Solving Myopia in Real-time Decision-making using Petri nets Models' Knowledge for Service-oriented Manufacturing Systems

Paulo Leitão[1,2], Joel Alves[1], Ana I. Pereira[1]

[1] *Polytechnic Institute of Bragança, Campus Sta Apolónia, Apartado 1134, 5301-857 Bragança, Portugal (e-mail:{pleitao,apereira}@ipb.pt).*
[2] *LIACC - Artificial Intelligence and Computer Science Laboratory, R. Campo Alegre 102, 4169-007 Porto, Portugal*

Abstract: This paper introduces a novel approach to the real-time decision-making in service-oriented manufacturing systems, addressing the myopia problem usually presented in such systems. The proposed decision method considers the knowledge extracted from the Petri nets models used to describe the services process behavior, mainly the T-invariants, combined with a multi-criteria function customized according to the system's particularities and strategies. An experimental laboratorial case study was used to demonstrate the applicability of the proposed real-time decision-making approach in service-oriented manufacturing systems, considering some productivity and energy efficiency criteria.

Keywords: Flexible manufacturing systems, Service-oriented systems, Petri nets, Decision systems.

1. INTRODUCTION

Companies are increasingly adopting more modular, flexible and re-configurable manufacturing solutions, based on intelligent and distributed control principles, to face the current challenges imposed by markets demanding highly customized products. Service-oriented principles are a suitable and promising computing framework to address these challenges in manufacturing and automation fields (Jammes and Smit, 2005).

In such systems, the manufacturing processes can be decomposed into smaller pieces (devices or logical components), so that the functionalities provided by each manufacturing piece are abstracted through services. The system behavior is translated into the correct use of these exposed services, as well as the creation of newer, larger ones, through composition and orchestration. This engineering practice promotes the modularity, flexibility and reconfiguration capabilities of manufacturing processes.

In flexible manufacturing control processes, and also those based on service-oriented principles, the occurrence of conflicts (e.g. which resource should perform the operation or which path should be taken by the pallet) and unexpected disturbances (e.g. a robot collision during its movement) are frequent. The resolution of such conflicts and unexpected situations requires decision-making support taking into consideration a set of criteria, for instance productivity and efficiency. Since manufacturing is traditionally an energy-intensive industry, using motors, steam, and compressed air systems to transform raw materials into durable goods and consumer products, a special attention should be given to energy efficiency criteria aiming to achieve sustainable manufacturing control practices.

Taking advantage of using the Petri nets formalism to describe and execute the service-oriented process behaviors, the real-time decision support system proposed in this work considers a multi-criteria function that uses the knowledge extracted from the structure of the Petri nets models. In fact, due to the associated powerful mathematical foundation, Petri net models contain richness knowledge about the process behavior, notably the description of service and device logics, and the description of available system's work cycles (Murata, 1989; Silva and Vallete, 1990).

The basic idea of the proposed decision-making method for service-oriented manufacturing systems is to combine the knowledge extracted from Petri nets models, mainly the T-invariants, with a flexible set of decision criteria, that do not only consider the optimization of manufacturing processes, but also the service quality and the reduction of the energy consumption in the manufacturing devices (Leitão et al., 2010). In terms of services, it means the selection of the best available service from a set of alternative options that represents the requester's demands, taking into account the process and energy efficiency.

However, this approach considers the decision of selecting the best solution taking into account only the execution of the next service (operation). This method may suffer of myopia and can lead to non optimal long-term solutions. The motivation of this paper is to extend the initial real-time decision-making approach for service-oriented manufacturing systems based on the Petri nets knowledge (presented at Leitão et al. (2010)), with proper mechanisms to solve the myopia decision problem. Having a non-myopic decision-making system, the best solution to perform a sequence of services defined in the process plan is probably different from that in which the execution of the first service is the best one.

The reminder of the paper is structured as follows: Section 2 overviews the decision-making process in service-oriented manufacturing systems, combining the knowledge extracted from the Petri nets models with a set of flexible decision criteria. Section 3 introduces an extension to this decision-making approach addressing the myopia problem. Section 4 uses an experimental case study to illustrate the applicability of the proposed approach and at last, Section 5 rounds up the paper with the conclusions.

2. DECISION-MAKING BASED ON THE PETRI NETS KNOWLEDGE AND ENERGY-AWARE CRITERIA

In flexible manufacturing environments, the occurrence of conflict situations is usual, since there are several alternatives to execute similar operations. Examples of conflicts are the selection of which workstation should perform a drill or which path should be taken to reach a specific workstation. Unexpected situations are also usual in manufacturing environments, for example the breakdown of a machine or a delay in the execution of one operation. These situations should be handled by decision-making systems that provide services to support their resolution. The complexity of the decision support system is strongly dependent on the flexibility that the system reveals (Leitão et al., 2008).

The procedure proposed in this work for the development of the decision-making systems for service-oriented manufacturing comprises a set of steps at the design phase (when workflows are defined and configured) and operational phase (when workflows are executed at runtime by devices). In the following sections, this decision-making approach is explained.

2.1 Petri nets to Represent Workflows and T-invariants

In service-oriented systems, the work-plan associated to services can be defined using different methods (Milanovic and Malek, 2004), namely the Business Process Execution Language (BPEL) (OASIS, 2007) and the Petri nets formalism (Murata, 1989). In this work, the process behavior in service-oriented manufacturing systems is formally described and executed using the Petri nets formalism, taking advantage of its powerful mathematical foundation (see (Mendes et al., 2008) for more information). The knowledge extracted from those models may constitute a useful and rich source to support the decision-making process. For this purpose, the behavior of resources, such as robots, machines and conveyors, is modeled using Petri nets. The models represent all possible discrete states of such a resource and also all manufacturing functions that this resource is able to expose as services, e.g. move-piece, pick-part and transfer-pallet. The individual resource models are then composed into a coordination model, which follows the same rules of configuring a required resource's layout, i.e. taking into account, amongst others, the competition, concurrency and shared resources behavioral relationships.

The knowledge extracted from the Petri nets models provides a rich interpretation of the system behavior. Namely, the following information can be extracted to support the decision-making process:

- The incidence matrix of the Petri net that represents the process behavior and the structure of the model.
- The marking of the Petri net that represents the current state of the system.
- The T-invariants that represent the several sequences of operations in the Petri net (i.e. the work cycles).

Of particular importance in this work are the T-invariants. A T-invariant is an integer solution x the homogeneous linear system $A^T x = 0$, being A the incidence matrix of the Petri net (see (Murata, 1989) for more details). The T-invariants can be determined, for example, by applying the algorithm described in (Martinez and Silva, 1982). The achieved T-invariants have a proper meaning in the physical system: co-relate exposed services belonging to, at least, one service-invariant (T-invariant in the Petri nets terminology). The set of service-invariants and their linear compositions represents all possible service coordination paths that the system is able to expose.

Due to the strong mathematical background that is behind the Petri net theory, the model can formally be analyzed and validated during the design phase (Murata, 1989; Giua and DiCesare, 1994). Only after verifying the correctness of the model, it is uploaded into the device.

2.2 Selecting the Decision Criteria

The traditional decision-making systems only consider productive related parameters as the unique criteria for the evaluation of the alternative possibilities for the system evolution. As examples, the costs related to the processing time, transportation time, resource utilization and maintenance are normally used in this process.

However, other decision criteria should be taken into account for a more efficient evaluation, namely the Quality of Service (QoS) and the reputation of devices. A special attention should be given to the energy efficiency criteria in order to reach a more sustainable and clean manufacturing system. In fact, since different devices spent different amounts of energy to execute the service, it is possible to choose the device that has lower energy consumption. A typical example of energy related parameters is the energy consumed during the execution of an operation (for example a workstation making a drill or a conveyor transferring a pallet).

The proposed approach allows defining, at design phase, the set of criteria to be used during the decision-making system, allocating weight factors to each criterion.

2.3 Combining T-invariants and Decision Criteria

When a decision point is detected, for instance a conflict, which is represented in Petri nets by a place that have multiple output arcs going to different transitions, the decision system should determine, in a first instance, which alternatives are valid to evolve, aiming to reach a particular objective. For this purpose, the knowledge extracted from the Petri nets models, especially the set of T-invariants, is used to identify the alternatives to evolve.

At this stage, the problem is solved if only one alternative is valid to execute the service (e.g. if for a conflict, only one path lead to the execution of the desired service). However, in case of more than one alternative to evolve, it is necessary to evaluate those alternatives. For this purpose, the proposed