A FRONT-END SYSTEM TO SUPPORT CLOUD-BASED MANUFACTURING OF CUSTOMIZED PRODUCTS

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ABSTRACT

In today's global market, customized products are amongst an important means to address diverse customer demand and in achieving a unique competitive advantage. Key enablers of this approach are existing product configuration and supporting IT-based manufacturing systems. As a proposed advancement, it considered that the development of a front-end system with a next level of integration to a cloud-based manufacturing infrastructure is able to better support the specification and on-demand manufacture of customized products. In this paper, a new paradigm of Manufacturing-as-a-Service (MaaS) environment is introduced and highlights the current research challenges in the configuration of customizable products. Furthermore, the latest development of the front-end system is reported with a view towards further work in the research.

KEYWORDS
Product customization, configurator, cloud manufacturing

1 INTRODUCTION

For many manufacturing enterprises, providing customized products has emerged as an important manufacturing strategy within a global and competitive environment (Da Silveria et al. 2001). It is considered that the key to achieving a successful customized product strategy must address multiple aspects from product design and configuration support to production and supply chain activities (Steger-Jensen and Svensson 2004, Blecker and Friedrich 2007). In this approach, the role of information technologies (IT) and supporting systems have become key enablers in supporting a customization environment. Whilst the ability to offer customized goods have been demonstrated in today's market (e.g. Dell Computers), increasingly complex engineered, customizable products present new technical challenges for both the customers who specify them and the multiple vendors who manufacture and supply them. The underlying requirement is on a flexible IT infrastructure that can dynamically configure and coordinate the supply chain in agile response from diverse and evolving customer requirements. In this context of customized production, supporting IT systems must effectively manage the specification, manufacture and supply chain phases involved in the delivery of sophisticated and highly-customizable products.

With this in mind, a new paradigm of Manufacturing-as-a-Service (MaaS) environment, based on cloud-computing concepts, has been proposed to better support the on-demand manufacturing of customized products (Meier et al. 2010). This relates to current work being undertaken in the FP7 project ManuCloud to develop a marketplace for virtualized manufacturing services and to achieve a next level of

integration of manufacturing networks based on the dynamic interconnection of multiple factories. In doing so, it is envisaged that the small series production of complex customizable products can be implemented by small-medium enterprises (SMEs) and offer value to customers. This is in reference to the initial application context of developing highly customizable organic photovoltaic (PV) and lighting (organic light emitting diodes (OLED)) solutions.

Supporting the objectives of the MaaS environment is the development of a front-end system, which will enable the specification of complex customizable products from manufacturing services provided by physically distributed production sites. The focus of this paper considers the research challenges at the front-end perspective in configuring customizable products and reports on the latest development of the proposed front-end system.

2 STATE-OF-THE-ART-REVIEW

Whilst many other technical and organizational factors are critical in supporting the customization of products, this review focuses on the field of product configuration and its current research issues. On the specification of customized products, development of product configuration systems has enabled companies to achieve a quick response to individual customer requirements (Salvador and Forza, 2004). Due to this, much research activity has been dedicated in the technical area of product modeling and methods to describe product information necessary for the configuration task. This has involved various approaches by different authors over the years to define a generic product model and the representation of configuration knowledge (Jiao et al 2000; Zhang et al 2005; Felfernig et al 2007; Haug 2010). The related tasks of acquiring and maintaining configuration data models are core knowledge management issues, which arise from the dynamic nature of customizable products. For instance, an adaptable product configuration system was developed by Chen and Wang (2009) based on an artificial neural network (ANN) approach to address these issues.

In a wider context, other research efforts have been to address the issues of product configuration with production and supply chain integration. The distributed configuration of products and services, based on multiple suppliers, was investigated in a previous study by Ardissono et al (2003). Steger-Jensen and Svensson (2004) proposed the integration of product configuration with an advanced planning and scheduling (APS) system to better support order promise and fulfillment within customized manufacturing. Furthermore, a recent study by Zhang et al (2010) presented an integrated prototype system to enable process plan generation and production execution from the configuration of a basic industrial product. A key limitation of the system concerned the lack of support for both complex products and new customized product designs.

With recent developments in information and communication technologies, these present promising new approaches to address customized products requirements within production and the supply chain. For example, the application of service-oriented architecture (SOA) was discussed by Dietrich et al (2007) and implemented for product customization in the shoe industry. The research demonstrated the feasibility of a SOA-based approach to support the dynamic configuration and coordination for a distributed supply chain network within a customization environment.

3 RESEARCH CHALLENGES

The definition of product specifications for customized production presents several technical challenges to be resolved across multiple tiers of the manufacturing supply chain. From a specification view, the majority of existing product configurators implement a unidirectional approach, in which the degree of customization freedom is limited to the design solution space defined by the manufacturer. Therefore, customized products can only be specified by the customer according to matching manufacturing capabilities. A consequence is that new design specifications or requests cannot be supported in this existing approach.

Another issue is introduced when the manufacturing capability is updated, which must be reflected in the design solution space to be able to offer new configurable products for customization. As the design

solution space is generally defined as a product model, this equates to the issue of modeling and maintaining dynamic product data in a product customization environment. This task becomes even more complex in a manufacturing network, when multiple distributed manufacturers are involved in the development of a customizable product.

Furthermore, there are technical challenges in providing a seamless integration from product configuration to the dynamic reconfiguration of the manufacturing supply chain to support downstream customized production. Overall, it is proposed that these issues can be addressed by enabling a bidirectional exchange between the definition of product specifications that can be configured and available manufacturing capabilities. The requirement is on the efficient definition of product specifications at the front-end with effective manufacturing supply chain integration and management of product information in the customization environment.

4 PROPOSED FRONT-END SYSTEM

In towards a more flexible manufacturing network based on the MaaS paradigm, a front-end system is proposed to better support the specification and manufacture of customized products. The proposed conceptual architecture of the front-end system components and its interface with the MaaS infrastructure is illustrated Figure 1. At the front-end layer, this consists of a Customized Product Advisory System (CPAS) with the provision of user interfaces for Infrastructure Management and supporting back-end manufacturing components. Furthermore, the front-end components are deployed as part of an integrated web-based portal to support collaborative development.

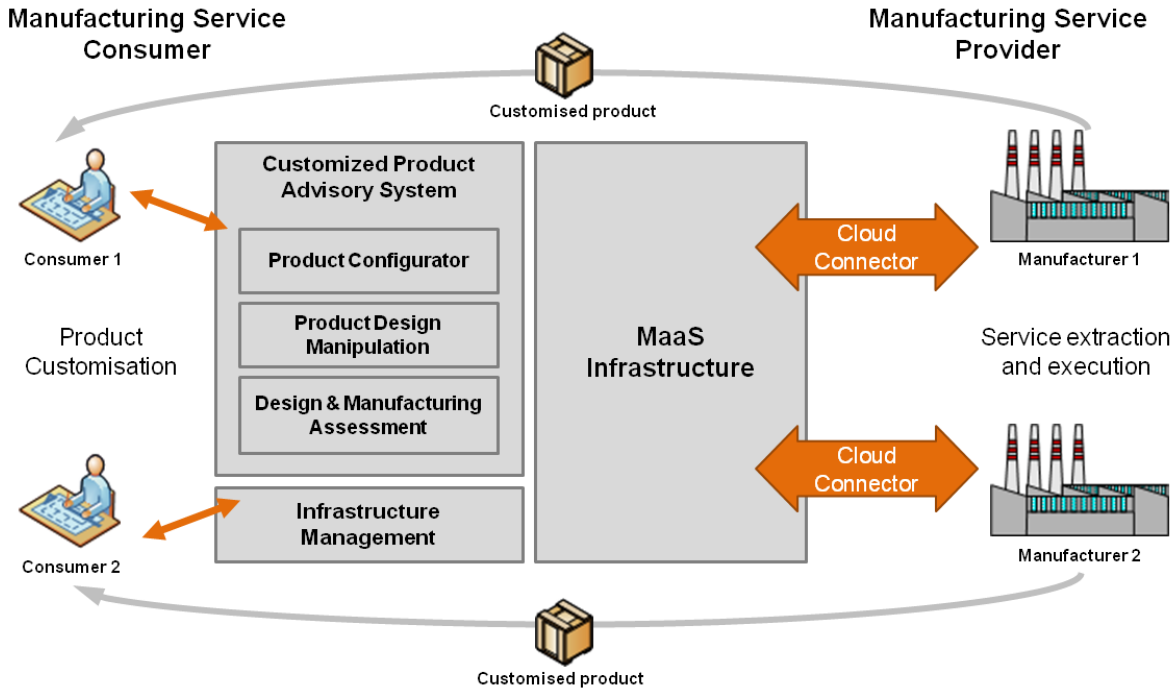

Figure 1: Conceptual architecture of Front-end system and MaaS Infrastructure

Based on the conceptual architecture, two main types of user who will interact with the front-end system are identified: manufacturing service consumer (e.g. a product designer) and manufacturing service provider (e.g. lighting product manufacturer). The consumer use-case relates to the front-end CPAS component as shown in Figure 1, which is further composed of the following three main pluggable subsystems:

- ***Product Configurator (PC):*** provides the overall functionality to configure and specify customizable products offered within the manufacturing cloud, according to the requirements of the consumer.
- ***Product Design Manipulation System (PDMS):*** provides the capability for product visualization and provides support for new customized product design,
- ***Design and Manufacturing Advisory System (DMAS):*** provides the capability for preliminary design and manufacturing assessment of new product design specifications.

The planned front-end CPAS is an integrated system which combines the functionalities of the three highlighted subsystems with a common graphical user interface and access to required data repositories within the MaaS infrastructure. In the envisaged application scenario, a product designer can browse available lighting products and configure to their specific needs using the PC. If the desired product cannot be currently configured due to limited degrees of customization freedom, the PDMS is intended to support the definition of new custom product design. This can then be initially assessed for design and manufacturability by the DMAS based on real-time integration from the MaaS infrastructure. Lastly, the product specification output of the front-end CPAS can be submitted to the corresponding manufacturers/suppliers to receive further feedback on the desired customized product.

For the second use-case, the user interfaces for the MaaS infrastructure management and other back-end manufacturing components are intended to enable the dynamic configuration of virtual production networks. This will be used by manufacturers to define the specific manufacturing services (e.g. offer an assembly service by the lighting product manufacturer) required to produce a customized product or sub-components required within a virtual value chain.

5 FRONT-END APPROACH AND WORK IN PROGRESS

The front-end system integration to the MaaS environment is established on the proposed core concept of a Manufacturing Service Description Language (MSDL), which provides the means of communication between the cloud-based components. The underlying MSDL provides a formal semantic description of both production and product-related information to enable the specification and manufacture of the customized products.

For the CPAS front-end, the configuration of customized products is based on the product-related aspect of the MSDL. This corresponds to a product data model that can be interpreted by the product configurator in the form of a product template document, which contains the relevant information (product attributes, constraints etc) to enable product configuration. The working principle is that a product template is configured to user requirements and is then processed in the MaaS environment to execute the manufacture of the customized product.

In this proposed approach, the front-end product model is defined as an integrated aspect of the manufacturing service descriptions. As the manufacturing service descriptions are updated by manufacturers to reflect new production capabilities or resources, the relevant changes can be easily propagated through the MaaS environment towards the product configurator and therefore can offer new product customization freedom to the customer. In other words, the integration allows a two-way exchange between the design solution space and the available manufacturing capability to produce a customized product. As a result, one of the goals is to reduce some of the issues involved in developing and maintaining product models used for product configuration and to provide further integration to the manufacturing supply chain.

Following an initial requirements engineering phase, the current work is focused on the specification, architecture development of the CPAS product configurator component. An important aspect of this work is the definition of the interface requirements with the associated back-end components. To this end, the ongoing objective is to investigate the acquisition and maintenance of the configuration-oriented product data model from the manufacturing service descriptions extracted from the MaaS environment, which is illustrated in Figure 2.

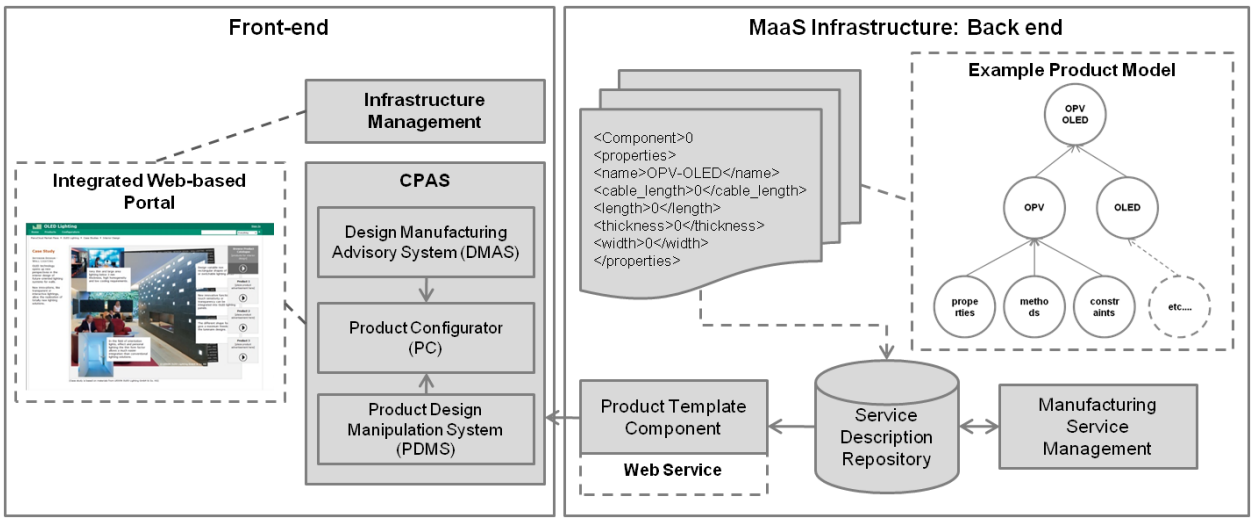

Figure 2: Front-end CPAS and Back-end system interaction

The basic structure of manufacturing service descriptions and corresponding front-end product model was implemented with a graph-based database as an initial approach, which provides a graph tree representation composed of nodes and edges. For the front-end product model, a basic product graphic tree was created to model all the relevant product data (attributes, values, constraints, rules, methods etc) for the configuration of example OPV/OLED product. A Product Template Component is to be executed as a web service to extract the configuration-oriented data model from manufacturing the service descriptions and define it as a Product Template. At present, extensible markup language (XML) technology is being investigated as a means to represent the data model and for the exchange of product information between the back-end and front-end CPAS.

In concurrent to the modeling and development work, a technology evaluation and selection has been completed regarding the integrated web portal at the front-end, based on important criteria including the runtime environment and user interface. Furthermore, an investigation has been initiated in evaluating concepts and technologies for product configuration and other specified CPAS subsystems.

6 CONCLUSION AND OUTLOOK

This paper has provided an overview of a proposed front-end system that aims to support the specification and manufacture of customized products based on the development of a new flexible cloud-based production IT infrastructure. The work presented here reports the initial approach and development of the front-end CPAS to address the some of the challenges involved from a product configuration perspective. A key advancement is the front-end system integration with production-IT and supply chain management. This is to enable a bidirectional exchange between customized product specification and the actual manufacturing capabilities distributed within the MaaS infrastructure, which would support the evolution of existing manufacturing system significantly.

As the front-end system is at an early stage of development, there remains much work to be done in the context of system specification, architecture and technology evaluation. The outlook in this research will be to begin development for a working prototype front-end CPAS, which can be integrated to the MaaS environment to realize the customization of complex engineered products and management of manufacturing services.

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