Bringing Cloud-based Rapid Elastic Manufacturing to Reality with CREMA

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ABSTRACT: *In order to meet the demands of today's manufacturing industry, ICT systems need to be able to support highly flexible and scalable inter-organisational manufacturing processes. One recent approach to achieve this is to bring forward well-known principles from the field of Cloud Computing to the manufacturing domain, thus achieving Cloud Manufacturing. To realise this concept, it is necessary (i) to allow leasing and releasing of manufacturing assets in an on-demand, utility-like fashion, (ii) to facilitate rapid elasticity through scaling leased assets up and down, if needed, and (iii) to enable pay-per-use through metered service. While the basic principles of Cloud Manufacturing are self-evident, there is a lack of holistic frameworks providing the underlying basic functionalities. Therefore, it is the goal of the EU H2020 Research and Innovation Action CREMA (Cloud-based Rapid Elastic Manufacturing) to provide exactly such a holistic framework.*

Within this paper, we will present the basic conceptual approach as well as some preliminary results of CREMA.

KEYWORDS: *Cloud Manufacturing, Cloud Computing, Industry 4.0*

1. Introduction

Due to the proliferation of ICT technologies, the manufacturing industry is currently undergoing substantial transformations not only in terms of hardware, but also in terms of Cyber-Physical Production Systems (CPPS), and the software and services used within production environments. In parallel, the manufacturing processes of the future are changing and need to be highly flexible and dynamic in order to satisfy customer demands for, e.g., large series production, mass customisation, or changing orders [MAT 13] [ZUE 10]. In order to keep pace with the needs of the manufacturing industry of the future, companies need to be able to flexibly react to these demands and to offer production capacities in a rapid way [SCH 12] [TAI 12].

To achieve this, one approach is to port successful concepts from the field of Everything-as-a-Service (XaaS) and Cloud Computing to the manufacturing domain:

- Leasing and releasing manufacturing assets in an on-demand, utility-like fashion,
- Rapid elasticity through scaling leased assets up and down, if necessary, and
- Pay-per-use through metered service.

By applying these principles, *Cloud Manufacturing* can move manufacturing processes from production-oriented to service-oriented networks by modelling single manufacturing assets as services in a similar way as Software-as-a-Service (SaaS) or Platform-as-a-Service (PaaS) solutions. By modelling all process steps and manufacturing assets as services, it is possible to realise cross-organisational process orchestrations and integrate distributed resources and ultimately manufacture products more efficiently [XU 12].

While the theoretical foundations for Cloud Manufacturing are manifest, there is a lack of holistic software frameworks in this area [SCH 14]. The goal of the EU H2020 RIA CREMA is to change this: By applying Cloud technologies, the CREMA framework is able to support very large process landscapes, thus bringing together potentially hundreds of companies in vast manufacturing networks. These networks are established in an ad hoc manner based on manufacturing processes, i.e., business process instances. Processes describe the sequence of tasks needed to achieve a particular goal (i.e., the product to be manufactured) and also which parties are responsible for delivering the tasks. Processes may be loosely or tightly coupled, i.e., it is possible to tightly specify in advance which suppliers or contributors are needed. However, CREMA also allows replacing single process stakeholders during manufacturing time, if process tasks are loosely coupled. New stakeholders might be selected based on different constraints, e.g., cost, deadlines, or trust. While CREMA supports large process networks, the single stakeholders are only supplied with exactly the process information they need. The ultimate goal is to provide stakeholders with a view on cross-border, inter-organisational processes as if the complete process was running on a single shop floor.

In this paper, we will provide more detailed information about the manufacturing process lifecycle support for process design, implementation, execution, monitoring, controlling, and optimisation in the CREMA framework.

2. CREMA Framework Overview and Process Lifecycle

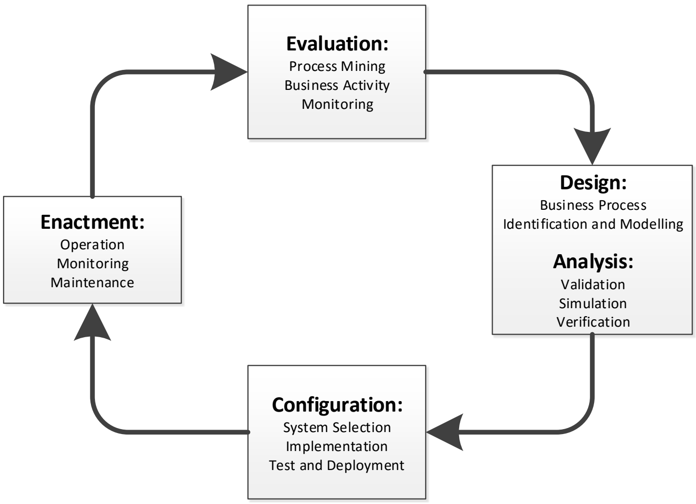

Figure 1. *Process lifecycle – adapted from [WES 12]*

In order to provide the envisioned Cloud Manufacturing functionalities, a software framework needs to provide holistic support for all phases of the manufacturing process lifecycle. Figure 1 shows a typical business process lifecycle, which provides the basic outline for process support within the CREMA software framework. As it can be seen, there are four major phases [WES 12]:

1. *Design & Analysis* describes design time activities, e.g., modelling a new manufacturing process model from scratch, or adapting an existing one.
2. *Configuration* covers the implementation of the process by adding technical information to the process model.
3. *Enactment* is the actual execution of the manufacturing process instances, both in the real world (e.g., on the shop floor), and in the software framework.
4. *Evaluation* describes the analysis of process enactments, both during the runtime of a process instance and afterwards, e.g., by evaluating execution logs. This information flows back into *Design & Analysis* in order to improve process models and subsequently process instances.

In order to support cross-organisational manufacturing processes, the CREMA software framework offers the *Cloud Manufacturing Process and Optimisation* software package. We will discuss this package in the next subsection. Afterwards, we will introduce the data integration layer of CREMA, i.e., the *Manufacturing*

Virtualisation & Interoperability package, which provides important helper functionalities.

2.1. Cloud Manufacturing Process and Optimisation Package

The CREMA Cloud Manufacturing Process and Optimisation package facilitates manufacturing processes both in the real world and in their virtualised representation in ICT. The package offers the functionalities to design and enact manufacturing processes, lease and release manufacturing services, and optimise processes both during design time and runtime. To design and adapt process models and process instances in a plug-and-play fashion, CREMA offers a graphical process editor. One particular functionality of the process editor is the possibility to integrate virtualised assets and services (see Section 2.2.) into process models. Process models may either be *generic*, meaning that only the abstract services needed to manufacture a particular product will be defined, but not the actual suppliers of such a service. The selection of a particular service provider would then happen immediately before or even during process runtime. Alternatively, process designers may also integrate services from *concrete* suppliers in their processes.

Once a process model has been defined, it can be enacted in terms of single process instances. Enacting process instances covers the core elements of Cloud Manufacturing, i.e., the leasing and releasing of manufacturing assets in an on-demand, utility-like fashion, rapid elasticity through scaling these assets up and down if needed, and pay-per-use through metered service.

During process enactment, it is necessary to check if real-world manufacturing assets are actually available at a particular point of time. For this, CREMA offers the *On-Demand Service Leasing and Releasing* component, which carries out automated Cloud Manufacturing procurement, enabling dynamic exchange of manufacturing assets and the relocation of process steps, if needed. All this is done both in the real world and on the virtualised level. In order to be able to support very large process landscapes, it is necessary to provide the means to dynamically scale the underlying computational resources up or down. Accordingly, CREMA provides the means to enact manufacturing processes on Cloud-based computational resources. The resources are automatically scaled up and down depending on the current workload.

For process optimisation during runtime, the monitored service execution data streams are pre-filtered by means of stream reasoning and complex event processing. This is followed by a KPI-driven process data analytics integrated with semantic service selection and composition replanning.

2.2. *Manufacturing Virtualisation & Interoperability Package*

The CREMA Manufacturing Virtualisation & Interoperability package allows to virtualise real-world manufacturing assets and services. This is a prerequisite to use such entities in manufacturing processes, i.e., to have a software representation of the real-world entity. To achieve virtualisation, two different aspects need to be taken into account: First, it is necessary to provide service descriptions, which do not only specify the functionalities and capabilities of a real-world entity, but also the technical information needed to directly integrate the assets into processes, including the means to monitor processes, assets, and services. In CREMA, data from arbitrary sources may be integrated, including, but not limited to data from Cyber-Physical Systems (CPS), smart objects, RFID, and wireless sensor networks.

The CREMA Manufacturing Virtualisation & Interoperability package provides process designers with tools to build the needed software services. The process of building, developing, and describing these services is called *virtualisation*, since a virtualised service abstracts from a real-world entity in a similar way a Virtual Machine in Cloud Computing abstracts from a Physical Machine. Through these virtualised services, it is possible to build manufacturing processes in a plug-and-play fashion, as described in Section 2.1. To decrease implementation efforts, CREMA offers so-called *Proxy Service Wrappers*, which include different interfaces for service monitoring, service availability checks, or simply starting and invoking services. Thus, service developers and process designers do not have to take care of these basic functionalities by themselves.

Second, data comes in heterogeneous formats. Especially sensor technology is characterised by a high degree of heterogeneity, as is reflected in different hardware platforms employed, different interfaces, and different communication protocols. This complicates the access to sensor data and poses substantial overhead to service developers and process designers, since specific implementations are required for each sensor type. In order to be able to integrate arbitrary data sources into manufacturing processes, it is therefore necessary to implement tools to connect to these data sources and wrap the data, so that it can be offered in a unified format.

Accordingly, the CREMA Manufacturing Virtualisation & Interoperability package offers a *Sensor Abstraction Layer*, which provides an intermediary layer, i.e., middleware, between various real-time data capturing systems and other components that require access to the corresponding data. The component implements a common interface which permits the acquisition of data from technically heterogeneous sensor systems. In order to facilitate flexibility and extensibility, the Sensor Abstraction Layer makes use of a wrapper concept. These wrappers translate method calls into specific function calls for the respective data source. In addition, a wrapper performs a translation/mapping of raw data from specific data sources into a harmonised, generic output format. The Sensor Abstraction Layer also allows to access aggregated data.

3. Conclusions

While Cloud Manufacturing has been discussed as a conceptual approach to realise agile and rapidly changing manufacturing processes, there is still a lack of concrete frameworks supporting it. Hence, within this paper, we discussed the CREMA software framework for Cloud Manufacturing, with a special focus on its process support capabilities. At the time of writing this paper, the foundations for the implementation of all of the described functionalities have been provided. Also, some first implementation results are available.

Because of space constraints, it was only possible to provide a very brief overview of the CREMA software framework in this paper. In the future, we will provide more detailed information and especially discuss optimisation approaches for manufacturing processes. Furthermore, we will present details about the implemented concepts for sensor abstraction and service virtualisation.

4. References

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Acknowledgements

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[1] http://www.crema-project.eu/