Engineering Applications of Artificial Intelligence 22 (2009) 897–905

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

journal homepage: www.elsevier.com/locate/engappai

Development and integration of a reactive real-time decision support system in the aluminum industry

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ARTICLE INFO

Article history:
Received 6 May 2008
Received in revised form
1 October 2008
Accepted 15 October 2008
Available online 20 December 2008

Keywords:
Rescheduling
Genetic algorithm
Real-time decision
MES
ERP

ABSTRACT

This paper aims at providing real-time decision support in reaction to disruptive events in manufacturing environments. More precisely, we demonstrate how this approach can support the rescheduling process in enterprise resource planning (ERP)-controlled environments. Our demonstrative example, based on a real scenario in the aluminum industry, illustrates how a genetic algorithm and a real-time discrete event simulation model can be integrated within the common enterprise information systems.

1. Introduction

As complexity and demand for new or customized products grow, companies are realizing that their supply chains need to be more flexible and responsive. Responsiveness can be achieved in different ways including exploiting flexibility in supply chain structures (Wadhwa et al., 2008), by reducing cycle time, and by implementing a customer-driven replenishment process. A responsive enterprise can eventually survive competition by operating as a effective member of a supply chain network and by its ability to make a rapid and balanced response to predictable and unpredictable change (Ranga and Dwivedi, 2003).

As reaction time decreases, however, shop floors become more complex, dynamic and consequently unstable. In dynamic supply chain networks, manufacturers have to react to various unforeseen events occuring within or outside the company boundaries (Saad and Gindy, 1998), which draws attention to the importance of tracking material flow and information flows and the necessity of making timely decision. The responsive system, therefore, needs to have access to critical real-time production information and combine different solving tools with multiple data sources to elaborate solutions in reasonable time compatible with the planning horizon.

In the supply chain literature, traditional simulation models have been used extensively for many years as strategic decision tools to either understand the system behaviour or to evaluate various off-line strategies for the system operation. However, simulation models are usually not employed for repetitive and real-time usage as the models are not directly coupled with the real information systems. By contrast, online decision support systems take a snapshot of the current factory status and predict future events according to certain modeling assumptions. In a rapidly changing and highly competitive business environment, the decision system, therefore, needs to have access to critical real-time production information. A typical area of application for online simulation, also called real-time simulation, is a proactive decision support for scheduling problems in manufacturing systems. For example, Kouiss and Pierreval (1999) present a combination of a Manufacturing Execution System (MES) and an online simulation model for controlling a flexible manufacturing system. Simulation is used to evaluate different scenarios proposed by the decision module, which takes into account the current state of the manufacturing system. The selected solution is proposed to a human operator for validation and execution. Shin et al. (2004) also discuss a decision problem faced by assembly line personnel when a breakdown occurs in a multiple production line system. A discrete event simulation-based approach is presented to help line personnel minimize throughput degradation of the line.

Using online simulation is attractive but requires the integration of the simulation model into the enterprise information

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0952-1976/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engappai.2008.10.021

system landscape and the communication network. It must also combine multiple optimization techniques in order to support different decision-making scenarios. Fortunately, the advances in computing power and memory over the last decades have opened up the possibility of online simulation-based optimization. This recent research development offers one of the most interesting opportunities in simulation and the potential benefits in this field are significant. In terms of a resolution approach, gradient-based search methods and heuristic methods are the most encountered online simulation-based optimization approaches (Carson and Maria, 1997). Gradient-based search methods cover finite difference estimation, likelihood ratio estimation, perturbation analysis and frequency domain experiments. These methods aim to estimate the retained performance measure with respect to decision variables. On the other hand, heuristic methods consist of a random exploration of the admissible solutions in the whole space of the decision. The search process ends when the stop condition is filled. At each point in the search process, the objective function value of the problem is estimated via the simulation model. Thus, no information regarding the analytic form of the objective function is required. This category covers simplex search, tabu search, simulated annealing and genetic algorithms (Azadivar and Lee, 1998; Carson and Maria, 1997; Chaudhry and Luo, 2005; Ruiz et al., 2007).

In this paper, we propose a generic manufacturing execution architecture in which a genetic algorithm integrated with a real-time discrete event simulation model complements the traditional information system landscape used by manufacturing organizations. The main objective of our architecture is to provide real-time decision support in reaction to disruptive events in manufacturing environments. The remainder of this paper is structured as follows. Section 2 presents the demonstrative example based on a real scenario in the aluminum industry. Section 3 presents our resolution approach. The integration of the proposed approach within an Enterprise Resource Planning (ERP) and MES platform is then presented in Section 4. Finally, a brief discussion of future perspectives will conclude this paper.

2. Case problem

The aluminum transformation process is a hybrid continuous and discrete manufacturing process. In the early stage of the process, anodes made of oil coke and tar are bathed in a hot electrolyte. The electrolyte then dissolves the alumina and the aluminum is collected in pots. The chemical reaction on anodes takes many days (continuous process). When a pot is full, it is then siphoned in a crucible (discrete process). The crucible is used to transfer the melting aluminum from pot lines to a furnace. In the furnace, alloys are prepared and mixed. At the end of the process, the alloy is transferred to the cast line to make alloy bars.

In our example, a pot line has a capacity of 240 pots. Pots are tapped individually every 24 h. Each individual pot has chemical properties and a scheduling time. Chemical properties can change over time and are updated with lab values. Chemical properties include the level of metal contamination. Depending on contamination levels, some pots may not be used for producing high-quality alloys (higher market value).

When the metal is put into crucibles, it is transported to the cast lines. Metal arrives in the cast house in an uncontrolled sequence which depends on the real tapping schedule.

Batches of alloys are produced in the cast lines. As metal always arrives in a non-controlled sequence, crucibles may need to be emptied into a waiting furnace. The chemical properties of the waiting furnace, therefore, vary according to the arrival and properties of new crucibles.

The operator of this manufacturing system aims at different objectives. At the corporate level, the objective is to optimize the allocation of alloys between plants according to the conditions and capacity of each plant. This problem is not the concern of this paper. Our focus will be rather on the plant level, where the objective is to optimize the daily schedule according to the real-time shop floor conditions. The latter objective is measured by comparing the quality of the metal produced to the quality sold to the customer. Globally, the objective of the shop floor personnel is to restrict the use of high-quality metal for customer orders of a higher valued alloy and minimize the use of high-quality metal for customer orders requesting low alloy grades.

Plant allocation of alloys and production orders are currently managed by the foundry ERP. The scheduler uses no particular tools to produce the detailed schedule. Orders are released in the ERP and the weekly schedule is sent to the shop floor. A MES system is used to track the production status and the aluminum quality at the earliest stage of the manufacturing process. When an order is partially or totally complete, the order status is updated in the ERP. When a new order is allocated to the plant, or when an order is partially completed (because of a lack of aluminum with a sufficiently high), the scheduler has to update the schedule that is made twice a week. Actually, decisions are made by the scheduler. Thus, the quality of the decisions depends strongly on his experience and the time available to make the schedule. This fact creates an important variance from one scheduler to another.

This reality-based application highlights the integration aspects of the different control systems and the need to complement them with real-time decision-making capabilities.

3. Resolution approach

As mentioned in the previous section, the existing ERP-controlled environment is insufficient in guaranteeing a quick response to random events as they occur on the shop floor. Moreover, it falls short of meeting the quality objectives of the company. To bring a feasible solution that can be easily integrated into the existing architecture illustrated in Fig. 1, there is a need to complement it with real-time decision-making capabilities. This section details the proposed architecture and highlights the interactions between the different components.

3.1. Proposed execution architecture

Our proposed architecture is presented in Fig. 2. The main objectives of our architecture are to provide real-time decision support in reaction to disruptive events in manufacturing environments and an optimization capability for daily scheduling

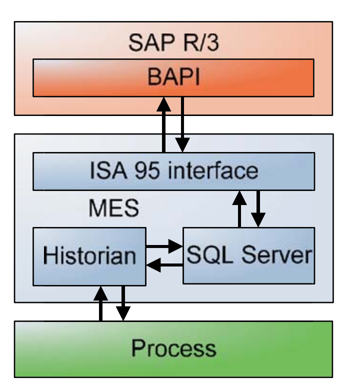

Fig. 1. System environment.