



A multi-agent system using iterative bidding mechanism to enhance manufacturing agility

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ABSTRACT

The global market has become increasingly dynamic, unpredictable and customer-driven. This has led to rising rates of new product introduction and turbulent demand patterns across product mixes. As a result, manufacturing enterprises were facing mounting challenges to be agile and responsive to cope with market changes, so as to achieve the competitiveness of producing and delivering products to the market timely and cost-effectively. This paper introduces a currency-based iterative agent bidding mechanism to effectively and cost-efficiently integrate the activities associated with production planning and control, so as to achieve an optimised process plan and schedule. The aim is to enhance the agility of manufacturing systems to accommodate dynamic changes in the market and production. The iterative bidding mechanism is executed based on currency-like metrics; each operation to be performed is assigned with a virtual currency value and agents bid for the operation if they make a virtual profit based on this value. These currency values are optimised iteratively and so does the bidding process based on new sets of values. This is aimed at obtaining better and better production plans, leading to near-optimality. A genetic algorithm is proposed to optimise the currency values at each iteration. In this paper, the implementation of the mechanism and the test case simulation results are also discussed.

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1. Introduction

Conventionally, the competitive advantage of manufacturing enterprises was attained by increasing the scale of manufacturing and reducing costs (i.e. price competitiveness). In the seventies and eighties, quality and other issues such as delivery performance and customer choice took higher priorities, leading to a drive for improved product quality and reduced inventory levels. Through the 1990s toward the present day, the world market has become increasingly global, dynamic, unpredictable and customer driven. This has led to increasing rates of new product introduction (i.e. decreasing product life cycle) and turbulent demand patterns across product mixes. As a result, customer satisfaction has become harder to achieve and manufacturing enterprises have to be agile and responsive to cope with market changes in order to compete with their business rivals in the competitive market. The competitive advantage is now largely dependent upon the rapid responsiveness to cope with dynamic changes of product mixes and demand patterns, as well as the opportunities in the market (i.e. market shifts). In addition, unforeseen situations in the manufacturing shop

floor, such as urgent pre-emptive jobs or machine breakdowns, may also need to be efficiently addressed simultaneously in order to enhance overall responsiveness. This has a profound implication to the strategies used to control the manufacturing systems.

Conventional control strategies for manufacturing systems were not designed to maximise system responsiveness. At the time when they were developed, costs, lead times, and inventory levels were more important issues. The strategies were developed to reflect the weighting of these factors. As responsiveness becomes a major concern, manufacturing systems that are based upon these strategies are struggling to keep pace with dynamic changes in the market. In order to compete with business rivals and maintain a lead within its respective market, the enterprise must adopt new manufacturing control strategies that are capable of not only improving product quality and increasing productivity and production efficiency, but most importantly, assisting the enterprise to achieve the characteristics of agility, reconfigurability, restructurability, reusability and scalability, so as to respond rapidly to the changes in product distribution caused by market shifts. Moreover, these strategies must also be able to support the enterprise in pursuing high flexibility and adaptive capability to cope with internal turbulences such as machine failures.

In order to achieve the substantial agility and responsiveness required, from an operational perspective, process planning and production scheduling must be dynamically and efficiently

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integrated. This integration will enhance the responsiveness, flexibility and adaptability of manufacturing systems toward changes and minimise manufacturing problems such as machine unavailability due to overloading (making the process plans infeasible), extensive bottlenecks, poor cost-efficiency, etc.

This paper introduces a *currency-based iterative agent bidding mechanism* used as an agent coordination mechanism in a multi-agent system (MAS) to effectively and cost-efficiently integrate production planning and control activities. The mechanism enables process planning options and production scheduling options to be evaluated and optimised simultaneously, so as to generate optimised process plans and schedules in response to dynamic changes in the market and production to support enterprises in achieving manufacturing agility. The iterative bidding mechanism is carried out using currency-like metrics; each interrelated operation to be performed is assigned with a virtual currency value and agents bid for the operation based on this value. These values are optimised iteratively and so does the bidding process based on new sets of values generated at each iteration. This is aimed at obtaining better and better production plans, leading to near-optimality. A genetic algorithm (GA) is proposed to optimise the currency values at each iteration. The proposed MAS also provides a platform where the possible reconfiguration of manufacturing systems can be assessed and the utilisation of manufacturing resources can also be optimised.

This paper is organised as follows. Section 2 provides a literature review of the approaches to integrating process planning and production scheduling. Following that, the generic problem to be solved in relation to process planning and production scheduling is defined in Section 3. Section 4 discusses the concept of MAS. In Section 5, the currency-based iterative agent bidding mechanism is introduced and the operational flow of the mechanism is also discussed (Section 6). Section 7 introduces the GA proposed to optimise the virtual currency values in order to achieve near-optimality. The implementation of the MAS with a test case and its simulation results will be discussed in Section 8. In addition, the comparison between the MAS and three non-agent systems are also provided in this section. Finally, Section 9 provides a conclusion of this paper.

2. Literature review

In the literature, there have been extensive studies of the approaches integrating process planning and production scheduling, namely non-linear process planning, flexible process planning, closed-loop process planning, dynamic process planning, alternative process planning, and just-in-time process planning (Huang, Mei, & Zhang, 1993; Kempenaers, Pinte, Detend, & Kruth, 1996; Kim, Chiotellis, & Seliger, 2009; Li, Shao, Gao, & Qian, 2010; Mei & Khoshnevis, 1993; Saygin & Kilic, 1999; Srihari & Emerson, 1990; Usher & Fernandes, 1996a; Wang, Feng, & Cai, 2003). These approaches can be broadly classified into three categories (Larsen & Alting, 1990): non-linear process planning (NLPP), closed-loop process planning (CLPP), and distributed process planning (DTPP).

NLPP entails a planning system based on a static shop floor situation, which generates not only one fixed plan but a set of possible alternative plans for each part/product prior to actual production on the shop floor. All these possible plans are ranked according to process planning criteria and are stored in a process planning database. The first priority plan is always used when the job is required. However, the scheduling function makes the final decision. If the first priority plan is not suitable for the current status of the shop floor, the lower priority plan will be provided to the scheduling. One of the typical examples of such system is FLEXPLAN (Tonshoff, Beckendorff, & Anders, 1989), which uses reactive re-planning strategies to allow fast reaction when unexpected

events occur in the shop floor during the execution of a schedule. In this approach, process planning is carried out prior to scheduling. Some researchers proposed the idea of having a two-stage approach, attempting to improve NLPP. At the first stage, all possible alternative process plans that do not take into account of operational status of the shop floor resources are generated. The second stage is dynamic process planning where the generated plans are retrieved and planning is completed taking into consideration the availability of the shop floor resources and the objectives or rules specified by the scheduler. The result of this two-stage approach is a set of ranked near-optimum alternative plans and schedules. The systems applying such an approach are PARIS (Usher & Fernandes, 1996a), DYNACAPP (Ssemakula & Wesley, 1994), and THCAPPG (Wang, Li, Liu, & Tian, 1995).

Although NLPP offers flexibility to the scheduling department with a list of alternative process plans, but there is only a single directional information flow (i.e. from the process planning department to the scheduling department). Process planning does not really consider which of the alternatives are of interest for scheduling; an arbitrary set is generated based on the experience of the process planner. Furthermore, scheduling only uses the alternatives that are available. The setup of an information feedback loop could provide the process planning department with detailed information of the shop floor situation as well as requirements from scheduling department, making process planning works more efficiently. No further effort would be spent on investigating alternatives that are of no use. Moreover, the risk of overlooking important aspects is also reduced. CLPP is the approach that would achieve the above issues.

CLPP generates plans for jobs in real time based on the feedback from the shop floor with respect to the status of the resources at that time. Production scheduling notifies process planning what machines are available on the shop floor for the coming job so that every plan is feasible with respect to the current availability of production facilities. Real time status has become a crucial issue for CLPP and therefore CLPP is also referred to as real time process planning or dynamic process planning. Khoshnevis and Chen (1989) developed a heuristic algorithm based on CLPP to facilitate the integration of process planning and production scheduling to overcome the drawbacks of NLPP. In the algorithm, a dynamic list of available machines and a list of features that can be processed are maintained for each part. When a match is found between the two lists, the part will be assigned to that machine. However, the algorithm has neglected one issue in relation to the allocation of producing the features to machines. For instance, the algorithm may have allocated a feature to a less desirable machine at a given instant, whereas had it waited for a short while, a more desirable machine might have become available. The authors then introduced the concept of time window into their improved algorithm to deal with this problem (Khoshnevis & Chen, 1990). Although the improved algorithm can yield better results, the computational complexity is increased. Another drawback of their approach is that because the process plans are generated in real time, if a feasible process for a given feature of a part is not found in the shop floor, the algorithm will fail.

There is another approach to perform both the process planning and production scheduling simultaneously in a distributed manner, starting from a global level (i.e. pre-planning) and ending at a detailed level (final planning), namely DTPP approach. DTPP performs process planning and production scheduling activities in parallel and in two phases. The first phase is pre-planning. In this phase, process planning function analyses the jobs/operations to be carried out based on product data. The features and feature relationships are recognised, and the corresponding manufacturing processes are determined. The required machine capabilities are also estimated. The second phase is final planning, which matches

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