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Industrie 4.0 Communication Guideline

Based on OPC UA



in cooperation with

Editorial



Hartmut Rauen

Innovations, solutions expertise and highest quality are key characteristics of the German mechanical engineering industry and Industrie 4.0 is exactly that. It is about integration of information and internet technologies in the production and factories. Goal ist the development of new innovative products and solutions based on profitable costs. The German machine and plant engineering sector is a key supplier of industrial 4.0 technologies. These companies integrate the latest technologies in its products and processes. They represent also the data source for Industrie 4.0: The companies of the German machine and plant engineering sector capture the data, interpret it, use it for innovation and develop new business models.

An important basis and the central challenge for the successful implementation of Industrie 4.0 is the manufacturer-independent exchange of data by establishing uniform interfaces in production.



Dr. Christian Mosch

The standard "Open Platform Communications Unified Architecture" (OPC UA) is increasingly establishing itself in the field of machine and plant engineering. OPC UA is an open interface standard that defines the mechanisms of cooperation in the industrial environment. It enables the industry to integrate its products and its production by information and communications technologies (ICT). Machines and plants can be redesigned as required by plug & work - irrespective of which manufacturers the machines and components originate. What is already common in the office environment with network interfaces and the USB standard will also be a reality in production. Condition monitoring, predictive maintenance and the optimization of production can be implemented independent of the manufacturer.

The VDMA prioritizes its activities on the interface standard OPC UA and gives an important orientation to machine and plant engineering sector. The VDMA guideline "Industrie 4.0 Communication Guideline Based on OPC UA" should be understood as a practice-oriented tool. It shows action steps that help to implement the industry 4.0 communication in the company. Industrie 4.0 is a development path on the way to the future of production. With this guideline, the VDMA realizes a further implementation module for the practice and extends the successful VDMA-Guideline series.

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.

Hartmut Rauen

Deputy Executive Director
VDMA German Engineering Federation

Dr. Christian Mosch

VDMA Industrie 4.0 Forum

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



Prof. Dr. Oliver Niggemann

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 and no 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.



Prof. Dr.-Ing. Jürgen Jasperneite

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. Oliver Niggemann

Fraunhofer Application Center
Industrial Automation (IOSB-INA)

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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 to access information from machines from different manufacturers. For example, condition monitoring systems can access information from machines via Industrie 4.0 communication. In a first step, relevant parameters for machine or system monitoring are manually integrated into the condition monitoring system. This approach is already beneficial compared to today's integration via many different communication solutions.

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. More and more operators request this interoperability, for example from plastic and rubber machines and devices for automatic identification via RFID.

Some component manufacturers, machine and plant builders have already moved towards Industrie 4.0 communication. A first result is the Companion Specification EUROMAP77^[6], which includes a uniform information model for plastic and rubber machines. EUROMAP77 can be used to especially support smaller companies in understanding the benefits of information models. Also, EUROMAP77 is a suitable example for the explanation of steps required for the development of a Companion Specification.

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.

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 (<http://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.

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. 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 for industrial communication. In addition, individualized production requires much more flexibility and interoperability compared to today's industrial communication technology.

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.

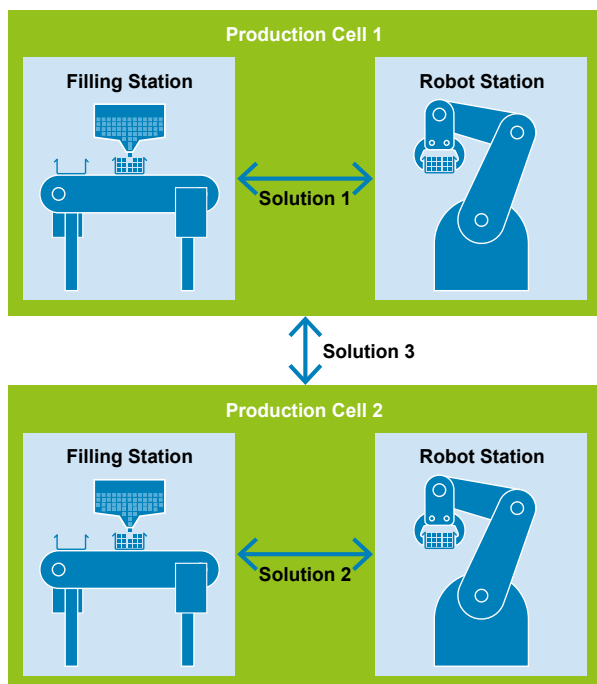


Figure 1: State of the art of industrial communication

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 the use cases. EUROMAP77 and AutoID are introduced as examples for OPC UA “Companion Specifications”. 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. The information model includes operating instructions for components, machines and equipment. Human beings, as well as devices can use these operating instructions. 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 the “Operating Instruction”, which describes the use of components, machines and equipment.

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. This is shown in figure 2.

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 that enables 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

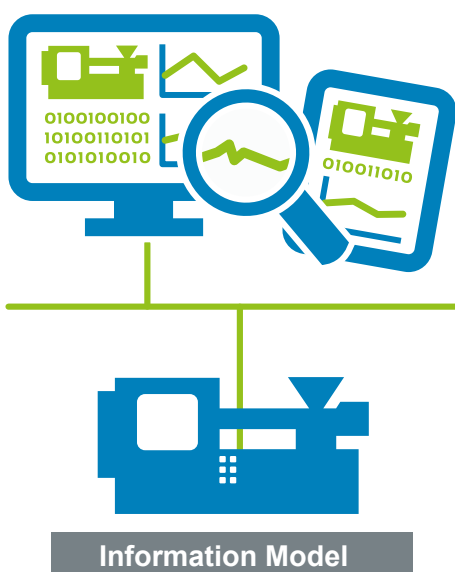


Figure 2: Condition monitoring

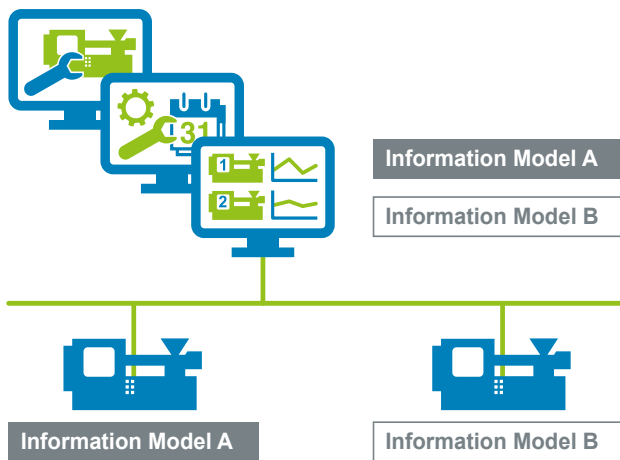


Figure 3: Uniform communication interface

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 this information model must be known in higher-level systems. This is shown in figure 4.

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 commu-

nication. 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. With Industrie 4.0 communication this integration can be significantly simplified. 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.

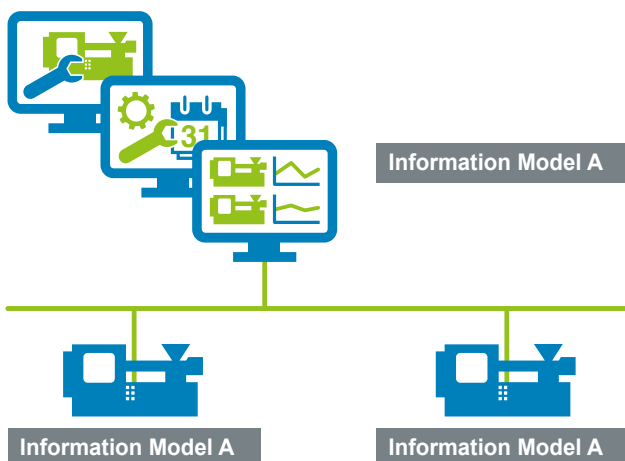


Figure 4: Uniform communication interface and uniform information model

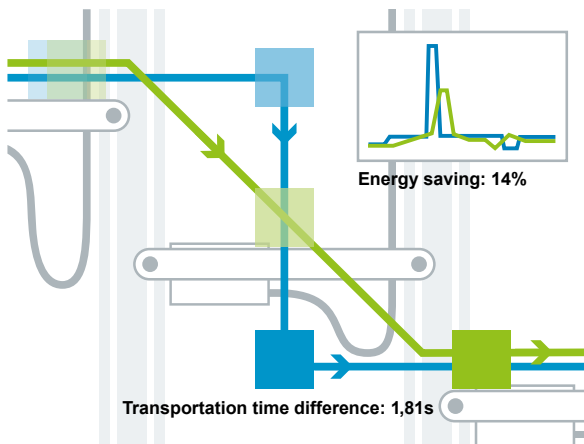


Figure 5: Energy optimization of a high-bay storage

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.

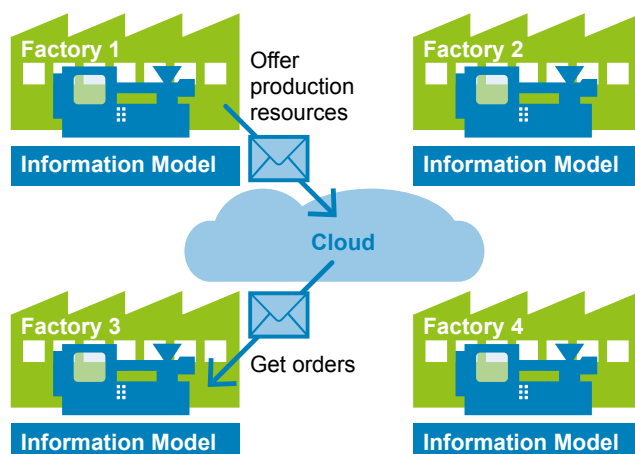


Figure 6: Factory-to-Factory Communication in the application scenario “Order-driven Production”

The Toolbox OPC UA for Industrie 4.0 Communication

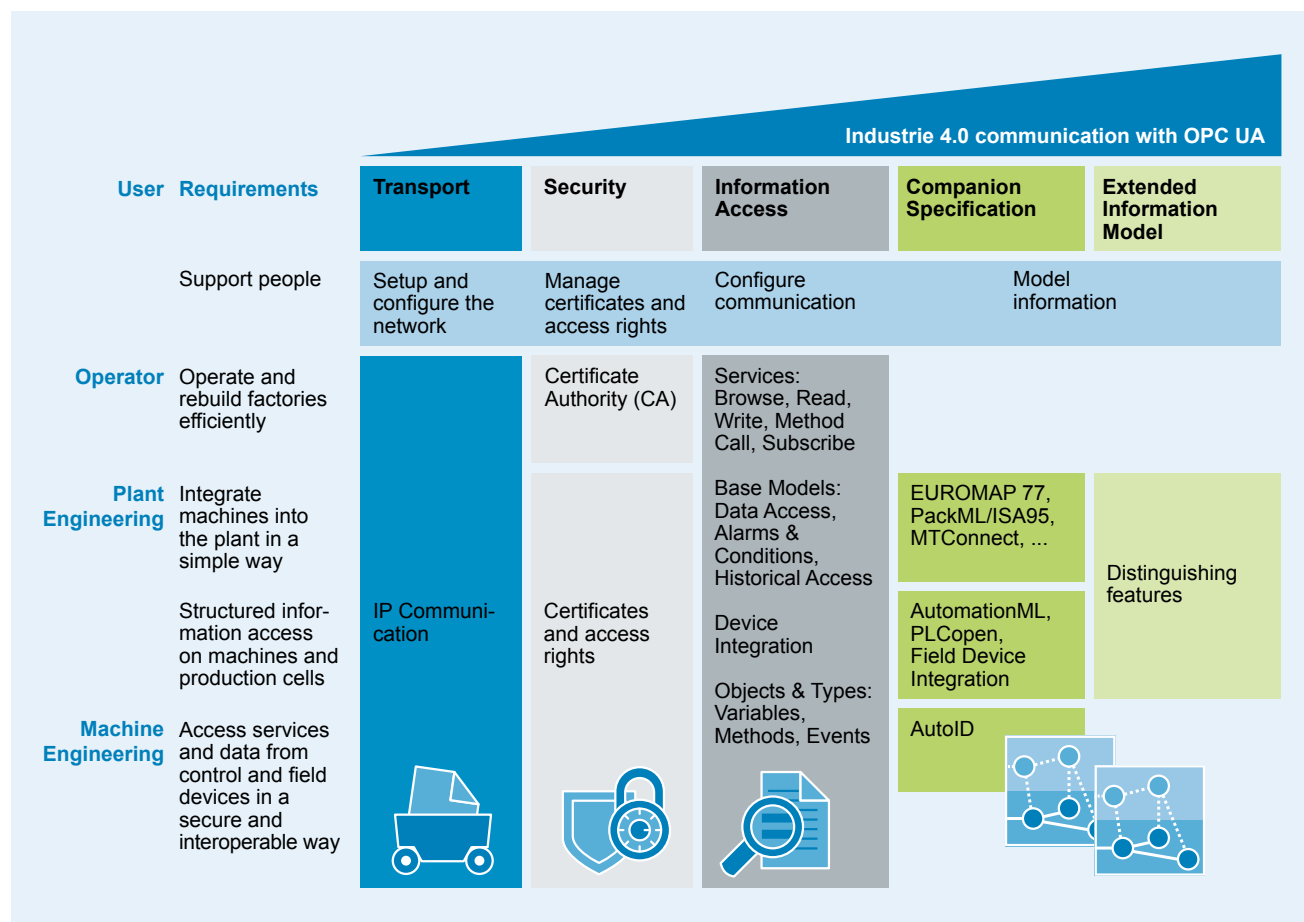


Figure 7: The toolbox OPC UA for Industrie 4.0 communication

The toolbox OPC UA depicted in figure 7 includes the following columns from left to right:

- Transport
- Security
- Information Access
- Companion Specification
- Extended Information Model

The degree of completion of Industrie 4.0 communication increases from left to right.

The rows of the OPC UA toolbox contain relevant elements for machine building, plant construction and operators.

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. The OPC Foundation is an industrial consortium and manages the standardization of OPC UA.

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

Transport



The transport layer implements information access by using different communication protocols and communication types, all of which are based 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, an injection-molding machine could provide material throughput and energy measurements that can be used by different services in the company (e.g. visualization, MES or energy balancing).

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).

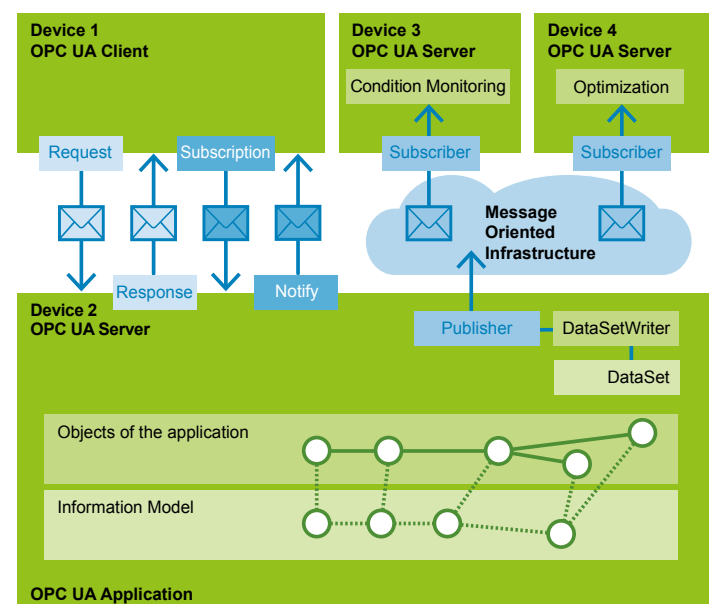


Figure 8: OPC UA Communication Patterns

A PKI can issue, distribute, and test certificates. The Certificate Authority (CA) shown in figure 7 might 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

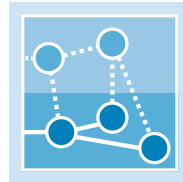


Information access includes method calls to read and write variables and to observe events.

Example:

An injection-molding machine provides information on material throughput and energy consumption (variables), the machine status (event), and the execution of orders (methods).

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 “injection-molding machine”, which includes all the general variables, methods and events of an injection-molding machine. The type and instances of this 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:

Manufacturer A and manufacturer B implement the same type of injection-molding machine. The two implementations represent two different instances. Uniform information access is implemented via the same type for both manufacturers. A manufacturer-specific information access is not necessary. This allows applications to be developed independent from devices, machines and systems. For example, an injection-molding machine can include a method „start job”, a variable “current power consumption”, and an event “temperature reached”.

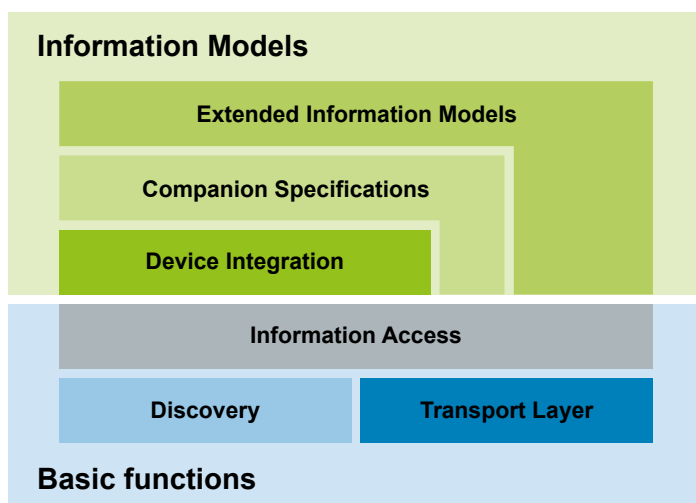


Figure 9: Logical layers of OPC UA

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 pub-

Companion Specification	Description
Automatic Identification Systems (AutoID)	AutoID is an information model for automatic identification systems, e.g. bar code, RFID, and NFC devices.
CNC Systems, Verein Deutscher Werkzeug- maschinenfabriken (VDW)	OPC UA Information model for the connection and data exchange of computer-supported numerical control systems (CNC systems).
EUROMAP77, VDMA Plastics and Rubber Machinery	Standardized interface for the connection of injection molding machines to MES and SCADA systems.
EUROMAP79, VDMA Plastics and Rubber Machinery	Interface for the connection of injection molding machines and robots.
Field Device Integration (FDI)	The Field Device Integration (FDI) information model describes devices that communicate via different protocols, typically used on the field layer.
Machine Vision, VDMA Robotics + Automation	Standardized interface between machine vision systems and its production environment.
Integrated Assembly Solutions, VDMA Robotics + Automation	Standardized interface between a handling assembly solutions and its production environment.
PLCopen	The PLCopen information model maps IEC 61131-3 to the OPC UA information model.
Robotics, VDMA Robotics + Automation	Standardized interface between a robot and its production environment.

Table 1: Overview of selected Companion Specifications

Additional Companion Specifications can be found on the OPC Foundation website in section "Markets & Collaboration" (<https://opcfoundation.org/markets-collaboration/>).

lishers and use them as clients or subscribers. The transport layer level describes the technical realization of the information access level and the discovery level describes possibilities to list OPC UA servers. OPC UA servers are used on devices, such as field devices, controllers, desk-top computers, or IT servers.

Figure 9 shows three categories of OPC UA information models: the information model for devices, the Companion Specifications, and the extended information models. The information model for devices and their integration (Device Integration) forms the basis for Companion Specifications and extended information models. It includes a device model (features and functionalities), a communication model (topology of communication) and an integration model (rules for the integration of devices).

The information model for devices (Device Integration) forms the basis for Companion Specifications and extended information models.

Table 1 lists some examples for Companion Specifications. Due to the large number of Companion Specifications, this is only an excerpt.

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.

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

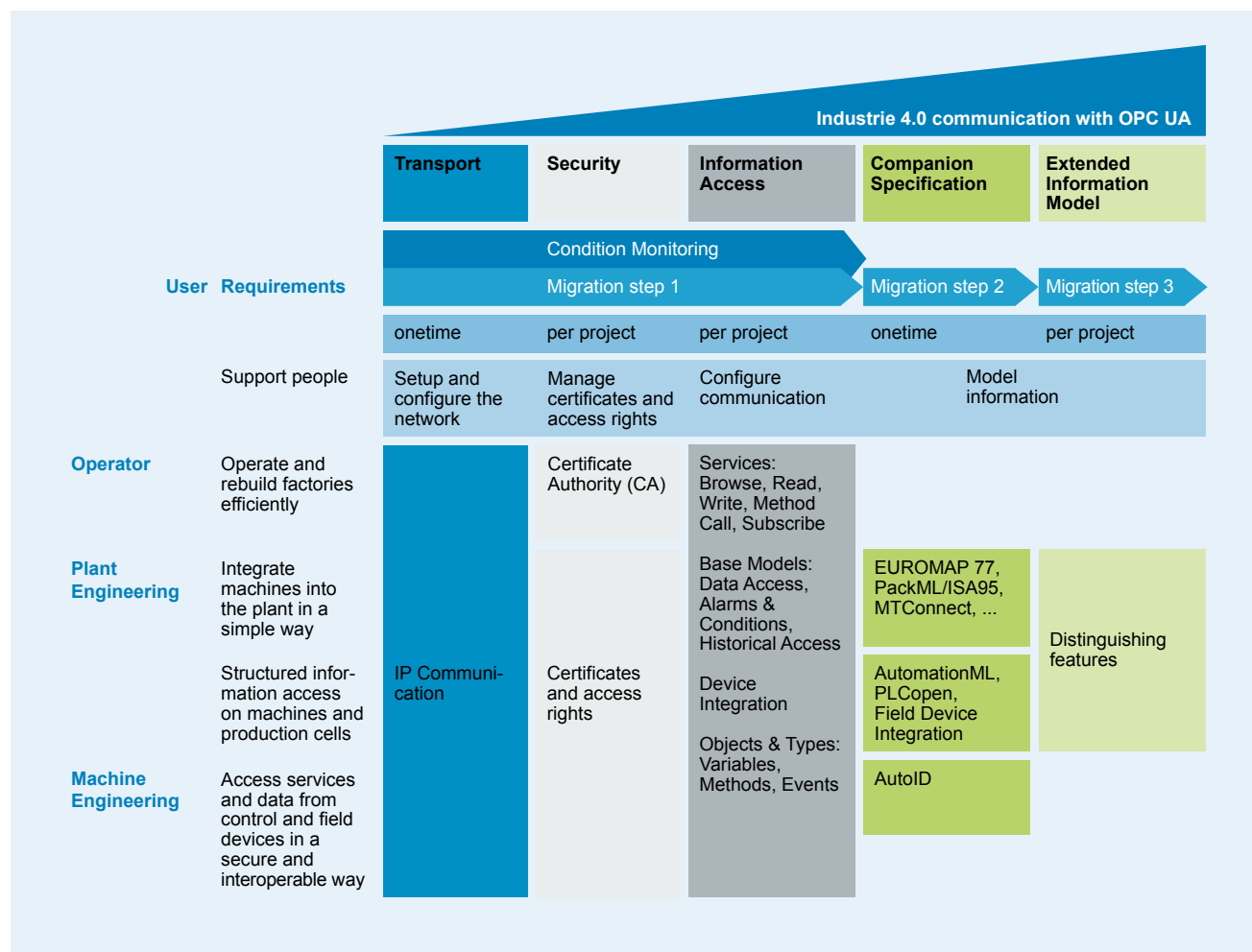


Figure 10: Condition monitoring as the first step towards Industrie 4.0 communication

Figure 10 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 10.

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

Figure 10 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 available security options. The OPC UA client can establish a connection to the server based on this 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.

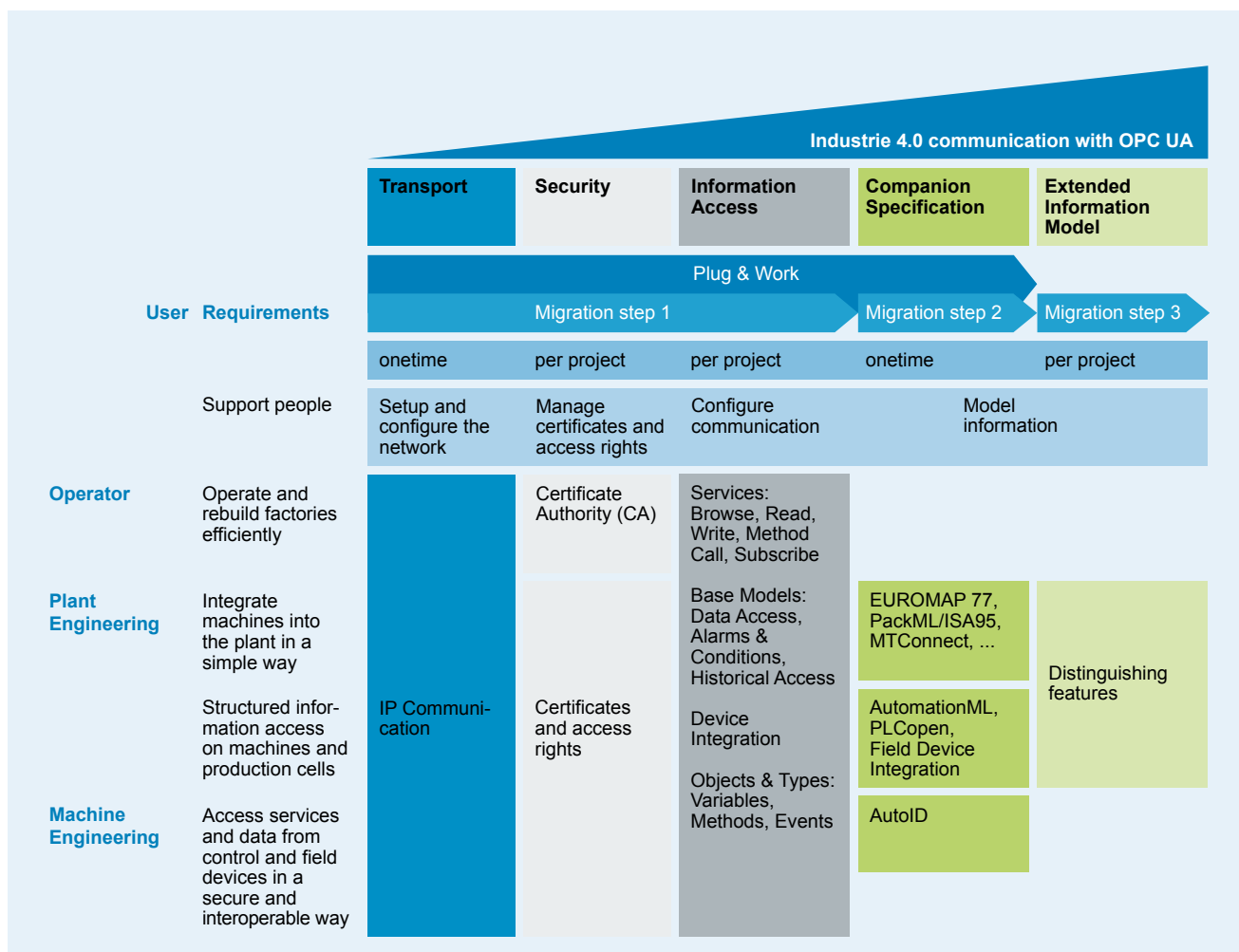


Figure 11: Plug & work based on Companion Specifications

Migration Step 2: Companion Specification

In the previous migration step, a machine builder or factory operator used the toolbox OPC UA in order to implement information access. In the second migration step, several operators and end users of one industry branch use the toolbox OPC UA in order to develop a standardized information model. The standardized information model is referred to as Companion Specification in the toolbox OPC UA. Companion Specifications are always based on

the information model for devices (Device Integration). It describes general characteristics and functionalities of devices and in which topologies they might operate. Companion Specifications define branch-specific devices and their application, e.g. field devices, PLCs or machines.

Companion Specifications are always based on the information model for devices (Device Integration).

The use of Companion Specifications increases interoperability and enables the use case plug & work depicted in figure 11. During commissioning and retrofitting phases, system integrators and automation companies nowadays adapt control programs manually. This adaptation is based on informally recorded information, e.g. manuals and data sheets, which differ from manufacturer to manufacturer. In the future, machine and plant builders will use the Companion Specification in order to enable an information exchange across manufacturers. A new machine can be integrated into a plant easily, since standardized information is available, which does not differ from manufacturer to manufacturer. For example, components, machines and plants can be easily integrated into an operator's MES. The principle is similar to the well-known consumer standard USB.

Machines from different manufacturers accept the same orders.

Example:

The Companion Specification EUROMAP77 ^[6] introduced later specifies information for injection molding and rubber machines. For example, EUROMAP77 ^[6] includes an information object for orders. Based on this approach, machines from different manufacturers accept the same orders. This facilitates the implementation of adaptive production planning systems and the integration into MES and ERP systems.

Example:

The AutoID Companion Specification focuses on devices such as barcode, RFID and NFC readers. For example, the Companion Specification includes methods that can be used for devices from different manufacturers. The reader should use the toolbox OPC UA to get an overview of existing Companion Specifications.

If a Companion Specification already exists for a certain industry, it should be used. If no Companion Specification exists, a new information model can be created. This information model can be standardized in form of a Companion Specification. For this purpose, the reader should contact the VDMA, which bundles the interests of its members and develops Companion Specifications in cooperation with the OPC Foundation.

The VDMA bundles interests of its members and develops Companion Specifications in cooperation with the OPC Foundation.

Companion specifications exist at the level of devices and controllers (e.g. AutoID and PLCOpen) and on machine level (e.g. EURO-MAP77 ^[6]). Table 1 lists further Companion specifications from the toolbox OPC UA.

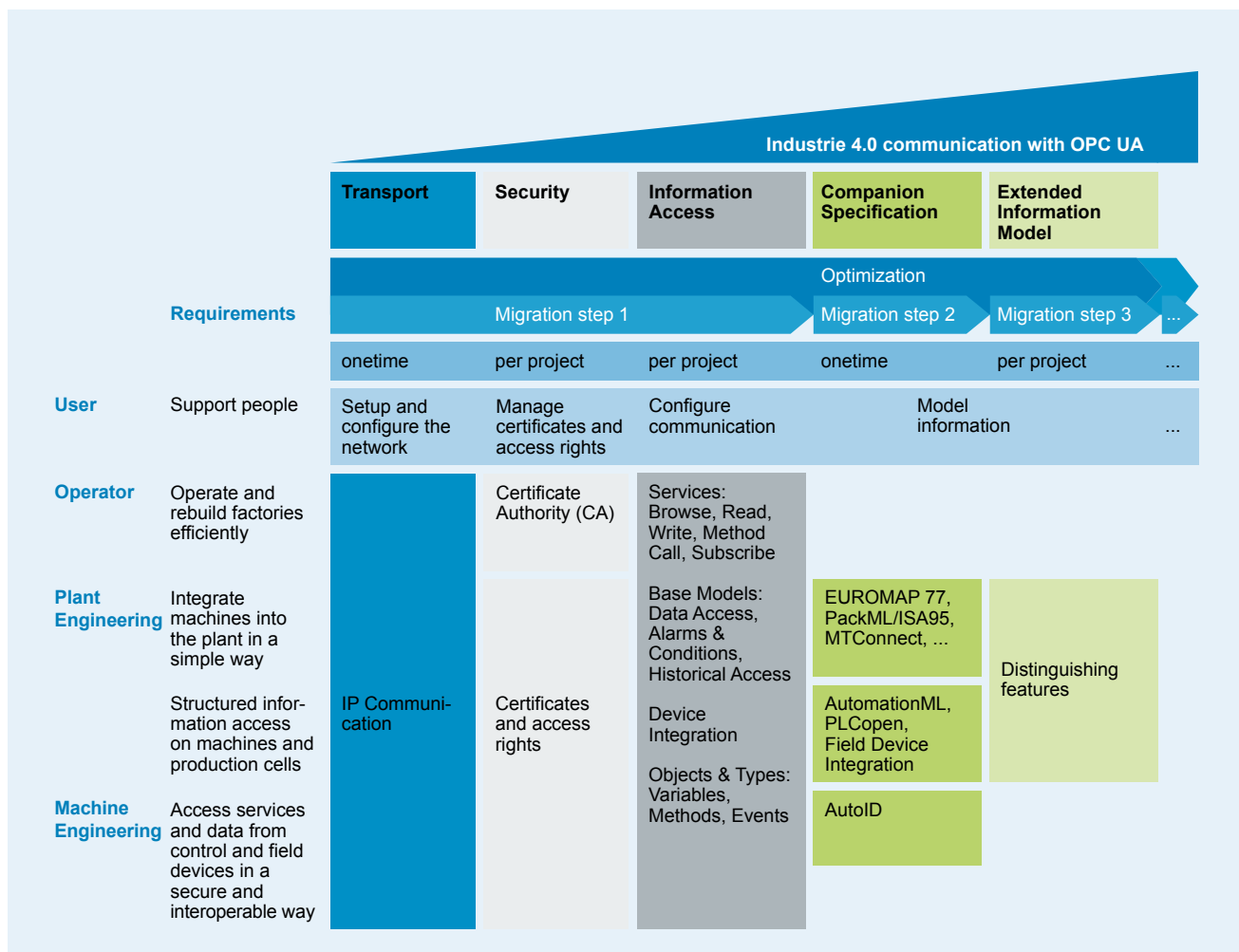


Figure 12: Optimization based on extended information models

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.

There can also be differentiation characteristics 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 12, 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

As this guideline shows, it is advisable for users to participate in the development of Companion Specifications to drive forward Industrie 4.0 Communication for the respective industry. The OPC Foundation provides access to working groups and provides an early insight into new trends and enhancements, including active participation in the definition of Companion Specifications.

In addition, the VDMA supports the development of Companion Specifications for its industries. The OPC UA Foundation will offer a certification of OPC UA Companion Specifications to ensure interoperability.

OPC UA development and toolkits facilitate implementation.

Cooperation with research partners

Industrie 4.0 communication is a subject of current research. To be able to benefit from the developments and results of this research at an early stage, cooperation with research partners should be considered. The Competence Centers of the German Federal Ministry for Economic Affairs and Energy (BMWi) "Mittelstand 4.0" and the Industrie 4.0 research factories provide additional support.

The VDMA and its alliance "Labs Network Industrie 4.0" (LNI4.0) can help to establish contact to research partners ^[5].

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?

Towards a Companion Specification – The EUROMAP77 Example

EUROMAP 77 is an OPC UA Companion Specification and describes the interface between injection molding machines and manufacturing execution systems (MES) for information exchange.

EUROMAP 77^[6] is an OPC UA Companion Specification for information exchange between injection-molding machines and manufacturing execution systems (MES). The VDMA association of plastics and rubber machinery developed EUROMAP 77 in cooperation with the European organization EUROMAP. Figure 13 shows the advantage of using Companion Specifications: Machines from different manufacturers support EUROMAP 77 and can be integrated into the MES in a uniform way according to this specification.

Information islands in production facilities

To date, injection-molding machines are mainly connected to the host computer and the MES based on the EUROMAP 63 standard. The EUROMAP 63 standard defines a text based interface, that can be used to send specific commands for controlling the injection-molding machine and to monitor production parameters. EUROMAP 63 is an example for a standard whose applicability is limited to a single type of machine. Other plant components, e.g. for material handling, processing, dosing, processing and post-processing, are generally based on other proprietary standards. In practice, there are still many manufacturer specific deviations in the concrete implementation of the EUROMAP 63 standard. In consequence, the use of heterogeneous standards does not allow standardized access to the information of individual machines and components in a production plant. Therefore, there is usually little communication between the collection of “black boxes”. The manufacturers of plastic and rubber machines expect advantages when the individual information islands communicate with each other and share more information than before. Comprehensive optimization processes based on the uniform communication standard OPC UA should enable quality increases, a reduction of downtime, as well as an increase in productivity.

Connecting information islands

To simplify the connection of injection-molding machines to each other and to other system components, the new EUROMAP 77 standard was developed as an OPC UA Companion Specification. To this end, a panel of German

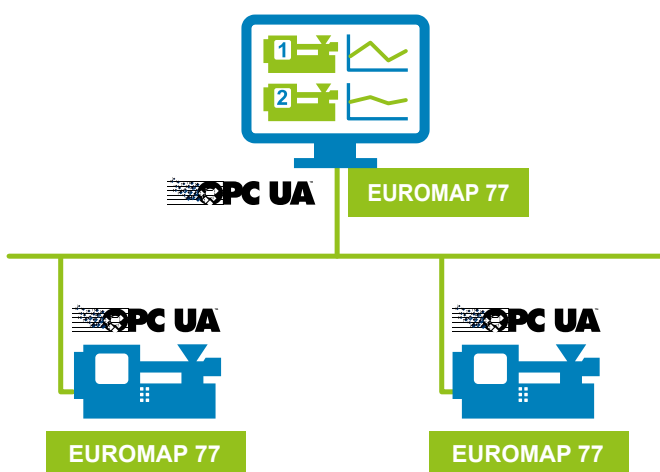


Figure 13: EUROMAP 77 can be used to connect injection-molding machines to MES

machine manufacturers came together at the beginning of 2014. The panel was expanded at European level in 2015. In addition, MES manufacturers and users were involved in the development. At the end of 2016, the EUROMAP 77 release candidate was published.

A Companion Specification such as EURO-MAP 77 specifies information exchange between standardized system components using an information model. The information model of EUROMAP 77 specifies the following information:

- Machine information
- Configuration of the machine
- Current machine status
- Information on the following components of the injection molding machine: mold tool, power supply, drives
- Logged events

To describe this information, EUROMAP 77 uses structured data types. Figure 14 depicts the MachineInformationType data type, which describes the machine information.

Much of the machine information relevant to injection-molding machines must also be specified for other equipment: Manufacturer information, operating instructions, serial numbers or revision numbers. Therefore, this information is defined based on the more abstract standard OPC UA for Devices (IEC 62541-100) and is inherited by an inheritance relation according to EUROMAP 77 (between DeviceType and MachineInformationType). In addition to the standard OPC UA for Devices, EUROMAP 77 specifies machine information which is only relevant for injection-molding machines (the attributes shown in figure 14 and the method “GetEuromapVersion”). In addition to the data type MachineInformationType, EUROMAP 77 specifies a series of additional data types in a similar form.

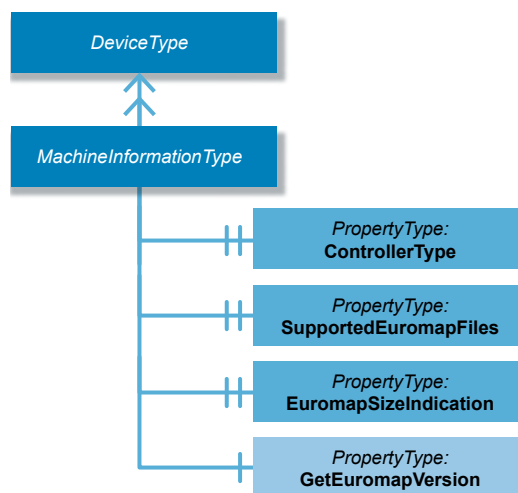


Figure 14: The data type MachineInformation Type^[6]

EUROMAP 77 enables the standardized exchange of information between injection-molding machines and other plant components.

The use of EUROMAP 77 as the OPC UA Companion standard for information exchange between injection-molding machines offers a number of advantages compared to proprietary standards. EUROMAP 77 enables the standardized exchange of information between injection-molding machines and other plant components. For this purpose, a structured information model with a modular structure is used. Inheriting from the OPC UA for Devices standard not only allows describing information from different injection-molding machines, but generally the same information from different system components in standardized form. In addition, the extensive possibilities for information transmission and security mechanisms of OPC UA can be used.



Figure 16: 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). AAS interact with each other via Industrie 4.0 communication (figure 16).

Asset Administration Shell as Migration Step 4

Figure 17 shows the AAS as migration step 4 for Industrie 4.0 communication. The implementation of the AAS can be based on OPC UA and include existing Companion Specifications and extended information models.

A core concept of the AAS revolves around properties that can be understood as a standardized vocabulary. With properties, not only domain-specific relationships are standardized in information models (Companion Specifications), but also individual terms that can be used in information models and that Industrie 4.0 components can talk about. A global unique

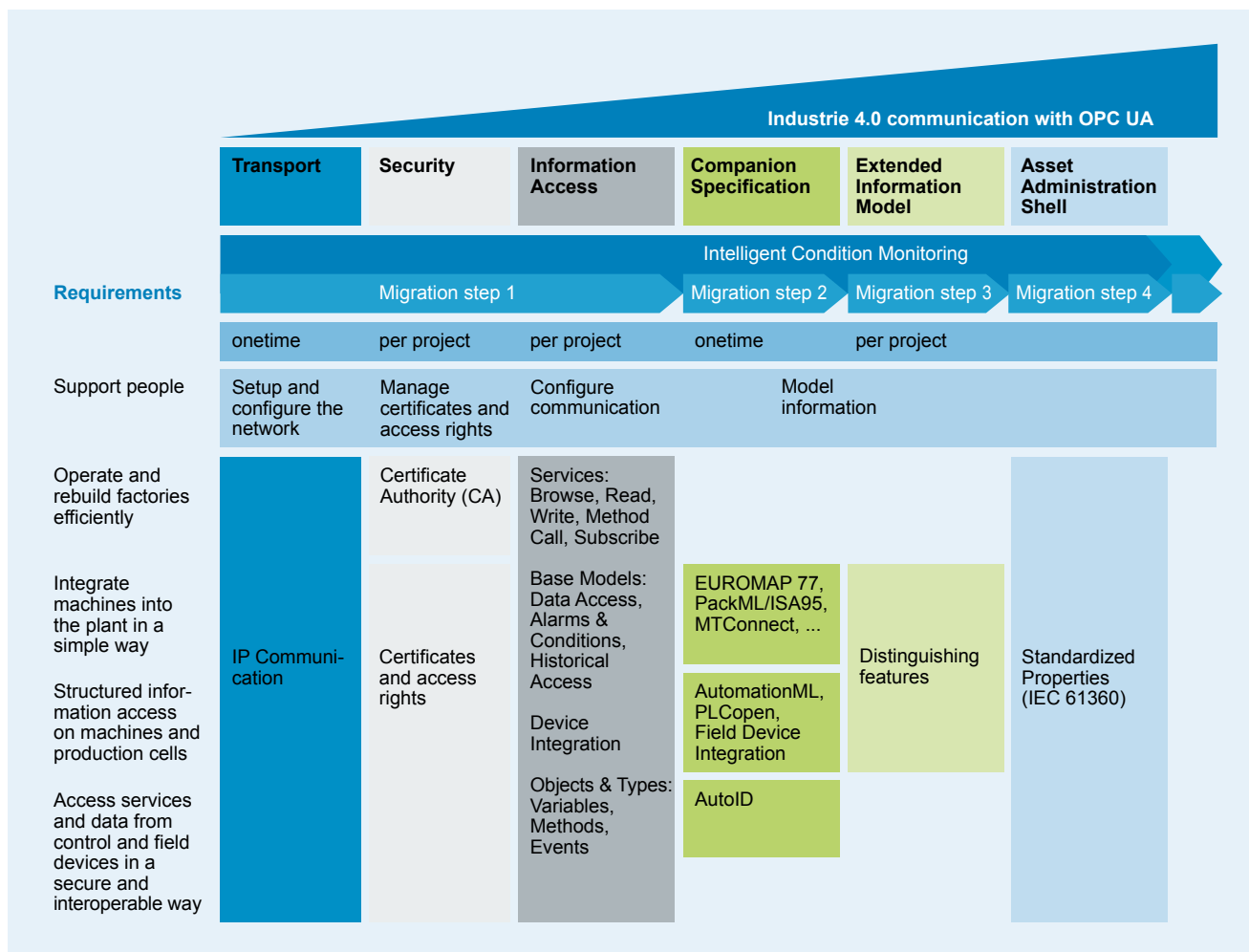


Figure 17: Asset Administration Shell as Migration Step 4

identifier, the International Registration Data Identifier (IRDI), identifies properties. Properties are therefore independent of different languages and domain-specific names, which often describe the same feature. The AAS uses standardized properties according to IEC standard 61360.

Use Case

„Intelligent condition monitoring“:

An example of a use case that can be implemented based on the AAS is the intelligent condition monitoring shown in figure 17. In this use case, properties simplify the configuration of a condition monitoring system.

Example

“Intelligent condition monitoring”:

The AAS of a machine contains information on limits, e.g. the maximum speed of a motor. If the motor is close to the maximum speed, a warning can be issued. If the motor is operated close to the limit over a longer period, maintenance can be scheduled. If a device replacement becomes necessary, the AAS already contains documentation and ordering information. This intelligent condition monitoring can be carried out based on standardized properties without further configuration or programming. If the motor is replaced by another model during the next maintenance, the limits applicable to the new model are automatically adopted.

Conclusion:

Industrie 4.0 Communication based on OPC UA

As this guideline shows, OPC UA meets the requirements for Industrie 4.0 communication. Industrie 4.0 communication based on OPC UA can be used on all levels of the hierarchy axis of RAMI4.0. OPC UA can be implemented in the smallest sensors as well as for cross-factory communication (Connected World). The information access based on the SOA of OPC UA can be found on the communication layer, while Companion Specifications and extended information models are assigned to the information layer. OPC UA is suitable for Industrie 4.0 communication between Industrie 4.0 components, as well as for connecting devices (assets) to their AAS. In latter case, OPC UA would in future also be found on the integration layer of RAMI 4.0.

OPC UA meets the requirements for Industrie 4.0 communication.

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Note

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