Planned lead times optimization for multi-level assembly systems under uncertainties

Oussama Ben-Ammar [a,*], Alexandre Dolgui [a], Desheng Dash Wu [b]

[a] IMT Atlantique, LS2N, UMR-CNRS 6004, La Chantrerie, 4 rue Alfred Kastler - B.P. 20722, 44307 Nantes, France
[b] Risklab, University of Toronto, Toronto, ON M5S 3G3, Canada

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ABSTRACT

Planned lead times are crucial parameters in management of supply networks that continue to be more and more extended with multiple levels of inventory of components and uncertainties. The object of this study is the problem of determining planned lead times in multi-level assembly systems with stochastic lead times of different partners of supply chains. A general probabilistic model with a recursive procedure to calculate all the necessary distributions of probability is proposed. A Branch and Bound algorithm is developed for this model to determine planned order release dates for components at the last level of a BOM which minimize the sum of inventory holding and backlogging costs. Experimental results show the behavior of the proposed model and optimisation algorithm for different numbers of components at the last level of the BOM and for different numbers of levels and values of holding and backlogging costs. The model and algorithm can be used for assembly contracting in an assembly to order environment under lead time uncertainty.

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1. Introduction

In today's global marketplace, planners have to take appropriate actions in response to supply disruptions [30,48,49] and supply uncertainty [22,46,53]. In comparison to supply-demand coordination uncertainties, Revilla and Sáenz [44] defined disruption as random, unplanned events that stop operation either completely or partially for a certain duration. Snyder et al. [49] specified that disruptions can often be viewed as a special case of lead time uncertainty.

In the last few years, academics and decision-makers have recognised that supply chains have become extremely vulnerable due to uncertain lead times, demand prediction and price variability. For planners, it seems difficult to improve the efficiency of the supply chain when lead times frequently have uncertain values [4]. They therefore have to manage assembly and delivery as an uncertain process.

In the Assemble-To-Order (ATO) environment, finished products are assembled only after customer orders have been received. This kind of environment enables firms to assemble on customer orders with a specific quantity and due date, and so unwanted inventory of finished products can be zero.

Despite the widespread adoption of the ATO environment, there are considerable weaknesses. Some input data are often considered as deterministic parameters, but in reality are inherently uncertain. For example, the assembly process can be interrupted by machine breakdown and components replenishment lead times may be significantly longer than planned ones. Therefore, the stock-out of one component may delay the delivery of finished products.

The literature reports many investigations into production planning that consider the randomness of the finished product demand [32,37,42], but few studies have examined how to cope with the uncertainty of lead times [10,24]. Safety stocks have largely highlighted how to handle different uncertainties, whereas safety lead times have not been sufficiently studied. Interested readers may refer to Van Kampen et al. [52], where the cases in which the use of safety stocks and/or safety lead times could be advantageous are explained, or to Jansen and de Kok [28] for further details on the importance of lead time anticipation. More generally, readers who are interested in supply planning models under uncertainty may turn to Aloulou et al. [1], Díaz-Madroñero et al. [11], Dolgui et al. [14], Ko et al. [31], Peidro et al. [42], Mula et al. [37] and Koh et al. [32].

Therefore, it is necessary to examine the influence of lead times on supply planning and to develop methods that minimize costs, considering the non-deterministic behavior of lead times. In this study, we consider an ATO environment. The whole supply network is configured for a given tailored finished product. This prod-

* Corresponding author.
E-mail addresses: oussama.ben-ammar@imt-atlantique.fr (O. Ben-Ammar), alexandre.dolgui@imt-atlantique.fr (A. Dolgui), dash@risklab.ca (D.D. Wu).

uct is customized according to the customers' requests and composed of a given set of personalized components.

Our problem arises at contract negotiation step. A client orders a specific product, we need to design the corresponding supply network and decide both (i) the due date for client delivery and (ii) the date when the overall process is launched at the bottom level. All partners of the supply network (local assembly units or suppliers) are independent enterprises. Thus we cannot coordinate activities inside them. But we are responsible for client delivery at the fixed due date, and we know, at the supply network design stage, the statistics on lead times of all partners. We are thus able to give to the client an estimate of the total lead time, and launch the overall process at the bottom level.

In our case, the demand of clients is not known in advance, and no stocks of finished products or components are planned to anticipate this demand. As stated in Berlec et al. [5], Chandra and Grabis [8], Arda and Hennet [2], Golini and Kalchschmidt [23], Farhani et al. [20], in this case, the planners need information about the tailored product, personalized components and assembly process to negotiate the delivery time with the customer, select suppliers and plan release dates based on cost and lead times.

Obviously, the lead time are uncertain because of different factors including capacity constraints, machine breakdowns, stochastic variations on operation processing times, etc. However, at the considered stage, we know only the distributions of probability for partners' lead times (based on statistical data). Different components produced by different partners need to be assembled to obtain a finished product. So to decide the client delivery due date and the start times for supply chains, a model based on the probability distributions of the partner lead times is developed. This is a common approach in contracting and planning under uncertainty [5,21,47,57], which is commonly used owing to the complexity of the problem [10,11,14,17,24,32].

The rest of the paper is organized as follows. Firstly, we make a short review of previous work on the optimization of assembly systems under lead time uncertainty (Section 2). A description of the problem is presented in Section 3. The analytical model is given in Section 4. In Section 5, a technique is given to reduce the initial space of research. It will be used with a Branch and Bound algorithm to optimize the mathematical expectation of the total cost (Section 6). Some results are shown in Section 7. Finally, we outline the work done in a conclusion, and give some perspectives for future research.

2. Related publications

An analysis of the literature shows that in the case of assembly systems, the lead time is most often considered deterministic and rarely uncertain. To handle the uncertainty of lead times, the studies found in the literature can be split into two categories: one-level and multi-level assembly systems [14]. Yano [54] was among the first to study assembly systems with supply timing uncertainties after her studies on serial production systems [55,56]. In Yano [54] only the case of the single-period model was considered. The assembly system is composed of one component at level 1 and two components at level 2. The lead times of these three components are considered stochastic. An algorithm was developed to find optimal planned lead times, which minimize holding and backlogging costs. This study has been cited 148 times and in subsequent publications, models have been limited to one or two-level assembly systems [7,9,14,19,25,27,36,50]. Chu et al. [9] addressed the same problem, but in the case of one-level assembly systems. The convexity of the expected total holding and backlog costs was proven, and an iterative algorithm was used to minimize it.

Dolgui et al. [16] and Dolgui [13] developed an approach based on the coupling of an integer linear programming and a simulation to model a multi-period problem. They studied one-level assembly systems under a deterministic demand and random lead times in the case of the lot-for-lot policy. The authors considered several types of finished product. Several types of component are needed to assemble a finished product, and for each component, an inventory holding cost is considered. In this study, both the number of components to be ordered at the beginning of each period and the number of products to be assembled during each period are determined.

Ould Louly and Dolgui [38], Dolgui et al. [15] and Ould Louly et al. [39] were focused on one-level assembly systems for one product under component lead time uncertainties. The demand for the considered product was assumed to be known and fixed and the capacity was considered unlimited. A multi-period under component lead time uncertainties was considered. A generalization of the discrete Newsboy model was suggested to find optimal release dates which maximize the customer service level for the finished product and minimize the expected inventory holding cost for the components for a specific case where the distributions of probability of lead times and holding cost are the same for all components. A Branch and Bound procedure was developed to solve it for a general case of distributions of probability and costs. In Shojaie et al. [45], the same model was studied, but for the case of POQ policy, service level constraints and over a single inventory. The authors explain that the proposed model can function with no major restriction on the type of the lead time distribution. However, a concrete example is missing in the study.

A two-level assembly system was studied by Tang and Grubbström [50] in the case of both stochastic lead times and the process time for components at level one of the BOM. Both the demand and the due date are assumed to be known. The capacity is considered unlimited. To determine the optimal safety lead times, which minimize the total backlogging and inventory holding cost, a Laplace transform procedure was introduced. Later, Hnaien et al. [25] treated only a one-period demand and a two-level assembly system, and developed a genetic algorithm to minimize the total expected cost, which equal to the sum of the backlogging cost for the finished product and the inventory holding costs for components. The authors assumed that the components at level 1 of the BOM were stored and the finished product was assembled only after the given due date. Fallah-Jamshidi et al. [19] exploit the same problem in a multi-objective context. An electromagnetism-like mechanism is proposed to reinforce the GA and to determine minimal expected costs. However, the authors focused on the number of components at the last level and neglected the influence of different costs. The case of a one-period inventory model for a one-level assembly system under stochastic demand and lead times was studied by Hnaien et al. [27]. A mathematical model and a Branch and Bound procedure were developed to determine optimal quantity and optimal planned lead times for components. Drawing on this work, Borodin et al. [7] proposed a joint chance constrained model and an equivalent linear formulation to solve this problem.

Recently, Atan et al. [3] considered a parallel multi-stage process feeding of final assembly process. To determine optimal planned lead times for different stages minimizing the expected cost for a customer order, an iterative heuristic procedure was developed. It could be considered as a special case of our problem. Bollapragada et al. [6] examined a multi-product, multi-component, procurement and assembly problem under supply and demand uncertainty. A numerical example illustrates the impacts of lead times and capacity on the performance of the assembly system. However, no resolution method is provided.

To our knowledge, in the literature, there is no other multi-level model that determines optimal order release dates with several levels in the BOM, several types of components and stochastic lead