Supporting Interoperability of Virtual Factories

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Abstract. The manufacturing industry is entering a new era. This emerging era starts with the integration of new ICT technologies and collaboration applications into traditional manufacturing practices and processes, such as manufacturing 2.0. Manufacturing 2.0 has been conceptualised as a system that goes beyond the factory floor, and paradigms of "manufacturing as an ecosystem" have emerged. The virtual factory is one of the important concepts and foundations central to the realization of future manufacturing. In this paper, we take a look into the current research on virtual factories and propose a new approach to improve interoperability through the integration of different proprietary, legacy and existing solutions. Interoperability as technical implementation finally supports collaboration among business partners for forming virtual factories.

Keywords: Collaboration, Interoperability, Virtual Factory, Virtual Manufacturing.

1 Introduction

One of the most important and visible trends in recent years for the manufacturing industry is towards the use of ICT to enable intelligent manufacturing [1] [5]. ICT enabled intelligent manufacturing has been identified as a key aspect in supporting the European manufacturing industry in the challenging transition from post-crisis recovery to European STEEP (Social, Technological, Economic, Environmental and Political) sustainability and regain competitive advantage in the global market competition [2]. ICT (and especially intelligent manufacturing) in this context is not only important for design, production, testing, distribution and recycling, but it is also crucial in supporting changing business trends. Intelligent manufacturing has seen massive adoption in large corporations, promising to close the gap between what companies or factories require and what IT is able to deliver. Many EU initiative programmes and projects, such as FI-PPP[1], FI-WARE[2], FInES[3], FITMAN[4], and

[1] FI-PPP: `https://www.fi-ppp.eu/`
[2] FI-WARE: `http://www.fi-ware.org/`

L.M. Camarinha-Matos and H. Afsarmanesh (Eds.): PRO-VE 2014, IFIP AICT 434, pp. 510–517, 2014.

MSEE[5], industrial advisory groups and research associations are investigating a more flexible IT infrastructure that is able to react to business changes more quickly than the classic monolithic IT manufacturing systems [3] [6].

New ICT technologies and collaboration applications are integrated into traditional manufacturing practices and processes. For example manufacturing 2.0. *Manufacturing 2.0* has been conceptualised as a system that goes beyond the factory floor; it allows paradigms such as “manufacturing as an ecosystem” to emerge. An extension of this paradigm, virtual factories, is one of the central concepts in providing the foundation of future manufacturing. A *virtual factory* allows the amalgamation of manufacturing resources to create timely, demand driven product lines. A virtual factory can also be seen as a specific virtual enterprise which focuses on manufacturing.

Surveys, previous research, and experience shows that traditional manufacturing, supply chain and business systems are primarily used for internal integration. Sometimes this integration is with a fixed number of external partners (for example traditional supply chain management systems). Only very few companies/factories can offer access to their (internal) services to a limited set of customers/suppliers. Even then these integrations are closed environments. It has been increasingly recognized that this is insufficient for the future.

Forming a virtual factory, collaborative partners need to communicate, cooperate, collaborate, or interoperate with others. These partners who can be located anywhere, with day to day collaboration coordinated over the Internet. Interoperability is essential to go beyond the small sets of limited interoperability to a dynamic environment with cost-effective, efficient and deep integration between multiple partners. This integration enables these partners to share information and services as well as to form collaborative processes.

In this paper, we look at how to use ICT to facilitate companies, organisations, and factories in interacting with each other to form supply chains and business ecosystems. More specifically, we look at the role of semantic discovery and interoperability in facilitating virtual factories, a key aspect of future of manufacturing.

The paper first looks at the technical challenges in manufacturing interoperability. Next, related issues to manufacturing interoperability are discussed. We provide the architecture of a manufacturing interoperability platform. Finally, the paper reviews related works and concludes with a future research direction.

2 Interoperability Issues and Enablement

The increased reusability of manufacturing systems leads towards globally interoperable factories. These are then able to provide services and develop products anytime and anywhere, independent of the technologies, culture or language in use at

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[3] FInES: `http://www.fines-cluster.eu/`
[4] FITMAN: `http://www.fitman-fi.eu/`
[5] MSEE: `http://www.msee-ip.eu/`

the different production sites [4]. Real-world virtual factories combine the resources of pre-existing organisations. Those resources are generally supported by existing legacy systems that cannot be changed for the purpose of the creation of a virtual factory. This means that an interoperability platform is a hard requirement for realising virtual factories. The interoperability platform further enables collaboration.

In the "factories of the future roadmap" [2] the European Commission sets out its strategy on the future of manufacturing. We have extracted a number of interoperability issues that have been identified in this document. These issues form the focus of this paper. The first issue is the need to realise a supporting infrastructure for manufacturing business Webs (MBW). Nowadays the Internet is a major driver in collaboration with very significantly reduced costs. The expectation is that collaborative supply processes are location independent, and work in cloud-like ways. The end users of the supply network perform end-to-end manufacturing services orchestration: covering activities of customer collaboration, collaborative service management, and collaborative manufacturing.

Second, to support rapidly evolving virtual factories it is needed to build commonly-used IT backend systems that form the backbone infrastructure for these factories. Such systems facilitate holistic representation, monitoring, and management of future (virtual) factories. A critical enabler of the implementation of a backend system of virtual factories is an integrated scalable and semantic model of manufacturing.

Third, enterprises are increasingly facing frequent design changes. It is essential for European manufacturing to have a high degree of reactivity in rapidly delivering new products and services based upon design changes. In this paper we look at how to increase this reactivity. This is in contrast to traditional research on supporting enterprise integration that focuses on supply chain aspects. To enable rapid change in the setup of virtual factories, potentially interrupting a long life cycle, a holistic approach is needed. A core aspect of the approach is an integrated vertical view on interoperation: not only the data level interoperation, but also service level or even process level interoperation.

To support the above mentioned requirements, a platform has to support interoperability on different inter-connected levels, namely a data/information level, a service level, and a process level.

- The *data/information interoperation level* is related to sharing and exchange of different data, documents, messages and content between different collaborating enterprises from different factory data resources. At this level, the data format, the semantics of contents and documents' structure are important for cross-enterprise collaboration.
- The *service interoperation level* is providing the capability to discover, aggregate, orchestrate and execute various services that have been independently designed and implemented. At service level, interoperability supports transparent composition and mediation among specified services in a cloud environment.
- The goal of the *process interoperation level* is to integrate internal processes of an organisation with the partners' processes to generate cross-organisational business processes.

Table 1 shows each level of interoperation and its enablement.

Table 1. Interoperation and Its Enablement

Interoperation Level	Interoperation Enablement	Examples
Data/information interoperation level	• Building an ontology or ontological models is a common solution to support interoperability.	MSE (Manufacturing System Engineering) ontology [14]; MASON (Manufacturing's Semantic Ontology) [15]
	• Building common virtual factory data model (VFDM) that consider as a shared meta-language providing a common definition of the content and intent of data within a virtual factory ecosystem.	Some existing work includes EU FP7 VFF (Virtual Factory Framework) project, a virtual factory data model is provided in [7] [18].

Service interoperation level	• Transforming manufacturing asset services
	• Specifying manufacturing asset services
	  ○ Manufacturing asset service specification language
	• Classifying manufacturing asset services
	  ○ Manufacturing asset services annotation
	  ○ Manufacturing asset services clustering
	• Marching and discovery manufacturing asset services
	• Manufacturing asset service composition
		Previous EU projects (e.g. SOA4All, FAST, ServFace, ATHENA, COIN, and COMMIUS) have provided frameworks for business service discovery relying on lightweight semantics; end-user dynamic service composition based semantic mediation and easy to use tools; and/or service composition or orchestration of annotated services to build interactive service-based applications. There are existing technologies and knowledge fragments that can function to inspire and inform our research.

Process interoperation level	Process level interoperation defines synchronisation steps and messages and defines coordination and collaboration mechanisms for collaborative processes.	The Process Specification Language (PSL) standard [13] specified a general ontology for manufacturing processes to exchange process information and knowledge. ANSI/ISA-95 [14] is another international standard, which provide a consistent terminology and information models as well as consistent operation models.

3 Architecture of Manufacturing Interoperable Platform

Figure 1 provides an architectural overview of the interoperability platform. The overall architecture can be structured in to four parts: the repository parts (the low three repositories), sematic supporting part (the middle part), interoperability parts (the top three blocks), and manufacturing standards (the right part).

The bottom part of the architecture provides related manufacturing resources. The *data repository/resources* represent manufacturing data resources, data from assets, machines, sensors, objectives, and workers. The *manufacturing asset service repository/resource* denotes manufacturing related assets and services resources. The *collaboration process repository* stores collaboration capabilities in a business process model format.

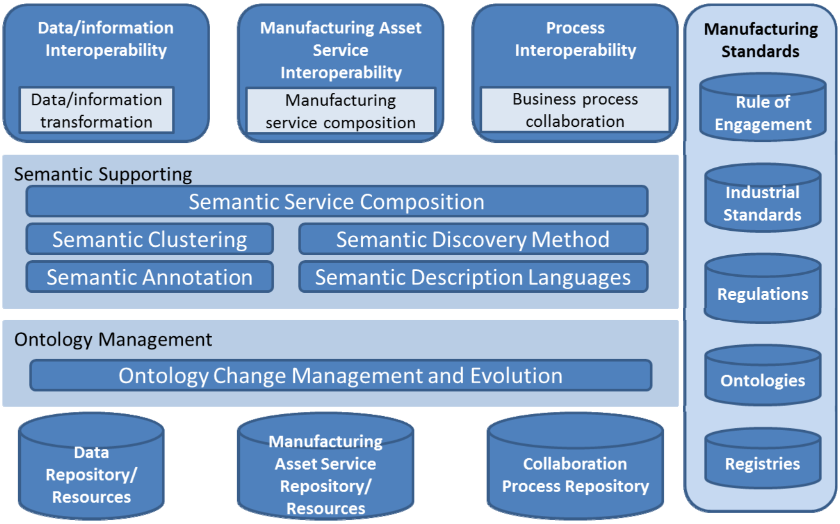

Fig. 1. Architecture of the Manufacturing Interoperability Platform

The middle part of the architecture provides semantic supports. All potential manufacturing related data, assets, services and collaboration processes need to be annotated using suitable methods. The *semantic annotation* provides a way to interpret the meaning of data, information or knowledge, which deals with data/information integration and consistency issues. Annotated data, information, or knowledge is foundation of supporting cooperation, collaboration and knowledge and information sharing around a virtual factory. The different *semantic description languages* describe both tangible and intangible assets of manufacturing services and manufacturing collaborative processes. The semantic description languages may comply with base upon existing languages, such as USDL (Unified Service Description Language). The *semantic discovery methods* contain a board collection of existing work on the dynamic discovery of semantically annotated manufacturing assets and services as well as collaborative processes.

The top part of the architecture supports interoperability. The *data/information interoperability* helps data/information transformation, which define the ability of sharing, aggregating or synchronising data or information across different partners within a virtual factory. The *manufacturing asset service interoperability* assists as service brokerage functionality to wrap service bundles or value-added services. The *process interoperability* brings collaboration capabilities within a virtual factory and deal with coordinating business processes.

The manufacturing standards part allows transforming textual rule of engagement, regulations of different countries, and industrial standards into computer understandable knowledge. This can then be used to ensure that new forming manufacturing processes or services comply with existing rules.

4 Related Work

Previous EU projects SOA4All, ATHENA, Super, and COMMIUS have discovered semantic interoperability which addresses standards based approaches, semantic technologies, architectures and frameworks, business vocabularies, modelling languages and methodologies. The above mentioned projects are not specific for manufacturing domain. Although the many design principles are adoptable, there are many specific issues for implementing interoperability in manufacturing domain. For example, service specification languages are not designed for manufacturing services. Manufacturing assets could be both tangible and intangible assets. To transfer different manufacturing assets into manufacturing services is certainly new for dealing with interoperability of virtual factory. Further manufacturing service clustering and discover methods are certainly different with general service clustering and discovery methods, a deep analysis is needed of characteristics of manufacturing services, which is critical for clustering services and optimising the service discovery process.

EU projects such as VFF, FITMan and MSEE are in the domain of virtual factories. There are still differences with our research perspectives though. None of these projects completely addresses end-user aspects, or setting up a useable BPaaS. Our work [16] on the area of interoperative end-user process modelling for process collaborative manufacturing and BPaaS (Business Process as a Service) [15] can certainly contribute to the new approach to support interoperability.

Paper [19] describes the development of a virtual factory application based on multi-touch interaction, high resolution projection technology and industry standards like X3D. Ding, *et al.* introduce how to using 3D technique to design and simulation of virtual factory layout [20]. Paper [21] presents a structure and architecture of an integrated simulation method (ISM) to meet the requirements of virtual factory engineering (VFE) which combine CAD, VR and discrete event simulation techniques. Above mentioned ontologies can be used for supporting our vertical interoperability of virtual factories.

5 Conclusion

In this paper we discussed what is needed to provide interoperability in virtual factories. We identifie three different levels of interoperability, i.e. data/information level, service level, and process level. For each level, the potential issues and applicable technologies were analyzed and specified. We also provided an overall architecture for implementing such interoperability in the domain of virtual factories. The interoperability of the three distinguishing levels is aligned with the concept of service-orientation. Core scientific challenges remain on the semantic level specification and integrating three-level interoperability as one.

Acknowledgments. This work is made possible by the support of the Natural Science Foundation of China (NSFC) under Grant No.61150110484, ESSENTIAL: Enterprise Service deSign based on ExistiNg software Architectural knowLedge, the National Basic Research Program of China under Grant No. 2014CB340404, and FIF Strengthening Service Computing Research in Bournemouth University, UK.

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