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Two-way scheduling optimization of the supply chain in one-of-a-kind production based on dynamic production capacity restrictions

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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

One-of-a-kind production (OKP) is the extreme mode of mass customization. An OKP supply chain is studied as a pull-based production model with time-variant nature and lean manufacturing feature in this paper; meanwhile, its characteristics and a systematic analysis of a core idea in OKP supply chains are demonstrated. Supply chain scheduling optimization in OKP requires a dynamic optimization involving stochastic demand and time-variable resource restrictions. To resolve this problem, the dynamic production capacity restriction, which is the dominant restriction mechanism in an OKP supply chain, is investigated based on a process-driven service performance analytical computation from the perspective of dominant members (i.e. core OKP enterprises) in an OKP supply chain. To address the contradiction triggered by the dynamic production capacity restriction relation, an integrated stochastic dynamic optimization model based on a dynamic pricing mechanismn is proposed for two-way scheduling optimization in an OKP supply chain. The two-way supply chain scheduling optimization, on one hand, coordinates every member's remaining production capacity and, on the other hand, schedules key orders and general orders from customers to reduce the total production cost and time.

1. Introduction

As a typical manufacturing paradigm, one-of-a-kind production (OKP) presents various production management challenges and is controlled differently than is mass production. An OKP industry can be characterized by the following: (1) The industry's product designs essentially change with every new order (Madsen et al. [13]). (2) Most of their customers' orders contain one and only one product type (Madsen et al. [13]). (3) Most OKP products are produced only once, and although certain OKP products may be repeatedly produced, there is no fixed repetition period (Mei et al. [14]). In this non-repetitive manufacturing mode that produces various customized products with unique components, "productivity improvements do not reproduce like in mass production" (Tietze et al., pp. 21 [25]). (4) Production stability is poor, and the production and process specialization degree are low owing to "varying production requirements, inadequate operation experience, the unique components and related operations in OKP" (Wang et al., pp. 20 [26]); most of the work requires multiple processes. Finally, (5) the production automation level is low compared to non-OKP industries (Mei et al. [14]). OKP is generally complex and flexible manufacturing that is time-variant because dynamics of production state should be "timely detected and controlled, otherwise serious order delays and work-in-progress redundancies would occur" (Wang et al. [26]). The traditional production management and control system, theory, and methods for mass production do not handle this situation well because these technologies are developed with a view to time-invariant or static production state in large batch scale "push-type" manufacturing based on demand forecast (make-to-stock) instead of actual demand.

Physical examples of OKP industries can be easily found in heavy-equipment-type industries, e.g., shipbuilding, large electrical equipment building, heavy machinery building, steel structure building, special equipment manufacturing. These large-scale OKP represent the extreme mode of mass customization, and thus is just-in-time (JIT) production which is based on the demand side and attempts to operate with zero inventory. Generally, JIT production in OKP is a "pull" and "one piece flow" type of production, which combines "dashboard management" and the core technology of JIT control to achieve lean production in all production links. A pull production system in OKP means make-to-order, in which one-of-a-kind products are produced based on actual demand from customers; in addition, one piece flow implies an ideal state of efficient operations, where parts are manufactured one at a time, and flow throughout the manufacturing and supply chain as single unit, transferred as customer's order. OKP enterprises represent the core of OKP supply chains, so OKP supply chains

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are typically modelled as pull-based lean production models that are time-variant.

From the aspect of supply chain at a macro level, scheduling optimization of an OKP supply chain is a typical dynamic optimization problem: the production resource utilization in an OKP supply chain should be maximized, which determines multiple aspects (e.g., minimize cost or production time) for evaluating the supply chain performance. From the aspect of OKP manufacturing at a micro level, the time-varying stochastic demand, which results from the arrival uncertainty of discrete customer orders and non-substitutability of time-varying production resources (are collectively called the time-varying stochastic demand), strongly influences the production system transient performance of OKP manufacturing and therefore necessitates the dynamic scheduling optimization based on dynamic production capacity restrictions in an OKP supply chain.

In this paper, OKP supply chain scheduling mechanism will be studied based on an analysis of the dynamic production capacity of the supply chain's dominant members, i.e. core OKP enterprises. The dominant members, known as chain leaders, have a strong direct or indirect influence on supply chain resource allocation and application. Furthermore, "two-way" scheduling optimization based on a dynamic pricing mechanism for an OKP supply chain will be discussed. The remainder of this paper is organized as follows. Section 2 presents a literature review. Section 3 describes the characteristics of the production pattern and dominant restrictive factors in OKP supply chain. Section 4 introduces an OKP dynamic production capacity analysis based on a process-driven service performance analytical computation of a case study in a shipbuilding block production yard. Section 5 presents an integrated stochastic dynamic optimization model for scheduling optimization in an OKP supply chain and discusses the performance of this dynamic optimization scheduling. Finally, Section 6 draws conclusions and proposes future research.

2. Literature review

Research on the scheduling optimization of supply chains and enterprise production planning has been performed for many decades, and the literature and research reports concerned with production operation management in manufacturing are extensive. However, to the best of our knowledge, there are only a relatively small number of references that discuss, to a meaningful extent, the relationship between a manufacturing enterprise's dynamic production capacity constraint and the scheduling optimization of an OKP supply chain. In this section, several representative papers are briefly reviewed and then the requirements for the substantial characterization of the dynamic production capacity of an OKP are discussed.

2.1. Literature review on make-to-order system or mass customization

Johansen et al. [11] discussed a decision structure model for OKP decision process. Xiao et al. [27] developed game-theoretic models to explore the interactions between channel structure decision and the price-leadtime decisions for a make-to-order duopoly system under three game scenarios. Thürer et al. [24] outlined a planning and control concept known as workload control (WLC) that integrates customer enquiry management, including a due-date setting rule, with order release control. Feng et al. [9] studied the coordinated contract selection and capacity allocation problem, in a three-tier manufacturing supply chain, with the objective to maximize the manufacturer's profitability. Sawik [22] analyzed the selection of a dynamic supply portfolio in make-to-order environment with risks. Gunasekaran et al. [10] provided a review of the literature available on the modeling and analysis of BTO-SC or MTO-SCM (the build-to-order supply chain or make-to-order supply chain management) that may be useful for developing a unified framework based on configuration and coordination level issues for the modeling and analysis of BTO-SC; and suggested some important problems in BTO-SC. Rubino et al. [21] considered a dynamic control problem for a make-to-order, parallel-server queuing system; and proposed a nongreedy outsourcing and resource allocation policy. Chen et al. [8] considered an integrated production-distribution scheduling model in a make-to-order supply chain consisting of one supplier and one customer; and found a schedule for order processing and a way of packing completed orders to form delivery batches such that the total distribution cost is minimized subject to the constraint that a given customer service level is guaranteed. Celik et al. [7] presented a method of dynamic pricing and lead-time quotation for a multiclass make-to-order queue. Yao et al. [29,28] discussed supply chain planning and scheduling optimization in mass customization. Ata [3] considered an admission control problem for a multiclass, single-server queue and proposed a nested threshold policy. Bish et al. [5] showed that the performance of the system depends heavily on the allocation mechanism used to assign products to the available capacity through a stylized two-plant, two-product capacitated manufacturing setting.

2.2. Literature review on production planning with stochastic customer orders

Pazour et al. [18] studied rental vehicle threshold policies that considered expected waiting times for two customer classes. Souza et al. [23] analyzed incorporating priorities for waiting customers in a hypercube queuing model in an application of an emergency medical service system in Brazil. Roy et al. [20] presented queuing models to analyze dwell-point and cross-aisle locations in autonomous vehicle-based warehouse systems. Altendorfer et al. [2] discussed the influence of order acceptance policies on optimal capacity investment with stochastic customer required lead times. Renna et al. [19] proposed an approach to deal with the multiple suppliers-manufactures problem within dynamic industry cluster. Altendorfer et al. [1] compared made-to-stock and made-to-order processes in multi-product manufacturing systems with variable due dates. Morabito et al. [16] examined approximate decomposition methods for the analysis of multicommodity flow routing in generalized queuing networks; their focus was on steady-state performance measures such as average delays and waiting times in the queue.

Some relevant contributions dealing with the multi-objective optimization of supply chains are as follows. Musavi et al. [17] presented a multi-objective sustainable hub location-scheduling model for perishable food supply chain; however, the parameters of the model like demand and travel times in this research are assumed as deterministic, which shows some limitations in tackling uncertain environments. Bortolini et al. [6] also proposed a tri-objective linear programming model for the design of multi-modal fresh food distribution networks.

From the aspect of production approach, OKP is the extreme mode for highly customized and low volume products, which is make-to-order; while from the aspect of production object, OKP is the production of one product type, rather than the production of large amounts of standardized products. "Make-to-order" is only considered as one attribute of OKP. Because of OKP's particularity and its characteristics, its production time-variant nature should be considered. Most researches on BTO-SC or MTO system lay stress on the conversion of stochastic problems which are caused by uncertainty of customer orders; however, do not focus on the time-variant nature of the system itself (especially OKP system) that results from the pull-based production which is based on actual demand. Methods generated from traditional push-type production or mass production, which is based on demand forecast and make-to-stock, are still widely used in the research of the above production pattern. These methods, in different extent, show limitations in the study of OKP system. In this paper, we reckon that time-variant nature of OKP system gives rise to time-variable resource restrictions; what's more, triggers the principle contradiction of system resource allocation.

For most of the OKP enterprises, although the average service time