# Planning and Scheduling for Dispersed and Collaborative Productive System

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Marcosiris A. O. Pessoa[1], Fabrício Junqueira[1], Paulo E. Miyagi[1], Diolino J. Santos Fo[1]

[1]University of Sao Paulo, Sao Paulo, Brazil
{marcosiris, fabri,pemiyagi}@usp.br, diolino.santos@poli.usp.br

**Abstract.** The advances of production technologies reflect a worldwide trend for sustainability and rational use of resources. As a consequence, some movements for industry reorganization can be observed in geographically dispersed systems with new productive systems (PSs) configurations. These PSs work with small and medium size production lots, product families with increasing variety, and hard delivery date. In this context, concepts of dispersed and collaborative productive systems (DCPSs), with new requirements for production scheduling are expected to be properly explored for improvement of PSs performance. Therefore, we here consider that productive activities can be treated as services and the SOA (service-oriented architecture) approach can be adopted for the integration of the DCPS. Then, a planning service based on time windows and a scheduling service that uses the APS (advanced planning and scheduling) heuristics is proposed to assure the expected performance of the DCPS.

**Keywords:** disperse productive system, planning and scheduling, scheduling heuristics, time windows.

## 1 Introduction

The international competitive pressure on manufacturing enterprises has strongly increased. Nowadays, consumers and delivery date orient products demands and the lots of products have small and medium size, while product families are increasing in variety [1]. Hence, technological advances and market changes have established new efficiency patterns in the production of products [2]. Moreover, there is the sustainability scope; customers are demanding sustainable green products and processes [3]. The use of the Internet can collaborate with the sustainability reducing personal displacement, travel costs, and the related carbon footprints [3]. In this context works that contributes for practical implementation of dispersed and collaborative productive systems (DCPS) are also a contribution for sustainability.

The DCPS are collections of autonomous machines connected and integrated through a communication network. The focus is on a method for integrating equipment and machine control strategies to ensure the accomplishment of productive processes [2], [4]. However, in these works, issues related from the planning and scheduling viewpoint are not treated; in others words, the optimization of where and when services should be available is not addressed. In this context, this work introduces a “planning service” based on “time windows heuristics” and a “scheduling service” to assure the expected performance of the PS.

Several works adopted service-oriented architecture (SOA), in which Web Service (WS) is a popular instance of this architecture [2], [4], [5], and [6]. In [2] and [4] was introduced a method to specify the productive processes aiming at the automation and coordination of their activities and services. In this sense, this work adopts the concept of SOA for DCPS, and the “planning service” allow customers to know if their orders are feasible at the requested delivery date without the need of a complete review of the scheduling. The “scheduling service” allocates the services assuring that they will be delivered at the requested time. The Petri net is used for modeling the integration of services and to evaluate the proposal.

This paper is organized as follows. Section 2 presents its contribution to sustainability. Section 3 presents the key concepts used in its development. Section 4 presents the DCPS with the planning and the scheduling service and a model in which these services are integrated with other parts of the PS. Finally, section 5 presents the conclusions.

## 2 Contribution to Technological Innovation for Sustainability

According to [7], living with “sustainability” requires a strong engagement of science, industry and politics. “Sustainability research” is expected to lead with three conflicting aspects: (i) contributing to economic development, (ii) being ecologically acceptable, and (iii) being socially fair. The reference [3] states that sustainable green engineering design and manufacturing are changing every aspect of our life and have already originated a wide area of research topics. One of these topics is about machine and process optimization, i.e., using real-time monitoring systems, with sustainability statistics integrated into the feedback-controlled system; it is possible to avoid out-of-control situations in any process step. Another topic is the Internet communication, which can be used in DCPS to reduce human displacement, direct and indirect production costs and the related carbon footprint. In accordance with some works ([8], [9], and [10]), the teleoperation approach, for example, causes social impacts such as: personnel trip reduction for meetings, operator activities improvement in unfavorable conditions, or dangerous environments, among other applications.

Besides the topics above mentioned, this work also contribute to waste reduction. In fact, considering a production environment, i.e., a DCPS in which each PS produces items for other PSs, the problem of planning and scheduling has no trivial solution and cannot be neglected. The delay in delivery of any intermediary item may directly interfere with the delivery date of the final product and the rational use of resources can be impaired.

The adopted SOA approach for DCPS that includes “planning service” and “scheduling services” is fundamental to improve the performance of the overall system, and represent a contribution to sustainability.

# 3 Fundamental Concepts

According to [2], the evolution of the Internet velocity and functionalities reduced the implementation cost of DCPSs and also increased teleoperated systems flexibility. These systems have computers called "clients" with applications that communicate with other applications located at other computers named "servers", which control remote equipment or resources directly. With this "client/server" structure, multiple operators can use, via Internet, equipment or resources that are geographically distributed in other places. Operators and equipment are installed in geographically dispersed locations and interact to accomplish the desired tasks [11].

This work uses the "time windows" [12] approach and the "constraint programming mechanism" [13] to plan the process; these two approaches are encapsulated at "planning services". For modeling the integration between services, the Petri net is used. Below is a description of "time windows" and "constraint programming mechanism".

## 3.1 Time Windows

In production problems with delivery priority dates, it is possible to determine, for each production lot, the latest instant of time at which this lot should be ready. This latter instant becomes the maximum delivery date for a production lot. The "time windows" are time intervals for the allocation of production lots; in other words, in a time scale, they are the limits at which the lots can be allocated (due dates), and each lot has its own "time windows". The four key parameters of a "time windows" (Fig.1) are:

- Earliest start time (*Est*) is the earliest time at which a lot can be started in the "time windows";
- Latest finish time (*Lft*) is the latest time at which a lot must be finalized in the "time windows";
- Earliest finish time (*Eft*), is the earliest time at which a lot can be finalized in the "time windows", and it is defined as the sum of *Est* with the process time (*Pt*) of the lot;
- Latest start time (*Lst*), is the latest time at which a lot must be started in the "time windows", and it is defined as the *Lft* subtracted from the *Pt* of the lot.

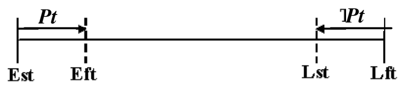


**Fig.1.** The four key parameters of a "time windows".

The "time windows" limits must be consistent with the restrictions of (*Est* and *Lft*) for all lots, and for this reason, a "constraint programming mechanism" is used. In this work, the following restrictions are considered:

- Capacity constraints [12] and [13] that ensure that the production lots do not overlap in time, i.e., it is not possible to process two lots simultaneously at the same resource;

- Precedence constraints by product recipe that ensures that: the *Est* of the consumer lot must be equal to or greater than the *Eft* of the producer lot, and the *Lft* of the producer lot must be smaller than or equal to the *Lst* of the consumer lot;
- Storage restrictions [14], related to the storage capacity.

### 3.2 Modeling Services Using Petri Net

The Petri net is a powerful modeling tool, and several works have used it to model dispersed systems ([2], [4], [15], [16], [17] and [18]). Thus, the reader is assumed to be familiar with the basic concepts of Petri net [19]. In [15], a survey into process modeling is presented. Verification techniques (based on Petri net, process algebra and state machine) are described as well as the tools developed to ensure the specification and composition of services via Internet. Relevant issues concerning Petri net and process algebra are also presented in [16], in which the graphical representation of Petri net is highlighted. In [17], the authors compare two semantics of Petri nets for the orchestration of services via Internet. The Petri net is used herein for modeling and evaluating the integration of services in DCPS.

## 4 DCPS with Planning and Scheduling Services

This study adopts the approach based on SOA (service oriented architecture) presented in [20] for coordinating the implementation of DCPS. Customers, operators and PSs are considered to be geographically dispersed. The adopted structure is multi-layered with three levels (Fig.2). At the top level (presentation layer), there is the service that exposes the functionality of DCPS for a communication network (Internet) and provides mechanisms for planning and scheduling the customers orders considering the available resources. At this level, the "time windows" and the "constraint programming mechanism" are used in the "planning services", and the "earliest" APS (advanced planning and scheduling) heuristic proposed in [21] is used for scheduling the services in the "scheduling services". In the intermediate layer (integration and coordination layer) there are the mechanisms for integration and coordination of services for PSs involved in the production process. The lower layer (productive services layer) treats the PS services that may be required to meet the orders. The possibility to reconfigure the service structures of each PS is considered.
In the DCPS proposed, the customers have access to the "customers interface", so that they can send requests to a repository of products through communication devices (PDAs, netbooks, web sites, 3G phones, etc.) and also monitor the state of the requested services. The interface ("management request services") accounts for managing the orders and for informing customers about the order feasibility. This service has interfaces with the "customers interface", the data base, and the "planning services". If the order is feasible, the "planning services" sends the considered "time windows" to the "scheduling services" and also sends a message to the "management request services" confirming that the order is feasible. Using APS heuristics, the "scheduling services" allocates the order and sends a message to the

"integration and coordination services". The architecture depicted in Fig.2 considers that global processes are centrally coordinated by an orchestrator for the integration and coordination of services. This orchestrator is realized by the "integration and coordination services" that coordinates the activities of all PSs involved in the execution of the processes. Each PS of the DCPS is encapsulated in one of the service "teleoperative system of production services", which exposes functionalities of the manufacturing system module as a service enabling the interaction between the module and the "integration and coordination services".

Fig.3 presents the Petri net model of the presentation layer, the integration and coordination layer and their relationship. The graph describes the flow of messages and the services that are activated to execute the production orders.

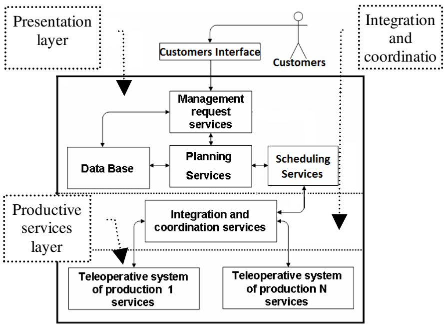


**Fig. 2.** DCPS architecture with "planning services" and "scheduling services".

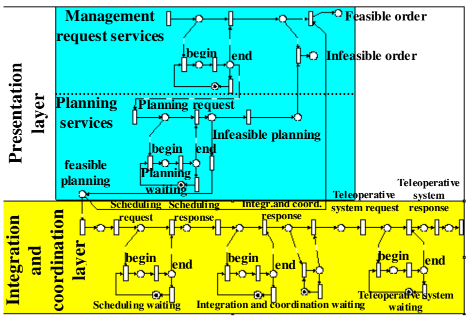


**Fig. 3.** Petri net Model of the integration of the "presentation layer" and the "integration and coordinating layer".

This model was developed with the support of Petri net tools (software packages such as HPSim [22]) that was also used for structural and behavior analysis based on the properties of the graph.

## 5 Results

The example (Fig. 4) considers the processing of the bill of material ([23]) to be produced in DCPS that operates in lots. It involves different lot sizes, successive operations, storage conditions and limited shared resources. This section uses the example presented in [18]. This is composed of a set of three PSs of the same DCSP, *Fab1*, *Fab2* and *Fab3*. There is a scheduling sector that remotely manages the scheduling of all PSs. *Fab1* provides products *Pro1*, *Pro2* and *Pro3*, and *Fab2* provides *Pro4*. Input *S30* is produced by *Fab1* and consumed by *Fab2*. Fig. 4 shows the STN (state-task-network) [24] of the PSs process.

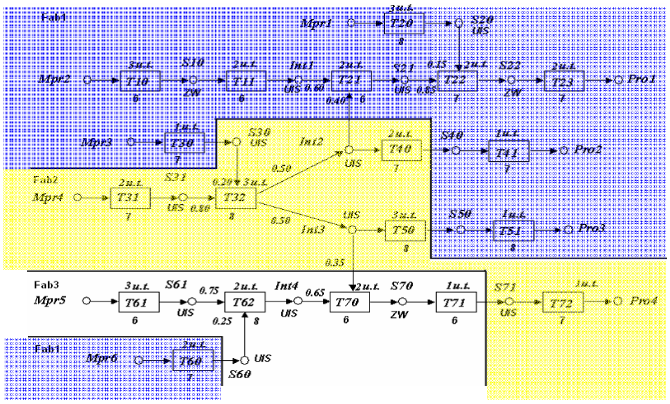


**Fig. 4.** Productive process of the example [18] using the STN [24].

The PSs are geographically dispersed, but the STN was used to demonstrate the relationship between processes and that the delayed delivery of *S30* may cause delay in delivery of products *Pro1*, *Pro2*, *Pro3* and *Pro4*. In Tab.1 and Tab.2 are presented respectively, the assignment of tasks to the resources, the demand for final products and delivery dates. The storage restrictions are only for items *S10*, *S22* and *S70*.

**Tab.1.** Tasks Assignment

| Productive Systems (PS) | Resources | Tasks |
|---|---|---|
| *Fab1* | *P1* | *T10, T21, T51* |
| | *P4* | *T23, T30, T60* |
| | *P7* | *T11, T22, T41* |
| *Fab2* | *P2* | *T32* |
| | *P3* | *T31, T72* |
| | *P5* | *T20, T40, T50* |
| *Fab3* | *P6* | *T61, T70* |
| | *P8* | *T62, T71* |

**Tab. 2.** Demand for final products and due date

| Productive Systems (PS) | Products | Clients | Quantity | Delivery Date |
|---|---|---|---|---|
| *Fab1* | *Pro1* | *Client1* | *70* | *64* |
| | *Pro2* | *Client2* | *50* | *88* |
| | *Pro3* | *Client3* | *50* | *86* |
| | *S30* | *Fab2* | *10* | *35* |
| | *S60* | *Fab3* | *20* | *14* |
| *Fab2* | *Pro4* | *Client4* | *50* | *67* |
| | *Int2* | *Fab1* | *32* | *44* |
| | *Int3* | *Fab3* | *32* | *44* |
| | *S20* | *Fab1* | *16* | *26* |
| | *S40* | *Fab1* | *56* | *66* |
| | *S50* | *Fab1* | *56* | *69* |
| *Fab3* | *S71* | *Fab2* | *54* | *55* |

Fig.5 presents the “time windows” generated by the “planning services” and the scheduling generated by the “scheduling services”. The horizontal line represents the time of the scheduling horizon.

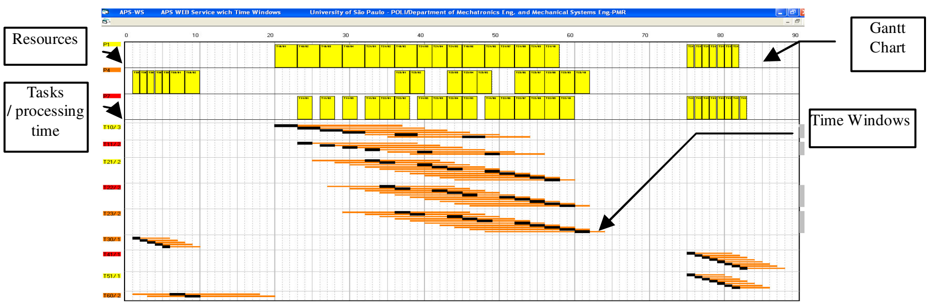


**Fig. 5.** The “time windows” and scheduling of *Fab1* orders.

In this example was used the APS (advanced planning and scheduling) heuristic presented in [21].

## 6 Conclusions

An architecture based on services towards a modular and scalable design of dispersed and collaborative productive system (DCPS) is presented. In addition, the use of a heuristic based on “time windows” and the “constraint programming mechanism” for “planning services” was proposed. Thus, “planning services” was developed and implemented as a web service, based on “time windows” that avoid improper task assignments. This service allows customers or others factories (productive systems) to know if their request is feasible without the need of a complete review of the scheduling. Thus the customer has a faster response about the feasibility of the order request. The “scheduling services” uses the earliest APS heuristic, which assures that the order will be delivered at the desirable time. The DCPS here considered assures the performance of the activities related to manufacturing products even if the production process is fragmented into several productive subsystems. The performance of the DCPS was analyzed by using the Petri net model and study cases.

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