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Reducing myopic behavior in FMS control: A semi-heterarchical simulation–optimization approach

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ABSTRACT

Heterarchical FMS control architectures localize decisional capabilities in each entity, resulting in highly reactive, low complexity control architectures. Unfortunately, these architectures present myopic behavior since decisional entities have limited visibility of other decisional entities' behavior and the alignment of an entity's decision with the system's global objective. In this paper, we propose a semi-heterarchical architecture in which a supervisor tackles different kinds of myopic decisions using simulation–optimization mechanisms and the current conditions of a flexible manufacturing system (FMS). The supervisor uses simulation results to calculate local and global performances and to evolve the solutions proposed by the optimization mechanisms. The approach proposed was configured to control a real assembly cell with highly heterarchical approaches. The completion time variance was used as the performance measure for myopic behavior reduction. The simulation results showed that the semi-heterarchical architecture can reduce myopic behavior whereby it strikes a balance between the ability to react to disturbances and maintaining low complexity, thus making it suitable for production control.

1. Introduction

Flexible manufacturing systems (FMS) were introduced in the eighties to cope with mass customization and to improve responsiveness to market and process variations. Such variations are handled by several types of built-in flexibility, e.g., sequencing, machine routing, product, process, volume, variety [17]. The complexity and uncertainty that FMS control has to deal with, comes from the product, the market, the processes and its own architecture [18].

In an attempt to handle such complexity, control architectures have evolved from centralized rigid architectures to more dynamic, heterarchical ones [66]. The idea is to decentralize the decision-making processes and information, seeking fault-tolerance, scalability, flexibility, adaptability and reactivity [15]. To achieve these characteristics, the control system is decomposed into a modular and self-configurable set of decisional entities [33]. A decisional entity is an autonomous unit able to communicate, to make decisions and to act within a manufacturing scenario [16]. In these "Heterarchical Flexible

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Manufacturing Control Architectures (HFMCA)",[1] cooperative mechanisms emerge among decisional entities, favoring reactivity and adaptability [66].

Several HFMCA have been proposed, particularly based on the agent [2,60] or holonic paradigm [11,64,36]. Nevertheless, despite their claimed benefits, these HFMCA are rarely adopted in industry due to, among other reasons, their unpredictable behavior and the lack of guarantee that a sufficient level of performance can be achieved [44]. The high degree of autonomy, local goal orientation and locally contained information give each decisional entity a myopic view of the entire system. This myopic behavior has been also recognized as a major barrier for the industrial adoption of HFMCA as it not only degrades overall performance, but also makes the system highly unpredictable [66].

There are several approaches to enhance the global performance HFMCA, such as optimization (e.g., heuristic rules, meta-heuristics and exact methods) and simulation methods (discrete-event, agent-based). In HFMCA, optimization can be achieved by either efficient/enhanced coordination mechanisms or by introducing decisional entity specialization, for instance with an optimization algorithm [60]. In turn, simulation has been identified as a key tool to predict the HFMCA global behavior by testing various scenarios, selecting optimal negotiation frameworks and/or predicting abnormal situations or performance degradations, for instance [12,44].

Unfortunately, most of these approaches focus on enhancing global performance but not explicitly tackling myopic behavior. As a result, they prove to be more complex, reducing important characteristics of HFMCA, such as reactivity, distribution, fault-tolerance and flexibility, yielding more hierarchy than heterarchy [33]. The aim of this paper is to propose a HFMCA in which a supervisor hosts simulation–optimization mechanisms to explicitly reduce the impact of myopic decisions. The resulting semi-heterarchical manufacturing control architecture is expected to reduce myopic behavior according to current plant conditions (adaptability) while favoring reactivity and low complexity. These manufacturing control requirements, related to myopic behavior, are understood as follows:

- *Adaptability:* is the capacity of the manufacturing control to respond to continuous and unexpected perturbations, by executing alternative solutions,
- *Reactivity:* is understood as the time required by the manufacturing control to adapt to continuous and unexpected changes,
- *Complexity:* is defined by the FMS components and the inter-relationship between them.

To support and position our approach, a literature review was undertaken to identify several simulation–optimization-based mechanisms that can be used to reduce myopic behavior in manufacturing. A classification according to their impact on the decision-making process and the target FMS control architecture is also proposed.

The remainder of this paper is organized as follows. Section 2 introduces the FMS control problem and presents myopic behavior in FMS control. In Section 3, we identify, review and classify the contributions which focus on simulation–optimization-based approaches to improve global performance in HFMCA. In Section 4, a semi-heterarchical manufacturing control approach based on simulation–optimization mechanisms to tackle myopic decision-making is proposed. In Section 5, three possible instantiations of the proposed architecture resulting from the combination of two highly heterarchical approaches with two heuristic optimization mechanisms and an agent-based simulation model are described. Section 6 presents the target FMS and a description of the experiments, the results and their analysis. Some conclusions and future prospects are offered at the end of the paper.

2. The FMS control problem

An FMS can be roughly defined as a network of machines, connected by a material handling system, working together under computer control [26]. In FMS, control consists in utilizing, three types of flexibilities in real time: sequencing, machine routing and material handling flexibility. Sequencing flexibility should be understood as the absence of constraints specifying the product launching order in the FMS, thus multiple product release sequences may exist. Machine-routing flexibility is the ability to provide alternative machines for the same manufacturing operation. This is one of the most studied types of flexibility. Last, material-handling flexibility refers to the alternative transfer paths allowed by the transportation system that connects the machines.

Based on these flexibilities, the control problem is composed of the following sub-problems: the product release sequencing problem, which deals with the products entry order (and time if release times are considered); the machine-routing problem, which defines the sequence of machines that a product requires to fulfill its operation sequence; and the material-handling problem, which specifies a path that a product can follow to visit the machines in its machine route [25]. Therefore, controlling an FMS requires monitoring and evaluating conditions in real-time, not only to deal with these three sub-problems [13], but also to handle process and market variations, as well as other kinds of perturbations. Consequently, the complexity of controlling an FMS comes from the physical constraints (i.e., processing times, flexibility, limited capacity, etc.) and the managerial policies (i.e., performance measures) taken into account.

[1] Herein after, "Heterarchical Flexible Manufacturing Control Architectures (HFMCA)" denotes flexible manufacturing control architectures characterized by the presence of heterarchical relationships among decisional entities, either purely heterarchical or semi-heterarchical (those including certain hierarchical relationships).