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A holonic approach for manufacturing execution system design: An industrial application

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Abstract

In the age of globalisation and virtual enterprises, industrial firms are challenged by a volatile and demanding market as well as an everyday more competitive environment. As a main actor of the enterprise integration, manufacturing control systems should be designed in order to answer these necessities of reactivity and profitability in a flexible way. Holonic manufacturing system (HMS) proposes a structure organized as a loosely coupled network of communicating and cooperating agents to solve this problem. Such approach offers concrete solutions to reconfigurability and evolvability issues of manufacturing control systems.

This paper presents a manufacturing execution system (MES), using the HMS concepts, and illustrates this approach on a real industrial application.[1] Such a structure is based on a typology of manufacturing system elements (products, resources, orders). Roles and behaviours for these manufacturing control elements are proposed. Product holons own reference models of products, for manufacturing execution and quality control. Resources holons are components used as bricks with local intelligent decision-making system embedded. Based on characteristics of the tasks they perform, a specialisation of resource holons is proposed. Specific heuristics are suggested for each class of resource holon. Finally, order holons are related to product demand, manufacturing task and product item. They own models of product item and a time model of the manufacturing task. Mechanisms are proposed to synchronize the execution of manufacturing tasks. These mechanisms guarantee the availability of components and enable to impose time constraints on task scheduling. This MES implements a product-centred approach, as shown by the active and opportunistic behaviour of order holons.

Keywords: Flexible manufacturing systems; Agile control; Agents; Industrial process; Holonic system and heterarchical architectures

1. Introduction

Today's manufacturing systems are challenged by a demanding fast changing environment. Industrial firms have to implement control policies and adapt their manufacturing systems to maximize their productivity, considering also the manufacturing–customer responsiveness as a main issue (McFarlane et al., 2003). Fitting to an ever-changing environment does not only mean that manufacturing systems have to undergo small changes on-the-fly, but it has to have the ability to co-evolve with continuously changing necessities, by way of significant transformations. Thus, besides well-identified characteristics such as reactivity, flexibility and productivity, new requirements such as reconfigurability and evolvability lead to drastically increase the complexity of the (re)design of manufacturing execution systems (MES).

Classical centralized and hierarchical approaches based on time or constraints aggregation allow reaching globally optimal solutions more easily. Nevertheless, such approaches show limitations to solve manufacturing control problems, particularly when the system faces numerous random events. Besides, structurally highly flexible systems, as those required for mass-customisation production,

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are poorly sensitive to minor changes, which are changes with short-term effect. Thus, no optimal solutions are considered acceptable as their results are not far from the optimal solution, and as they do not induce unrealistic resource use (time and effort) to be determined (Gou et al., 1998). This is particularly true within an environment where time constraints are critical, and which undergoes short-term changes.

Mass customisation, small volume/high variety order management and maximisation of the profitability of the firms are long-term challenges that require new approaches. These approaches support the use of cooperative and autonomous unit self-organized in an open structure to offer a very high operational and structural level of flexibility (Chirn and McFarlane, 2000). It implies to use distributed artificial intelligence (multi-agent systems, MAS) to be implemented.

Holonic manufacturing system (HMS) is such an approach which combines the best features of hierarchical and heterarchical organisational structures (McFarlane and Bussmann, 2003). This concept can preserve the stability of hierarchy while providing the dynamic flexibility of heterarchies and offers a suitable background to develop a distributed MES (Valckenaers et al., 2003).

This paper proposes an MES using the HMS concepts and illustrates this approach on an industrial case. The considered manufacturing system produces laminated bullet-proof security glasses ready-to-assemble on vehicles. This type of glass, called transparent armour-plate, is an expensive product and is very sensitive to quality problems. Materials come from high technology industries and the system must provide an accurate environment to minimize the wastes. Design-to-order (DTO), make-to-order (MTO) and assemble-to-order (ATO) management policy are used to manufacture this highly customisable product. The process suffers from a lack of robustness and is subject to numerous random events. Moreover, the firm has a high activity in prototype design. As a result, numerous normal and corrupted flows intermix, due to rejection or reworking. Minimisation of raw material consumption and maximisation of the productivity of each cells are main objectives, considering time constraints as critical. As a consequence, dynamic cooperative and/or competitive lot-sizing and scheduling mechanisms have to be developed. Controlling such a complex system at the execution level requires the coordination of various complex models as well as the integration of this control in an existing control structure (Baïna et al., 2005).

The use of a holonic structure to perform the control of such an industrial manufacturing system makes possible to consider a reality left out by many other approaches: the hierarchical and heterarchical nature of decision-making within manufacturing systems, as well as the physical reality of these systems. PROSA (product, resource, order, staff architecture) is reference architecture for HMS (Valckenaers et al., 1998; Van Brussel et al., 1998). PROSA is based on a typology of the manufacturing system elements: products, resources, orders and specialized decision-making centres (hierarchical and/or functional). It allows identifying and defining the roles and behaviours of the manufacturing control elements.

In this paper, we propose a PROSA-based model for a MES. We describe class models for PROSA holons and dynamic mechanisms to control the execution of manufacturing orders. These mechanisms allow guaranteeing the availability of components required for each order and enable to impose time-limit constraints on task scheduling (Blanc et al., 2006). The proposed HMS is product-centred as the working of the whole system stand on the life-cycle activities of order holons. We also propose a typology of resource holons, based on characteristics of the tasks they perform: supply, transformation, assembly or disassembly. For each type of resource holon, specific heuristics are used to solve the tasks scheduling problem, taking into account the own model of each one.

These mechanisms and algorithms are implemented within a multi-agents system, which supports the development of the manufacturing control system. To evaluate this manufacturing control, the use of discrete-event simulation is proposed as an emulator of the physical system. This proposition makes possible to solve problems of redundancy during the development of manufacturing control. It also permits to reuse objects of the simulation model, and allows some savings in the development effort, as the evaluated MES is the same as the one used in the real context. Finally, this MES has been partially developed and integrated into the management system of the company, as it interfaces the enterprise resource planning (ERP), and the physical system (Baïna and Morel, 2006).

The contribution is organized as follows. In Section 2, the context of the manufacturing control system is described, specific problems related to this control are addressed and a structure to perform the decision-making process, including the holonic approach, is presented. The use of a PROSA-based holonic approach, the definition of holons and the mechanism to perform the manufacturing control are presented in Section 3. Finally, Section 4 applies the proposed manufacturing control system to an industrial case.

2. Manufacturing control

A manufacturing system can be considered as a set of resources used to transform raw material into finished goods in order to satisfy a demand. In a systematic way, it is now usual to structure this system in three subsystems: physical, informational and decisional.

The physical subsystem is composed of the set of physical devices of the manufacturing system: machines, transport devices, workforce. The transformation of raw material into finished goods is the result of successive transformations of single or multiple components into items by way of operations completed by physical devices of the system. These devices may perform three types of