Master's thesis, Economics and Business Administration, Business Analytics

Predicting Stock-Out in Supply Chain

A Machine Learning-Based Policy for Proactive Lateral Transshipments in Online Retail

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Abstract

As online customers increasingly demand one- and same-day shipping, the inventory location is imperative; laws of physics requires inventory to be close to the customers. In a supply chain network of multiple warehouses that covers a large geographical area of customers, a warehouse may face stock-out while another warehouse has excess inventory.

What is the problem?
A stock-out in a warehouse will increase the distance of the inventory to the customers located around this warehouse.

Why is it important?
In order to deliver within a day or less, inventory needs to be close to the customer.

What is the solution?
By using proactive transshipments from a warehouse with excess inventory to a warehouse facing stock-out, the distance to customers is reduced, which is likely to increase delivery speeds.

How are you contributing to the literature?
There is little research available on stock-out prediction in supply chain, and none using real data. This thesis aims to close this gap by applying available theory on a real-life example.

There is no literature on using machine learning in a lateral transshipment policy. This thesis adds to the existing literature on lateral transshipments by using machine learning in the policy.

What is the result?
Using a snapshot of the supply chain, a machine learning classifier predicts whether a warehouse will face stock-out in the next week. If yes, a machine learning model will predict additional units needed to avoid a stock-out. These predictions are used in a policy for lateral transshipments. If a warehouse has excess inventory, it can initiate a lateral transshipment to a warehouse which faces stock-out. As a result of the rebalancing, distance to customers is likely to reduce, which facilitates fast delivery offered by the retailer.

Limitations: cost, doest it make sense (only when customer in-stock value + contribution profit exceed transshipment cost).

Acknowledgements

It's what you all been waiting for, ain't it?

I can't even explain it, I surprise myself too

Contents

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Introduction

Agenda Monday 2021-05-24

- Skriv lateral transshipment policy proposal
- Skriv teori om lateral transshipment
- Skriv ferdig inventory theory
- Beslutning om data, fetch code and data.
- => generate plots and metric on performance
- Beslutning om ARIMA osv?

https://www.mckinsey.com/industries/retail/our-insights/same-day-delivery-ready-for-takeoff

https://www.wsj.com/articles/the-prime-effect-how-amazons-2-day-shipping-is-disrupting-retail-1537448425

It is all about e-commerce now. Online sales has increased at a 1% compound annual growth rate from 2016-2020 (McKinsey, 2020), and traditional retailers are forced to follow customers to the Internet (MIT, 2013). Consumers enjoy the wide selection, low prices, customer reviews and the overall convenience online retail offers (HBR, 2011). In recent years, increasing competition in e-commerce has left consumers demanding more – they also want their orders to be delivered quickly. Traditionally, online retailers could achieve cost advantages by leveraging economies of scale at large warehouses in low-cost areas (MIT, 2018). However, as online retailers such as Amazon has popularized one-day shipping, and even same-day shipping, this strategy is no longer viable. Inventory needs to be in proximity to customers, and advanced analytics is the only way to achive this without dramatically increasing costs (ibid).

In general, retailers tend to have lower profit margins compared to other sectors (Stern, 2021). The high elasticity of demand translates to fierce competition and a need for operational excellence. In other words, supply chains compete, not companies (Christopher, 1992). The highly dynamic and volatile nature of supply chain is a great challenge, characterized by conflicting goals. On the one hand, the goal is to minimize a supply chain's costs. On the other hand, the goal is to maximize customer service level. A key part of this trade-off lies in inventory optimization. Holding inventory is expensive, so it is beneficial to hold as little as possible. However, if the retailer does not have sufficient inventory to cover demand, customers are likely to go to competitors. This is particularly true for online retailers, where the barrier to choose a competitor is extremely low.

Retailers purchase inventory based on forecasted demand. Since actual demand will deviate from the forecast, a buffer of safety stock is required to mitigate the risk of stockouts due to uncertainty in supply and demand. In a supply chain network with multiple demand regions, a typical problem is that warehouses in some regions are overstocked while others are understocked. In these cases, a *lateral transshipment* from the overstocked warehouse to the understocked warehouse will reduce the risk of stockout without increasing the overall inventory in the network. That is, by using lateral transshipments, the same service level can be achieved with a lower safety stock (Ge, 2019). Finally, if the understocked warehouse is the only one that can enable fast delivery to customers in the region, avoiding stockouts is essential for maintaining fast shipping speeds.

This paper will present a model that predicts stockouts in a warehouse. The prediction is then used in a policy for lateral transshipments, where one warehouse can send excess inventory to the warehouse at risk of being out of stock.

Motivation and research question There is very little research on stock-out prediction in single-echelon systems and (to the best of our knowledge) none on multi-echelon systems. No papers on lateral transshipments with real data (only simulations). No papers on lateral transshipment using machine learning.

1. To what extent can a machine learning model predict stockout in a warehouse, and how reliable are the predictions? 1. To what extent can a machine learning model predict how many additional units are needed to avoid stockout? 2. How can these predictions be a used in a policy for proactive lateral transshipments in the supply chain of an online retailer?

1.1 Problem Definition

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Background

Introduksjon til kapitlet.

2.1 Inventory Theory

* EOQ model * Newsvendor problem

The inventory management problem is a trade-off between service-level and cost. Holding inventory is costly, so why hold inventory at all? Firstly, assuming lead time between the purchasing order and delivery from the vendor, the retailer needs to hold inventory to satisfy demand during lead time. Secondly, since customer demand is hard to predict, we need to hold inventory to cover the forecasted demand, plus additional safety stock to protect against demand uncertainty. Safety stock is ... In general, the uncertainty the supply chain faces in terms of customer demand and vendor lead time. Finally, by ordering large quantities, economies of scale are achieved since the vendors likely offer bulk discounts and transportation is generally cheaper for large quantities.

Definition of safety stock.

The now-classic Economic Lot Size Model introduced by Ford Harris (1913/15) showed... Even though the assumptions used is unrealistic, it is considered essential still to this day (Snyder, 2008).

2.2 Inventory Pooling

Risk pooling is an important concept in supply chain management, as it can reduce the need for safety stock. Conceptionally, aggregated demand across locations will reduce demand variability since higher-than-expected demand in one location is likely to be offset by lower-than-expected demand in another location. Similarly, aggregated forecasts are more accurate than... hence reduce the risk and need for safety stock.

A strategy for risk pooling could be to centralize inventory in one central warehouse. In our case, instead of one warehouse each in Bergen and Oslo, we could have one central warehouse in between, which would serve both Bergen and Oslo customers. Demand for Bergen/Oslo area would then be aggregated, and demand variability would be reduced. Since safety stock is the stock to cover demand variability, this would be reduced, hence the average needed inventory position needed will also reduce.

The benefit of risk pooling increases as demand variability increases. An increase in the coefficient of variation translates to an increased need for safety stock. If two demand regions are aggregated, however, the coefficient of variation would reduce, hence reducing the need for safety stock and also the average inventory needed. This would drive down cost of storing inventory, or it can free up resources for new inventory, which will increase the selection for customers.

The benefit of risk pooling comes from the fact that increased demand in one region is offset by decreased demand in another region. Consequently, the benefit is reduced when demand in different locations becomes more positively correlated.

Due to the risk pooling effect, retailers might favor centralized over decentralized systems, i.e. a central warehouses over having one warehouse in each demand region. In terms of safety stock, service level and fixed costs, it will be beneficial. As demand variability decreases, safety stock can be reduced. When the central warehouse has the same inventory as the regional warehouses combined, and demand for the regions are not perfectly correlated, the service level will be higher for the centralized system. Finally, fixed costs is lower with one warehouse compared to multiple.

Definition of service level.

However, centralized systems are not always favorable over decentralized ones. First, since the distance to customers will be larger, customer lead times are likely to be much higher. Since transportation costs are a function of distance, these are also likely to be higher. In the online retail industry, customer lead time is a major competitive advantage (source). In our case, it is not possible to deliver same-day delivery using a centralized warehouse. Since this is a major concern for our company, a centralized system is not an option.

- A table with centralized vs decentralized might be useful here

Trade-off inventory levels

* High safety stock costly * Low safety stock risky as it increases the chance of lost sales (especially in online retail) * First rule of inventory management: Forecast is always wrong * Second rule: Aggregate demand information is always more accurate than dis-aggregate data * => Combined: Risk pooling

2.3 Supply Chain Networks

* Illustration of network * Single-echelon, multi-location, continuous review (s,S), with partial pooling.* * Få frem hvorfor vi vil være nærme kunden * Two warehouses, Oslo and Bergen. They serve Norway's national demand, but only the warehouse in Bergen can fulfill to customers the same day. However, we can transfer inventory from Oslo to Bergen, and then fulfill to customers within one day. Receives inventory from vendors. Retail. Continuous order policy (s,S). * Assumption: Oslo+Bergen has all the inventory customer demands, hence only difference is that Oslo warehouse can fulfill same-day to Oslo customers.

2.4 Lateral Transshipments

Lateral transshipments are shipments between warehouses at the same echelon (level) in the supply chain. It can be viewed as another form of inventory pooling, where warehouses of the same echelon share inventory since one warehouse can send a shipment that is needed in another warehouse.

By using transshipments, one can achieve the benefits of risk pooling without a central warehouse.

Paterson (2011) categorizes lateral transshipments as either proactive or reactive. A proactive transfer, or preventive transfer, is a

Nice overview https://core.ac.uk/download/pdf/41829234.pdf: . Lateral Transshipments based on Availability (TBA) policy (Banerjee et al., 2003): in literature it is often named as Emergency Lateral Transshipment (ELT). In this case, at time t, it is checked if one or more warehouses are in stock shortage.

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Data

Introduksjon til kapitlet.

3.1 Descriptive Statistics

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Methodology

Introduksjon til kapitlet.

5

Results

Introduksjon til kapitlet.

6

Discussion

Introduksjon til kapitlet.

6.1 Transshipment policy

* Link to SLRP Lee et al. (2007)? * Combine proactive and reactive as mentioned in Paterson (2011), use SLRP from Lee (2007).

1. Predict stockout on a weekly basis (proactive) 2. If stockout is likely in a warehouse (reactive), take inventory from a warehouse with (the most) surplus inventory to the stockout warehouse 3. Transship as much as possible of the excess inventory up until the optimal inventory level

* ABC, ie one stragegy for A = fast items, B = slow, C = ultraslow etc, from risk pooling ref book? * Fast: Optimize for recall * Slow: Optimize for precision

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Conclusion

It is possible to predict stockout. Machine learning is better than logistic regression / heuristics. The best way to implement the model is by running it proactively (weekly), then initiating transshipments if stockout is predicted (reactive).

+ future work: predict more than one period ie not myopic

Notes * Inventory pooling: https://www.hbs.edu/faculty/Lists/Events/Attachments/163/Pooling.pdf * Stockout prediction: https://arxiv.org/pdf/1709.06922.pdf * See references for inspiration of supply chain theory etc * Optimize precision for slow and recall for fast ASINs? Nice discussion

* 2019, Retail supply chain management: a review of theories and practices : https://www.researchgate.net

* Shipping speed increasingly important, competitive advantage. * Tremendous increase in demand for online retail, which could be more sustainable than driving to the store. * Very few players have achieved reasonably priced 1-day shipping.

* aggregated forecasts more accurate

Supply chain is a highly volatile environment which changes constantly, and where a small change makes a huge difference (bullwhip effect). The high demand variability makes it hard to forecast, which is evident from the saying "all forecasts are wrong". This illustrates the importance of having a flexible supply chain that can adapt to an every-changing customer demand.

Naturally, a high selection makes physical warehouse space a scarce commodity.

For online retail, the purchase order decision is based on a forecast. However, as demand changes, this might lead to being overstocked or understocked. Retailers adds a buffer inventory, safety stock, in order to combat this problem. Another way is to leverage inventory pooling, where critical low inventory in one warehouse can be replineshed, either completely or partially, from another warehouse in the same echelon. Another benfit of using this approach is that the inventory decision is deferred from the purchase order to a time closer to the customer purchase.

As demand eventually deviates from the forecast, different regions in the market will either be understocked or understocked, creating imbalances in the supply chain network. One way to mitigate these imbalances is to use lateral transshipments. Lateral transshipments is when an overstocked FC can replenish the understocked FC. This effectively illustrates how inventory pooling can rebalance the network and mitigate the risk of inaccurate forecasts.

The consequence of a stockout is lost sales opportunity. Buying more inventory is a process that takes time, depending on the wholesaler's lead time, and lateral transshipments are a better fit to combat demand fluctuations.

- Agile supply chain

Agile supply chain: https://www.sciencedirect.com/science/article/abs/pii/S0019850199001108

Stern School of Business: http://pages.stern.nyu.edu/ adamodar/New$_{H}ome_{P}age/datafile/margin.html$

https://pdfs.semanticscholar.org/0243/d7560941f72c5b7b6592aa34ef8d8c6247f2.pdf :

- Uncertainty - Three effects: deterministic chaos, parallel interactions, demand amplification (bullwhip effect)

Supply chains compete, not companies (Christopher, 1992).

87% of online shoppers identified shipping speed as a key factor in the decision to shop with an e-commerce brand again.: https://www.mhlnews.com/transportation-distribution/article/22051729/delivery-time-top-priority-for-online-shoppers

Supply chain management is a highly complex field, characterized by uncertainty.

This guy has interesting papers: https://scholar.google.com/citations?user=rtjA2vQAAAAJhl=en

McKinsey 2020: https://www.mckinsey.com/ /media/McKinsey/Industries/Retail/Our

MIT Technology Review, 2013: https://www.technologyreview.com/2013/11/04/175533/its-all-e-commerce-now/

HBR 2011: https://hbr.org/2011/12/the-future-of-shopping

MIT 2018: https://webcache.googleusercontent.com/search?q=cache:P9lHXptd8ggJ:https://sloanreview.
the-speed-price-trade-off/+cd=1hl=enct=clnkgl=lu

Christopher, M. (1992). "Logistics and Supply Chain Management: Strategies for reducing costs and improving services.". Financial Times/Pitman Publishing.

The inventory placement problem (also some on lateral transshipments): https://dspace.mit.edu/handle/1