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An integrated model for production and batch shipments for ramp-up production

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ABSTRACT

The cost-effective fulfillment of demand requirements during a ramp-up period should be deliberately managed since both production rate and demand rate are variant due to the learning effect in a production system as well as a demand growth during this period. In this work, the issue of integrative scheme of production and supply planning from a manufacture to a retailer is studied to minimize the overall relevant cost during a ramp-up period. Basic decisions from the developed model are the composition of work cycles during a ramp-up period, the resource deployment plan for each production period and the amount of batch shipments while considering the learning effect of manufacturing resources (for example, machines, human workers, and so on). Detailed solution procedure for determining those decisions is proposed and the numerical analyses with it are done to analyze the effects of several key operating parameters. Based on correlation analyses with randomized test instances, several managerial implications are finally discussed.

1. Introduction

In terms of "time-to-market" as well as "time-to-volume", a responsive supply chain should be designed and implemented by effectively controlling the ramp-up period, which is an early stage of product life cycle after new product introduction. A successful arrival at the mature stage to ensure stable sales volume depends on how the company effectively and efficiently manages the ramp-up period. One of critical performance measures must be to satisfy the demand growth without incurring any shortage by synchronizing two inter-connected functions, i.e., production and distribution. Thus, a responsive fulfillment for demand requirements during the ramp-up period after introducing new product to the market must be deliberately implemented while controlling the overall cost which is incurred for investing resources for production and holding the inventories for satisfying the expected future demand. It is clear that one outstanding and noticeable situation which characterizes the ramp-up period is the growth in demand after new product appears in the market. In addition to the dynamics in demand pattern, it is also expected that the production rate itself is a function of experience for production from the time of production initiation because of the learning effect. In other words, the production rate would be proportional to the time length of experience for production regardless of resource types such as manual worker and mechanical system. Thus, the management of production resources should be also incorporated into the issue of production and delivery decision to provide timely fulfillment while controlling the operational cost for those resources. The issues of managing the successful ramp-up period with the learning effect could be found out on the various business situations such as the re-location of current production facility to new site, the employment of new workers, and the re-configuration of existing production system and so on (Abele, Meyer, Naher, Strube, & Sykes, 2008; Fleischmann, Ferber, & Henrich, 2006). One critical concern for those business situations is the learning effect of the production resources as a function of experience in time for manufacturing since it is a definitely key factor for production capacity. In addition, the policy for fulfilling the market demand should be carefully developed to establish the competitive supply chain since the performance of demand fulfillment at the early stage must be a significant measure for business excellency. Thus, to be more competitive supply chain operation, it is absolutely necessary to integrate other business functions such as the demand planning, distribution policy and resource management plan in addition to managing the ramp-up period. We observe that it has been rarely studied to develop the model coordinating both production and distribution policy with the consideration of the production resource deployment plan even though the scope of integration over .

The remainder of this paper is organized as follows. Section 2 briefly shows the related previous works for several key topics which are related to the developed problem in this paper and problem description is provided in Section 3. In Section 4, we develop the mathematical model for optimizing the problem and then solution procedure is proposed in Section 5. From the extensive numerical analyses, several key managerial findings are described in Section 6. Finally, Section 7 draws the conclusion and proposes the directions for future works.

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2. Literature review

A manufacturing period for ramp-up (or start-up) production is an essential one when either new product would be introduced or the existing production facility (or machine) is relocated. Recently, Surbier, Alpan, and Blanco (2014) presented a thorough state of the art on the ramp-up production problems. They defined several different overviews such as comparing definitions, characteristics and problems of the ramp-up phase and classifying papers according to their industrial context. In addition, they proposed interesting issues which are worth of being studied. Also, Glock and Grosse (2015) provided extensive overview of decision support models for production ramp-up by making categories for typical planning problems and process characteristics of the ramp-up phase.

From the perspective of strategy for ramp-up production to be aligned with the market development, the first step would be the strategical investigation about the economical and valid approach for building up the ramp-up for new product at the current locations or new location for the current running product. Terwiesch, Bohn, and Chea (2001) tried to explain the concept of a “copy-exactly” ramp-up strategy, which does not allow for any change in the production process. Terwiesch and Xu (2004) presented a case study of product transfer and production ramp-up in the hard disk drive industry and provided a detailed description of the ramp-up period. They documented detailed time-series of several operational measures and showed the various forces that allow an organization to increase its target production volume. Also, Wan, Wang, and Fung (2005) proposed a quantitative approach to screen product to the market. They classified new product into four groups based on their benefit curve and parameters. And then, they developed a 0–1 semi-infinite programming model for choosing the new products which are introduced to the market. Niroomand, Kuzgunkaya, and Bulgak (2012) studied the issue of allocating alternative manufacturing systems such as dedicated manufacturing systems, flexible manufacturing systems and reconfigurable manufacturing systems for the ramp-up period. In addition, Li, Shi, Grefory, and Tan (2014) studied the issue of how technology-intensive manufacturing firms operate to achieve rapid new product volume ramp-up capabilities within an international collaborative supply network based on an exploratory multiple-case longitudinal research methodology for three large Japanese multinational corporations and their respective international manufacturing supply networks. Hansen and Grunow (2015) developed a capacity planning model for a new pharmaceutical drug, which determines the number and location of new production lines and the build-up of inventory to assure the availability for market launch. In addition, Wochner, Grunow, Staeblein, and Stolletz (2016) developed a mixed-integer linear programming model to support the activities for sales and operations planning for ramp-ups and new product introduction in the automotive industry. Both Ennen, Reuter, Vossen, and Jeschke (2016) and Klocke, Stauder, Mattfeld, and Muller (2016) have tried to develop a new ramp-up model which could predict the ramp-up behavior of manufacturing technologies and the mechanism to control the ramp-up production system.

The most significant and sensitive concern would be to take into account the learning effect for new production system, i.e., new product or new location. Hiller and Shapiro (1986) developed mixed integer programming models to optimize the coordinated production and capacity expansion plans by taking into account the learning effects. Mazzola and McCardle (1996) presented a Bayesian decision theoretic model for optimal production planning in the presence of learning-curve uncertainty. They extended the well-known learning-curve model to allow for random variation in the learning process with uncertainty in some parameter of the variation. Also, Mazzola and McCardle (1997) studied a stochastic learning-curve model by taking into account random variation in the decreasing cost function. First, they studied a discrete-time, infinite-horizon, dynamic programming formulation for monopolistic production planning structure in case when costs follows a learning curve. And then, this model was extended to incorporate random variation in the learning process. Carrillo and Franza (2006) investigated investment strategies related to the timing and duration for investments in both design and process capacity over a given planning horizon and developed the guidance for the optimal time-to-market and ramp-up time necessary to fulfill peak demand for the newly introduced product. Glock, Jaber, and Zolfaghari (2012) presented a production-planning model for ramp-up period in case that the learning effect exists in production and growth in demand rate during the ramp-up period. Based on available empirical data, they tried to use the validated labor production and demand functions. Their work also showed that the total production cost could be minimized if there is no interruption or idle time during the ramp-up phase and both production and demand rate are closely synchronized as much as possible. Kazemi, Shekarian, Cardenas-Barron, and Olugu (2015) developed a fuzzy EOQ inventory model by taking into account the backorders with the human learning over the planning horizon. Also, Jin, Thomas, and Hewit (2016) studied the optimization techniques for minimizing the makespan in case that human learning is explicitly considered. As seen in these works which took into account the learning effect, the learning effect would be surely a meaningful and attractive influential factor for more sound production system. Above all, at the design phase for the production system, one possible concern would be to assess the alternative production systems and then choose the best alternative by considering the economic feasibility of production system. Secondly, during the operating phase after realizing the production system, the works for composing the production plan would be so significant with the updated information for the learning effect.

In addition, the issue of designing and implementing the stable and robust quality management must be also critical parameter for successful ramp-up production. Chakraborty, Giri, and Chaundhuri (2009) developed integrated production, inventory and maintenance models for a deteriorating production system in which the production facility may not only shift from an ‘in-control’ state to an ‘out-of-control’ state but also may break down at any random point in time during a production period. Jeang (2012) studied the integrated issue for production-inventory management with process-quality design for determining production lot size and process parameters under the possibility of process deterioration. The quadratic quality loss function was introduced to assess quality loss within the system. The developed model could be applied at an earlier time in the process design and production management stage.

As Glock and Grosse (2015) discussed, several operational decisions should be carefully addressed such as the composition of production capacity deployment, scheduling/rescheduling issues, lot-sizing decision, and decision for worker assignment to designed workstations. Thus, to be effective and successful ramp-up production, it is absolutely basic requirement to establish the economical operational decision on the production resource deployment considering the learning effect over the inter-related functions and activities such as the integration of production-delivery activity. More concentrated works for lot-sizing in a ramp-up phase could be observed in the several works (Manna & Chaudhuri, 2006; Manna & Chiang, 2010; Panda, Saha, & Basu, 2009; Skouri, Konstantaras, Manna, & Chaudhuri, 2011)

Thus, from our brief overview of the related literature as presented above, one of the most critical success factor for the successful ramp-up production must be the time-to-market and even time-to-volume during the planned ramp-up period. To the best of our knowledge, it is hard to find out the works for studying the extending the issue of ramp-up production plan with other related business areas such as the detailed production resource planning and the distribution to the retailer(s). Thus, the close integration between production with a learning effect and delivery of the manufactured goods to the retailer(s) or market should be managed in an integrative manner. Thus, it is expected that this work could reduce the research gap by developing the optimization model and solution approach to optimally manage this managerial concern.