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A neuro-fuzzy model for a new hybrid integrated Process Planning and Scheduling system

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A R T I C L E I N F O

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A B S T R A C T

In customized mass production, isolation of Process Planning (PP) and Scheduling stages has a critical effect on the efficiency of production. In this study, to overcome this isolation problem, we propose an integrated system that does PP and Scheduling in parallel and responds to fluctuations in job floor on time. One common problem observed in integration models is the increase in computational time in conjunction with the increase of problem size. Therefore in this study, we use a hybrid heuristic model combining both Genetic Algorithm (GA) and Fuzzy Neural Network (FNN). To improve GA performance and increase the efficiency of searching, we use a clustered chromosome structure and test the performance of GA with respect to different scenarios. Data provided by GA is used in constructing an FNN model that instantly provides new schedules as new constraints emerge in the production environment. Introduction of fuzzy membership functions in Artificial Neural Network (ANN) model allows us to generate fuzzy rules for production environment.

1. Introduction

Process Planning (PP) and Scheduling are production system components determining how and when to produce with respect to available resources. In today's manufacturing environment, generally PP and Scheduling are considered isolated activities from each other, and consequently these two production activities are carried out by different departments in a factory. This isolation creates a large time gap between PP and Scheduling, which in turn decreases the total production efficiency. The work done up to date in the field of Scheduling and PP mostly focuses on mass production environment. On the other hand, the isolation of PP from Scheduling and the resulting time gap between these activities is a critical problem that requires more attention. Being inspired by this fact, in this study our objective is to provide a model that does PP and Scheduling simultaneously in a customized mass production environment.

Integration of PP and Scheduling is an NP-hard (non-deterministic polynomial-time hard) problem and it is not possible to find the optimal solution in polynomial time. Generally, companies do not have the luxury of spending hours/days to iteratively plan production activities that dynamically change throughout the production process. Therefore, companies mostly prefer PP and Scheduling activities to be planned and coordinated by heuristics in reasonable time. To achieve coordination of PP and Scheduling activities, the necessity of reconfiguring PP and Scheduling departments arises. Tan and Khoshnevis (Tan & Khoshnevis, 2000) studied this issue, but their study has certain limitations. On the other hand, in the literature a more popular approach for this integration problem is to focus on the exchange of information between PP and Scheduling activities (Gaalman, Slomp, & Suresh, 1999; Gindy, Saad, & Yue, 1999; Guo et al., 2009; Shen, Wang, & Hao, 2006; Wang et al., 2009; Zhang, Saravanan, & Fuh, 2003).

Process plans usually provide inputs to scheduling just after the product design is completed and this corresponds to an earlier time than the start of production. In the meantime, job floor conditions change dynamically because of several reasons such as replacement of old machines, crises, strikes, disruptions in the supply chain, etc. A survey on this issue shows that 30% of the process plans need to be revised just before the production plans (Detand, Kruth, & Kempenaers, 1992). For detailed process plans and schedules, alternative production routes should be defined and chosen, followed by planning of operations for the chosen routes. The purpose of this study is to provide efficient production plans that are generated for the integrated problem of PP and Scheduling. Determining the alternative operations, machines, and sequence of operations during production are all parts of this integrated problem. As another objective, we do not want to sacrifice system flexibility and computational time for solving this integrated problem.

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Huang, Zhang, and Smith (1995) propose a nonlinear model for the integration problem, yet the assumption of one-way information flow from PP to Scheduling does not allow finding the optimal solution. As another drawback of their approach, some process plans created according to real-time production conditions may not be feasible. Later, based on Huang et al. (1995) approach, Tonshoff, Beckendorff, and Andres (1989) create process plans before manufacturing stage, they appoint a scheduling function for selecting the appropriate process plan according to the state of resources, and finally they apply active re-planning for fluctuations in the job floor. However, in this approach, repeating PP and Scheduling is very time-consuming operations and this makes their method not suitable for mass customization. In our study, by ensuring the information flow between PP and Scheduling and by using ANN, it is guaranteed to obtain effective production plans instantly as the shop floor conditions change. In addition, the use of ANN allows us to generate several feasible process plans to be stored in PP department for the case of manufacturing changes.

Kim and Egbelu (1999) compare a pre-processing algorithm, a mixed integer programming model, and a heuristic. They observe that the pre-processing algorithm takes shorter time than the mixed integer programming model, but longer than the heuristic. Increasing the number of jobs or process plans reduces the quality of heuristic's solution whereas increasing the number of machines has no effect. On the other hand, Weintraub et al. (1999) prove that scheduling with alternative routes has significant impact in meeting due dates in changing production environment. Considering both the positive and negative effect of available process plans in solution models, in this study we limit the number of process plans by eliminating non-promising routes in terms of processing time. Supporting our approach, Lee and Kim (2001) show that selecting process plans by a GA instead of using random combinations of process plans reduces the production time by 20%. Moon, Kim, and Hur (2002) prove that GA approach gives better results than "Tabu Search", a metaheuristic local search method that can be used for solving combinatorial optimization problems (Glover, 1989; Glover, 1990), in terms of calculation time for scheduling problem. Also GA gives better results than "Tabu Search" as problem size increases. They notice that population size and number of operations are main factors effecting GA's performance. Grabowik, Kalinowski, and Monica (2005) propose a new integration model that does PP several times to respond to fluctuations in job floor. Having alternative process plans before rescheduling increases the effectiveness of scheduling and flexibility of production system.

Iwata and Fukuda (1989) suggest that Scheduling and PP departments of a factory should be reorganized in order to get full use of Closed Loop approach (one of the approaches to the integration problem that require iterative PP and Scheduling). In addition to this, Closed Loop approach needs high capacity hardware and software. As production processes become more complex, this approach becomes unrealistic (Gindy et al., 1999). To overcome the deficiency of Closed Loop approach, in this study we use ANN, which eliminates the requirement of iterative PP and Scheduling. In our proposed model, both process plans and schedules are generated separately in an integration module and there is no need for reorganizing the factory.

Distributed integration is another solution approach for the integration of PP and Scheduling. Similar to Closed Loop approach, Scheduling and PP departments of a factory should be reorganized to apply distributed integration effectively (Haddadzade, Razfar, & Farahnakian, 2009). However, distributed integration is not accepted as an efficient method since it responds to changes in job floor through continuous feedback between PP and Scheduling, which requires longer computation time and more effort (Kempenaers, Pinte, & Detand, 1996).

During literature review, we observe that most of the earlier studies on integration problem suggest a solution model that uses a single algorithm, but as the solution and search space increase, the computational time increases dramatically. Therefore, in this study we propose a solution model that uses appropriate algorithms (shortest-path, GA, and ANN) to exploit specific structures embedded in the integrated problem.

As another observation, most studies in the literature ignore the fluctuations in job floor especially after scheduling. In addition to this, the majority of the available studies do not consider the fact that internal and external fluctuations make the available schedules infeasible before production. In this study, we propose a solution model using ANN. In the proposed system, ANN is trained by the outputs of PP and Scheduling integration module and by this way the production system is able to respond the fluctuations in job floor and regenerate new schedules on time. In the next section, we provide a mathematical programming model for the integrated PP and Scheduling problem and explain the main steps of our solution model. In Sections 3 and 4, the details of GA and ANN used in this study are given respectively. In Section 5, we analyze the experimental results. In Section 6, we discuss how fuzzy logic can be used in this model. Finally in Section 7, we provide our conclusions and suggestions for future studies.

2. Integration model for mass customization

The integrated PP and Scheduling problem is NP-Hard and it is not practical to use exact optimization algorithms to find the optimal solution. Yet, a mathematical programming model for this integrated problem with the objective of minimizing makespan would be as indicated in that thesis (Seker, 2013). However, it is not practical (and mostly not possible) to find the optimal solution for a mathematical model dynamically each time as shop floor conditions change. In this study we provide a new model that keeps process plans and schedules up to date according to changing customer demands and production conditions (most prominent features of mass customization production environment). The advantages of this model compared to the existing models in literature are:

1. There is no need for reorganizing PP and Scheduling departments. The communication between these departments is kept at optimal level (No iterative Scheduling and Process Planning).
2. Both schedules and process plans are stored in separate departments.
3. By using ANN, the model creates feasible and efficient process plans and schedules to respond the changes in production environment dynamically.

The main steps of the hybrid algorithm used in this model are:

Step 1 At time $T1$, for each job alternative process plans are created according to the job floor conditions.

Step 2 Under the terms of the job floor conditions at the time of $T2$ in PP department, alternative process plans are ranked by respective makespan lengths. Selected process plans with shorter makespans are sent to scheduling department. In Scheduling department, by using GA, schedules are generated subjected to makespan minimization objective. At the same time, best routes (process plan) used for scheduling is stored at PP department.

Step 3 At time T3, process plan fed back from Scheduling department to PP department is regenerated by using ANN. During this period, in Scheduling department optimal