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► To cite this version:

Oussama Ben-Ammar, Alexandre Dolgui, Faicel Hnaien, Mohamed Aly Ould-Louly. Supply planning and inventory control under lead time uncertainty: a literature review and future directions. MIM 2022: 10th IFAC Conference on Manufacturing Modelling, Management and Control, Jun 2022, Nantes, France. 10.1016/j.ifacol.2022.10.138 . hal-03709647

HAL Id: hal-03709647

<https://hal.science/hal-03709647v1>

Submitted on 30 Jun 2022

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Supply planning and inventory control under lead time uncertainty: a literature review and future directions

O. Ben-Ammar* A. Dolgui** F. Hnaien***
M.-A. Ould-Louly****

* *EuroMov Digital Health in Motion, Univ Montpellier, IMT Mines
Ales, Ales, France*

(e-mail: oussama.ben-ammam@mines-ales.fr)

** *IMT Atlantique, LS2N-CNRS, La Chantrerie, 4 rue Alfred Kastler -
B.P. 20722, 44307 Nantes, France*

(e-mail: alexandre.dolgui@imt-atlantique.fr)

*** *Université de Technologie de Troyes, ICD-LOSI, 12 rue Marie
Curie, 10010 Troyes, France*

(e-mail: faicel.hnaien@utt.fr)

**** *Ecole Supérieure Polytechnique, Nouakchott - Mauritanie
(e-mail: ma.louly@esp.mr)*

Abstract:

The majority of publications in the scientific literature investigate stochastic demand processes with constant order lead times. In practice, inventory management software like MRP is used by companies even if ignored the uncertainty of lead times. In this work, we investigate the influence of this type of uncertainty and existing solutions proposed in the scientific literature. To do this, ARTIREV tool is used to identify the major schools of thought competing in the field and highlight the current and emerging research themes. One conclusion is obvious from this preliminary work. Even though lead times are very disruptive to supply chain, as seen during the Covid crisis, most of the work is still only interested in the uncertainties related to demand.

Keywords: Assembly, Purchasing, Supply, Lead time uncertainty, Supplier selection.

1. INTRODUCTION

The planning function consists of answering the following questions: how much and when? How many products do we need to manufacture, how many components do we need to order, how many operators do we need, etc. for each planning period. A period can be a few days, a week or a month. At this level of detail, it is not necessary to give an exact schedule for the use of all the resources, but only to define volumes. The planning function is very important in business, because it defines a framework for the other functions of production management. A mistake at this level is expensive.

The planning function has several facets: planning deliveries of finished products to customers (distribution centres), planning the production of semi-finished products and the assembly of finished products, planning the supply of components and raw materials, etc. In the past, in companies and in the academic world, particular attention was paid to the problems of production and distribution planning. This part is relatively well studied. Currently, there is another tendency which is to highlight the problems of restocking and purchases (Golmohammadi and Hassini, 2020). But for now, this last area is still insufficiently studied. Aware of this situation, many researchers speak of the need to focus more research on this issue and to

develop specific decision-making tools. This discussion is gaining momentum especially after the emergence of new supply chain concepts.

Different sources of uncertainty exist along the supply chain. To compensate for this, companies use stocks or safety lead times. Following Lee and Billington (1993), a great current challenge is to find a way, through effective replenishment planning, to control stocks and costs along the supply chain, while maximising the service offered to customers, by taking into account uncertainty.

Much work exists on inventory management and replenishment planning under conditions of random demand. They have advanced the general reflection on the planning of systems subject to hazards and the corresponding mathematical methods. Planning issues for systems subject to the vagaries of lead times are not as well studied. The situation is further aggravated if, to the problems of the vagaries of lead times, there are problems due to inventory management for assembly systems, because in this case several components are necessary to manufacture a finished product, which creates interdependence between stocks.

The objective of this paper is to: review the literature, classify the literature based on the modelling approach, and Identify future research directions. We do not describe

in detail the models that have been considered. This paper is organised as follows. In next section, we present the used methodology to select papers. Section 3 gives a brief overview of published studies with random lead times. A discussion of future directions are drawn in Section 4.

2. METHODOLOGY

In this section, the process used to select papers is explained:

- (1) *Tools*: We use ARTIREV tool. It offers a different approach. The first one examine the citation schemes in a research topic before looking at their content. It provides two maps with several points of entry into the field. The first map provides the key schools of thought competing in the topic under investigation, as well as their founding and essential literature. The second map displays the field's current and developing research themes, along with the key texts for each. The findings of ten years of bibliometrics study went into the creation of these maps.
- (2) *Keywords*: "assembly planning uncertainty lead time".
- (3) *Subjects*: We are only limited to the following subjects: "engineering", "social sciences", "mathematics", "computer science", "economic econometric and finance", "multidisciplinary", "business "management and accounting", and "decision sciences".
- (4) *Limit to documents*: We only consider conference papers and reviews, articles, books and book chapters. We note that we are limited to journals, books, book series and conference proceedings. Only articles in Press and Final documents are taken into consideration.
- (5) *Refinement*: We use the several calibrations proposed by ARTIREV tool.

Figure 2 illustrates the current and emerging research themes of the field with the central works.

3. ASSEMBLY SYSTEMS UNDER UNCERTAINTY OF LEAD TIMES

In the literature, several studies exist in the field of supply planning and inventory control under lead time uncertainty. The most well-known studies are listed in Table 1.

Mula et al. (2006b) offered an excellent overview of existing studies that have focused on supply and production planning under uncertainty. The authors noted that the majority of these works have concentrated on handling demand uncertainty (see for example Guillaume et al., 2013; Peidro et al., 2009; Grabot et al., 2005; Mula et al., 2006a). Modelling the whole system under lead time uncertainty is often presented as the biggest obstacle to study this type of uncertainty. The fact that each process is random makes it difficult to mathematically model the dependencies between assembly system components, BOM levels, and planning horizon periods. Without attempting a complete review of the literature, we will concentrate on probabilistic methodologies. Dolgui et al. (2013) provided a literature survey categorising supply planning and inventory control methodologies and techniques under

stochastic lead-times. Most models have considered (i) one-level assembly systems with mono- or multi-period planning or (ii) two-level assembly systems with mono-period planning, as stated in Table 1.

Yano (1987a,b) were among the first to note the effects of the variability of lead-times. They proposed the case of serial production systems and mono-period planning, which was later generalised by Elhafsi (2002). In a third study Yano (1987c) studied a two-level assembly system and one-period planning. One component is assembled from two components and lead-times follow stochastic Poisson and negative binomial distributions.

Yano (1987a,b) were among the first to recognise the difficulty of modelling the uncertainty of lead-times. They addressed the problem of serial production systems and mono-period planning, which Elhafsi (2002) later generalised. Yano (1987c) investigated a two-level assembly system and one-period planning in a third research. In this work, the lead-times follow stochastic Poisson and negative binomial distributions, and the finished product is obtained from the assembly of two components. The expected total cost (ETC) is the objective function, which is constituted of delay penalty and inventory holding cost. The optimal planned lead-times are determined using an algorithm based on an analysis of the characteristics of the objective function. Kumar (1989) investigated one-period planning and one-level assembly systems. He minimised the total expected cost and provided optimal order release dates, as in Yano (1987a). An exact analysis based on certain forms of distribution assumptions was proposed (uniform, exponential and normal).

Chu et al. (1993) investigated the example of a one-level assembly system: the convexity of the expected total cost is demonstrated and an iterative algorithm is suggested to optimise it. Hegedus and Hopp (2001) presented a technique based on a Newsboy-like analytical formulation to overcome this issue for the case of a two-stage production model. The fundamental limitation of all these research is that they only consider one or two-level assembly systems for mono-period planning horizon.

Following that, Axsäter (2006) looked into a three-level assembly network with independent random operation times. The goal was to select beginning times for various activities in order to reduce the ETC, which is made up of component inventory holding costs and end-item delay penalties. An approximation decomposition approach based on the repeated application of a single-stage issue solution was proposed. The error in the numerical solution for the first example of a two-stage problem was just 1%, i.e. the relative cost rise due to approximation. However, in the second three-stage case, the error was around 10%, which cannot be ignored.

Previously, Dolgui et al. (1995) and Dolgui and Ould-Louly (2002) used simulation and integer linear programming to study a multi-period planning model and to simulate one-level assembly systems. Several distinct types of finished products were obtained from various types of components. The authors considered an holding cost for each component, as well as a backlog cost for finished products. For each period, they optimised the quantity of finished

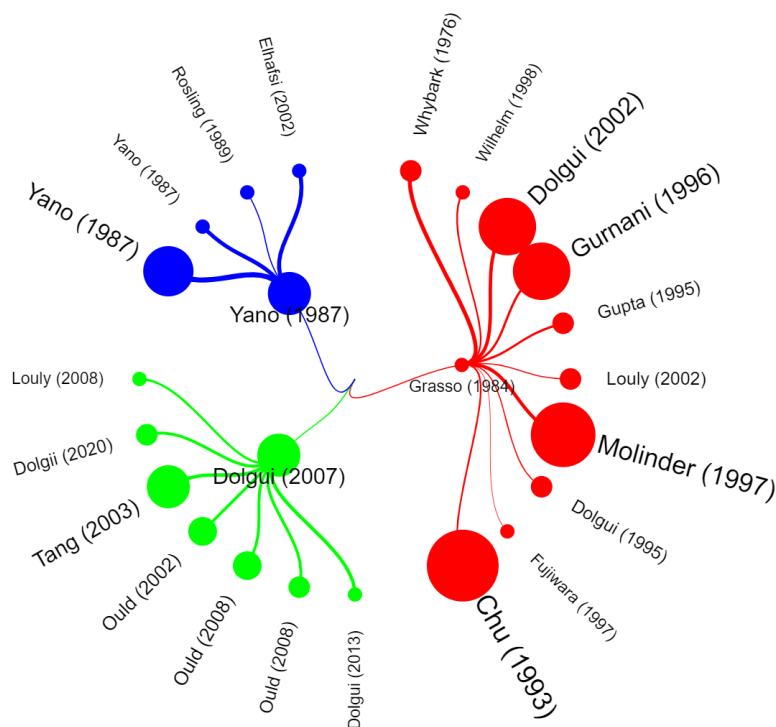


Fig. 1. Research themes with key words: assembly planning uncertainty lead time.

product to be assembled and the quantity of each order component. Proth et al. (1997) investigated the same problem and implemented a heuristic to decide which products should be manufactured and which components should be ordered.

In the context of one-level assembly systems and a multi-period planning horizon, several studies developed analytical models in order to optimise planned ordered quantities under uncertainty of lead times (Ould-Louly and Dolgui, 2002a,b, 2004, 2011, 2013; Ould-Louly et al., 2008b,a; Shojaie et al., 2015). All of these works are limited to a known and constant demand over the planning horizon and an unlimited capacity of assembly. Recently, Hnaïen and Afsar (2017) investigated the min-max robust lot-sizing problem with a scenarios-based approach. The authors proved that the considered problem is NP-hard even when only two scenarios are considered. Several indicators such as tardiness penalties, inventory holding costs, set-up costs and service level are measured in order to investigate the impact of lead-time uncertainty. For some classic inventory ordering policies (lot for lot, economic order quantity, periodic order quantity), the authors proposed several analytical models and efficient optimisation approach that give the best ordering strategies for components.

In the cases of one-period planning and two-level assembly systems, Tang and Grubbström (2003) modelled both process times and lead-times for components. They considered a fixed demand, unlimited capacity, and a known due date. A Laplace procedure was used to calculate the optimal safety lead-times to minimise backlogging and inventory holding costs. Later, Hnaïen et al. (2009) and Fallah-Jamshidi et al. (2011) treated the same problem using genetic algorithms (GAs) to minimise the expected value of the same total cost. Hnaïen et al. (2009) supposed that

components at level 1 of the BOM were stored and that the finished product was only assembled after the given due date. Fallah-Jamshidi et al. (2011) explored the same problem but in a multi-objective context, and reinforced the GA by a reliable technique called the electromagnetism-like mechanism.

Tang and Grubbström (2003) modelled both process times and component lead-times in the case of one-period planning horizon and two-level assembly systems. They took into account a fixed demand, infinite capacity, and a known delivery date. To minimise backlog and inventory holding costs, the ideal safety lead-times were calculated using the Laplace approach. Later, Hnaïen et al. (2009) and Fallah-Jamshidi et al. (2011) used genetic algorithms (GAs) to minimise the expected value of the same total cost. Hnaïen et al. (2009) assumed that components at level 1 of the BOM were stored and that the finished product was assembled only after the due date. Fallah-Jamshidi et al. (2011) investigated the same problem but in a multi-objective situation, and supplemented the GA with a reliable approach known as the electromagnetism-like mechanism.

Hnaïen et al. (2016) investigated a one-period inventory model for a one-level assembly system with stochastic demand and lead-times. To optimise the component quantities and planned lead-times, an analytical model and a Branch and Bound (B&B) method were developed. Although the authors' model was confined to a single period, it may be expanded to multi-period planning to account for potential trade-offs between stocks from different periods. Building on this work, Borodin et al. (2016) offered a novel way to solving the same problem based on chance-constrained programming and a linear model. However, due to the reliance between levels, they were confined to

Authors	Type of system			Criteria	Lot sizing	
	#Levels	#Periods	#Demand		rules	Comments
Kumar (1989)	1	1	1	Hc, Tc	L4L policy	Generic study of inventor control.
Chu et al. (1993)	1	1	1	Hc, Tc	L4L policy	Iterative algorithm.
Hegedus and Hopp (2001)	1	1	1	Hc, Sl	FPO policy	Combinatorial optimization method.
Hnaïen and Afsar (2017)	1	1	1	Sc, Hc, Sl	L4L policy	Mixed integer programming models.
Chauhan et al. (2009)	1	1	1	Hc, Tc	L4L policy	ATO environment, continuous model, simulated annealing.
Atan et al. (2016); Jansen et al. (2019, 2018)	1	1	1	Hc, Tc	L4L policy	CTO environment, assembly process fed by a multi-stage parallel process, EV, recursive equations, iterative heuristic.
Jansen et al. (2019, 2018)	1	1	1	Hc, Tc	L4L policy	CTO environment, EV, Newsboy formulae, commitment lead-time decisions, blame policy.
Borodin et al. (2016)	1	1	<i>c</i>	Hc, Tc	L4L policy	Joint chance constrained model, MIP.
Dolgii (2001)	1	<i>p</i>	<i>c</i>	Hc, Tc	Reorder point	ILP models, simulation, heuristics.
Ould-Louly and Dolgui (2002a)	1	<i>p</i>	<i>c</i>	Hc, Tc	L4L policy	EV, Markov, Newsboy formulae, all components share identical properties.
Ould-Louly and Dolgui (2004)	1	<i>p</i>	<i>c</i>	Hc, Tc	POQ policy	EV, Markov, Newsboy formulae, specific assumptions on costs and probability distributions.
Ould-Louly et al. (2008a)	1	<i>p</i>	<i>c</i>	Hc, Sl	L4L policy	Generalisation of Ould-Louly and Dolgui (2002a).
Ould-Louly and Dolgui (2013)	1	<i>p</i>	<i>c</i>	Sc, Hc, Sl	POQ policy	EV, Newsboy formulae.
Shojaie et al. (2015)	1	<i>p</i>	<i>c</i>	Hc, Sl	POQ policy	EV, POQ policy, optimisation.
Proth et al. (1997)	1	<i>p</i>	<i>d</i>	Hc, Tc	L4L Policy	Disc. event systems, gradient descent, heuristic algorithm.
Yano (1987c)	2	1	1	Hc, Tc	L4L policy	EV, Nonlinear programming.
Tang and Grubbström (2003)	2	1	1	Hc, Tc	L4L policy	Laplace transform procedure.
Hnaïen et al. (2009)	2	1	1	Hc, Tc	L4L policy	EV, GA, B&B.
Hnaïen et al. (2010)	2	1	1	Hc, Sl	L4L policy	EV, GA, multi-objective, elitist selection.
Fallah-Jamshidi et al. (2011)	2	1	1	Hc, Tc	L4L policy	EV, Hybrid GA.
Sakiani et al. (2012)	2	1	1	Hc, Sl	L4L policy	EV, GA, multi-objective, tournament selection.
Guiras et al. (2019)	2	1	1	Mc, Hc, Tc	L4L policy	EV, GA, maintenance cost.
Ben-Ammar and Dolgui (2018)	2	1	1	Hc, Tc	L4L policy	EV, B&B, GA.
Axsäter (2006)	3	1	1	Hc, Tc	L4L policy	Approx. decomposition technique, continuous distrib.
Ben-Ammar et al. (2018)	<i>m</i>	1	1	Hc, Tc	L4L policy	ATO environment, EV, recursive formula, B&B.
Ben-Ammar et al. (2020)	<i>m</i>	1	1	Hc, Tc	L4L policy	ATO environment, EV, generic model, iterative process, hybrid GA.

Tc: Tardiness cost, *Hc*: Holding cost, *Sl*: Service level, *Sc*: Set-up cost, *Mc*: Maintenance cost, L4L: Lot for lot policy, EOQ: economic order quantity, MIP: Mixed integer programming, EV: Expectation value, *m*: Multi-level, *p* Multi-period, *c*: Constant demand, *d*: Dynamic demand, FPO: Fixed Period Ordering policy, POQ: periodic order quantity.

Table 1. Assembly systems: summary and classification of publications.

one-level assembly systems. This barrier is readily overcome, as demonstrated in Ben-Ammar et al. (2020), by employing independent lead-time uncertainty models at each level.

Atan et al. (2016) recently considered a final assembly process fed by a multi-stage parallel process. Each stage had a stochastic throughput time and the system was controlled by planned lead-times at each stage. The considered system contains a one-assembly process and took into account the planned assembly dates at intermediate levels. The latter are optimised using an iterative heuristic in order to minimise the expected total cost. The studied case could be considered a special case of the one introduced by Ben-Ammar et al. (2020). More recent papers (Jansen et al., 2019, 2018) feature an interesting investigation into the combination of planned lead-time and commitment lead-time decisions. In Ben-Ammar et al. (2018) and Ben-Ammar et al. (2020), the authors modelled multi-level assembly systems for the case of one customer demand.

A generalised probabilistic model and several optimising approaches are developed to optimise the expected total cost. An iterative process and a recursive procedure are introduced in order to take into account inter-level dependency. However, the limitation of these earlier studies was that only consider one-period planning horizon.

4. DISCUSSION AND FUTURE DIRECTIONS

In this preliminary work, we have analysed the existing works in the scientific literature that study the uncertainty of assembly and delivery times. Most studies are limited to analytical approaches with limitations on the number of levels, the number of components and the number of planning periods. Work using linear programming and scenario-based approaches is non-existent. However, these techniques are promising and have been used successfully for multi-period procurement planning (Ben-Ammar et al., 2019) and the optimisation of multi-level disassembly

plans (Slama et al., 2022). Another promising avenue is to use robust optimisation to explore other performance indicators and better control the size of the problem under consideration (Thevenin et al., 2022; Thorsen and Yao, 2017).

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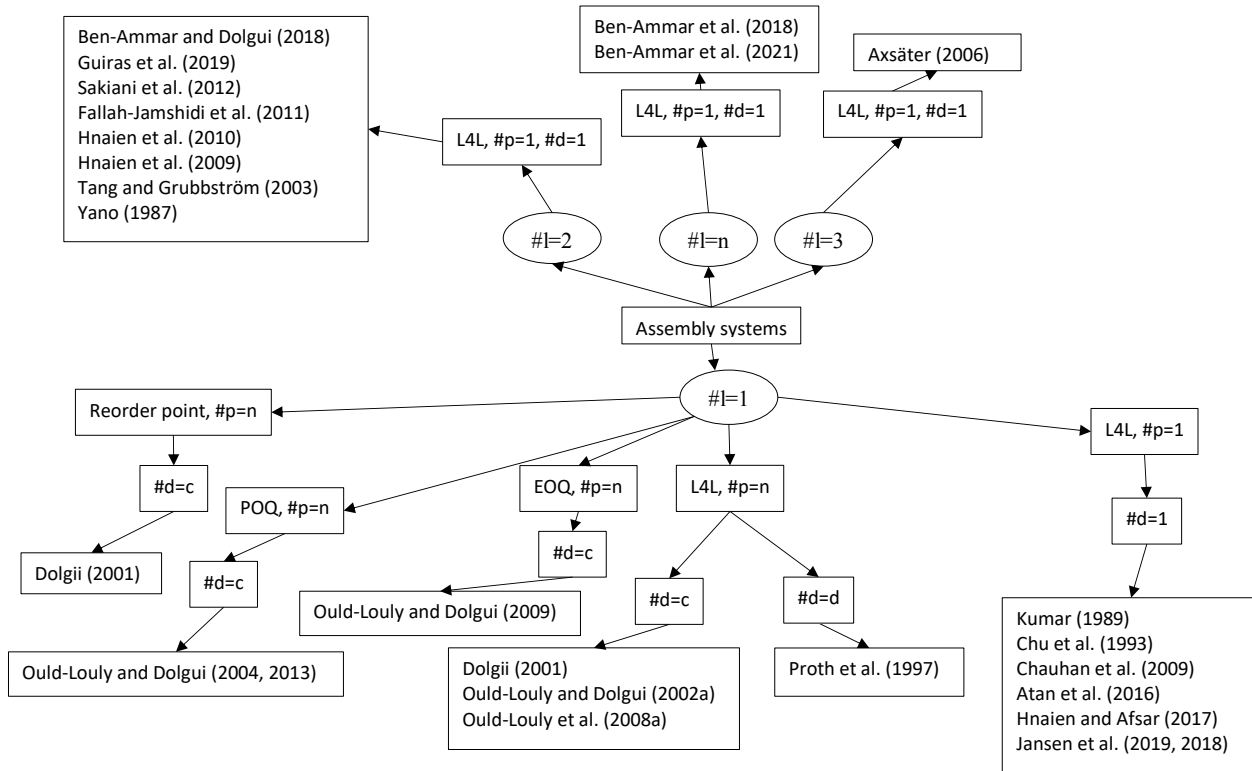


Fig. 2. Classification of publications.

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