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An Innovative Business Model for a Multi-echelon Supply Chain Inventory Management Pattern

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Abstract. Nowadays, companies are experimenting novel organizational solutions to efficiently operate in uncertain and highly dynamic scenarios. As a potential solution, this paper proposes a new business model for a multi-echelon Supply Chain inventory management pattern. Specifically, an inventory model with proactive lateral transshipments was developed and subsequently tested carrying out 288 experiments with the aim of assessing transshipments impact on the performance of a two-echelon Supply Chain. The final goal was to investigate the potential reduction of the overall cost of the enterprise and, conversely, whether this approach could promote significant improvements in the level of service, achievable through a more efficient management of resources. The analyses and simulations indicate the use of large batches and/or low-cost products did not demand the necessity of transshipment events. These preliminary findings could be potentially validated and tested in the future considering more complex networks or multiple products.

1. Introduction

In this historical period, strongly conditioned by the rapid evolution of environmental variables, companies are committed to implementing and experimenting new flexible organizational and management solutions. Currently, high quality, competitive costs, and short development times are necessary to guarantee customer assets [1–4]. Companies that intend to implement these services and adapt to the context of reference must be aware of the current situation and, consequently, should implement a strategic system [5] using different management techniques [6, 7] and optimize tools to analyse several data [8–15] to achieve customers satisfaction [16-18]. Thus, similar improvements may also derive from recent investigations carried out in the context of Industry 4.0 [19-21].

The paper shows the necessity to achieve customers satisfaction with the aid of several external factors.

1.1. Supply Chain Inventory Management: Evolution, Characteristic and Limitations
Until the end of the 1970s, the organizational model, which dominated the literature, referred to a vertically integrated company. Subsequently, with the increase of personalized customers' requests, the development of communication and information technologies allowed a radical change also in logistic aspects. All these changes promoted the economic integration of business process, with a consequent reduction in transition costs [22] and a personalized service with shorter delivery times. These were the decisive factors in the development of "Supply Chain Management". With this new management approach, the company becomes part of a network of different entities. The aim is to provide highly customized products and services [22, 23]. Therefore, the Supply Chain concept is much broader than that of logistics.

In this perspective, the success of the system depends on the interaction capacity of the single network nodes and on an efficient use of interactive technology. Fluctuation and diversification of the demand are the principal parameters to control in our dynamic market system. Variability could depend on the" Forrester effect" or the "Bull-whip effect". It increases backwards in the supply chain, determining a higher level of stock than necessary. An effective and efficient Supply Chain shows the following features [24]:

- Stable and collaborative organizational relationships;
- Appropriate coordination;
- Efficient information flows;
- Outsourcing;
- Make-to-order strategy, with current market conditions;
- Efficient warehouse management through the logic of Just in Time approaches [25].

1.2. Management of Up-stream and Down-stream Reports
In the previous section, it was introduced the concept of Supply Chain. The two interested areas of action are up stream integration with upstream suppliers and downstream integration with consumers. Over the years, these relationships have undergone a continuous evolution, due to the increase in environmental complexity and both variety and variability of several adoptable technological solutions. Interestingly, each supply relationship has not the same weight for the company. Indeed, it is possible to identify two types of suppliers:

- Tactical suppliers, or suppliers of materials of minor importance;
- Strategic suppliers, suppliers who play a strategic role for the lead company.

In the first case, the costs associated with changing the supplier are low and a multiple supply is possible. The relationships with suppliers that belong to the second category are necessary to achieve the business success. A second type of relationship connects the physical distribution of the products and allows an ideal organization of storage and the integrated management of information flows and supply systems. The most advanced distributors use distribution centers or logistic structures managed directly by the distributors. The primary task of a distribution center is to monitor in real time the network needs and the time necessary to receive and deliver the products to destination. The aim is to constitute a single stockpile for the entire distribution network, significantly reducing costs and maintaining the control over the level of service.

2. Innovative Models of Supply chain

Supply chain management is an innovative approach which deals with planning and control of materials and the information from suppliers to final consumers. A fundamental aspect of this approach is the cooperation between all parties to optimize system-level performance. In recent years, there has been an evolution in management processes and the creation of new concepts such as: Outsourcing, Vendor Managed Inventory, Virtual Inventory and Lateral Transshipments [26–30].

2.1. Outsourcing

The non-core activities are enthusing companies for which the last described activities constitute the true core business. Generally, the contract is long-term and implies mutual trust and professionalism in the processing of sensitive data. The relationships between the company that outsources and the company to which the activity is sold (the outsourcer) are in fact collaborative, there is no conflicting element that most often characterizes the customer/supplier relationship. These motivations lead outsourcing to economic, financial, operational and strategic advantages. Nevertheless, the most common drawbacks are the potential loss of activities control, drainage of the company resources, resentments of the personnel dedicated to specific activities and a trade-off between flexibility and internal control Vendor Managed Inventory (VMI), one of the most used strategies to improve the Supply Chain [31, 32].

2.2. Vendor Managed Inventory

Through the VMI, the supplier makes the main inventory replenishment decisions for the organization. It checks the retailer's inventory levels and perform replenishment decisions basing on order quantities, transport and times. This allows to reduce production peaks, valleys and coordinate orders from different buyers, thereby increasing the number of on-time deliveries and also decreasing the Bull-Whip effect [33].

2.3. Virtual Inventory

This model involves sharing of the stock availability of several companies active in a territorial context. The goal is to reduce stocks of identical items in all warehouses [34]. The operation of this strategy is ensured by a service provider who knows the inventory levels through information technology systems and dedicated management procedures. The service provider manages the warehouses according to companies needs and the quantity of redundant materials. The provider, finally, receives the orders and then proceeds to the procurement, using the on-hand stock of the warehouses belonging to the virtual inventory, or possibly, turning to an external supplier.

2.4. Lateral Transshipments

The lateral transshipments allow rapid flows of materials and information from one echelon to another nearby echelon. Two different application modes can be distinguished: proactive and reactive. In proactive transshipment, lateral transfers are used to redistribute stocks between all the storage points of the same echelon, at predetermined intervals over time. Therefore, a proactive transshipment can be planned and organized in advance to generate the lowest possible management costs. Reactive transshipments, on the other hand, fit to situations where one or more storage points are in stock-out while one or more storage points present excess stock. This type of transfer is therefore suitable in environments where the costs of transshipment are relatively low compared to the costs associated with the storage of large quantities of stocks and the failure to meet the demands of end consumers [35, 36].

3. Methods

The proposed inventory sharing model with proactive later transshipments for a two-echelon Supply Chain integrates the concepts of VMI and Inventory Sharing. The objective of this work is to evaluate the impact of lateral transfers on the performance of a supply chain and to research the conditions in which lateral transfers are advantageous both in terms of the overall supply chain costs and in terms of the service level. This model considers a network consisting of two local warehouses (retailers) that must satisfy the demands of end consumers and a central warehouse from which local warehouses periodically refuel. Each local warehouse faces a variable demand *Dj* (*j* = *h*, *l*) defined in the following equation (1):

$$D_j = \begin{cases} d_j - \delta_j & with\,probability\ k \\ d_j & with\,probability\ 1-2k \\ d_j + \delta_j & with\,probability\ k \end{cases} \quad with \quad \begin{cases} d_j \geq 0 \\ 0 \leq \delta_j \leq d_j \\ 0 \leq k \leq 1/2 \\ d_{high} \geq d_{low} \\ E[D_j] = d_j \\ Stdev[D_J] = (2k)^{\frac{1}{2}} \cdot d_j \end{cases} \tag{1}$$

In particular, one of the two local warehouses has a low average demand (d_{low} = 30 pieces / day) while the other has a high average demand (d_{high} = 50 pieces / day). The replenishment policy is at reorder point, with reorder point *s* described by the following equation (2):

$$s = d \cdot \tau + z \cdot \sigma_d \cdot (\tau)^{1/2} \tag{2}$$

with *d* average annual demand, σ_d standard deviation of demand, τ = 10 days deterministic and constant lead time and *z* a parameter whose calibration depends on the level of service to be ensured.

During the lead time the demand is uncertain so that the retailer could see the safety stocks reduced and consequently find themselves in stock-out with significant backlog costs to be incurred. To guarantee a more efficient material management, the model foresees the possibility of using lateral transshipments between the two local warehouses, in a preventive manner, to avoid that the warehouse with negative stock on hand goes into stock-out. The decision-making system is centralized and local warehouses adopt inventory sharing; therefore, it operates in a VMI context in which the vendor (central warehouse) - usually a manufacturer, but eventually a reseller/distributor - makes the main inventory supply decisions for the entire organization. The model therefore begins with a check of the inventory levels followed by an evaluation of the stock on-hand (*SoH*) of each local warehouse. At the end of the evaluation phase of the on-hand stock, three cases may arise:

- SoH_1 and $SoH_2 < 0$, both local warehouses have negative on-hand stocks, are likely to go into stock-outs and need stocks that neither can supply to the other, which is why the transfer is not activated;
- SoH_1 xor $SoH_2 < 0$, the stock with negative on-stock stocks is likely to go into stock-out, needs stocks, while the other with positive on-hand stocks can sell a quantity of stocks at least equal to *SoH*. In this case, the costs associated with the transfer are compared with the backlog costs that the warehouse with $SoH<0$ would support if it went in stock-out;
- SoH_1 and $SoH_2 > 0$, the warehouses have sufficient stock on hand to meet the demand that is generated during the transshipment lead time, which is why they do not need stocks and the transfers are not activated.

The objective of the model is to find the Lot Size and Service Level values of each local warehouse which minimize an objective function, following described in the equation (3), created by weighing the different costs and events.

$$Total\ cost = C_o \cdot (n_{W1} + n_{W2}) + C_m \cdot (S_{W1} + S_{W2}) + C_{fT} \cdot (t_{W1W2} + t_{W2W1}) + C_{vT} \cdot (q_{W1W2} + q_{W2W1}) + C_b \cdot (b_{W1} + b_{W2}) \tag{3}$$

where C_o, C_m, C_{fT}, C_{vT}, C_b are respectively the cost of ordering, the cost of stock keeping, the fixed cost of transshipment, the variable cost of transshipment and the cost of backlog. Moreover, n_{W1}, n_{W2}, S_{W1}, S_{W2}, t_{W1W2}, t_{W2W1}, q_{W1W2}, q_{W2W1}, b_{W1} and b_{W2}, respectively, represent the number of orders for *W1*, the number of orders for *W2*, the average stock of *W1*, the average stock of *W2*, the events transshipment from *W1* to W2, transshipment events from *W2* to *W1*, items transshipped from *W1* to *W2*, items transshipped from *W2* to *W1*, backlog *W1* and backlog *W2*.

4. Results

288 experiments were examined and for each experiment it was estimated the optimal value of several decision variables, evaluating the fitness function (namely, the iteration presenting the minimum Supply Chain cost) for each possible combination of the Lot Size and Service Level values (node 1, node 2). These combinations were obtained by considering 25 Lot Size values for each node (from 0 to 500, with step 20) and 10 Service Level values for each node (from 0.9 to 1, with step 0.1). Therefore, 62500 simulations were considered considering a fixed duration of 365 days. The model and the simulation have been implemented in Python. Finally, the iteration with best fitness function was selected for each experiment.

Once the 288 results were obtained, an analysis was carried out using Pivot Tables which proved to be fundamental for identifying the relationships between lateral transshipment and Lot Size and between lateral transshipment and product cost. Firstly, it was noted that as the Lot Size of both local warehouses increased, transshipment events decreased (Figure 1). This leads to the conclusion that the use of large batches means that lateral transshipments are not indispensable.

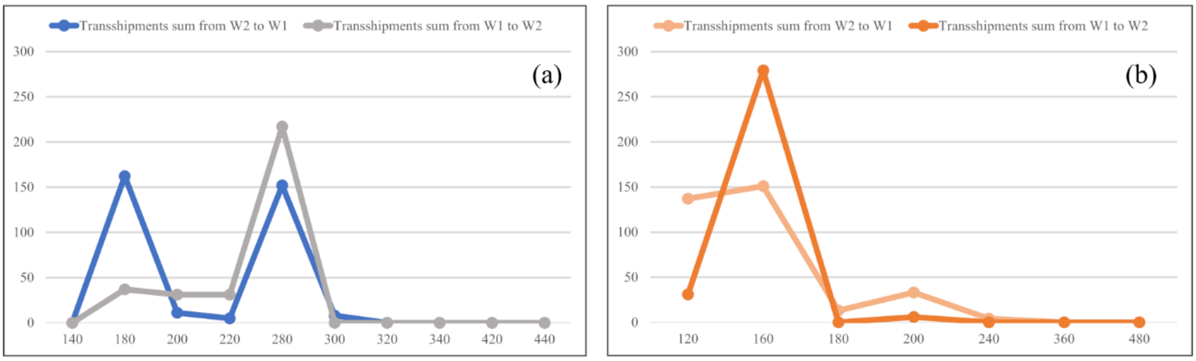

Figure 1. Line charts showing transshipment events (y axis) considering increments for a single lot size. (x axis). Transshipments evolution for (a) the increasing lot size 1 and (b) the increasing lot size 2.

Secondly, analysing the fitness function of both the Lot Size, it was possible to deduce that with a high product cost both the Lot Size (considered one at a time) has no influence on the fitness value, as shown in Figure 2.

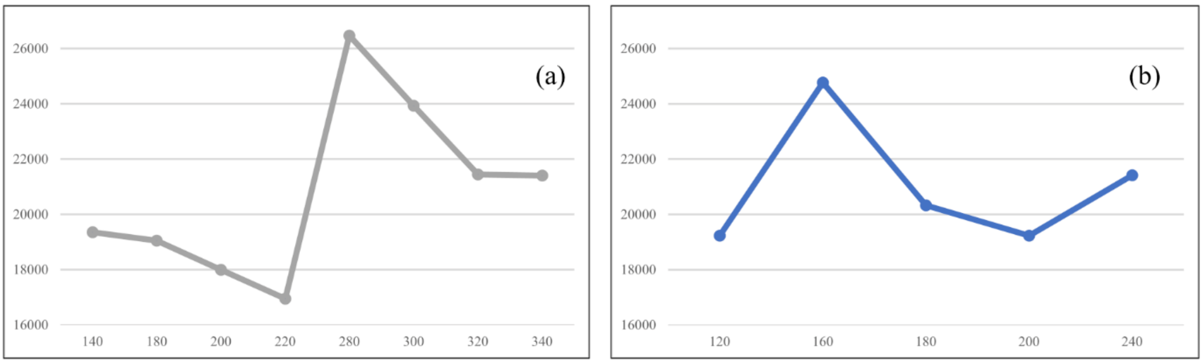

Figure 2. Line charts showing fitness function values (y axis) considering increments for a single lot size (x axis) for high product costs. Fitness evolution for (a) the increasing lot size 1 and (b) the increasing lot size 2.

In the presence of a low product cost, instead, both the Lot Size (considered one at a time) do not influence the fitness value (Figure 3).

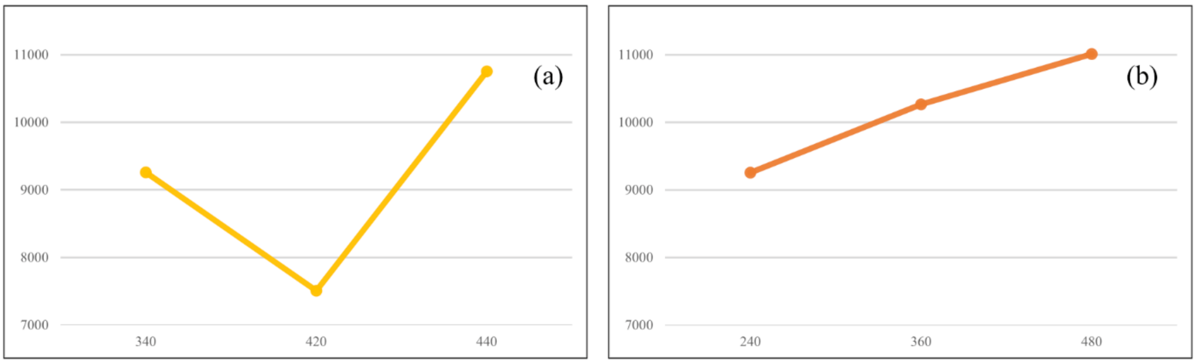

Figure 3. Line charts showing fitness function values (y axis) considering increments for a single lot size (x axis) for low product costs. Fitness evolution for (a) the increasing lot size 1 and (b) the increasing lot size 2.

These results indicate large batches are convenient with items which present a low product cost.

5. Discussion and Conclusion

In this work, a simulation model that integrates the concepts of inventory sharing and VMI was in Python. The model used preventive lateral transshipments with the aim of finding the Lot Size and Service Level values of each local warehouse to minimize the total cost of the supply chain (namely, the fitness function). The first simulations were carried out according to the 288 experiments considered which indicated lateral transshipments implementation is suggested in the presence of small lots and items with a high product cost.

Unlike other inventory models which consider lateral transshipments, the model developed and described in this paper integrates the concepts of VMI and Inventory Sharing and it is aimed at evaluating the impact of lateral transshipments on the performance of a Supply Chain and at finding the conditions in which lateral transshipments are advantageous. The obtained results, when compared to the relevant literature on this topic, show the proposed model offers an effective alternative to other approaches. In particular, the proposed strategy is based on proactive lateral transshipment, which can bring a further cost reduction compared to other models based on reactive transshipments only, as also demonstrated in other literature studies [37] where the benefits of using proactive lateral transshipments emerges especially in those systems characterized by partial pooling, as the ones simulated in this work. In fact, while it is generally known that there is no benefit for a proactive approach in a complete pooling network, since the transshipment decision rules are irrelevant when all warehouses are as one source [37, 38], here we give an additional proof of how the optimization models for lateral transshipments can effectively make a difference in the decision-making process for a partial pooling network.

Despite we deeply investigated the effect of lot size, effects of demand variability have not been studied and interpreted yet and they could be the objective of the next steps of our research in order to validate the proposed model and the relevance of the designed decision rules in highly dynamic business environments, as also highlighted in other studies [38, 39].

Moreover, while this model is generally proposed for small systems, it will be worth exploring the possibility to extend the proposed approach also to larger systems with three or more non-identical retailers and to inventory problems of larger multi-echelon supply chains.

On the other hand, the proposed model has a straightforward and easy-to-adopt logic leading to lower computational times compared to other more complex models available in the literature, which requires time-consuming computational efforts to solve inventory problems [38]. In this direction, a computationally efficient approach has been attempted in a more recent study [40]. However, similarly to our model, such approach assumes that supplier lead times are fixed [40], which is a limitation since, in practice, supplier lead times are uncertain, with an adverse impact on the overall performance of the supply chain. Therefore, future efforts could be also devoted to improve the proposed model considering a certain degree of uncertainty when estimating lead times.

Furthermore, while our model includes the most relevant parameters affecting the performance of the supply chain, there are also other non-negligible factors, e.g. additional costs (contractual, maintenance, discounts), that could be taken into consideration to get more insights into the value of strategic supply chain decision making, as also suggested in a previous study [41]. Finally, by analysing other scientific works present in literature which deal with the same issues [42-44], it was found the substantial differences of the analysed items compared to the proposed study are linked to the mix of supply chain models used. Indeed, such studies present a mix of models with a higher number of decision factors and variables, e.g. combining the lateral transshipment with additional support models. The possibility of combining the proposed model with others to achieve more reliable results could be explored in future works.

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