A literature Review on Multi-echelon Inventory Management Policies: Case of Assembly Systems

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Abstract

Inventory control presents a major issue in supply chain management. Many businesses understand the importance of an effective inventory management system. When dealing with demand fluctuations, proper inventory management assists in providing a high level of customer service. The necessity for an integrated approach to inventory management had become vital especially in the current complex supply chain networks where inventories are located throughout the system as raw materials or finished goods. Multi-echelon inventory management allows considering various challenges and issues related to the interdependencies between different stages of the supply chain. Stocks of raw materials, components, and finished goods are all interrelated in production. Multiple multi-echelon inventory models for production systems were developed by researchers to solve issues related to either the supply chain efficiency or responsiveness. In this paper, we provide a literature review on multi-echelon inventory management policies for the assembly structure. Different alternatives for managing multi-echelon inventory systems for the case of assembly systems are generated.

Keywords
Multi-echelon inventory management, Assembly systems, Inventory management, Supply chain management

1. Introduction
Multi-echelon inventory management and theory have more than 50-year study and publishing history (de Kok et al., 2018). Since the work of Clark and Scarf (1960), a variety of new and improved research directions were introduced to the literature. Multi-echelon inventory models have gotten more attention and prominence as supply chain management complexity has grown enormously. The concept of multi-echelon inventory management has grown in popularity over the last decade due to the complexity of supply chains and the rapid advancement of information technology, which allows for integrated control of supply chain networks with several installations and multiple stages (Czwajda and Kosacka, 2017).

Inventory management in a multi-echelon supply chain is significantly more challenging than inventory control in a single echelon system. Most supply chain systems contain numerous stages or locations (Shenoy and Rosas, 2018). Excess inventory is generated by optimizing inventory one echelon at a time without a significant improvement in the supply chain responsiveness (Gumus et al., 2010). The multi-echelon inventory management concept considers interdependencies between different components of the supply chain which enables controlling the network as a whole system.

Each echelon of a multi-echelon inventory system includes facilities, which can represent installations, stored items, or work-in-progress inventory. One or more downstream installations receive orders from upstream facilities (Clark, 1972). A multi-echelon inventory system may involve many suppliers and customers for each level. More details about the four basic structures of the multi-echelon inventory system can be found in a previous paper (Sbai and Berrado, 2018).

The serial system is the first structure. Each installation in this system deals with only one supplier and one direct customer. In general, this structure is the easiest to manage. The distribution system is the second type. As a distributor, each installation has only one source of replenishment and may have several customers. The assembly system is the third structure, in which inventory sites have just one customer but can replenish from several sources. Finally, any of the three previous forms can be combined into a single system to build a "generic multiechelon inventory system" (Axsäter, 2015). We focus in this paper on the case of assembly systems.

As a result of general findings published in previous papers (Sbai and Berrado, 2019, 2018), we noticed that a literature review on multi-echelon management policies for the assembly system structure is not established yet in our knowledge. For this reason, we aim in this paper to provide a detailed literature review for the case of multiechelon assembly systems to generate multiple inventory control policies that are specific to this structure type.

There are five sections in this paper. we define in the following section the assembly structure of the multi-echelon inventory system. After that, a literature review on multi-echelon inventory management policies for the case of assembly systems is conducted. Finally, multi-echelon inventory control policies alternatives are generated for the case of assembly systems.

2. Multi-echelon inventory system: Assembly systems

2.1 Definition and characteristics

Stocks of raw materials, components, and finished goods are all interrelated in production. Inventory systems having multiple parallel stocking points early in the material flow and progressively fewer inventories later in the system referred to as a convergent flow, are more common in production (Axsäter, 2015). Many industrial and consumer goods can be perceived as having an assembly structure, in which the output of two or more stages of processing is combined by further processing at a successor level, which then supplies its successor until the final product is produced several stages later. These stages, referred to as " nodes " or " facilities ", can refer to a specific physical location or any activity, such as the purchase of raw materials or parts, monitoring, storage, delivery, assembly, and so on, that aids in the manufacturing of the product for the final customer (Williams, 1983). We have an assembly system if each installation has just one direct successor. Figure 1 presents a simple illustration of an assembly system structure.

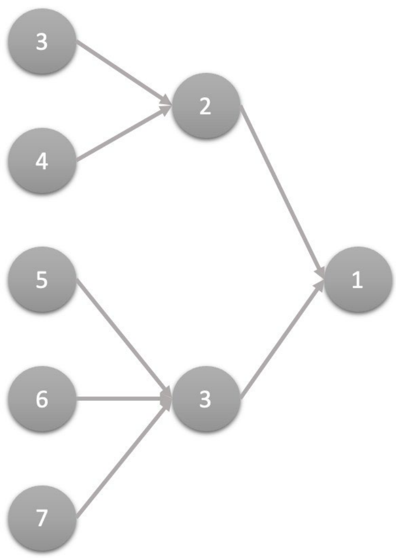

Figure 1. An illustration of an assembly system

In a given multi-echelon inventory system in production as shown in Figure 1, stock 1 (relative to the inventory of a given item 1) can be considered as finished product inventory that is composed or produced from items 2 and 3. On the other hand, Item 3 is manufactured from items 5, 6, and 7. Besides, it is common in manufacturing to use more than one unit of a component when producing another item. Item 1 would, for example, be composed of three units of item 2 and two units of item 3.

In a single product, multi-stage assembly production inventory systems, many manufacturing organizations face the challenge of planning production/purchase quantities for goods. Such systems have a single product, or end item (such as item 1 in Figure 1), that is used to meet customer demand and is composed of several components, each of which may be made up of one or more additional items. The components may be produced or supplied.

2.2 Inventory control policies in assembly systems

There are several reasons for holding stock early in the material flow in an assembly system. In upstream stages, raw materials and components have significantly lower values than subassemblies and final products at the most downstream stages. As a result, the holding costs are reduced. Besides, High setup costs in the early phases of production may necessitate the use of large batch sizes (Axsäter, 2015).

We mentioned in previous work (Sbai and Berrado, 2019) the general main inventory policies used in the context of multi-echelon inventory management. Replenishment policies, ordering policies, lot sizing/batch quantities decisions, and safety stock allocation policies are the main four inventory control strategies for the multi-echelon inventory management problem. In this paper, we provide insights on the control policies for the case of assembly systems. We illustrate in Table 1 the multi-echelon inventory control policies used in the literature for the case of assembly systems.

Table 1. Multi-echelon inventory control policies: Case of assembly systems

Multi–echelon inventory control policies		Definition and description
Replenishment policies	Continuous inventory policy	The inventory status at all facilities is monitored and tracked continuously. When demand arrives and the inventory position of a certain installation is sufficiently low, an order is triggered (Zhou and Yang, 2016).
	Periodic inventory policy	Periodic review policy refers to how an inventory control system is set up so that the inventory status is only reviewed at specified periods in time. The "review period" refers to the time between reviews (Snyder et al., 2016).
Ordering policies	Installation stock (R, Q) ordering policy	When using this ordering policy, each installation is controlled by an (R, Q) policy that is based on the installation inventory position of this facility. Each location considers its inventory position, which is defined as the inventory on hand added to outstanding orders minus backorders. When the inventory position falls below R, a quantity of size Q is ordered (Axsäter and Rosling, 1994).
	Echelon stock (R, Q) ordering policy	When each installation uses echelon stock (R, Q) policies, orders are not only based on installation inventory but on echelon stock, which includes items that are part of downstream products at other installations (Axsäter and Rosling, 1993).
	Order – up – to S policies	An order is placed when the inventory position falls below S. The order size is determined such that after order placement, the inventory position equals S (Babai et al., 2011).
	Material Requirement Planning (MRP)	The MRP is a reorder point system where the reorder points are frequently updated. In a production system, the MRP is widely used. The planning procedure is frequently carried out with a periodic review and is related to various data such as the Master Production Schedule (MPS), external demands for products, a bill of material for each component, stock levels for all products, constant lead times for all items, safety stocks policies, and batch quantities (Axsäter, 2015) .
Lot sizing / batch quantities		This crucial problem must be tackled regardless of the type of ordering process adopted. It is not optimal to handle each facility independently when determining order sizes for a multi-echelon inventory system. The batch quantity chosen at one location will have an impact on the demand structure at the next upstream location. The determination of batch quantities becomes significantly more difficult because of this interdependence. Although it is not ideal to estimate batch quantities for each site separately, it is a common practice because it is simple. In most cases, this will result in orders being placed in small quantities (Axsäter, 2015).

Safety stock allocation policies	The major question asked by researchers is identifying component stockouts and combining possible stock-outs of the items in the assembly (Desmet et al., 2010). Axsäter (2015) stated that early in the material flow, holding costs in production are usually minimal. As a result, having large safety inventories of different components in an assembly system can be a good strategy. Besides, it was assumed by the literature and the work of Clark and Scarf (1960) that the decomposition technique is optimal for assembly systems under certain conditions. This approach considers the most downstream installation facing customer demand. To define the optimal policy for the next upstream site, we evaluate the costs caused by shortages.

3. Multi-echelon inventory management policies in assembly system: Literature review and related work

3.1 Literature review

Several publications in the literature have addressed the challenge of identifying optimal production or purchase plans in the context of associated production and inventory holding costs. It is often difficult to generate exact optimal production strategies. The number of components in the product structure has a major impact on the calculation (AXSATER and NUTTLE, 1987).

Since the work of Clark and Scarf (1960), many authors started investigating the multi-echelon inventory management in production systems to provide new approaches and improvements to this novel research work. For multi-stage assembly systems, Crowston et al. (1973) analyze the optimal lot size problem, where each site may have several predecessors but only one successor. It is demonstrated in the paper that the optimal lot size at each location is an integer multiple of the lot size at the successor site under the condition that lot sizes stay stationary and invariant in time. Williams (1983) proposed a dynamic programming approach and algorithm in this research for determining production batch sizes in an assembly system. The goal was to reduce the average cost per period over an infinite horizon to the lowest possible value. In another research article, Afentakis et al. (1984) proposed a new formulation of the multilevel assembly systems lot-sizing problem that results in an efficient optimization methodology. The problem studied is considered using the echelon stock. The paper published by Schmidt and Nahmias (1985) discusses an inventory system in which a finished product is assembled using two items that are procured from a third-party supplier. The results give an accurate analysis of an MRP assembly system for stochastic demand. AXSATER and NUTTLE (1987) created a production/purchase strategy for an N-item assembly system that minimizes total setup as well as inventory holding costs over a T period timeframe. An inventory modeling approach of an assembly system with random demand and proportional production and carrying costs is studied (Rosling, 1989). Simple reordering policies were proven to be optimal and require relatively less computational capabilities. Simple approximate strategies were recommended for cases where systems may be out of long-run balance for a brief time interval. In their research work, Goyal and Gunasekaran (1990) conducted a literature review on multi-stage production-inventory systems. The literature on the multiechelon production inventory system has been categorized into three main sections: system designs and structures; objectives investigated; and modeling and solution methodologies. Considering setup costs at all levels and stochastic demands, Chen and Zheng (1994) offer lower constraints on the minimal costs for managing different production networks. Serial, assembly, and on-warehouse multi-retailer systems were provided as examples of these systems. For multi-stage inventory control, the research study of Axsäter and Rosling (1994) compare Material Requirements Planning (MRP) with reorder point approaches. Between MRP and installation stock (r, Q) policies, the findings indicated that echelon stock (r, Q) policies are included in this ranking list for serial and assembly inventory networks. As a result of this research findings, all policies must use the same review period. Aside from that, they're relatively generic.

Chen (2000) derive optimal policies for multi-level serial and assembly systems with fixed batch quantities. The policies suggested are simple, and their parameters are easy to calculate. The multi-echelon inventory theory is developed in various ways in this study. It extends the Clark-Scarf approach by enabling batch inventory exchanges. In another paper, Bollapragada et al. (2004) look at stock allocation in an assembly system with installation base stock policies. The authors analyze the system's inventory characteristics when part suppliers have the variable capacity and finished product demand is unpredictable. A decomposition technique is suggested in which each component's near-optimal stock levels are determined separately using an internal level of service. The base-stock levels for all parts can be estimated separately using this method, allowing for distributed computing of optimal inventory levels. DeCroix and Zipkin (2005) looked at an assembly system that had unpredictable returns of final products, components, or subassemblies, as well as uncertain consumer demand. The authors established limitations on the item-recovery sequence and inventory policy limits that ensure long-run balance, allowing the system to be addressed using well-known tools for series systems with returns. Two heuristic approaches for general assembly systems were presented. The heuristics are simple to compute and apply, and they demonstrated good performance in numerical testing. Bernstein and DeCroix (2006) assume a system in which parts are assembled into a final product. The final product's demand is both stochastic and stationary, while supply and assembly lead times are both constant. Unmet demand is backordered. The authors conclude that using pipeline information presents benefits under echelon base-stock policies. Using pipeline information, on the other hand, may probably increase costs for some businesses depending on local policies. The topic of minimizing predicted delay and holding costs for a large assembly system with independent stochastic variables has been addressed in (Axsäter, 2006) . The solution to the problem has been proposed as an approximate decomposition approach. The method entails applying the solution to a single-stage problem several times. Two sets of problems were used as illustrations to test the approximate method. Chao and Zhou (2009) investigate and determine the optimal control strategy for a periodic-review multi-echelon inventory system with batch ordering and fixed replenishment intervals in this research. The authors show that when all the stages' ordering periods are synchronized, the system achieves the lowest expected average cost and that the optimal reorder point for each level is the smallest as well. It is further proven that a site's optimal ordering point increases in the lead times of its own and related downstream facilities, as well as the stochastic demand.

Multi-echelon inventory models for the case of assembly systems have been the focus of many researchers in the last decade. The challenge of optimizing safety stocks in a two-echelon assembly system was addressed in (Desmet et al., 2010). It introduces and examines several approximation models for assembly lead times based on the assumptions of normal assembly demand and normal nominal lead times for components. Following that, these approximation models were applied to optimize safety inventories across a two-echelon assembly system. Benjaafar et al. (2011) look at an assembly system that has several stages, goods, and customer categories. The system is composed of "m" separate production facilities, each of which produces a variety of items. Items are made in different lot sizes, one at a time, with batch production times being exponentially distributed. The authors concluded that the optimal production strategy for each item is a state-dependent base-stock policy, with the basestock level non-increasing in downstream items' inventory and nondecreasing in all other components' inventory. It was also demonstrated how to formulate the optimal control problem in the function of echelon inventory and how to reinterpret the important aspects of the optimal policy based on echelon inventory. DeCroix (2013) investigated a system with a single final product and a general assembly configuration in which one or more part suppliers or (sub)assembly production processes are subject to supply disruptions. The author demonstrated how to reduce the system to an appropriate structure by replacing some subsystems with a series design. This reduction makes it easier to determine optimal ordering strategies and compare disruption impacts throughout systems with diverse supply chain structures. For general assembly systems, Li et al. (2013) applied the guaranteed-service approach (GSA) to establish optimal echelon batch ordering policies. The problem of determining the optimal echelon batch ordering policies for the considered system may then be broken down into two subproblems: order size determination and reorder point choice. The purpose of (Pal et al., 2014)' research work was to investigate a supply chain model that takes into account critical factors such as supply disruption, machine breakdown, stock-outs, backlog, and multi-echelon supply - chain management. Klosterhalfen et al. (2014) elaborated on the guaranteed-service framework for safety inventory optimization to create an exact mathematical model for static dual supply in a general acyclic n-echelon inventory system. The model was illustrated by five echelons and three dual-sourced components in a real-world example from the industrial electronics sector. Axsäter (2015) provided in his book many insights regarding managing multi-echelon inventory systems in general. The assembly structure-related inventory control policies were tackled in detail. A literature review on the implementation of Discrete Event Simulation and optimization approaches for assembly systems is conducted in (Prajapat and Tiwari, 2017) . Data from publications is gathered and grouped according to the application area, optimization objective function modeling, and optimization methodologies. The classification provides insight into major trends in the research. Woerner et al. (2018a) studied the problem of determining base-stock levels that minimize holding costs underfill rate level limitations over an infinite horizon is investigated a type of capacitated assembly systems managed by base-stock policies. The authors use the constrained level technique (CLM) and infinitesimal perturbation analysis to propose a new simulation-based optimization method to address this nonconvex constrained optimization issue. In assembly systems, Woerner et al. (2018b) investigate the joint optimization of capacity and safety stock allocation. The authors consider capacitated systems with base-stock policies and periodic reviews. The aim is to reduce total inventory carrying costs while meeting service level and budget requirements. An approach for estimating optimal capacity allocation and base-stock levels jointly is suggested as well. Ben-Ammar et al., (2018) focused on the problem of determining scheduled lead times in multiechelon assembly systems with uncertain lead times of multiple supply chain partners. A general probabilistic model that uses a recursive technique to calculate all the required probability distributions is provided in this research paper. In production systems with various inventory sites and a production facility running under linear and concave costs, Bayram et al. (2019) investigate the demand, inventory, and capacity allocation issue. The authors presented a new formulation of the demand allocation problem and showed that the best customer allocations are not always single-sourced. Along with demand and inventory allocation, the new formula allows for the incorporation of other decisions. To maintain a constant balance between safety stock inventory and customer demand fulfillment, it is vital to design optimal inventory policies for various manufacturing scenarios. As a result, the aim of (Samson et al., 2019)' research is to identify and describe the underlying trends as well as the most recent methods of inventory replenishment under varying demand, with a focus on multi-echelon production. In a very recent work, an integrated optimization control technique is suggested by (Liu et al., 2020) for reassembly systems. To characterize the transfer mechanism of the reassembly process, the state-space model of the remanufacturing assembly process and the transfer matrix of reassembly are built. Then, to accomplish the online guiding of the reassembly station, an optimization control framework based on dynamic programming is developed. Under the guaranteed service approach, the study of Ghadimi et al. (2020) addresses the joint optimization of manufacturing capacity and safety inventories in supply chains. In the cases of general acyclic and spanning tree systems, the integrated problem is represented as a mixed-integer nonlinear program (MINLP), and solution strategies are given.

3.2 Classification of Multi-echelon inventory management policies in assembly systems

As seen in the previous part, developing multi-echelon inventory management policies for the case of assembly systems was a matter of concern for many researchers. We summarize and classify in this part relevant and recent multi-echelon inventory management models proposed for the assembly system structure.

In Table 2, we classified various multi-echelon inventory management policies developed by the researchers for the case of assembly systems. The classification is based on the multi-echelon inventory management policies defined in Table 1.

Table 2 : Classification of the literature on multi-echelon inventory policies for assembly systems

Research Paper	Multi-echelon inventory policies in assembly systems							
	Replenishment policies		Ordering policies				Lot sizing and batch quantities	Safety stock allocation policies
	Continuous inventory policy	Periodic inventory policy	Installation stock ordering policy	Echelon stock ordering policy	Order – up – to S policies	Material Requirement Planning (MRP)		
(Crowston et al., 1973)				X			X	
(Lambrecht et al., 1982)		X	X					X
(Williams, 1983)				X			X	
(Afentakis et al., 1984)				X			X	
(Schmidt and Nahmias, 1985)						X		
(AXSATER and NUTTLE, 1987)				X			X	
(Rosling, 1989)				X				
(Goyal and Gunasekaran, 1990)			X	X			X	
(Chen and Zheng, 1994)	X			X				

(Axsäter and Rosling, 1994)			X	X		X		
(Chen, 2000)		X	X				X	
(Bollapragada et al., 2004)					X			
(DeCroix and Zipkin, 2005)		X		X				
(Bernstein and DeCroix, 2006)			X	X	X			
(Louly and Dolgui, 2009)		X	X					X
(Chao and Zhou, 2009)		X		X			X	
(Desmet et al., 2010)	X		X					X
(Humair and Willems, 2011)								X
(Benjaafar et al., 2011)				X	X			
(DeCroix, 2013)		X		X				
(MoncayoMartínez and Zhang, 2013)								X
(Li et al., 2013)				X			X	
(Klosterhalfen et al., 2014)		X			X			X
(Pal et al., 2014)							X	X
(Axsäter, 2015)	X	X	X	X	X	X	X	X
(Albrecht, 2017)								X
(Woerner et al., 2018a)					X			
(Woerner et al., 2018b)		X			X			X

4. Definition of multiple multi-echelon inventory management alternatives for assembly systems

Inventories may exist in any manufacturing point of the supply chain. They may consist of raw materials, work in progress, or final products (Ghadimi et al., 2020). In an assembly system, two items can be gathered as components to be assembled into a finished product. Controlling stock in an assembly system can differ from other types of multi-echelon inventory systems. Holding costs are lower in upstream installations. In other words, it is convenient to keep more stock of raw materials as they have lower values than finished products (Axsäter, 2015).

We presented in Table 1 key inventory policies used in the assembly structure. we provide in the following part key inventory policies to be used for the alternatives formulation process. We apply the general alternatives generation process presented in previous work (Sbai et al., 2021) to the case of assembly systems.

- **Defining inventory policies**
  - Replenishment policies: continuous or review policy
  - Ordering policies: echelon stock ordering policy or installation stock ordering policy
  - Using MRP system to manage inventory
  - Safety stock policies: it was assumed by the literature and the work of Clark and Scarf (1960) that the decomposition technique is optimal for assembly systems. This approach considers the most downstream installation facing customer demand. To define the optimal policy for the next upstream site, we evaluate the costs caused by shortages.
  - Lot sizing: if the system is facing constant demand, upstream batch quantities are set as integer multiples of downstream batch quantities. If the supply chain is having time-varying demand, then it is convenient to implement sequential lot-sizing (Axsäter, 2015).
- **Determining decision nodes**

We can define three main decision nodes while generating alternatives for the case of assembly systems:

- The ownership of an information system that controls continuously the inventory status at all sites.
- Safety stock policies and batch quantities are already fixed by managers or not.
- Type of the decision system: centralized or decentralized.

- **Generating alternatives**

After defining the different inventory policies used in multi-echelon inventory assembly systems, determining the decisions that should be considered while formulating possible alternatives, and investigating some results found in the literature synthesized in Section 3, we present in Figure 2 the detailed process of generating alternatives for the case of assembly systems.

At the beginning of the alternatives formulation process illustrated in Figure 2, an important question is asked: are safety stock policies and batch quantities already fixed or not? If it is the case, with the support of an information system to control inventory status at different facilities, the implementation of an MRP system could be the best choice for the decision-maker (Axsäter, 2015). If it is not the case, it would be convenient to adopt the decomposition technique demonstrated first by the work of Clark and Scarf (1960) extended by the literature in other research papers (Desmet et al., 2010; Moncayo-Martínez and Zhang, 2013). We followed the process illustrated in Figure 2 to build the options listed in Table 3.

Table 3: Multi-echelon inventory system alternatives for assembly systems

Alternative	Replenishment policy	Ordering policy	Description
A1	Continuous review policy	Echelon stock ordering policy	The replenishment policy chosen is a continuous review policy as the supply chain has already an information system to track inventory at all sites. An echelon stock policy is implemented under a centralized decision system.
A2	Continuous review policy	Installation stock policy	The decision system is decentralized. Each installation makes orders separately. An installation stock policy is implemented in this case.
A3	Periodic review policy	Echelon stock policy	The absence of an information system to enhance tracking inventory at all installations makes the implementation of a periodic review policy more suitable. An echelon stock policy is adopted in this case. The inventory position at a stage is the inventory position at this stage added to all downstream installations inventory.
A4	Periodic review policy	Installation stock policy	An order is placed in each installation after a certain order-upto level. The decision system is decentralized, each installation makes its orders separately without considering other installations inventory.

A5	Implement an MRP system	Assuming the safety stock policies and the batch quantities are already fixed as well as the presence of an information system, the MRP system is adopted as an appropriate option.

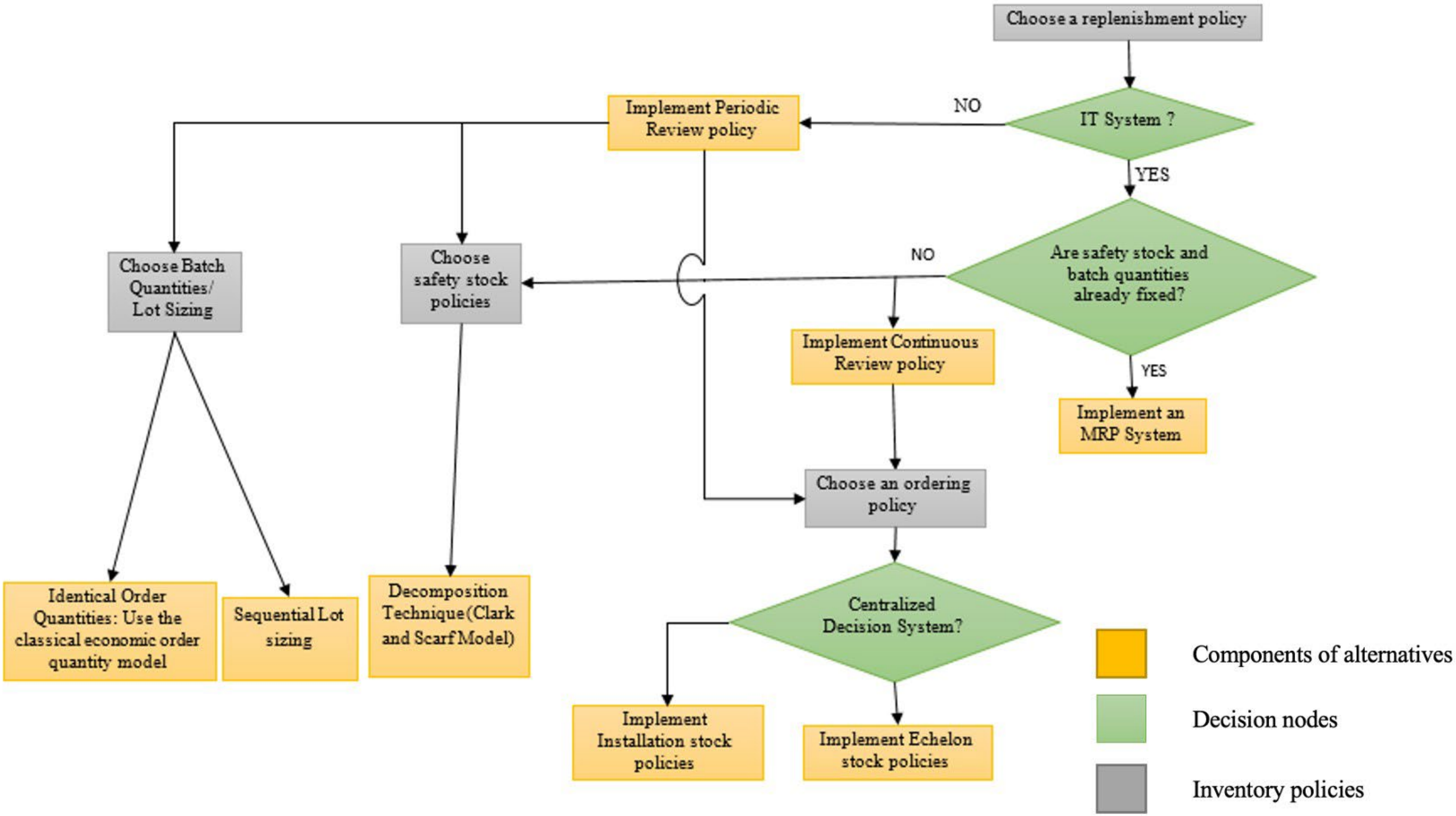

Figure 2: Process of generating alternatives for multi-echelon inventory system selection: the case of assembly systems

5. Conclusion

Multi-echelon inventory management allows for the effective management of inventories while considering interdependencies between different facilities. In this paper, we presented a literature review on multi-echelon inventory management policies for the case of assembly systems. A classification of several multi-echelon inventory models developed by researchers for assembly systems was provided. After that, different alternatives for multiechelon inventory systems for the assembly structure were formulated.

The definition of the multi-echelon inventory policies for assembly systems and the literature review conducted allowed for generating different alternatives for multi-echelon inventory management for the case of assembly systems. The detailed process for formulating the alternatives was presented in this paper. The process resulted in the formulation of five different alternatives that are based on the main inventory policies used in the assembly systems. Lastly, the literature review conducted, and the alternatives generated in this paper will help simulate and compare different options of multi-echelon inventory management for assembly systems to guide decision-makers in the field to choose and validate the appropriate alternatives that respond to their preferences in terms of the level efficiency and responsiveness. This will be tackled in our future work.

References

Afentakis, P., Gavish, B., Karmarkar, U., 1984. Computationally Efficient Optimal Solutions to the Lot-Sizing Problem in Multistage Assembly Systems. *Management Science* 30, 222–239. https://doi.org/10.1287/mnsc.30.2.222

Albrecht, M., 2017. Optimization of safety stocks in models with an order service level objective or constraint.*European Journal of Operational Research* 263, 900–909. https://doi.org/10.1016/j.ejor.2017.05.011

Axsäter, S., 2015. I*nventory Control,* 3rd ed, International Series in Operations Research & Management Science. Springer International Publishing. https://doi.org/10.1007/978-3-319-15729-0

Axsäter, S., 2006. Planning order releases for an assembly system with random operation times, i: Liberopoulos, G., Papadopoulos, C.T., Tan, B., Smith, J.M., Gershwin, S.B. (Eds.), *Stochastic Modeling of Manufacturing Systems: Advances in Design, Performance Evaluation, and Control Issues. S*pringer, Berlin, Heidelberg, pp. 333–344. https://doi.org/10.1007/3-540-29057-5_14

AXSATER, S., NUTTLE, H.L.W., 1987. Combining items for lot sizing in multi-level assembly systems. *International Journal of Production Research* 25, 795–807. https://doi.org/10.1080/00207548708919877

Axsäter, S., Rosling, K., 1994. Multi-level production-inventory control: Material requirements planning or reorder point policies? E*uropean Journal of Operational Research,* Lotsizing models for production planning 75, 405–412. https://doi.org/10.1016/0377-2217(94)90084-1

Axsäter, S., Rosling, K., 1993. Notes: Installation vs. Echelon Stock Policies for Multilevel Inventory Control. *Management Science* 39, 1274–1280. https://doi.org/10.1287/mnsc.39.10.1274

Babai, M.Z., Jemai, Z., Dallery, Y., 2011. Analysis of order-up-to-level inventory systems with compound Poisson demand. *European Journal of Operational Research* 210, 552–558. https://doi.org/10.1016/j.ejor.2010.10.004

Bayram, V., Gzara, F., Elhedhli, S., 2019. Joint capacity, inventory, and demand allocation decisions in manufacturing systems. *IISE Transactions* 51, 248–265. https://doi.org/10.1080/24725854.2018.1490045

Ben-Ammar, O., Dolgui, A., Wu, D.D., 2018. Planned lead times optimization for multi-level assembly systems under uncertainties. *Omega* 78, 39–56. https://doi.org/10.1016/j.omega.2017.11.004

Benjaafar, S., ElHafsi, M., Lee, C.-Y., Zhou, W., 2011. TECHNICAL NOTE—Optimal Control of an Assembly System with Multiple Stages and Multiple Demand Classes. *Operations Research* 59, 522–529. https://doi.org/10.1287/opre.1100.0889

Bernstein, F., DeCroix, G.A., 2006. Inventory Policies in a Decentralized Assembly System. *Operations Research* 54, 324–336. https://doi.org/10.1287/opre.1050.0256

Bollapragada, R., Rao, U.S., Zhang, J., 2004. Managing Inventory and Supply Performance in Assembly Systems with Random Supply Capacity and Demand. *Management Science* 50, 1729–1743. https://doi.org/10.1287/mnsc.1040.0314

Chao, X., Zhou, S.X., 2009. Optimal Policy for a Multiechelon Inventory System with Batch Ordering and Fixed Replenishment Intervals. *Operations Research* 57, 377–390. https://doi.org/10.1287/opre.1080.0636

Chen, F., 2000. Optimal Policies for Multi-Echelon Inventory Problems with Batch Ordering. *Operations Research* 48, 376–389. https://doi.org/10.1287/opre.48.3.376.12427

Chen, F., Zheng, Y.-S., 1994. Lower Bounds for Multi-Echelon Stochastic Inventory Systems. *Management Science* 40, 1426–1443. https://doi.org/10.1287/mnsc.40.11.1426

Clark, A.J., 1972. An informal survey of multi-echelon inventory theory. *Naval Research Logistics Quarterly* 19, 621–650. https://doi.org/10.1002/nav.3800190405

Clark, A.J., Scarf, H., 1960. Optimal Policies for a Multi-Echelon Inventory Problem. *Management Science* 6, 475–490. https://doi.org/10.1287/mnsc.6.4.475

Crowston, W.B., Wagner, M., Williams, J.F., 1973. Economic Lot Size Determination in Multi-Stage Assembly Systems. *Management Science* 19, 517–527. https://doi.org/10.1287/mnsc.19.5.517

Czwajda, L., Kosacka, M., 2017. The challenges of concept Multi-Echelon Inventory Management. *Research in Logistics & Production* Vol. 7, No. 5. https://doi.org/10.21008/j.2083-4950.2017.7.5.3 de Kok, T., Grob, C., Laumanns, M., Minner, S., Rambau, J., Schade, K., 2018. A typology and literature review on stochastic multi-echelon inventory models. *European Journal of Operational Research* 269, 955–983. https://doi.org/10.1016/j.ejor.2018.02.047

DeCroix, G.A., 2013. Inventory Management for an Assembly System Subject to Supply Disruptions. *Management Science* 59, 2079–2092. https://doi.org/10.1287/mnsc.1120.1660

DeCroix, G.A., Zipkin, P.H., 2005. Inventory Management for an Assembly System with Product or Component Returns. *Management Science* 51, 1250–1265. https://doi.org/10.1287/mnsc.1050.0394

Desmet, B., Aghezzaf, E.-H., Vanmaele, H., 2010. Safety stock optimization two-echelon assembly systems: normal approximation models. *International Journal of Production Research* 48, 5767–5781. https://doi.org/10.1080/00207540903164636

Ghadimi, F., Aouam, T., Vanhoucke, M., 2020. Optimizing production capacity and safety stocks in general acyclic supply chains. *Computers & Operations Research* 120, 104938. https://doi.org/10.1016/j.cor.2020.104938

Goyal, S.K., Gunasekaran, A., 1990. Multi-stage production-inventory systems. *European Journal of Operational Research* 46, 1–20. https://doi.org/10.1016/0377-2217(90)90293-K

Gumus, A.T., Guneri, A.F., Ulengin, F., 2010. A new methodology for multi-echelon inventory management in stochastic and neuro-fuzzy environments. *International Journal of Production Economics,* Integrating the Global Supply Chain 128, 248–260. https://doi.org/10.1016/j.ijpe.2010.06.019

Humair, S., Willems, S.P., 2011. TECHNICAL NOTE—Optimizing Strategic Safety Stock Placement in General Acyclic Networks. *Operations Research* 59, 781–787. https://doi.org/10.1287/opre.1100.0913

Klosterhalfen, S.T., Minner, S., Willems, S.P., 2014. Strategic Safety Stock Placement in Supply Networks with Static Dual Supply. *M&SOM* 16, 204–219. https://doi.org/10.1287/msom.2013.0472

Lambrecht, M., Luyten, R., Muckstadt, J.A., 1982. Safety stock policies for multi-echelon production systems. *DTEW Research Report* 8208.

Li, P., Chen, H., Che, A., 2013. Optimal batch ordering policies for assembly systems with guaranteed service. *International Journal of Production Research* 51, 6275–6293. https://doi.org/10.1080/00207543.2013.801571

Liu, C., Zhu, Q., Wei, F., Rao, W., Liu, J., Hu, J., Cai, W., 2020. An integrated optimization control method for remanufacturing assembly system. *Journal of Cleaner Production* 248, 119261. https://doi.org/10.1016/j.jclepro.2019.119261

Louly, M.-A.O., Dolgui, A., 2009. Calculating safety stocks for assembly systems with random component procurement lead times: A branch and bound algorithm. *European Journal of Operational Research* 199, 723–731. https://doi.org/10.1016/j.ejor.2007.11.066

Moncayo-Martínez, L.A., Zhang, D.Z., 2013. Optimizing safety stock placement and lead time in an assembly supply chain using bi-objective MAX–MIN ant system. *International Journal of Production Economics* 145, 18– 28. https://doi.org/10.1016/j.ijpe.2012.12.024

Pal, B., Sana, S.S., Chaudhuri, K., 2014. A multi-echelon production–inventory system with supply disruption. Journal of Manufacturing Systems 33, 262–276. https://doi.org/10.1016/j.jmsy.2013.12.010

Prajapat, N., Tiwari, A., 2017. A review of assembly optimization applications using discrete event simulation. *International Journal of Computer Integrated Manufacturing* 30, 215–228. https://doi.org/10.1080/0951192X.2016.1145812

Rosling, K., 1989. Optimal Inventory Policies for Assembly Systems Under Random Demands. *Operations Research* 37, 565–579. https://doi.org/10.1287/opre.37.4.565

Samson, O.O., Afolalu, S.A., Ojo, S.F., Oladipupo, S., 2019. Inventory replenishment in multi-stage production setting under stochastic demand: a review. *J. Phys.: Conf. Ser.* 1378, 032072. https://doi.org/10.1088/1742-

6596/1378/3/032072

Sbai, N., Benabbou, L., Berrado, A., 2021. Multi-echelon Inventory System Selection : Case of Distribution Systems. *International Journal of Supply and Operations Management (IJSOM)*. https://doi.org/10.22034/ijsom.2021.109031.2138

Sbai, N., Berrado, A., 2019. A Strategic Framework for Multi-Echelon Inventory System Selection, in: 2019 *International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)*. Presented at the 2019 International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA), pp. 1–8. https://doi.org/10.1109/LOGISTIQUA.2019.8907306

Sbai, N., Berrado, A., 2018. A literature review on multi-echelon inventory management: the case of pharmaceutical supply chain. *MATEC Web Conf.* 200, 00013. https://doi.org/10.1051/matecconf/201820000013

Schmidt, C.P., Nahmias, S., 1985. Optimal Policy for a Two-Stage Assembly System under Random Demand. *Operations Research* 33, 1130–1145. https://doi.org/10.1287/opre.33.5.1130

Shenoy, D., Rosas, R., 2018. *Multi-echelon Inventory Models*, in: Shenoy, D., Rosas, R. (Eds.), Problems & Solutions in Inventory Management. Springer International Publishing, Cham, pp. 267–277. https://doi.org/10.1007/978-3-319-65696-0_11

Snyder, L.V., Atan, Z., Peng, P., Rong, Y., Schmitt, A.J., Sinsoysal, B., 2016. OR/MS models for supply chain disruptions: a review. *IIE Transactions* 48, 89–109. https://doi.org/10.1080/0740817X.2015.1067735

Williams, J.F., 1983. A Hybrid Algorithm for Simultaneous Scheduling of Production and Distribution in MultiEchelon Structures. *Management Science* 29, 77–92. https://doi.org/10.1287/mnsc.29.1.77

Woerner, S., Laumanns, M., Wagner, S.M., 2018a. Simulation-Based Optimization of Capacitated Assembly Systems under Beta-Service Level Constraints. *Decision Sciences* 49, 180–217. https://doi.org/10.1111/deci.12260

Woerner, S., Laumanns, M., Wagner, S.M., 2018b. Joint optimisation of capacity and safety stock allocation. *International Journal of Production Research* 56, 4612–4628. https://doi.org/10.1080/00207543.2017.1380323

Zhou, S.X., Yang, C., 2016. Continuous-Review (R, nQ) Policies for Inventory Systems with Dual Delivery Modes. *Operations Research* 64, 1302–1319. https://doi.org/10.1287/opre.2016.1538

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