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A Virtual Factory Data Model as a support tool for the simulation of manufacturing systems

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Abstract

The design of a manufacturing systems is a complex and critical activity entailing decisions with an impact on a long time horizon and a major commitment of financial resources. Indeed, the modelling, simulation and evaluation of manufacturing systems are relevant activities both in the design and the operational phases of a factory. This paper grounds on the results of the Virtual Factory Framework (VFF) Project and addresses the use of an ontology based model of a production system to support the construction of a performance evaluation model.

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Keywords: Data model; Ontology; Performance evaluation; Finite state machine; Production systems; Cyber-physical systems;

1. Introduction

The design of a production system involves various and different business processes, as well as different classes of analysis, since it entails decisions with a medium to long time horizon impact and also having a significant influence on the financial commitment of an industrial company [1]. Complex decisions ask for a consistent support through digital tools implementing design methodologies and/or providing an assessment of key performance indicators to be taken into consideration. However, when a large set of digital tools are used, it is also difficult to guarantee an effective interoperability among them, thus reducing the effectiveness of the solution. Moreover, the current standard for design tools asks for a virtual representation of the production system that also needs to be continuously updated during both the design and operational/execution phase, thus guaranteeing an overall coherence of the obtained results. The described requirements call for a common framework to support the interoperability and exploiting the cooperation of different actors with different competences and expertise in the design and management of a factory.

Semantic Web technologies, and in particular the Web Ontology Language (OWL) [2], have been used as an enabler for the interoperability between systems using different data structures and heterogeneous technologies. The use of Semantic Web technologies in the context of factories and manufacturing systems has been addressed in the European projects LinkedDesign [3] and Virtual Factory Framework [4]. In particular, the Virtual Factory Framework (VFF) is an integrated collaborative virtual environment aimed at facilitating the sharing of resources, manufacturing information and knowledge, while supporting the design and management of all the factory entities along the phases of the their lifecycles. The VFF architecture is based on a Virtual Factory Data Model (VFDM), i.e. a coherent, standard, extensible, and common data model for the representation of factory objects related to production systems, resources, processes and products [5]. Starting from the preliminary results reported in previous works [6,7], this paper focuses on providing a complete data model for production systems and their resources by linking the

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static characterization of the production resources with the results of performance evaluation activities in terms of a performance history that can be as detailed as needed.

2. Structuring production systems' data

A comprehensive representation of a production system needs to consider several aspects ranging from tangible (e.g. machine tools, part types to be produced, etc.) to intangible (e.g. process plans, production logics, etc.), from geometric (e.g. placement of production resources in the factory layout) to organizational (e.g. roles of the involved actors), from static (e.g. nominal power consumption of a machine tool) to dynamic (e.g. evolution of the states of a resource). From the other side, several scientific contributions and technical standards have been developed in the manufacturing system area, each of them focusing on a set of aspects of the overall problem.

ANSI/ISA-95 [8] is an international standard for developing an automated interface between enterprise and control systems addressing all industries and all sorts of processes (batch processes, continuous and repetitive processes, etc.). ANSI/ISA-95 standard enables the user to freely define customized properties that can be attached to most of the classes representing processes and production resources. However, such flexibility can be a drawback from the interoperability point of view, furthermore, it does not provide a complete support for modeling physical data such as the placement and shape representation of objects.

A different approach is offered by the Process Specification Language (PSL) standard [9], an ontology to formally describe a process and its characteristics. This standard is however scarcely adopted in the industrial domain, probably due the perceived complexity at the enterprise level.

The Industry Foundation Classes (IFC) standard by buildingSMART [10], partially based on STEP standard [11], was mainly conceived for Architectural Engineering Construction (AEC) industry domains (e.g. Building Controls, Structural elements, Structural Analysis, etc.) and provides most of the definitions needed to represent tangible elements of a manufacturing systems. Furthermore, generic definitions of intangible characteristics (e.g. processes, work plans, etc.) are provided.

Ontologies represent a possible way to generate flexible data model integrating different knowledge domains, enabling knowledge sharing between several applications and a fluent flow of data between different entities [12]. Moreover, ontologies provide methods for integrating fragmented data models into a unique model without losing the notation and style of the individual ones [13]. Various ontologies have been developed in the scope of manufacturing domain. Lin et al. [14] designed a Manufacturing System Engineering (MSE) ontology to provide a common understanding of manufacturing-related terms and to enhance the semantic and reuse of knowledge resources within global extended manufacturing teams. Léger et al. [15] presented a Manufacturing's Semantics Ontology (MASON) that is built upon three main concepts: entities, operations and resources. Similarly, Martin and D'Acunto [16] developed an ontology decomposed into product, process and resource areas.

2.1. Virtual Factory Data Model

The advantages of an ontology-based data modeling were exploited for the development of the Virtual Factory Data Model (VFDM) [5] in the scope of the Virtual Factory Framework. The VFDM aims at formalizing and integrating the concepts of product, process, production resource and building as handled by the digital tools supporting the factory life-cycle phases. Moreover, the VFDM was designed to exploit already existing technical standards and extends their definitions to represent the characteristics of a manufacturing system in terms of the products to be manufactured, the manufacturing process they must undergo and the resources entitled to operate the different manufacturing operations. The current version of VFDM is mainly based on the IFC [10] and STEP-NC [17] standards that were translated into a set of ontologies [18].

The Entities in the IFC standard are mapped to OWL Classes in the VFDM. Most of the classes derived from IFC are specializations of two fundamental classes named IfcTypeObject and IfcObject, both being subclasses of IfcObjectDefinition. The former class is the generalization of any thing or process seen as a type, the latter seen as an occurrence. IfcObject has the following subclasses: IfcProduct, IfcProcess, IfcResource, IfcControl, IfcActor, IfcGroup. IfcProduct represents the occurrence of a generic object that can be related to a geometric or spatial context (e.g. a manufactured products, machine tools, transport systems, etc.). IfcProcess defines a process that can be used to transform an input into output (e.g. an assembly operation, machining operation, etc.). IfcResource represents the information related to resource needed to execute a process. IfcControl is the generalization of the concepts that control or constrain the use of products, processes, or resources. IfcActor defines the actors or human agents that are involved in a project. IfcGroup is the generalization of any group. The subclasses of IfcTypeObject (i.e. IfcTypeProduct, IfcTypeProcess, IfcTypeResource) can be paired with the corresponding subclasses of IfcObject.