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Handling disruptions in manufacturing systems: An immune perspective

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ABSTRACT

One of the major issues in the monitoring and control of manufacturing systems is to determine how to effectively deal with unexpected disruptions (e.g. material unavailability, resource failures, unavailability of operators, rush orders, etc.). Existing approaches and tools offer few concepts that are specific enough and sufficiently generic to help in handling a broad variety of such unexpected events. The biological immune system potentially offers interesting features to face the threats (bacteria, viruses, cancers, etc.) that may harm an organism. This research aims to investigate this potential for the monitoring and control of manufacturing systems at the occurrence of disruptions. Based on analogies that we point out, we suggest a framework to help with the design of software tools that are more able to assist decision makers in dealing with various types of disruptions occurring in a manufacturing system. A first prototype implementation, developed using a multi agent approach, contributes to show the feasibility and the interest of this immune based framework.

1. Introduction[1]

The monitoring and control of production systems is an intrinsically complex activity, where decision makers have to deal with complex and interdependent problems. Basically, decisions are taken in order to manage production activities and resources, such that good performance levels are reached and different kinds of constraints (financial, legal, technical, environmental, etc.) are satisfied. Unfortunately, preliminary decisions are often compromised by the occurrence of disruptions, such as late deliveries, resource failures, modification of customer demand, or quality problems. These disruptions are unpredicted events of various types, which may severely impact the performance of a production system (Aytug et al., 2005; Mula et al., 2006).

Being able to cope with these disruptions and to assist decision makers in reacting in the best way are important issues. Indeed, several monitoring and control tools and approaches were developed. For example, Manufacturing Execution Systems (MES), which are tools commonly used in industrial practice, usually include direct connections to functions, such as maintenance and quality management, resource allocation and status, data acquisition and performance analysis (MESA, 1997). However, these tools only focus on particular problems, typically related to maintenance and quality. They offer limited support to identify and handle more complex consequences of disruptions, to which reactions from decision makers are still needed (Saenz de Ugarte et al., 2009).

The related scientific literature shows that a lot of research effort has been directed towards designing distributed control architectures, featuring the multi agent, holonic or bionic paradigms (Trentesaux, 2009). Unfortunately, as it will be shown in Section 2, although these paradigms allow integrating intelligent strategies within agents or holons, they do not provide general concepts devoted to the mechanisms that have to be implemented to face disruptions. As a consequence, a general conceptual framework, which would help to characterize how to deal with disruptions, would be quite useful.

In nature, biological immune systems are able to deal with numerous threats (such as bacteria, viruses, cancers, etc.) that are likely to cause diseases and to endanger one host organism. Biological immunity relies on a reduced set of concepts and mechanisms, which are able to efficiently protect the organism against a broad variety of elements disturbing its normal functioning. The adaptation of such concepts and mechanisms would be pertinent to meet the manufacturing systems needs for protection against different types of unexpected disruptions. Therefore, this research investigates the potential of biological immunity to provide concepts and mechanisms that are useful to

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deal with various types of disruptions during the monitoring and control of manufacturing systems. We derive a conceptual framework that is intended to help with the design of more dedicated and generic disruption handling tools. The purpose of this framework is to assist the designers of Manufacturing Execution Systems (MES) in better taking the management of disruptions into account. A prototype of an agent based system, called ARTIMOS, has been built on the basis of this framework.

In this respect, our article is organized as follows. First, in Section 2, we review disruption handling capabilities in current typical monitoring and control approaches and we highlight their limitations. Then, in Section 3, we introduce some important features of the biological immune systems that are used to face biological threats. In Section 4, we review existing artificial immune applications to manufacturing systems. This review indicates that biological immunity does not seem to be applied to handle disruptions in production monitoring and control systems. In Section 5, we identify the main immune concepts and mechanisms that are relevant to the monitoring and control of production systems, and we suggest a conceptual framework to deal with disruptions, more explicitly and more generically than in conventional approaches. Section 6 introduces ARTIMOS, an agent based prototype implementation that is built based on this framework. Next, in Section 7, an illustrative example shows how this conceptual framework can be used. Finally, we discuss some features of the proposed approach and suggest possible future research directions.

2. Disruption handling in production monitoring and control systems

Disruption management in production planning and control consists in dealing dynamically with unanticipated events that make the production plans deviate from their intended course (Cauvin et al., 2009). Several approaches exist, which aim at solving several types of quality, maintenance, reliability, and error recovery problems. These approaches are generally specific and devoted to a particular kind of problem (Bruccoleri et al., 2006; Chen and Nof., 2012; Saenz de Ugarte et al., 2009; Radhoui et al., 2010). In this article, a more global point of view is adopted: emphasis is put on the management and control decisions, which need to be found in a reactive manner, in order to help in reducing the impact of disruptions on the flow of products through a manufacturing system.

To deal with disruptions, industrial practices are either based on simple and "home-made" software systems, designed for limited and specific purposes, or rely on *Manufacturing Execution Systems* (MES), which are a set of integrated tools designed to bridge the gap between the planning system and the controlling system. MES allow decision makers to access accurate, reliable and real time information to both oversee and record results of activities in a production facility. MES give a plant-wide view of the status and operation of processes, materials, human resources, machines, and tooling. According to MESA International, which is a normalization association for MES, such a system includes eleven (11) main functions (MESA, 1997), namely:

(1) Operations/detailed scheduling,
(2) Resource allocation and status,
(3) Dispatching production units,
(4) Document control,
(5) Product tracking and genealogy,
(6) Performance analysis,
(7) Labor management,
(8) Maintenance management,
(9) Process management,
(10) Quality management,
(11) Data collection and acquisition.

Although these functions support, guide, and track each of the primary production activities, we can notice that MES offer no function explicitly dedicated to disruption handling (Saenz de Ugarte et al., 2009).

In order to make monitoring and control systems more responsive to change and reactive to disruptions, a large amount of research has been directed towards designing decentralized, distributed, heterarchical architectures, which are believed to provide more flexibility and robustness to change and disruptions than centralized hierarchical architectures (Chen and Nof, 2012; Shen et al., 2006). According to Trentesaux (2009), distributed control may be achieved using three kinds of approaches, namely:

- Bionic and bio-inspired, such as in (Sallez et al., 2009),
- Multi-agent, such as in (Bussmann and Schild, 2001; Bruccoleri et al., 2003; Odrey and Mejia, 2003; Tranvouez et al., 2006; Cauvin et al., 2009),
- Holonic, such as in (Leitao and Restivo, 2008).

Indeed, these approaches can lead to modular, flexible, and scalable control architectures. Yet, most of them only consider particular types of disruptions, or provide limited assistance to how to react. Actually, most of the papers deal with some types of disruptions, such as machine breakdowns (e.g. Bussmann and Schild, 2001; Bruccoleri et al., 2003; Tranvouez et al., 2006), or demand variation (e.g. rush orders and cancellation of orders, Leitao and Restivo, 2008). Other types of disruptions, such as supply failures or quality problems, are either not addressed or not mentioned.

In most cases, to deal with these particular disruptions, specific reaction strategies are designed for each disruption type, using formalisms such as strongly typed state graphs, as in (Tranvouez et al., 2006), or Petri net graphs, as in Leitao and Restivo (2008). These reaction strategies are specifically tailored to the disruption case encountered. They offer a very limited "genericity" to cope with a variety of disruption types and address more various disruption management problems.

In most published works on distributed control systems (Shen et al., 2006), negotiation is used for resource allocation to take advantage of the operational flexibility of the system (Reaidy et al., 2006). Negotiation is achieved using protocols such as the voting mechanism, the Contract Net Protocol or its modified versions, game theory based protocols, and Market-based protocols using the so-called bargaining or auction process. Such auction and bidding processes are used for example by Bussmann and Schild (2001) to handle machine failures in a product centered multi-agent based approach called WEST for the automotive industry, and by Leitao and Restivo (2008) to handle machine failures and demand variation in a resource centered holonic approach, called ADACOR, for an FMS system. Consequently, disruptions are dealt with based on concepts and mechanisms intrinsically due to the distribution of decisions rather than concepts and mechanisms which allow explicit disruption representation and processing.

Furthermore, in many papers, disruption decisions are often concerned with (re)scheduling, (re)assignment or (re)sequencing, without integrating other important and useful considerations, such as reconfiguration or maintenance. Finally, we notice that existing approaches offer little help in capitalizing and reusing the expertise stemming from disruption handling.