modelling exist?

Enable optimization in migration step 3

- ☑ Are extended information models being developed?

Plant builder’s view

Prepare migration step 1

- ☑ Is Machine-To-Machine (M2M) communication being considered?

Carry out migration step 1 in a secure fashion

- ☑ Have roles and access rights for machines been specified?
- ☑ Does infrastructure for IT security exist, e.g. for company-wide administration of certificates?

Use migration step 1

- ☑ Is information being exchanged between controllers?

Work together in migration step 2

- ☑ Are Companion Specifications being standardized together in order to enable Plug & Work functionality for customers?
- ☑ Are information models known for the application domain?

Enable optimization in migration step 3

- ☑ Are extended information models being developed?

Operator’s view

Prepare migration step 1

- ☑ Does an IP based network infrastructure exist?
- ☑ Are aspects like segmentation and firewalls being considered during the planning phase of big networks?

Carry out migration step 1 in a secure fashion

- ☑ Is the issue of information security being discussed in the company?

Use migration step 1

- ☑ Is condition monitoring used?

Work together in migration step 2

- ☑ Is Plug & Work being used in order to increase flexibility?

Use migration step 3 for optimization

- ☑ Are optimization functions from extended information models being used?

The way to a Companion Specification using the example of OPC UA for Machine Tools

The Companion Specification OPC UA for Machine Tools, or UA4MT for short, specifies an interface for data exchange between machine tools and higher-level IT systems.

The Companion Specification was developed by the VDW (German Machine Tool Builders' Association) with the world's leading machine tool manufacturers between 2018 and 2020. Part 1 enables technology-neutral machine monitoring and an overview of production orders. Further parts and technological specifications are in preparation. This means that these machines can be integrated into the operators' higher-level systems independently of the manufacturer.

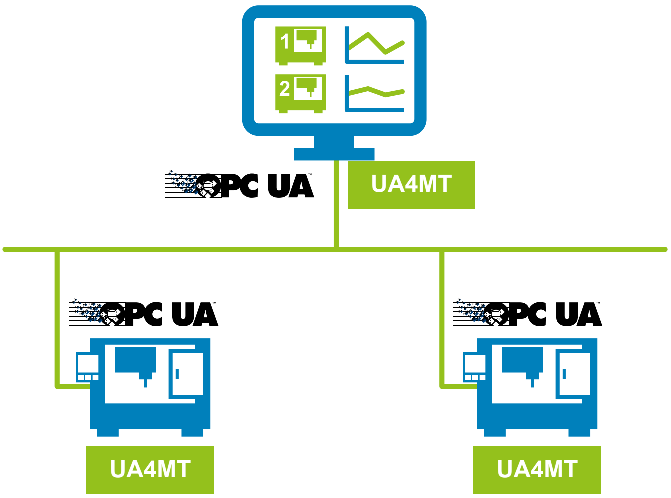

Figure 14: OPC UA for Machine Tools used for connecting machine tools to higher-level systems

Until now, many manufacturers already used OPC UA technology or comparable technologies such as MTConnect. However, when it came to mapping machines from different manufacturers or integrating the interfaces, there were always new or company-internal data models.This ensures an integration effort on the manufacturer's and operator's side with the associated expenses for each individual new machine.

In order to create a uniform description for machine tools, the working group for the creation of the standard was started in 2019 with international participation. Furthermore, a first extension of the standard was published in 2022.

A Companion Specification defines the content for data exchange between system components. For this purpose, it defines an information model that contains and describes the relevant data. The OPC UA for Machine Tools Companion Specification addresses the following use cases in its information model.

- Identification of machines from different manufacturers
- Quick overview of the production status
- Overview of the workpieces in a job
- Overview of the running times for a job
- Overview of the status of the machine tool
- Overview of pending manual tasks
- Overview of errors and warnings
- Provision of data for KPI calculations
- Overview of tool data
- Providing the use cases of OPC UA for Machinery

The information models are structured according to the concept of object orientation - objects structure the data from production and object types act as blueprints for these objects. Since not every object defined in the Companion Specification is needed for every use case, so-called profiles are also defined. These summarise which parts of the specification must be used in combination to enable a particular use case.

This enables the machine manufacturers to easily implement the necessary OPC UA types and profiles in their machines. The integration into the higher-level systems of an operator is then only a one-time effort, as shown in Figure 14.

To offer the information of the machine tool on the interface, the MachineToolType is used. Figure 15 shows an instance of this type definition as an example. All information whose definition was taken from the harmonised specification OPC UA for Machinery is highlighted in green in the figure. Here you can see that for the use case " Identification of machines from different manufacturers" the definition from OPC UA for Machinery is used. This use case is not limited to the area of machine tools, but is relevant to the entire machine and plant construction industry. For this reason, the contents for the identification of machines and components are defined in the Companion Specification OPC UA for Machinery, whose focus is generally on the entire machinery and plant engineering sector. Likewise, one sees the use of MachineryBuildingBlocks and Components in the context of the MachineTools specification. These elements are also defined by OPC UA for Machinery for all types of machinery and equipment.

In the illustration, all elements that are directly defined by the OPC UA for Machine Tools are shown in blue.

NamespaceURI	NamespaceIndex
http://opcfoundation.org/UA/	0
http://opcfoundation.org/UA/DI/	2
http://opcfoundation.org/UA/Machinery/	3
http://opcfoundation.org/UA/IA/	4

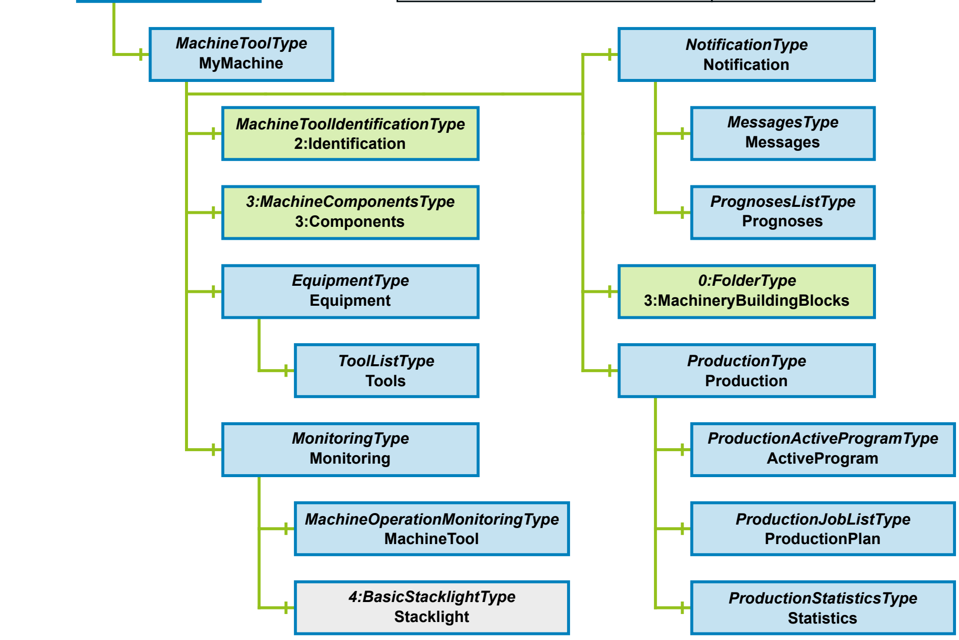

Figure 15: Overview of the OPC UA for Machine Tools information model

Specific to the machine tools are, for example, the tools, more specifically in the case of a milling machine, the milling tools. These are shown as a list of tools under the Equipment node. Figure 16 shows that the individual tool is specified by a ToolType. This ToolType describes, independent of manufacturer and control, which variables and properties are to be used to represent a tool. This includes a general identification (Identifier) and the identification to the control (ControlIdentifier1 and 2), information about the last use (LastUsage) and information about the service life (ToolLife).

This standardised description of tools enables monitoring of all tools during production in different machine tools in a uniform way. This allows the machine operator to monitor the use but also the presence of a specific tool. At the same time, he can successively replace proprietary tool monitoring interfaces and use the data not only in his tool management software but also in other systems.

The Companion Specification OPC UA for Machine Tools represents a structured information model for the representation of a machine tool for communication. This model has a modular structure that can be adapted to the respective use cases used. By using specifications with a more general focus, such as OPC UA for Machinery, interoperability with other components of machine and plant engineering is also given. All of this is based on the OPC UA framework. This means that, depending on the intended use, suitable communication profiles and encryption and security mechanisms can be used in a standardised form.

A Companion Specification represents a structured information model for the representation of a machine.

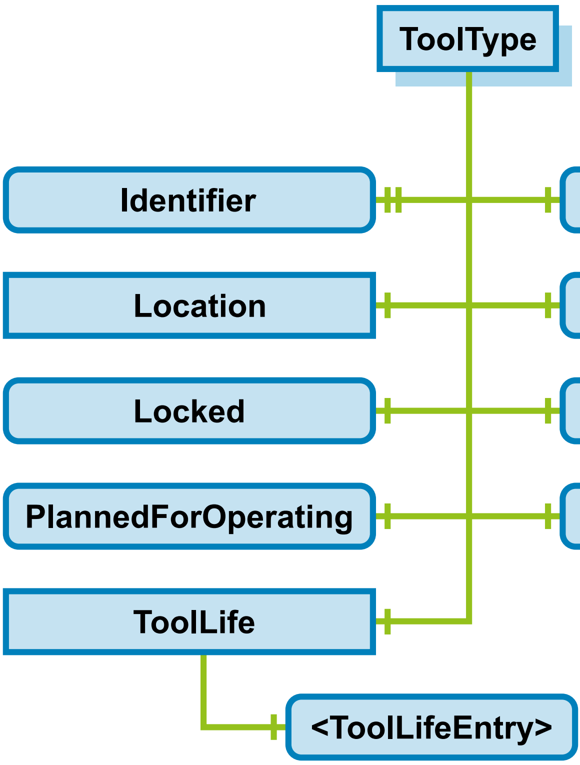

Figure 16: ToolType for specifying tools

Mapping the Guideline to the Reference Architecture Model Industrie 4.0 (RAMI4.0)

RAMI4.0 and Industrie 4.0 Components

The Plattform Industrie 4.0 bundles activities on Industrie 4.0 in Germany. Main standardization results include the RAMI4.0 (see figure 15) and the Industrie 4.0 Component (see figure 16). They are specified in DIN SPEC 91345 [7].

Mapping the Guideline to RAMI4.0

RAMI4.0 enables the classification of technologies for Industrie 4.0 by means of relevant hierarchical levels, technical functions and their position in the lifecycle of components.

DIN SPEC 91345 specifies Industrie 4.0 communication as the transmission of standardized information based on SOA [7].

As shown in Figure 17, OPC UA can be found on the communication layer, while companion specifications and extended information models are assigned to the information layer. The use cases condition monitoring, Plug & Work and optimization included in this guideline are added values assigned to the business layer. They are implemented via functions on the functional layer. The functions use Industrie 4.0 communication. In the lifecycle, the use cases refer to the operation of instances of components, machines and plants.

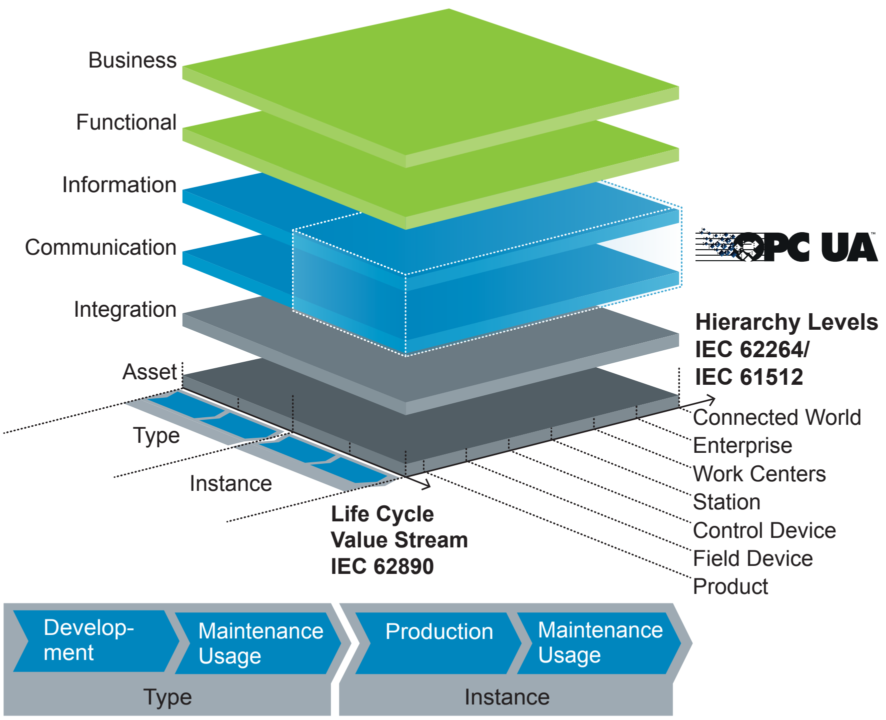

Figure 17: OPC UA in the reference architecture model Industrie 4.0 (RAMI4.0)

Figure 18: The Industrie 4.0 Component

The Industrie 4.0 component consists of an asset and its virtual representation, the so-called Asset Administration Shell (AAS).

Conclusion: Industrie 4.0 Communication based on OPC UA

As this guide shows, OPC UA meets the requirements for Industrie 4.0 communication. Industrie 4.0 communication based on OPC UA can be used at all levels of the RAMI4.0 hierarchy axis. OPC UA can be implemented in the smallest sensors as well as for cross-factory communication (Connected World).

OPC UA meets the requirements for Industrie 4.0 communication.

Since many Companion Specifications have already been created and many more are being developed, nothing stands in the way of implementing the migration steps shown in the guide. By combining OPC UA and the Companion Specifications, interoperability can be achieved for individual domains as well as across domains and so Industrie 4.0 communication can be realised.

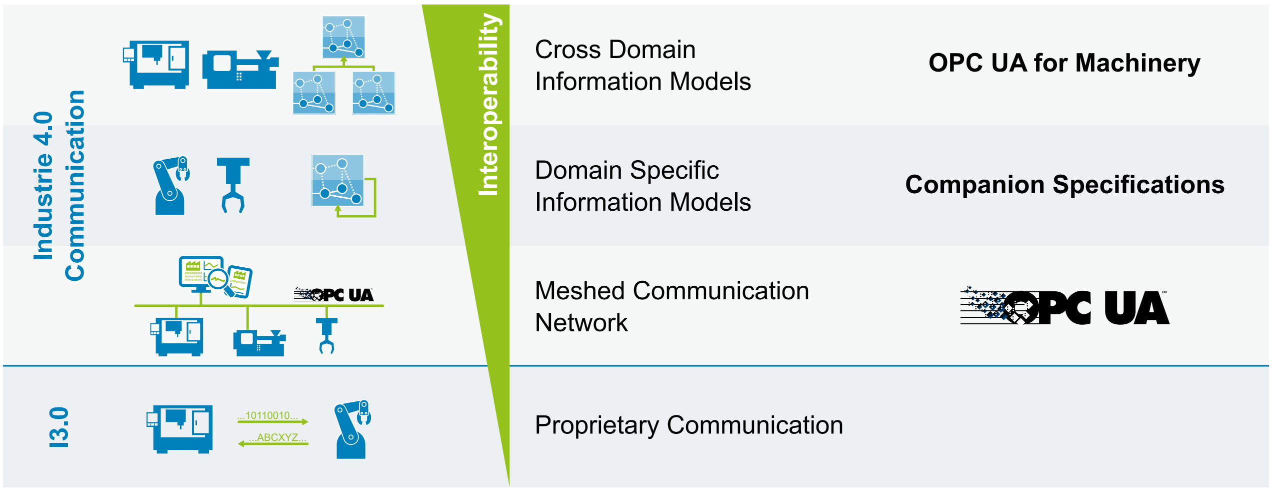

Figure 19: Interoperability through Industrie 4.0 communication

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