Master of Science Thesis

MIOM05 Degree Project in Production Management
Popular science summary

Comparing single- and multi-echelon methods for inventory control of spare parts at Volvo

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Faculty of Engineering LTH

Division of Production Management

By:

Jakob Bengtsson & Alexander Larsson

Supervisor:

Johan Marklund

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Background

The supply chain management area is recognized by most top management to be crucial for a company's success. The control of in- and outflow of goods are of strategic importance for the company in order to achieve its purpose and further customer satisfaction. The area of inventory control has evolved during the 20th century as companies' have recognized the area to be of a significant competitive advantage. (Axsäter, 2006) Inventory managers are continuously confronted with the trade-off between inventory holding costs and customer service. On the one hand, a company should strive for minimizing the total tied up capital, nevertheless, there are also costs associated with unsatisfied customers not receiving their orders in time (van Donselaar et al., 2021). Advances in technology and progress in research during the past decades have enabled companies' to deal with this trade-off more efficiently. (Axsäter, 2006)

In recent years, an increasing number of companies have realized the value of approaching the trade-off between holding costs and customer service more holistically. Several inventory control techniques have evolved from research with the aim to reduce total inventory costs while reaching customer service targets for the entire supply chain, as opposed to optimizing inventory control routines at each warehouse one-by-one. One of the main difficulties to overcome in such an approach is to coordinate decisions at different warehouses within the supply chain with a limited amount of information. (Andersson et al., 1998)

An industry area especially concerned with challenges related to inventory control is the distribution of spare parts. Spare parts are often of high importance in the process of securing the functionality of critical equipment for many companies and, as a result, reliable supply of such goods is critical. Simultaneously, spare parts networks can retain tens of thousands of different spare parts which make the inventory control process complex. Moreover, the distribution of spare parts is particularly challenging due to its variable demand, which can be of both slow-moving, lumpy and erratic character to name a few. (Turrini and Meissner, 2019)

This thesis will focus on the distribution of spare parts at Volvo Group, and more specifically, how a holistic inventory control method, e.g. a multi-echelon inventory control model, performs when used with real data from the case company. The department at Volvo concerned with the distribution of spare parts, have historically used a single-node optimization for their inventory control. As the company is currently developing a new centralized platform for their inventory control, there is an interest to understand to what extent a more holistic approach to their control could benefit their operations. With global reach and an international distribution network including many nodes and a wide range of customers, the inventory control process, inevitably, becomes a challenge to manage.

The Volvo inventory control process

The current inventory control process at Volvo is described in Figure 2. The process can be divided into the four steps: (i) segmentation, (ii) TSL-optimization, (iii) Inventory modeling and, (iv) Real world order process. In step (i), all SKUs are divided into segments, then in step (ii) each segment is provided a target service level by an optimization procedure aiming to minimize total holding- and backorder costs of the system. In step (iii) the inventory management system at Volvo mathematically models the distribution system in order to compute appropriate inventory policy parameters. Lastly, in step (iv) orders are requested from dealer to RDC and from RDC to CDC based on suggestions from the inventory management system as well as human experience.

Purpose of the study

In the third step in the Volvo inventory control process the modeling is done on a single-node basis. This study aims to investigate the effects of an implementation of a holistic modeling approach. The reason to use an holistic model is to get more reliable estimations of stock levels and customer service. In the literature a model taking multiple levels of the supply chain into account is called a multi-echelon model. The term echelon refers to a level in the supply chain. E.g. the retailers facing customer demand is the first echelon, the distribution center supplying the retailers is the second echelon and so on. This thesis aims to find a suitable multi-echelon method to model the Volvo supply chain. Furthermore, the thesis aims to give answers to what differences and improvements such model would bring to the inventory system.

Theoretical context

The overall objective in inventory control is usually to minimize inventory related costs while adequately satisfying customer demand. First, an ordering policy must be established, here we will use the common (R, Q) - policy where Q units are ordered when the *inventory position* (= stock-on-hand + outstanding orders not yet received) drops down to (or below) the reorder point R. The task now is to find the optimal R and Q to minimize inventory related costs. This is done by solving an optimization problem and in literature there exist two common approaches on how to formulate this problem.

The first approach is to decide upon a backorder cost penalizing unsatisfied demand, i.e. when a customer cannot get their order due to a stockout. Then this

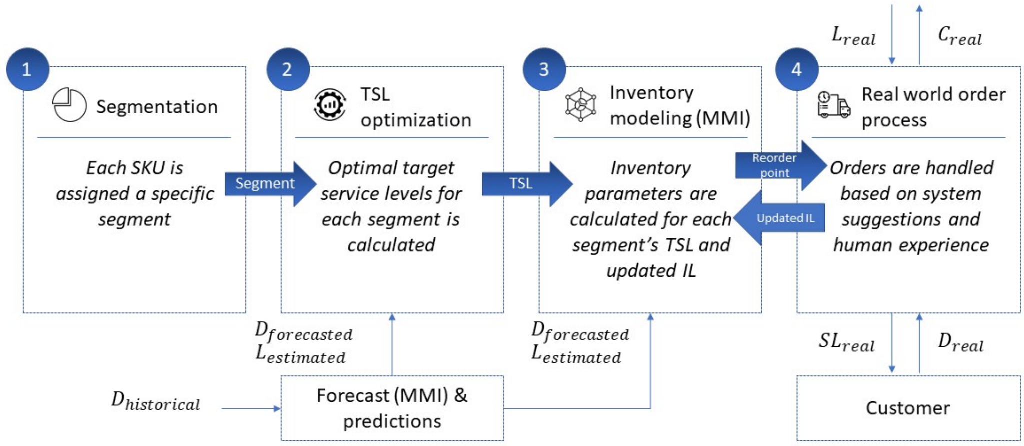

Figure 2: Volvo inventory control process.

backorder cost is balanced against the cost of holding inventory. The holding cost increase with R and Q and the backorder cost decrease with R and Q, thus, the optimal inventory parameters can be found that balances these costs. The problem here is to find a mathematical model that can give an estimation of the holding- and backorder costs that can be expected for a given set of R and Q.

While this approach is highly appreciated by researchers, in practice another approach might be more suitable. The decision upon a penalty cost is often subjective and complicated to validate. Thus, it might be more effective to disregard the penalty and replace it with a constraint on customer service. The optimization problem is instead formulated as to find the inventory parameters that produce the lowest holding cost while achieving a customer service objective. Now, the problem is instead to find a suitable target service level, but this is often perceived as an easier task.

The purpose of analytically modeling the inventory system in this context is to derive expressions to give estimations of the functions required in the optimization problem. Thus, the model needs to give estimations on the costs and inventory levels that can be expected for a certain set of inventory parameters. Furthermore, the model is required to compute estimations of the service level.

As a multi-echelon model is considering all installations in the system jointly, the optimization problems become multi-dimensional. In comparison to a single-echelon model, this is more computationally complicated. Therefore, the task at hand is to find a multi-echelon method of modeling the network that provide accurate estimations of the discussed functions while also being computationally tractable. In this thesis the model presented in Berling and Marklund (2013; 2014) was used, a model that decomposes the multi-echelon network into N+1 single-echelon problems (where N corresponds to the number of retailers). In this thesis the model is referred to as the Berling-Marklund model (BM-model).

Numerical study

A numerical study was performed with two objectives: (i) to investigate and understand what systematic changes to expect if implementing a multi-echelon approach (the BM-model) for optimizing the reorder point in the Volvo inventory control process compared to the single-node optimization currently in use and, (ii) to assess the potential of this method to achieve target service levels, decrease total inventory in the system as well as holding- and backorder costs. This numerical study was vital in answering the research questions of the thesis. The study encompass 52 items in a distribution system located in South Africa consisting of one RDC supplying 15 dealers spread across the country. The numerical study can be divided in three steps:

- Data was collected and analyzed to provide the inputs required.
- Based on the inputs, two sets of reorder points, as well as estimates regarding service level, stock levels and costs, were found analytically. One set was produced using a multi-echelon (ME) approach (the BM-model), the other using a single-echelon (SE) model made to resemble the current system.

- With the inputs and the two sets of reorder points, discrete-event-simulations were performed aiming to resemble a real-world setting in order to assess the accuracy of estimations produced by the analytical models.

In this study, two sets of single-echelon policies used by the case company in the South African network were studied. One is characterized by a service level at the RDC close to 100 %, and follows the general case at Volvo, in this thesis referred to as the "regular policy SE-model". The second policy is to our knowledge specific to the South African network and was implemented ad-hoc in order to keep more stock at dealers and let the RDC only act as a cross-docking facility for SKUs on their way to the dealer. In order to put this policy into effect the target fill rate is set to 10 % at the RDC while also manually setting the safety stock at dealers to an amount equal to 22-30 days of demand forecast. This model is referred to as the "special policy SE-model".

Results and conclusion

Based on the findings in this thesis, the authors suggest the Berling-Marklund model (BM-model) to be a suitable choice for modeling the Volvo supply chain.

The scaling potential for this model is promising, which is deemed important for Volvo as their supply chain consists of a large number of nodes and the current single-echelon optimization models used today is computationally demanding.

Furthermore, the BM-model decompose the network into single-echelon problems making the model an attractive choice as this should increase compatibility with the current system in use. In addition, it was shown in the numerical study that the model performs well with a shifting number of dealers. The model also allows for optimization of reorder points using both backorder costs or fill rates constraints, providing extra flexibility.

In terms of improvements in the system, the study showed that using the BM-model compared to the single-node approach produce significant cost reductions for almost every item in the study. Using the BM-model, 66.6 % cost reduction of the average holding- and backorder costs is exhibited for the items currently controlled by the South African special policy. Furthermore, a 22.0 % reduction of average holding- and backorder costs is displayed for the items governed by the regular policy.

Regarding the comparison between the BM-model and the special policy SE-model, the BM-model also renders satisfying results in terms of spare parts availability. The study showed that reorder points produced by the special policy SE-model was unable to reach fill rate targets for dealers with stocked items, on average being 18.4 *pp.* (percentage points) below target. The BM-model, on the other hand, confidently reached target fill rates for each of these items, on average achieving fill rates 1.35 *pp.* above target. However, the suggested reorder points by the BM-model also resulted in more stock than before. Average expected stock-on-hand was increased by 85.3 % over all the items associated with the special policy. Nevertheless, the extra stock-on-hand reduces backorders, and thus backorder costs. This reduction is greater than the increase in holding costs resulting in the total cost reduction mentioned above.

The main reason for superior performance of the BM-model compared to the special policy SE-model can be attributed to a more appropriate selection of reorder point at the RDC as well as a superior lead time estimate. The optimal reorder points at dealers obtained from the special policy SE-model assumes no delayed orders due to stockouts at the RDC, setting the lead time to the transport time between RDC and dealer. When in reality, the low reorder point at the RDC chosen due to the low fill rate target results in large delays. As the dealers are not taking this delay into account, the service to customers is lower than expected. The BM-model handles this both by including the delay in its lead time estimates as well as proposing an RDC reorder point providing higher service.

For items governed by the regular policy, the BM-model did perform equally satisfactory to the regular policy SE-model in terms of reaching target fill rates. The BM-model was on average 1.67 *pp.* above target while the regular policy SE-model was slightly below target at a 0.08 *pp.* undershoot. However, the BM-model provided reorder points that could reach target fill rates while keeping a lower amount of stock-on-hand. The average total stock-on-hand of the items studied was reduced by 35.6 %. The BM-model managed this by suggesting a set of reorder point so that stock was allocated further downstream in the supply chain. Thus, the system faced a slight increase in stock at the dealers while experiencing a large reduction of stock at the RDC and in the system as a whole.

References

J. Andersson, S. Axsäter, and J. Marklund. Decentralized multiechelon inventory control. *Production and Operations Management*, 7(4):370–386, 1998.

S. Axsäter. *Inventory Control*. International Series in Operations Research & Management Science: 90. Springer Science+Business Media, LLC, 2006. ISBN 9780387332505.

P. Berling and J. Marklund. A model for heuristic coordination of real life distribution inventory systems with lumpy demand. *European Journal of Operational Research*, 230(3):515 – 526, 2013. ISSN 0377-2217.

P. Berling and J. Marklund. Multi-echelon inventory control: an adjusted normal demand model for implementation in practice. *International Journal of Production Research*, 52(11):3331 – 3347, 2014. ISSN 00207543.

L. Turrini and J. Meissner. Spare parts inventory management: New evidence from distribution fitting. *European Journal of Operational Research*, 273(1):118 – 130, 2019.

K. van Donselaar, R. Broekmeulen, and T. de Kok. Heuristics for setting reorder levels in periodic review inventory systems with an aggregate service constraint. *International Journal of Production Economics*, 237:108137, 2021.