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Hybrid stage shop scheduling

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ABSTRACT

The proposed hybrid stage shop scheduling (HSSS) model, inspired from a real case in the high-fashion industry, aims to fully exploit the potential of parallel resources, splitting and overlapping concurrent operations among teams of multifunctional machines and operators on the same job.

The HSSS formally extends mixed shop scheduling (a combination of flowshop and open shop), which is able to model routing flexibility, and hybrid shop scheduling, which provides resource flexibility. To also include operational flexibility through alternative plans obtained by reordering operations linked by undefined or arbitrary (immaterial) precedence constraints, the proposed model integrates process planning and group shop scheduling.

A mixed integer linear programming model and a theory based on disjunctive graphs have been proposed to explore the composite relations between nodes involving immaterial relations and deploying their routing rules.

A constructive $O(resources \times jobs^2)$ algorithm to generate a feasible plan/schedule in the most general case has been developed and applied to a case study.

1. Introduction

We consider a rather general model of *mixed shop* in which a set of operations for a given set of jobs has to be scheduled on a set of machines, which includes two extensions to the standard scheduling problem as defined by Dauzère-Pérès, Roux, and Lasserre (1998):

1. An operation can be processed by one resource chosen in a given set (*resource flexibility*); for the sake of generality, we use the standard term *resource* from the scheduling theory instead of machine.
2. The routing of products in the shop floor is not necessarily linear, i.e. an operation can have more than one predecessor and more than one successor on the routing (*nonlinear routing*).

The mixed shop type considered here is a *hybrid* (or *flexible*) *shop* type combination of *flowshop* and *open shop*. A hybrid flowshop is a flowline with parallel resources. In a flowshop, the sequence of operations of each job (routing) is linear and predefined; in an open shop the sequence of operations is immaterial (or undefined). In a mixed shop, the set of constraints between operations is partitioned into two sets: flowshop type set and open shop type set (Masuda, Ishii, & Nishida, 1985).

1.1. Integration of process planning and shop scheduling

Mixed shop is the paradigm for the integration of process planning and shop scheduling (Tan & Khoshnevis, 2000). Process planning has been defined by the Society of Manufacturing Engineers as the systematic determination of the methods by which a product is to be manufactured economically and competitively. Traditionally, process planning and shop scheduling are applied separately and sequentially. If a single output of process planning (the plan) is considered as the input to flowshop scheduling, routing constraints from planning may create bottleneck situations on some resources while other can be starving. Also the line balancing may be affected. Consequently, the global system performance can be improved by integrating planning and scheduling. However, the integration of process planning and shop scheduling does not consider operations belonging to the set of open shop type but rather the assignment of optimal process plans among a number of (predefined) alternatives. Stecke and Raman (1995) described a scheme for classifying different types of flexibility conventionally associated with the ability to manufacture a variety of part types by flexible manufacturing systems. In this classification *operation flexibility* assumes that more alternative plans can be generated by the process planner for a given job. Kis (2003) and Leung

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(2010) modeled an integrated process planning and shop scheduling system by disjunctive AND/OR graphs. The branches of an OR-subgraph constitute a set of alternative subroutes: exactly one of them must be chosen during scheduling. AND/OR graphs are a generalization of the resource alternatives of individual operations; however, immaterial constraints among operations cannot be considered effectively. Go, Wahab, Rahman, Ramli, and Hussain (2012) and Bentaha, Battaïa, Dolgui, and Hu (2014) approached the design of disassembly lines for end-of-life products with the objective to maximize the line profit. An AND/OR graph was used to model the precedence relationships among tasks and subassemblies and the disassembly alternatives. Doh, Yu, Kim, Lee, and Nam (2013) considered alternative machines for each operation (resource flexibility), in addition to specifying multiple process plans alternative operations and their sequence by a network model with AND/OR nodes. Otto and Otto (2014) described a precedence graph approach that is based on learning from past feasible production sequences and forms a sufficient precedence graph that guarantees feasible assembly line balancing in the automotive industry. The assignment of tasks to stations is due to restrictions, which can be expressed in a precedence graph that includes direct and indirect conjunctive precedence relations. Phanden, Jain, and Verma (2013) developed a simulation-based genetic algorithm (GA) to integrate the process planning and scheduling function that can be quickly implemented in a company with existing process planning and scheduling departments. Bensmaine, Dahane, and Benyoucef (2013) proposed a new heuristics to integrate the process planning and scheduling problem for reconfigurable machine tools, each with multiple configurations, and can perform different operations with different capacities. They considered only direct precedence graph relations.

1.2. Mixed and group shop scheduling

In order to reduce the gap with real manufacturing systems, the mixed shop scheduling problem has been regarded as a mixture of flow (or job) and open shop scheduling problems, where operations with immaterial precedence constraints are grouped in the route of the related job. In 1997, the *group shop scheduling* problem was first introduced in the context of a mathematical competition (Whizzkids '97, 1997). Regarding the group shop scheduling problem, Blum and Sampels (2004) used a disjunctive graph representation for group shop scheduling and applied an ant colony algorithm to tackle the problem complexity. Liu, Ong, and Ng (2005) proposed a tabu search for group shop scheduling and evaluated the algorithm performance on a set of benchmark problems. Ahmadizar and Shahmaleki (2014) considered the stochastic group shop scheduling problem where both release dates and processing times are random variables, normally, exponentially or uniformly distributed.

From the literature above, it can be observed that the mixed shop model includes the models on integration of process planning and scheduling and those on group shop scheduling, by allowing alternative plans produced simply reordering operations connected by immaterial constraints (Fig. 1).

According to Stecke and Raman (1995), in addition to operation flexibility, *routing flexibility* is another aspect of the scheduling flexibility related to the ability of generating alternative paths, which can be followed through the system for a given process plan. As discussed by Rossi and Lanzetta (2013), shared buffers between stages allow routing flexibility, by the permutation of job sequences on resources.

Fig. 2 shows as an (exclusive) OR node (node 0 towards O_{31} and O_{32}) that can be reworded as a no-exclusive OR by an immaterial relation, which allows more alternative routings for the scheduler module.

As shown by Masuda et al. (1985), the mixed shop problem is NP-hard. Relatively few papers were proposed on the subject. Shakhlevich, Sotskov, and Werner (2000) discussed the complexity of mixed shop problems under various criteria and clarified the boundary between polynomially solvable and NP-hard problems. Blazewicz and Kobler (2002) reviewed the properties of simple

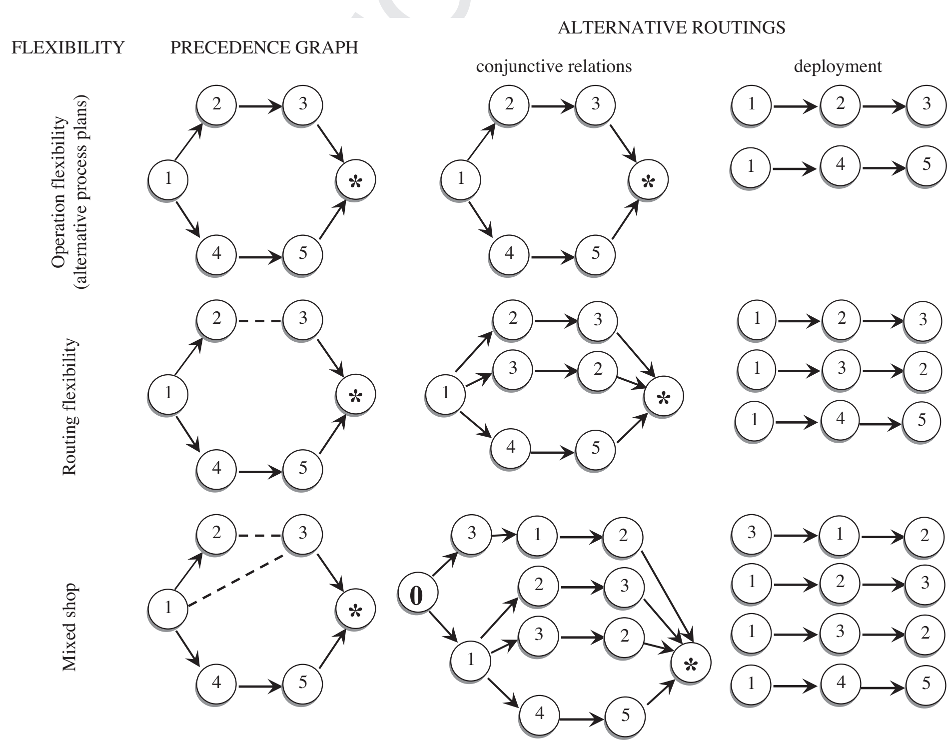

Fig. 1. Example of mixed shop precedence graphs achieved by operation and routing flexibility (according to Stecke & Raman, 1995). No-exclusive OR nodes described by immaterial relations give alternative routing for the scheduler module in order to minimize the completion time.

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