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Technical Paper

The stochastic lot-sizing problem with lost sales: A chemical-Petrochemical case study

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ABSTRACT

The recent evidence shows that production planning problems (e.g. lot sizing) in the manufacturing systems in general, and in the petrochemical sector in particular, can be very challenging. This fact, that the flows of chemical materials usually are continuous and the demands of chemical-petrochemical products inherently are uncertain, motivating researchers and practitioners to deal with stochastic lot sizing models in this manufacturing systems. This paper formulates such problems by taking distribution functions (discreet and continuous) into account. Moreover, lost sales are considered under the "static uncertainty" strategy. A solution methodology, additionally, is presented to determine the optimal timing and level of orders, when demand is defined by a discrete distribution function. To show the efficiency and effectiveness of proposed models and solution algorithm, a chemical-petrochemical case study as well as two other numerical example are described and solved.

1. Introduction

With an attentive look, one could realize that all parameters inherently are uncertain, particularly when a long planning horizon is considered. On the other hand, the continuous flow of materials in chemical process industries makes the production planning of such production systems more complex. For the sake of understandability; we consider currently both continuous and discrete demands.

The literature commonly recognizes that the last developments obviously demonstrate a massive progress on the integration of the decision-making processes with optimization algorithms. Whereas, some open issues have been reported recently by the literature. The computational performance, modeling uncertainty, multi-scale optimization, or the modeling task itself are the most common ones [1]. In this paper, a methodology is addressed to integrate the decision-making processes with the lot sizing model-based approaches. In particular, we propose a lot sizing problem in the chemical–petrochemical industry from an integrated perspective. This integration was strongly motivated by the necessity of solving, in close collaboration with a company, a day-to-day lot sizing problem. This need triggered off the process industry, and in this paper a solution algorithm is adopted and has been proven by solving real world chemical-petrochemical examples.

The rest of the paper is structured as follows: a literature review on lot-sizing problems is presented in Background Section to understand the conceptual framework, find out some gaps of the literature, and show the main contributions of this study. Problem Statement and Developed Model Section describes details of the proposed problem and formulates the model. We start by presenting the assumption, defining the notations used, and then we translate the proposed problem into two models, under continuous and discrete demand distribution. Since by increasing the size of problem the discrete demand model becomes very complex, a solution algorithm is developed in Solution Methodology for Discrete Demand Distribution. A real world lot sizing problem from the chemical-petrochemical industry and two other numerical examples are solved to show efficiency and effectiveness of proposed models and solution methodology, in Computational Results. Finally, the concluding remarks are presented in Conclusions.

2. Background

Planning and scheduling decisions are two critical challenges to perform in industries. They seek to allocate limited resources to functions, over a given time window. Among those, production planning and inventory management have received a great deal of attention, due to their huge importance for companies to reduce their costs, be more flexible, faster, more responsive, and finally gain more competitive advantages.

Production planning involves the allocation of limited production resources to production operations, while satisfying

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customers' demand and requirements, often by trade-off conflict production goals over a given time window, is called the planning horizon [2,3]. In terms of the planning horizon, production planning activities can be categorized into: (a) the long-term planning accounts for the structure of the supply chain, called strategic network planning; (b) the mid-term planning deals with the determination of material requirements planning (MRP), and production targets in the given planning period, while meeting supply chain's constraints (e.g. demand requirements, capacity restrictions, etc.) in order to optimize predetermined decision criteria such as minimizing the overall costs, maximizing the net present worth of profit, minimizing the environmental impacts, and maximizing the social performance; and (c)the short-term planning is responsible for day-to-day scheduling of production operations.

Lot sizing is a mid/short term production planning that involves finding out the optimal level and timing of production [4]. Lot sizing models can be classified according to the demand distribution and planning horizon. The early model in this field dates back to the famous Economic Order Quantity model (EOQ) by Harris [5]. This model considers constant and deterministic demand rate, and infinite planning horizon. A generalization of the EOQ model is the model of Wagner and Whitin [6], which is known as the dynamic lot-size model. The demand for the product, in this model, is not constant and varies over time. The Economic Lot Scheduling Problem (ELSP) by Elmaghraby [7] is another extension of the EOQ model in which multiple items and constant production rates are taken into account.

According to the literature, the lot sizing problem can be categorized in terms of several dimensions. A plethora of classification schemes exists in the literature to classify lot sizing problems. Most of them take specific aspects of a certain problem into account, instead of universal scheme [8]. Glock et al. [9] present a technical scheme to classify lot sizing problems. They consider the nature and conditions of the Product, the prevailing supply, and demand as the most important aspects to classify lot sizing problem (see also [8]). Existing lot sizing problem can be distinguished along these attributes: (a) whether parameters can vary over time in the model (dynamic models vs. stationary models) or not; and (b) whether uncertainty is taken into account by model or not (stochastic models vs. deterministic models). The current work studies an interesting combination of both of these attributes to formulate a stationary problem under uncertainty condition, called the stochastic stationary lot sizing model.

As discussed, demand conditions influence inventory process. In this light, lot sizing models cast into the two major groups which are: (a) deterministic demand lot sizing models, and (b) stochastic demand lot sizing probes. There are a lot of research work regarding the inventory problems with stationary demand assumption while there are few work carried on the dynamic stochastic demand case (see the work of [10,11]). Martel et al. [10] and Sox [11] presented a static control policy over a rolling horizon. Resembling the Wagner and Whit in [6] algorithm, Sox [11] developed an algorithm to deal with a mixed integer non-linear formulation of the dynamic lot-sizing problem with dynamic costs. Martel et al. [10] transformed the multi-period multi-item production problem into a multi-period static decision problem under risk. In addition, some other well-known participations employed the (s,S) or base-stock policies in this context. Iida [12] developed a myopic policy to support decision making in the periodic review dynamic inventory problem in the infinite horizon. He showed that this policy results in close approximation of an optimal decision. Sobel and Zhang [13] elaborated a modified (s,S) policy that is generally optimum, if demand arrives from both deterministic and random source simultaneously. Gavirneni and Tayur[14] showed that the (s,S) policy could be applied for broader variation in the problem parameters. Even though, Sox [11]indicated that the static-dynamic uncertainty model is a more accurate representation of industrial practice, Gavirneni and Tayur[14] adopted static control policies in a rolling horizon framework or dynamic control policies like (s,S).

The model of Aksen et al. [15] is a valuable example of former category, in which the single-item multi-period lot-sizing problem with lost sales is presented. They consider a deterministic nature for demand over the time period. Also conventional stochastic models for production systems can be split into single or multi-period systems. In this regard, Lodree [16] supposed single period problem which consisted backorders, lost sales and a lost contract. This issue is common in the supply chain where costs consist of linear ordering, inventory and shortage costs. Tarim and Kingsman [17] also explained a multi-period single-item stochastic lot-sizing assuming in which shortage is considered as the backlogged demand. Their model was provided with a constraint that the probability of the closing inventory in each period is set to at least a certain non-negative value. Afterward, Tarim and Dogru [18] provided a computational approach to solve the mixed integer programming (MIP) model of Trim and Kingsman [17] under the static-dynamic uncertainty strategy. Axsäter [19], like previous researchers, only considered backlogged shortage. Zhang et al. [20] elaborated a simulation based approach to optimize the scheduling of fuel gas system in refinery. A dynamic lot-sizing problem for a multiple product single machine is presented by Kang et al. [21]. Since the relationship between the output and lot sizes level is nonlinear, they used queuing models to deal with this nonlinearity. A heuristic method for solving such stochastic lot-sizing problems was proposed by Piperagkas et al. [22]; where it has been supposed that unsatisfied demand is fully backlogged and a backlogging cost is assessed at the end of each period per unit backlogged. Completing their work, Alem and Morabito[23] suggested a robust optimization for production planning. Hill [24] developed a system model with lost sales and a fixed lead time; and demand for an item was generated by a Poisson process. The holding cost per unit of inventory and lost sale cost for each shortage, for every unit of time, were considered. The objective was to find a stocking policy which minimizes the expected value of total cost per unit time. In fact, the author considered a continuous-review lost-sales inventory model with Poisson demand. In Donselaar and Broekmeulen [25], the authors studied a single-item inventory model with periodic reviews at a single retailer location. Bijvank and Vis [26] extended this model with a penalty costs for lost sales as cost models and used the average fill rate as service level, which is defined as fraction of demand directly satisfied by stock on hand. A MIP model is elaborated by Ramezanian et al. [27] to formulate a multi-stage capacitated lot-sizing problem. They integrate lot-sizing with maintenance planning to present real manufacturing systems.

Due to the competitive environment in most of the today's business markets if one supplier cannot fulfill consumers' needs immediately, other suppliers will satisfy them. According to Gruenet al. [28] and Verhoef and Sloot [29], just a small portion of customers, who observe a stock out, will wait for the item to be on the shelves again. In other words, the majority of customers will buy a different product, visit another store, or do not buy any product at all. Therefore, there are many commercial systems where shortage costs should be considered as costs of lost sale. To the best of our knowledge, the most work in the literature consider back-ordering for the multi-period single-item stochastic lot sizing problem. This fact happens due to the complexity and difficulty of modeling discrete time inventory models, under stochastic demands, over a constant lead-time, and with lost sales [30]. Karlin and Scarf [31] and Morton [32] dealt with lost sale as a function of the inventory on hand, sought to determine the optimal timing and level of orders. They figured out that the state space increased rapidly as the lead-time increased. Hence, finding optimal points