Deliverable 5.3: CREATE Interoperability

CREATE

Creating Evolution Capable Co-operating Applications in Industrial Automation

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Project number: ITEA 2 ip10020

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Date: 25.08.2014

Document version no.: *1.0*

Revision History

Date	Version	Description	Author
02.07.2014	0.0	Template and contents of the deliverable	Anastasios Martidis (TIE)
11.07.2014	0.1	First draft of Dutch contributions	Anastasios Martidis (TIE)
30.07.2014	0.2	Second version of Dutch contributions	Anastasios Martidis (TIE)
11.08.2014	0.3	MDH contributions	Ivan Tomasic (MDH)
18.08.2014	0.4	Final Dutch contributions	Anastasios Martidis (TIE)
22.08.2014	0.5	Final MDH contributions	Peter Funk (MDH)
25.08.2014	1.0	Final version	Ivan Tomasic (MDH)

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1.1 Introduction to Interoperability

Interoperability in a broad definition of the word, describes the ability of independently developed components or systems to interact, cooperate and communicate over mutually understood information. This so called commonly understood information includes content, format and semantics of the exchanged data. The interoperability is ranging over different levels, from concrete to abstract:

- technical, which refers to common tools, interfaces and infrastructures
- syntactic, which refers to exchange of data through formats and communication protocols
- functional/pragmatic, which refers to common sets of functionalities and service definitions, and
- semantic, which refers to common understanding of the meaning between the exchanged information.

In terms of reducing costs interoperability holds a crucial role in today's industrial automation applications [1], but also in entire capital facilities industry. The US National Institute of Standards and Technology report from 2004 [2] estimates the cost of inadequate interoperability in the U.S. capital facilities industry to $15.8 billion per year. This shows that interoperability can have important macroeconomic consequences.

Furthermore the interoperability is tightly related to the free market principles. Products can be non-interoperable because they are protected by patents, trade secrets, or are just non-interoperable by design. This can however lead to monopoly or market failure. For this reason, there exist user communities and organizations that encourage and enforce interoperability. Standards Defining Organizations (SDOs) provide open public specifications to facilitate interoperability; examples include the International Organization for Standardization (ISO) [3], the Oasis organization [4] and buildingSMART [5] in construction industry (formerly the International Alliance for Interoperability). An example of user communities is the Internet Engineering Task Force (IETF) [6] which develops and promotes voluntary Internet standards, in particular the standards that comprise the Internet protocol suite (TCP/IP). The OSLC (Open Service for Lifecycle Collaboration) Community [7] is working on finding a common standards that enable software to easily integrate with other software.

Industrial applications require the organization and cooperation of humans, production machinery and ICT systems, not only at the Field level but also across all levels of the automation pyramid (fig. 1) till the Enterprise level.

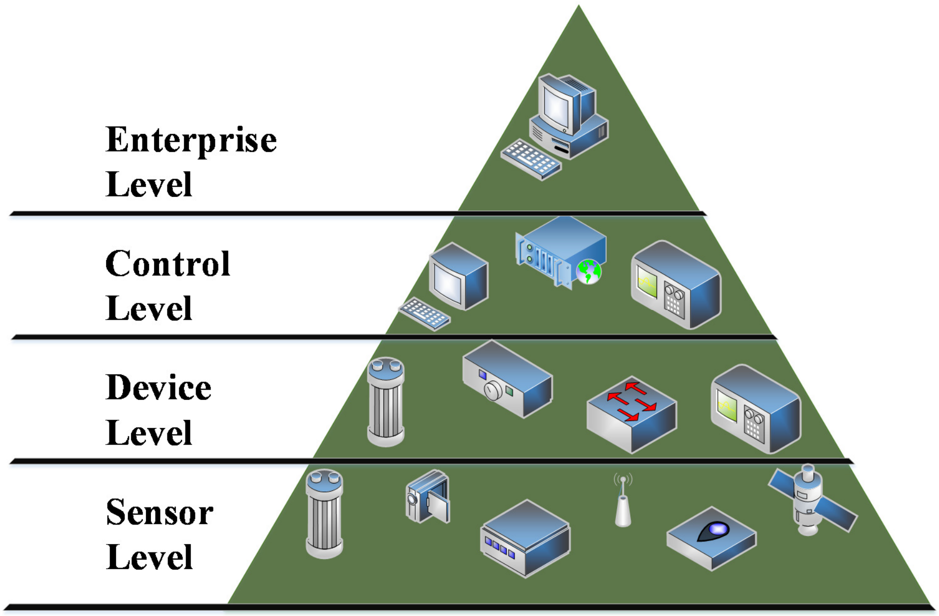

Figure 1: Automation Pyramid

Industrial automation systems include numerous distributed components in heterogeneous environments, which have to communicate and cooperate. Furthermore, these systems are far from static, with many components being added or replaced, whereas new technologies and methods are introduced in order to keep the industry's competitive edge. Moreover, industrial automation and production lines require the integration of humans, hardware and software components and their interaction in a fast and efficient way, as well as the fast and reliable reconfiguration of the systems and enhanced human-machine interfaces. The production processes can be complex and critical so there is a need for modelling, simulation and control of the operations and technologies to turn data into efficient decision making. Finally, industrial automation strives for minimization of waste production and energy consumption. All these characteristics of industries and automated production lines are closely related to interoperability. In the following are described the most significant benefits of interoperability in the industrial automation.

Innovation is possible when new technologies and components can be combined with existing ones. Obstacles that complicate the integration of new technologies are particularly obvious in industrial automation systems. Production lines are composed of expensive systems that cannot be replaced altogether at once, and even if that was possible, the time required for changing the production system could cause unbearable costs. Interoperability allows the integration and replacement of components in a plug and play approach, since it allows heterogeneous components developed separately to work together and to be integrated with minimized reprogramming effort, so interoperability allows industries to attempt innovation.

Flexibility and choice over the components that compose the production lines is possible through interoperability. Being able to select from a variety of components/system parts and vendors is an indispensable "luxury" when setting up and maintaining such production systems. Interoperability also facilitates an *enhanced competition* due to the choice it provides reducing lock-in effects and lowering the entrance barriers as well as allowing industries to attempt innovation at lower costs and reprogramming efforts.

Industries and production lines incorporate in many cases various business units and definitions of business processes, together with planning and management of these operations. In most cases the business planning and management is based on different forms and representations. Interoperability can also help in *unifying business processes* from different business units and representations, to a common and mutually understandable/exchangeable representation. Furthermore, communication between the industry with external partners or clients in most cases requires time for "translation" of information schemas (e.g., product catalogs, orders, etc.) from one to the other. Interoperability between these *information schemas* will decrease processing time and will free-up resources. In general interoperability allows companies to innovate, provides them with choice and flexibility, and helps them decrease costs in regards of money, time and reprogramming efforts.

In addition to the diverse aspects and benefits that interoperability provides to industrial automation and production lines, the areas and forms of interoperability are also quite various. Following are described the main areas where interoperability comes into play in industrial automation.

1.2 Forms of Interoperability in Industrial automation

Interoperability is necessary in the c*ommunication* between different components such as devices, sensors, production machinery, monitoring and Enterprise Resource Planning (ERP) systems. The communication takes place constantly during operation both horizontally and vertically; horizontally between devices and sensors on the field level (e.g., Machine to Machine (M2M) communication) and vertically starting from the field/sensor level and moving to the enterprise level (for example to control and monitor devices/sensors or provide decision support to human operators in the production line [8]). The components that come together to build such systems usually originate from various providers and have different specifications and communication protocols. For this reason, setting up such systems requires careful planning to ensure their ability to communicate. However setting up the systems is not the end, since as mentioned before, components are replaced and added in a regular basis. Interoperability in the communication for this reason is very important if not downright mandatory.

Production also involves exchange of information with various (internal and external) partners, vendors, systems, and representation of different kinds for information that is used for production processes. The representation and exchange is based on *information schemas* but these schemas differ both when it comes to external partners and between different units in the same industrial automation system/production line. For example data sent from different devices and sensors are represented usually in diverse information schemas and in order to process and use the accumulated data they must be consolidated to a certain information schema the processing application uses, which can be a challenging and time consuming task. Another example is the exchange of operational data between different production units which represent information in different ways but need to consolidate the schemas in order for the units to cooperate. Thus, information schema interoperability is another very important area that when achieved decreases time and costs during production.

Additionally to the diverse information schemas, the *data format* of the exchanged information, especially on the lowest levels of the automation pyramid, is a very common and time consuming problem. In many cases, production processes involve the manual "translation" of data from one format (e.g., CSV) to another (e.g., Excel). Manual translations like these slow down the production processes and consume useful resources (i.e. human operators) for tedious tasks which should be automated. Interoperability between different processes in regards to the data formats they handle would again decrease time and costs of the production. Additionally, the conversion between data formats is prone to errors and loss of data. Accurate interoperability between systems that expose interfaces with different data format is necessary for correct communication and data integrity within a whole industrial system.

Another area, in which interoperability is crucial, is between *business/production processes* and their descriptions. In big industries and productions, it is almost always the case that different business/production units plan their processes and tasks, and need to communicate them to other units in order to achieve their common goals. In order to exchange and share their business/production processes, planning and management specification, the descriptions and models between business/production units should be commonly understood and easily integrated, or else they have also to be transformed in each unit to their local versions. Thus, interoperability has an important role to defining and managing business/production units' processes as well.

Finally, another area worth mentioning in regards to interoperability is the *functional interoperability* between software components and their service interfaces. Devices and their software as well as ICT systems in general are cooperating and interact during production. New components are added, other are replaced which many times requires slowing down or pausing the production line to re-program and set up the production line and its components to work together. The delays or decreased production rate could mean substantial costs and is therefore usually avoided as much as possible.

It is a common approach today that when a need for a new functionality is detected, a new ICT system that provides this functionality is bought and integrated to the existing system, normally by the new system's vendor. This approach however hurts production lines in a number of ways, including the decreased innovation chances due to the high entry barriers for new technologies. As the number of software systems grows in an industrial systems, the number of interfaces that a new system needs to implement grows accordingly. The needed effort for developing the interfaces can even surpass the effort spent for developing the new and innovative technology. Because of this increased need for integration we can lately withes an emergence of a number of companies specializing only in integration between different systems. Functional interoperability between software components that is a priory specified and ensured, can decrease significantly the time and costs for the integration, and enable the introduction of new components in such length that can even happen real-time in a plug and play approach, with no need to pause production operations.

2. Interoperability in CREATE

The previous sections provided the reader with an overview of the importance and benefits of interoperability, the challenges of how to achieve it, and the forms and aspects of interoperability in the industrial automation domain. In this section is described how the CREATE approach enforces and increases interoperability in the industrial automation domain, providing as proof of concept the enhanced interoperability in the prototypes developed within the CREATE project. Initially let's recap the CREATE architecture based on which the interoperability is achieved.

2.1 CREATE Architecture

The architecture proposed by CREATE enhances industrial automation via communication. This communication is performed both vertically and horizontally across the automated production lines. CREATE employs a physically distributed but logically centralized architecture based on modular and autonomously cooperating modules called Smart Neighborhood Modules (SNMs). These modular composites can be physical devices, sensors, control and monitoring systems, data stores and knowledge bases, legacy systems and human operators. Interoperability is crucial for the optimal communication and cooperation of such components. The CREATE architecture provides an abstract theoretical framework for grouping such components and allows the loose coupling between them employing Service Oriented Architecture (SOA) approach. The building blocks of the CREATE Architecture are depicted in figure 2 and are described briefly below:

- *Physical devices* which include sensors, actuators and other devices present in production lines (Field level). These devices are exposed into the virtual world and can communicate both with each other (M2M) as well as with systems in higher levels of the automation pyramid (fig. 1) to communicate information during their real-life, real-time operation.

The exposure of the devices into the virtual world is built on top of their associated automation software

- The *automation software* of devices allow their control and monitoring from remote locations as well as the realization of automated applications on top of them. The automation software is important on many aspects; first it is required for devices to be able to communicate with each other and act based on the input they get from other devices. Moreover, the devices must be able to get "instructions" from humans so that they control their actions and behavior which is also facilitated by automation software. Finally, the huge amount data generated during production require AI applications to extract knowledge that will contribute to the optimization of production processes

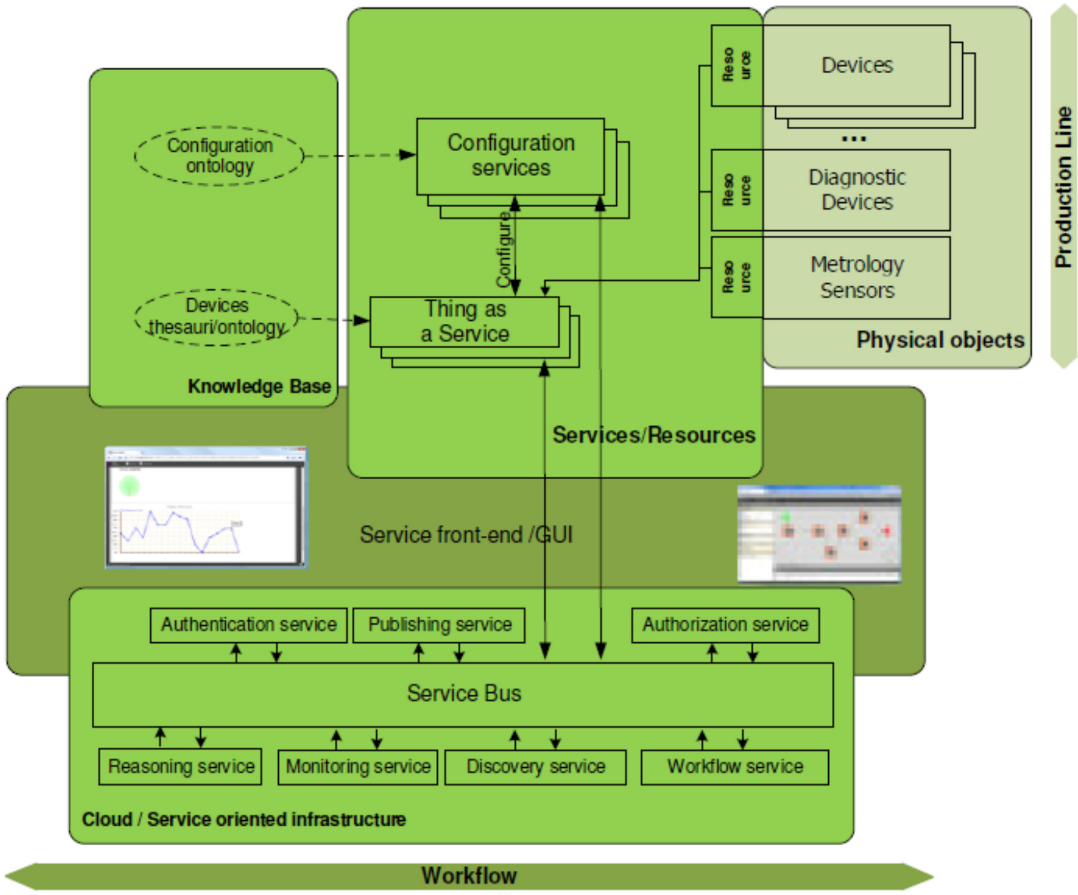

Figure 2: Overview of the CREATE Architecture

- *Knowledge bases* in the context of the CREATE architecture concern data repositories for knowledge management. Data generated during various production processes and information related with the production line and production processes is stored in these so called Knowledge Bases. Artificial intelligent application over these data can provide decision support for optimization of the production processes as shown in the Dutch use case for the reconfiguration of the production lines and in the Swedish use case with Case Based Reasoning for adjustment recommendations for defective car parts
- The *Graphical User Interface* (GUI) is another important component of the CREATE architecture, providing an easy and intuitive interaction between human operators in the production line with the rest of the system. This GUI is intended to complement human work, helping humans to be more effective and productive
- The *communication platform* plays a central role in the CREATE architecture for integrating the different components in the production line (e.g., devices, knowledge bases, user interfaces, etc.), allowing their communication and cooperation.

The next section provides a description of how the above architecture allows the realization of enhanced interoperability between the different components in the production line and how this enhanced interoperability was shown in the use cases developed within the CREATE project.

2.2 Enhanced Interoperability in CREATE Demonstrators

The CREATE approach addresses almost all aspects of interoperability described in section 1.2 with the most catalytic element for this enhanced interoperability being the realization of a Service Oriented Architecture (SOA) in industrial automation systems [9]. As described in the previous section of the CREATE architecture, the different components in a given industrial automation system are operating as separate services that are loosely coupled and integrated in the whole system. The web services are wrapped around existing applications, legacy systems, and new components, to enforce the interoperability in CREATE demonstrators.

The first aspect of interoperability that is enhanced in this approach is *communication interoperability*. Communication with the CREATE approach is achieved over the network and through standards and protocols. Each component can have its own technology stack, language or implementation but using web services the communication is performed independent of these parameters. Another aspect of how the interoperability is enhanced is the *functional interoperability*. SOA and web services allow decoupling of software components but at the same time the cooperation between components becomes easier and more automated.

This is achieved with the use of services description using description languages such as WSDL and WADL, which components can use to see the exact functionalities, endpoint and properties of services. The CREATE approach, as it was implemented in the national (i.e. Dutch, Spanish and Swedish) demonstrators as well as currently in the Cross Domain Demonstrator, is heavily based on SOA and web services, and therefore provides the systems with enhanced communication and functional interoperability.

Information schema/model interoperability was also confronted and achieved by the CREATE project. More specifically, in the Dutch use case where it was described how the reconfiguration of a production line is a costly, error prone and time consuming procedure. The selection of devices and parts to be inserted or replaced in a production line would require examination of a variety of choices, with a large number of characteristics that need to be taken into consideration for comparison. Due to the fact that different devices, models and types are provided from different vendors, and since there are no standards for the schema in which the characteristics of the devices are described, each vendor uses its own schema for the description.

The comparison of the characteristics from the different schemas was one of the critical reasons for the time and error prone performance of the reconfiguration. With the CREATE project (and its proposed architecture for use of knowledge bases), an ontology model was developed (as documented in the D3.1 Evaluated demonstrators v1 deliverable). This ontology provided an explicit description of device characteristics (e.g., dimensions, communication protocols, software, etc.). The different specifications of the devices in this way, can be translated in a common description and be reasoned with [10]. Moreover, facilitated by the use of semantic web technologies for the development of the model and the data storage, and in line with the CREATE architecture, an artificial intelligent application was developed that performs device matchmaking to support the decision making for the reconfiguration.

The translation of the of the information schemas of each individual vendors to the defined ontologies, is related to another aspect of interoperability in which CREATE helps industries and production lines, which is the *data format interoperability*. The data format interoperability is mainly achieved via the Enterprise Service Bus (ESB) [11] as defined in the CREATE architecture. The industrial automation systems and production lines involve various distributed components that need to communicate, and for their communications they use different formats. The Enterprise Service Bus not only facilitates their communication, but also transforms data formats between cooperating components, providing interoperability in their communication and at the same time ensuring data integrity.

This enhancement for the data format interoperability is achieved in the Dutch national demonstrator via the TIE SmartBridge (TSB), as well as in the Cross Domain demonstrator. The automatic transformation of messages from one format to the other is based on mappings performed between formats once and then the mapping can automatically continue as long as necessary. An example of how the above applies to a real life scenario is in a part of the Dutch demonstrator mentioned before, that considers device specifications from a vendor which are in a specific schema that uses XML to describe and communicate the data. The information schema is mapped (using a tool such as TIE SmartIntegrator) from the vendor's model to the defined ontology for the defined description. Then, these mappings are used by the ESB (e.g., TSB) to translate the data from the XML format they are in, to another schema and another format, specifically to an ontology schema and owl format. This exchange of information between the vendor and the production system can continue automatically for as long as necessary (provided that the schemas and formats do not change between the vendor and production system in which case new mappings are required).

Finally, one of the most important drivers of interoperability is *standardization*. Organizations such as ISO endorse the definition of open standards and the adherence to such standards by organizations, companies and individuals facilitates (see [12] for ISO standards on interoperability). In CREATE project partners both contributed to standardization as well as based their implementation on established and open standards (i.e. web services and semantic web). In terms of contributing to standardization, the Swedish national demonstrator and its SAC module during the research and developments for the CREATE project have published and ongoing activities to the ISO and Swedish Standard (SS) organizations.

3. Conclusions

The CREATE project is motivated by real business needs which were specified as a set of use cases in the industrial automation domain. Based on the market needs for their respective domain, partners defined use cases for Flexible Material Flow, Industrial Metrology and Monitoring and Quality assurance. Within the CREATE project extensive research took place for the definition of an architecture that would be easily implemented and would significantly enhance the automation domain. The CREATE architecture is detailed in almost all deliverables during the project with the most focus being put on the architecture definition, in deliverables D2.1 and D2.3. After the architecture definition partners performed a SotA research to identify the best technologies to implement the CREATE architecture. Following the research and selection of the needed technologies, tools and frameworks, partners developed the prototypes for the respective use cases following the CREATE approach. The prototypes were evaluated and tested providing proof of concept for the validity and benefits of the CREATE approach along with very important feedback and lessons to be learned. Partners utilized all these to provide the "CREATE Method" which describes the CREATE approach for enhancement of industrial automation along with the proof of concepts and guidance for the readers to implement it in their own cases.

The CREATE project is currently in its final year of life and partners are working on the Cross Domain Demonstrator (CDD) which combines components developed in the different prototypes for the CDD use case (see deliverable D6.1 CDD Design and Specification). The integration of the parts in a plug and play approach is easy due to the flexibility and interoperability that the CREATE architecture provides. As was argued in this deliverable, interoperability is crucial in industries and production lines (section 1.1) and it brings many benefits such as innovation, flexibility and choice, unification of business processes and information schemas. Within the CREATE project many different aspects of interoperability were considered and through the evaluation of the national prototypes it was shown that the CREATE approach significantly enhances interoperability on the areas of communication, functional, information schema and data format interoperability. The variety of areas where the CREATE approach enhances interoperability in combination with the importance of interoperability in industries and production lines motivated this deliverable. Partners aspire that this deliverable will facilitate readers to gain a clear and complete insight of the "toolset" for the enhancement of the interoperability in their systems, with an adaptation of the CREATE method.

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