Interoperability for Human-Centered Manufacturing

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Abstract. Interoperability is of high focus for the manufacturing industry that is currently undergoing a transformation into the fourth industrial revolution. Factories are adopting smart technologies and implementing decentralized and human-centered manufacturing systems. To use ICT for cognitive automation and information sharing is becoming more common and increasingly important for factory workers. To implement these ICT solutions, it is important to consider their interoperability with the entire manufacturing system. This study suggests a framework that combines the context of human-centered manufacturing with areas of concerns in enterprise systems. The framework is presented and discussed regarding its usefulness to assess and/or improve system interoperability.

Keywords: Interoperability · Human-centered manufacturing · ICT

1 Introduction

Interoperability is a broad term that many people associate with the technical issues of computer interactions but it also includes a soft side of human communications and organizational aspects. Interoperability is of high focus for the manufacturing industry that is currently undergoing a transformation into Industry 4.0, the fourth industrial revolution. On a general level this is achieved by implementing the concepts of Cyber Physical Systems (CPS), Internet of Things (IoT), Internet of Services, and Smart Factory [1]. As new technologies are adopted, new dynamics will be introduced opening doors to external service providers, increasing the relevance of interoperability [2]. Interoperability has been thoroughly researched and several reference frameworks and evaluation models have been presented over the years. These models [3–7] have been mostly focused on the technical issues that disregards the human perspective [8]. The focus towards more dynamic and flexible manufacturing systems have also increased the focus of humans role in the system [9]. Today, the Industry 4.0 framework has the potential to include also humans into its highly innovative processes. When the physical and cognitive level of automation and complexity within manufacturing increases, the importance of support to the remaining workers are vital [9]. With the recent advances of information and communication technologies (ICT), it is a tempting proposition to increase the utilization of ICT as cognitive automation to enable context aware information and information sharing for manufacturing operators [10]. The development will continue and the competences needed from manufacturing

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operators is bound to change when the industry adapts to more smart solutions [11–13]. This shift puts more emphasis on collaboration between information systems and operators [14]. Context-aware information requires a system that acknowledges the need of individuals and can provide the right information at the right place in the right time [12]. A powerful technical infrastructure is needed to facilitate this bottom up engineering of interoperable solutions. The infrastructure needs to allow and support the creation of interoperability solutions within and between technical systems, exchanging data and organizational systems that are part of a common business process.

This paper aims to present an interoperability framework that can be used to evaluate system strengths and weaknesses, which enables flexibility and adoptability between Information Technologies (IT) and Information Systems (IS) and thereby creates a more human-centered manufacturing system.

2 Interoperability Framework

According to the classic IEEE definition, interoperability is "the ability of two or more systems or elements to exchange information and to use the information that has been exchanged" [15]. By this definition, interoperable systems need to be able to both communicate and to be able to interpret what is being communicated. These abilities are often represented in four separate interoperability levels: technical, syntactical, semantic, and organizational [8]. These levels can be used as a maturity measure of interoperability where interoperability barriers prevent reaching to higher levels. Interoperability models usually divide these barriers into different areas where they can occur. In the interoperability maturity model, LISI [3], the areas are procedures, applications, infrastructure, and data. This is similar to the Framework of Enterprise Interoperability (FEI) that use business, process, service, and data [7]. Without connecting them to interoperability barriers or levels in an explicit framework, Koussouris et al. [6] presented twelve different research areas, divided into four granularity levels, that can connect interoperability with the enterprise system. The first granularity level is based on a description of the basic components of an enterprise: infrastructures, data, processes, policies, and people. From those five components, they suggest six fundamental areas: data, process, rules, objects, software systems, and cultural. These areas are chosen to represent different enterprise interoperability aspects. Unlike other frameworks the interoperability areas are not directly mapped against levels or barriers, instead the focus is towards the human perspective.

Interoperability is strongly linked to the concept of collaboration, which is the sharing of information, resources, and responsibilities between distributed entities of humans or machines [16]. Since the framework focus on human-centered manufacturing, it underlines the usage of ICT as a tool for collaboration, which from a human perspective concerns other humans and machines.

Table 1 shows the framework which is a matrix of 24 different areas of interoperability solutions and/or concerns. The vertical axis are the six fundamental interoperability areas and the horizontal axis represents human operators' collaboration with humans and computers using ICT. The table is partly populated with color-coded data.

Text with a blue background represents an industrial use case to exemplify how the framework can be populated (described in the next chapter). A green background highlights shorter examples that are used in the discussion below.

Table 1. Interoperability framework for human-centered manufacturing.

<table>
<tr><th rowspan="3">Interoperability areas for enterprise systems [6]</th><th colspan="4">Manufacturing operators use of ICT</th></tr>
<tr><th colspan="2">Human-Human collaboration</th><th colspan="2">Human-Computer collaboration</th></tr>
<tr><th>Internal (Manufacturing Operations)</th><th>External (Outside MO)</th><th>Monitor and control</th><th>Cognitive automation [17]</th></tr>
<tr><td>Data</td><td></td><td>AML [18-20]</td><td colspan="2">IO-Link [21]</td></tr>
<tr><td rowspan="2">Process</td><td colspan="2">Preventive maintenance [22]</td><td rowspan="2">Production overview with alarm info [22]</td><td>Adapts timing and content of checklist [22]</td></tr>
<tr><td>Disturbance reporting [18, 19]</td><td>Engineers and operators view of the automation equipment [18, 19]</td><td>Instructions [18, 19]</td></tr>
<tr><td>Rules</td><td>Disturbance reporting [22]</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Objects</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>QR codes [22]</td></tr>
<tr><td>RFID [18]</td></tr>
<tr><td rowspan="2">Software</td><td colspan="2" rowspan="2">RESTful web service [19, 23]</td><td colspan="2">OPC UA [18, 24]</td></tr>
<tr><td>ISA 95 / B2MML [25]</td><td></td></tr>
<tr><td>Cultural</td><td></td><td>Translation aid</td><td></td><td></td></tr>
</table>

2.1 Data - Accessibility of Relevant Data

The data interoperability area is about ensuring the access of all the relevant data needed for a specific ICT implementation. Many **human-computer** implementations in the manufacturing industry rely on sensor **data** to trigger events in the system. One way to improve accessibility of this sensor data is to support, or even force, a specific system standard for sensor connections e.g. I/O link [21].

2.2 Process - Alignment with the Manufacturing Process

Process interoperability is the easiest to imagine and exemplify. In a previous study by the authors a customized mobile application was introduced to manufacturing operators [22]. This mobile tool included many functions that fits well in this area. First of is a digital preventive maintenance checklist. This checklist helped the operators to perform the preventive maintenance, an important part of the manufacturing **process**. This tool also helped others, like maintenance engineers, to trust the results. Therefore, it can relate to both **internal** and **external** collaboration. Two other functions can exemplify **human-computer** collaboration. One is an overview of the manufacturing systems with current alarm info, which is a typical **monitor and control** function. The other is an automatic reminder and dynamic content of the maintenance checklist, which is an example of **cognitive automation**.

2.3 Rules - Inclusion of Relevant Rules and Regulations

Another function from the mobile application mentioned above was a digital disturbance report tool. Anyone could input information about things that was out of the ordinary, which was then accessible to other operators regardless of where they were or what shift they belong to. This tool improves the **internal** communication and it helped them keep the production area free from problems, which is necessary from a safety viewpoint and is highly regulated (**rules**).

2.4 Objects - Identification and Interconnection with Relevant Objects

With increased focus on Cyber Physical Systems (CPS) and demand for traceability, being able to identify and interconnect with relevant objects are crucial in the manufacturing context. Let’s go back to the example of the preventive checklist in the mobile application [22]. Each checkpoint provided some instruction on how and what to inspect (**cognitive automation**). These instructions could be started by scanning a QR code next to the checkpoint, connecting the right instruction to the correct station (**object**).

2.5 Software - Interconnectivity with Relevant Software Systems

Interconnecting software is perhaps what most people naturally connect to interoperability. This can be aided by utilizing a sound model, e.g. service oriented architecture (SOA), or by committing to well documented standards. For example, if you wanted to connect to an existing enterprise resource planning (ERP) system (**software**) to gain access to e.g. production KPI's (**monitor and control**), it would be easier if it already followed the ISA 95 [25] standard and implemented B2MML to transfer the data.

2.6 Cultural - Different Traditions, Languages, Social Norms etc.

The last interoperability area, cultural, refers to the fact that people that collaborate have different traditions, languages, social norms etc. To accommodate this in ICT implementations for human-centered manufacturing can sometimes be very relevant in a global context. One example could be to include translation aid for human-human collaboration over organizational borders (**external**).

3 Exemplifying the Framework

This section exemplifies how the interoperability framework could be utilized in an industrial case example. The case refers to a mobile dynamic assembly system developed in a research project [18].

3.1 Human-Human Collaboration

Part of the assembly system, an automation management platform, mogas [19], was developed as a Web application built with the Play Framework [23]. Play framework automatically build web applications that are accessible with a RESTful API, which improves system integration (**software**). The application consists of a database that represents an automation system and its components. For each component, users can add, edit, and use issue reports and instructions. The system allows several different organizations and users. Each organization can have one or several manufacturing systems and each system have an automation equipment hierarchical structure.

An interesting feature of this system is how the database (**data**) is originally populated, which is through automatic generation from an Automation ML file [26]. If this file is updated, it is possible to regenerate the structure with maintained system information. Automation ML files can be generated from other systems with such support or created with the specialized editor that can be downloaded from the official AML website. Figure 1 shows the assembly system represented in the Automation ML editor and in the automation management platform respectively.

The Automation ML (AML) data format is built on the CAEX (Computer-Aided Engineering eXchange) model, which is an internationally standardized file format, which provides an object-oriented structured meta-model [27]. AML aims to simplify information exchange between tools used during the automation engineering process. It supports storage of plant topology, geometry and kinematic (COLLADA), behavior description (PLCopen), references, and relations. Automation ML consists of class libraries and a concrete instance hierarchy [20].

From an interoperability perspective, this platform aligns the view of the automation system (**process**) between manufacturing operators and maintenance engineers (**external**) that also can be extended to automation developers. This is made

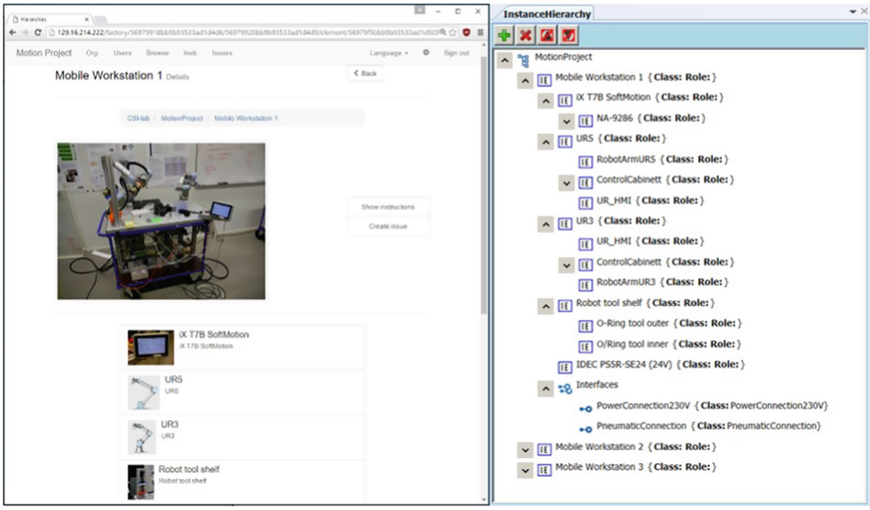

Fig. 1. To the left: The platform mogas (Management of Generic Automation Systems) exemplified with an assembly system from the research project MOTION. To the right: The same structure in Automation ML Editor.

possible by sharing the same semantic structure derived from the automation design tool (AML). AML also allow for an automatic population and structure of the database, which is relevant from data interoperability point of view.

3.2 Human-Computer Collaboration

Each mobile station has an HMI and a PLC to control various automation equipment. A purposeful limitation within the project was that each HMI/PLC combination came from different suppliers. This hindered copy pasting code to control common automation equipment, which in this case was the RFID system to identify different pallets. To remedy this problem, a separate RFID system was implemented using a Raspberry Pi connected to a RC522 RFID reader. OPC UA was supported by all the suppliers so it was chosen for top level communication. Thanks to the fact that OPC UA is open and platform independent [24], it was relatively easy to use this standard to also connect the Raspberry Pi and the RFID solution to the HMI's.

When populating the framework regarding human-computer collaboration there are three important features. Dynamic instructions (**cognitive automation**) were implemented to better aid the assembly tasks (**process**). The dynamic feature was possible by connecting the RFID system, that identified the pallets (objects). In general, human-computer collaboration was also made possible by OPC UA that enabled interconnection between different systems (**software**), such as a traditional PLC/HMI implementations and a RFID system built on a Raspberry Pi.

4 Conclusion

This paper provides an interoperability framework that aims to create a common language between decision makers in manufacturing industry and ICT/IS developers. According to Rezaei et al. [8] it is important that an interoperability evaluation model is easy to use and that it considers every aspects of interoperability. The result matrix can be a step towards such a model for the human-centered manufacturing context.

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