Multiple supplier/delivery inventory models

A review from an after-market perspective

Christopher Schmidt

Student
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M.Sc Industrial Engineering & Management
Optimization and Logistics, 300 Credits
Partner: Syncron International AB

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– *A review from an after market perspective*

For Syncron International AB

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Department of Mathematics and Mathematical Statistics
Umeå University

SE-901 87 Umeå, Sweden

Supervisors:
Per-Håkan Lundow, Umeå University
Mikael Blom, Syncron
Victor Söderberg, Syncron

Examiner:
Gerold Jäger, Umeå University

Abstract

After decades of industrial manufacturing markets have become saturated which is followed by decreased growth in sales, increased competition, and razor thin profit margins. This opens up for a new field of business competition, the after-market. Delivering value over time for customers is now a competitive advantage with too much potential to overlook. The after-market differs from regular industrial inventory management by being managed by service-levels based on probability distributions as break-downs occur randomly. This review aims at investigating the potential benefits of using multiple-sourcing/delivery modes and assessing available models in the context of the after-market. Three categories in the field are outlined: strategy, emergency-delivery, and order-splitting, each with significantly different value propositions. Aspects such as risk mitigation, importance of supplier competition, and operational flexibility are being discussed.

Seven models from the category "Emergency-delivery" are subjected to a closer inspection where two models could be of further interest. It is found that a majority of available models are based on back-order penalties, thus not feasible in practise. No model that caters to the formulated problem has been found, nor seem to exist due to complexity. Instead, an alternative problem is suggested and formulated as a matching problem which approaches the multiple-sourcing/delivery concept from an aggregate level.

Syncron is recommended to keep using the same approach as today and investigate the suggested problem instead.

Keywords: After-market optimization, Inventory management, Multiple supply modes; Supply chain management, emergency-delivery, order-split.

Sammanfattning

Efter årtionden av industriell tillverkning börjar marknaden bli mättad vilket följs av minskad försäljning, ökad konkurrens, och lövtunna marginaler. Det här öppnar upp för ett nytt affärsområde - eftermarknaden. Att leverera värde till kunder över tid är numera en konkurrensfördel med allt för stor potential att bortse från. Eftermarknaden skiljer sig från den ordinarie lagerhanteringen då den hanteras utifrån service-nivåer baserade på olika sannolikhetsfördelningar eftersom reservdelar går sönder slumpmässigt. Den här litteraturstudien syftar till att undersöka de potentiella fördelarna med att använda multiförsörjning/leverans-metoder och bedöma nyttan av tillgängliga modeller ur
ett eftermarknadsperspektiv. Tre kategorier inom området beskrivs: strategi, nödleverans, och orderdelning, där respektive kategori har olika fördelar att erbjuda. Aspekter såsom riskreduktion, vikten av konkurrens mellan leverantörer, och operativ flexibilitet diskuteras. Sju stycken modeller från kategorin "nödleverans" analyseras mer i detalj där två stycken kan vara intressanta att studera närmre. Studien visar att de flesta tillgängliga modellerna baseras på bristkostnader och är således inte lämpliga i praktiken. Ingen modell som svarar mot behoven i det formulerade problemet har hittats, eller verkar finnas på grund av komplexitet. Istället föreslås ett alternativt tillvägagångssätt för att uppnå multiförsörjning/leverans-fördelar från ett aggregerat perspektiv. Det nya tillvägagångssättet formuleras som ett matchningsproblem.

Syncron rekommenderas att fortsätta med dagens tillvägagångssätt och istället undersöka det föreslagna matchningsproblemet istället.

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Syncron

Founded 1990, Syncron is a supplier of solutions- and services that optimizes processes and make complex after-market supply chains more efficient. The company has a global presence with its headquarter in Stockholm, Sweden and company offices can be found in Europe, North America, and Asia. Syncron's customers are mostly multinational, globally leading companies in distribution and manufacturing such as Deutsche Bahn, Daimler Trucks North America, Volvo, Komatsu, Alfa Laval, and Atlas Copco. Syncron offers world leading solutions in Global Inventory Management, Global Price Management, Global Order Management and Master Data Management delivered as a cloud(Software-as-a-Service) to customers.

Contents

Thesis dictionary

Backorder	A demand for a product that has not been satisfied
Book inventory	What stock on hand is according to accounting
Buffert-stock	The amount of stock used to hedge against uncertainties primarily in demand and lead time
Cycle stock	The amount of inventory available for a demand during a normal time period, also called working stock
Deterministic system	A system where no randomness is involved in the development of the future states of the system. A set of input will always generate the exact same output.
Effective lead time	Quoted factory lead time, time between placing order until receiving the goods
Effective stock	On-hand inventory + outstanding orders
Fill rate	Fraction of the demand that can be filled directly from stock, See "S2"
Fixed order cycle	Orders are generated at predetermined intervals
Fuzzy methodology	Approximation technique used when there is no "hard data" available. Can be used to translate subjective assessments to values
Inter-channel competition	Market situation where actors in the same distribution network has to compete with each other for the same customer
Heuristic	A general technique used to immediately solve a given problem, not guaranteeing optimal results but instead with sufficient results
Inventory level	On-hand inventory minus backorders
Inventory on hand	Physical units in inventory, ready to serve customers
Inventory position	inventory on-hand - backlog + orders outstanding
Lead time	Time from placing an order to receiving the order
Make-to-order	A "pull" business strategy. The manufacturing of a product is initiated once there is a placed order for that specific item. This allows more flexible customisation in exchange for additional waiting time for the customer.
Monte Carlo simulation	Iteration method used to calculate approximative values for problems that are not possible to solve analytically
Outstanding order	Placed order that not yet has been delivered, i.e pending order
Phantom inventory	Goods in inventory systems that are registered as on-hand but are unavailable

Purposive sampling	Sampling techniques where the units that are investigated are based on the judgement of the researcher.
Software-as-a-Service	Cloud service. Software delivery model licensed on subscription basis and is centrally hosted. Also known as on-demand software
Substitutable goods	Products that a buyer perceives as similar or comparable and can be used to substitute one another.
Service level	Measurement of availability to customers. Primarily two different used. S1 and S2
S1	Service level measurement, “probability-of-no-stock-out-during-cycle”
S2	Service level measurement,“the fraction of the demand that can be filled directly from stock”. Also called Fill-rate
Spot-market	Commodities bought are immediate effective

1 Introduction

This chapter gives some background for the presented work and outlines its objective and scope.

1.1 Background

Running a business is an endless chase for cost minimisation and profit maximisation. Not moving forward implies movement backwards in an industrial business context. For decades the target goal for industrial production has been economy of scale and keeping up with your competitors in performance, price and quality. After decades of business the market slowly becomes saturated, implying decline in sales growth, increased competition, and razor thin profit margins. New business circumstances has opened up another field of competition, the after-market services.

After-market involves any product service or support provided over the complete life-cycle of an end customer product, after the original purchase has been made(Bundschuh & Dezvane 2003). After-market services implies spare-parts and after-service solutions to customer problems such as spare parts, repairs, installing upgrades, day-to-day maintenance, consulting, technical support, and training.

The discovery of the after-market potential has led to a shift in main focus regarding industrial business models. A major part of it is now about delivering value over time. One could say that the customer value proposition has been extended to maintain the product value during its lifetime, and thus prolonging customer relationships. This serves as a pay-off in several ways. For example, it is cheaper to retain customers and increase sales on service- and parts than it is to find new customers. By supplying customers with service through the item's entire life cycle it gives a company a unique insight to customers businesses and needs, a competitive advantage hard to mimic. Implying that investments in after-market services will monetize over years until the original product is replaced. It must, however, be emphasised that the after-service supply chain requires extensive inventory management using ABC-categorisation in order to keep track of articles characteristics and predetermined service levels as it can have severe impact on the bottom line if managed poorly.

Putting a price on a service is more difficult than pricing a newly manufactured product. Services are less tangible and it is harder to create adequate ordering policies to match a random demand.

In manufacturing there is an ordered quantity with a due date which represents a forecast, to manage orders a manager has to decide when to place orders for material to arrive just in time. When dealing with after-market services the circumstances are different. Forecasts are in this case probability distributions because breakdowns occur randomly. As companies grow their service supply chain grows with them and so does the complexity of it.

1.2 Today's practise

This chapter serves to enlighten the reader about methods used in logistics and how they are used in today's practice in order to facilitate further understanding

There are 3 reoccurring questions in inventory management which are: When, How much, from Whom?

- *When should an item "I" be ordered from a supplier/production/other warehouses?*
- *How much should be ordered, i.e quantity*
- *What supplier can best provide for the buyer's needs?*

1.2.1 Inventory policies

How inventory levels are managed in practice depends partly on how they are reviewed, inventory level in relation to re-ordering points. In inventory management a distinction between two main types of inventory policies can be made. In the following matrix it is possible to see what method is best suited to the circumstances. These ordering-policies goes under a variety of different names, in this thesis they are addressed to as in Table 1.

Inventory policies	Fixed order intervals	Varying intervals
Fixed quantity	1. Non existing in practice	2. Continuous (Q,s)-review
Varying quantitiy	3. Periodic (r,S)-re-view	4. Misc

Table 1. Inventory policies

1. Fixed order intervals - Fixed quantity
For example: Order X units every friday. In order for this to work in practise the demand would have to be known in advance and perfectly even. Deviations would result in stock-outs or unnecessary stock-buildup, thus not feasible in practise.

2. Varying intervals - Fixed quantity
Continuous(Q,s) inventory policy(Figure 1.), also called perpetual policy(PI). Today it often implies that each item is being tracked in real-time and that inventory is updated every time a product is sold/removed. This technique can highly effective when integrated with reliable inventory management systems. A retailer's bar-code scanner or radio frequency identification(RFID)

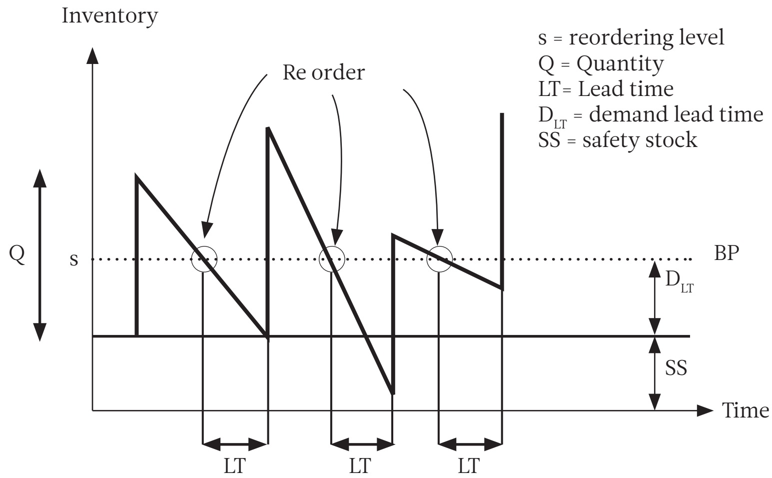

Figure 1. Example of the continuous (Q,s)-review policy

can be used as tool to update inventory level after each product sale(Sarac et al. 2010). This method facilitates the issue of differences in book inventory and stock-on-hand but is prone to systematic errors such as phantom inventory, resulting in overestimation of inventory levels. Conversely it might underestimate inventory levels due to incorrectly scanned goods, theft, and untracked goods.
The method consists of a fixed order quantity being placed when the inventory level reaches a predetermined level s. The order quantity consists of a forecast(over periods to cover) after lead- time. The point of reordering can be determined by the size of the safety stock and the demand during the lead-time. The continuous (Q,s)-model is easily administered and when the reorder point is set a manager only needs to track the inventory as more planning should not be needed. The continuous review is a simple, easy to understand- and implement inventory policy.

3. Fixed order-interval - Varying quantity
When using a periodic inventory (r,S)-policy inventory levels are review on a periodic basis(Figure 2). Generally no effort is being made between review points to keep records up-to-date. An example could be a store owner that decides to control his inventory once a month. In comparison to the perpetual policy, the periodic inventory method has to keep a safety stock not only for the lead-time but for the period itself as well (Axsäter, 2006). Periodic inventory policies are common among smaller businesses that might not use an electronic tracking system such as barscanners.
An (r,S)-inventory policy generates orders between fixed intervals(review time, r.) to the "order-up-to" level S which arrives after lead-time L. If the initial inventory level is "k" in the beginning of a period then there are two possible outcomes when reaching a review point in this simplified example.

- if k < S then the quantity S-k will be ordered
- if k ≥ S then no order is placed

4. Varying intervals - Varying quantity
There are several other methods on how to order goods, such as lot sizing. Lot sizing can be efficient in the context of manufacturing in a non-stochastic environment. Because the model is deterministic it can be effective if the influx of material can be controlled and the capacity of production is known, e.g for creating production schedules. It is, however, not feasible in the stochastic environment of the aftermarket. For example, dynamic lot sizing models can be used to calculate optimal results by using dynamic programming using a push-type manufacturing forecast. Lot sizing models(LS) falls in to the category of mixed integer programming and will not be further explained.

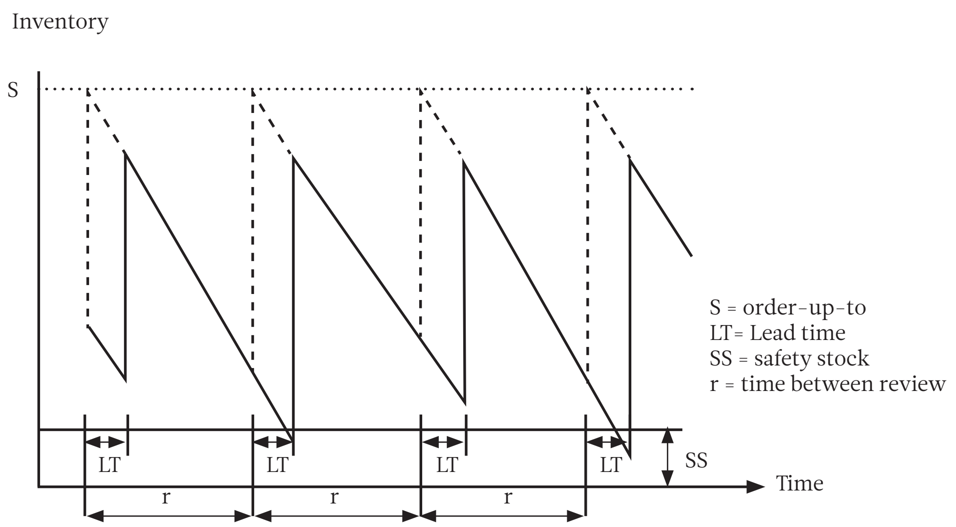

Figure 2. The periodic (r,S)-review policy

1.2.2 Safety stock and service levels

In all kinds of material planning there are different kinds of uncertainties. Customer demand will fluctuate and suppliers will usually have fluctuations in lead times. If an assumption of deterministic demand and deterministic lead-time is made there would be no need for safety stock as demand would be met at all times.
There are multiple ways to decide the amount of safety stock. The first is based on intuition, i.e by experience. The second is by proportion of average demand, safety stock is set to match the average demand for X days. Third, statistical methods, takes both average demand and variations in consideration and can be described by different probability distributions. Fourth and last, back-order methods, are also based on probability distributions but optimises with the help back-order costs.
In the category of statistical methods there are primarily two dominating techniques to determine availability by amount of safety-stock. S1 is defined as "probability-of-no-stock-out-during-cycle", and S2(Fill-rate) is defined as "the fraction of the demand that can be filled directly from stock". The calculations used to determine safety stock(S1 or S2) according to these measures are dimensioned for one independent item-type in a single echelon. Thus not dimensioned for order-splitting. Meaning that today's practise assigns an item's demand to a single average "best" supplier.

The S1-service level assuming normal distributed demand is the most common method taught in textbooks because of its simplicity and that it is very user-friendly. It does, however, come with some disadvantages. The method does not take quantities in to consideration, meaning that if a stock-out is avoided in 19 out of 20 cases the service level of the S1 is 95%, regardless of the amount "lost". If a batch of goods is large and is supposed to cover demand over a longer time it does not matter if S1 is low, there will still be plenty of stock held due to the large batch size. Conversely, if the batch is small the obtained "real" service level might be very low, even though S1 service-level is high. It follows that items with higher turnover are more prone to stock-outs than "slower" items even if the demand deviations are the same. The amount of replenishment-cycles with stock-outs fails to inform regarding the length and the volume of the stock-outs, merely that they have occurred.

Zeng and Hayya (1999) make a comparison between the measures S1 and S2 using different probability distributions and items. It is found that the same service-level results in different inventory turnover-rates and inventory related costs depending on the chosen measure. What type of service-level to be used in practise depends on the characteristics of the studied item "I". This means that it is not useful to compare the different types of service-levels to each other as they represent different measures. Therefor, it is of paramount importance to not confuse the two with each other. A common technique in inventory management is to divide articles/goods to different categories based on the amount of control needed, impact on overall inventory cost, and revenue generation, known as ABC-classification. The technique provides increased control over inventory and allows different categories of stock being managed accordingly to their characteristics.

1.2.3 Global Inventory Management

One of Syncron's products, Global Inventory Management(GIM), facilitates the inventory management in the after-service market for world-leading companies such as Volvo and Atlas Copco by applying mentioned tools(and much more) integrated to a SaaS(Software as a Service)-solution. Syncron's GIM automatically categorises items to one out of nine demand-types characterised by their position in a life-cycle(Figure 3.). This is done in order to choose the right forecast algorithm to forecast a demand where every demand-type is described by a probability distribution. Item service-level will be determined accordingly to the characteristics of said item. Fast moving revenue generating items will have a high service-level whereas items in decline will moving towards the right in figure 3 and see its service-level gradually decrease until ultimately being phased out. This means that service-levels are of paramount importance to manage the after-market. This technique is used to create optimised replenishments-routines to customers operating in multi-echelon environments. GIM creates order suggestions for customers to approve or reject. Recently the feature of delivery mode optimisation was included which allows GIM to suggest alternatives to current delivery mode(if a cheaper delivery mode is calculated by the system). As a result, Syncron's solution helps customers to produce accurate forecasts and plan across the entire supply chain to optimize right-size inventory. Replenishment plans take inventory carrying costs, cost of replenishment, and target service levels in to consideration which leads to increased efficiency, lowering costs and achieving higher service-levels.

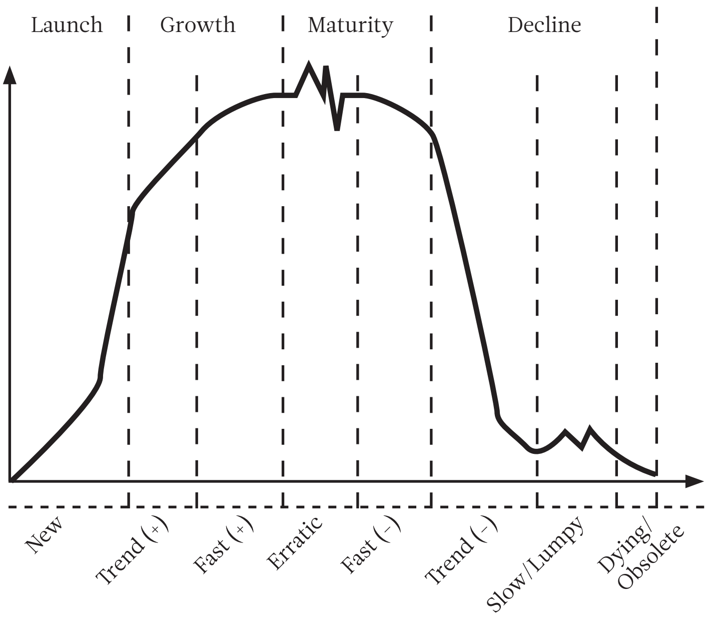

Figure 3. A life cycle with its nine categories of demand

1.3 Could multiple-sourcing/delivery be an alternative?

Definitions

Multiple sourcing can be defined as "purchasing from two or more suppliers an identical good or service" where single sourcing can defined as "purchasing a good or service from only one vendor". Multiple delivery refers to the possibility of using more than one delivery mode. For example, shipping by boat and airplane. However, "many sources" can both be multiple delivery modes and multiple suppliers. An important concept in the multiple-sourcing environment is the concept of "order-splitting" which refers to an replenishment order being simultaneously split instead of placing a single order.

Benefits and concerns

In an industrial environment when dealing with large numbers of articles and products it is often possible to order an article or product from several suppliers. Most arguments for multiple-sourcing can be back-traced to the influential market-based exchange paper made by Michael Porter in 1985 which emphasises the need of continued competition on the market in order to reduce supplier dependencies. There are other benefits such as supplier continuity, implying the need of a second source in case of supply chain disruptions or other risk management measures. Other benefits to multiple sourcing lies in global sourcing in low-cost country sourcing(LCCS) where low costs can be achieved at the expense of longer lead times and higher risk. An opportunity for lower costs could possibly lie in a combination of different delivery modes among suppliers to achieve reliability and cost benefits. Opponents to the concept of multiple-sourcing is primarily basing their arguments on increased risk, transaction costs(Williamson, 1975) and administration costs. The following table shows the potential strengths and weaknesses between single versus multiple-sourcing/delivery. A summary of potential strenghts and weaknesses can be found in Table 2.

Table 2. Potential strengths and weaknesses among multiple-source/delivery.

	Single source	Multiple sources
Potential strengths	• Simplicity(Choose one "best") • Easy to calculate service levels • Economies of scale • Close relationship with supplier	• Reduce agent problems • Lowers cost for a buyer through competition • Buyer independency from supplier • Supply continuity • Risk mitigation(e.g disruptions) • Safety stock reduction • Stock-out reduction • Cost reduction by LCCS.
Potential weaknesses	• Dependency • Opportunistic behavior from supplier • Disruptions can be very costly	• Higher administrative and transaction costs • Reduced scale benefits(Diseconomy of scale) • Less loyalty of the supplier • Multiple supplier relationships requires time and effort • Harder to control operations • Increased risk(Financial, operational etc.) • More maintenance • Complexity

1.4 Problem statement, objectives, research questions and scope

Requirements on potential models – the problem to solve
Item "I" is sold at warehouse W, obliged to serve this item to its customers at a given service-level (X% of customers who ask for the item should get it "over the counter"). A demand-forecast for the future months is available. The forecast is stochastic with a mean value and distribution depending on the item's demand pattern.
Provided that a given item can be supplied from multiple sources(two or more suppliers, or two delivery modes from a single supplier) define a replenishment policy which will minimise average stock value of item "I" at warehouse "W", while maintaining item I's target service level.

Objective
To review the literature regarding different types of multi-supplier/delivery models which intend to suggest a solution to the formulated problem or similar ones in order to assess the usefulness for Syncron and similar companies.
Bring Syncron up-to-date on current research being made on the topic.

Research questions

- *Why might it be better to use several sources instead of one?*
- *What models can be used for multi-sourcing?*

Scope and limitations
Focus is primarily on multiple-sourcing/delivery models using stochastic demand and deterministic lead times. This is because this best resembles the business situation of Syncron. More detailed information regarding lead-time is rarely available in practise and demand in the after-market is stochastic. This review will focus on underlying strategy to multiple-sourcing, emergency-delivery, and order-splitting in a single item, single echelon setup. Primarily from a total costs perspective.
Models of interest are based on the periodic and continuous methods as previously presented.

2 Method

This chapter's purpose is to enlighten the reader on the chosen approach, search- and selection procedure, and comparison tables for the presented models.

Method of investigation

This review will consist of a literature study in order to map prior and current research to create an understanding of the formulated problem and possible solutions.

Search procedure

The collecting of empirical material has been via Umeå University's library search tools to access resources such as books, research papers, dissertations and more. The search for empirical material is done with purposive-sampling. Various search terms have been used to find related literature and authors. Article reference lists are used as a source for further research when literature of interest is found. Empirics such as mathematical models are compared systematically accordingly to a table made to distinguish essential properties. Because of the nature of the problem, different models will be deemed applicable only during certain circumstances. This will be addressed in the discussion that will follow the review. Strategical reasons for multi-sourcing will be discussed in a more general sense in order to understand as to why it is of interest and will not be as thoroughly mapped.

Search terms used

multi supplier, multiple supplier system, multi supplier service level, single-product single echelon, multiple sourcing service-level, service level inventory, multi delivery optimisation, multiple-supplier inventory models, two delivery modes, service level delivery, statistical inventory, service-level inventory, service-level inventory management, emergency delivery, single echelon emergency, inventory management, multiple supply modes, supply chain management service level, order-splitting, Inventory control, emergency supply

Selection procedure

Research papers that apply standard continuous- or periodic replenishment. Strategy-articles are chosen to supply the reader with as broad view as possible as to why multiple-sourcing/delivery is of interest but are not mapped as extensively.

Properties of the presented models will be compared to each other using comparison-tables in order to supply the reader with an overview over technical details(see Table 3). The selection process for the presented models is not only based on the demand type, lead-time type, and their inventory policies but also simplicity, fundamental ideas/approach, and combination of review-policies. Stochastic demand and simplicity for the potential use of service-levels, deterministic lead times because more detailed information is rarely available in practise, and various of inventory policies to fit different situations. Order-splitting can have somewhat different objectives in their models in comparison to the emergency-delivery category. Order-splitting can be divided in to: "Total cost analysis", "cycle-stock reduction", or "effects on effective lead time".

Table 3. Comparison table for models.

Demand type	Leadtime type Regular/ Emergency	Replenish-ment policy. Regular/ Emergency	Push/Pull system	Backorder/ Service-level constraint
For example, Normal, Poisson	For example, Stochastic/ Determin-istic	What re-plenishment methodol-ogy is being practiced? Continuous/ Periodic-re-view	Which system is the model con-nected to.	Which category the model belongs to.

3 Findings in the literature review

A total of 44 relevant papers were found and presented in Table 4 (right). They are sorted in three groups: Order-splitting, Emergency-delivery and Strategy. I have chosen to present the findings on two levels: First I try to summarize the theories that make a general foundation for multiple supplier models. Secondly: Six studies belonging to the "Emergency-delivery" category are presented and discussed more in depth(Tagaras and Vlachos 2001, Chiang 2010, Chiang 2002, Gronevelt and Rudi 2003, Jaine et al. 2010, and Pérez and Geunes 2014). I chose the emergency-category because the fundamental concept and value proposition of expedited orders allows a buyer to enjoy cheaper supply sources on a large portion of the demand while having the operational flexibility to respond quickly with expedited orders in case of fluctuations in demand. A majority of the emergency models operates under stochastic demand along with deterministic lead times, much alike the data available in practise. The value propositions from order-splitting can be questioned in several ways, hence none selected for closer inspection. The presented models were chosen on the potential of their fundamental operational ideas and simplicity, but also to show how different combinations of inventory policies for regular/expedited orders can be applied given a push or pull system.

Table 4. Categorization of relevant articles found in the review.

Strategy research papers	Emergency-delivery research papers	Order-splitting research papers
Dong and Tomlin (2012)	Pérez and Geunes (2014)	Sazvar et al. (2013)
Babich et al. (2012)	Sheopuri et al. (2010)	Glock and Ries (2012)
Iakovou et al. (2010)	Chiang (2010)	Teimoury et al. (2011)
Zeng et al. (2009)	Jaine et al. (2010)	Iakovou et al. (2010)
Tang (2006)	Veeraraghavan and Scheller-Wolf (2008)	Chandra and Grabis (2008)
Wu and Choi (2005)	Axsäter (2007)	Burke et al. (2007)
Norman and Jansson (2004)	Gallego et al. (2007)	Thomas and Tyworth (2006)
Kotabea et al. (2004)	Groenevelt and Rudi (2003)	Dullaert et al. (2005)
Minner (2003)	Minner (2003)	Ryu and Lee (2003)
Cachon (1999)	Chiang (2002)	Minner (2003)
Kouvelis (1999)	Tagaros and Vlachos (2001)	Chiang (2001)
	Johansen and Thorstenson (1998)	Kelle and Miller (2001)
	Chiang and Gutierrez (1996)	Ganeshan et al. (1999)
	Zheng (1992)	Chiang and Chiang (1996)
	Moinzadeh and Nahmias (1988)	Chiang and Benton (1994)
	Barankin (1961)	Lau and Lau (1994)
		Lau and Zhao (1994)
		Ramasesh et al. (1993)
		Ramasesh et al. (1991)
		Kelle and Silver (1990)
		Moinzadeh and Nahmias (1988)

3.1 A holistic view on multiple supplier/ delivery - the theoretical foundation

The purpose of this section is to give the reader a deeper understanding as to why multiple-sourcing/delivery is an interesting topic for practitioners as well as theoreticians by reviewing conducted research from different branches on the topic. Presented under different assumptions, circumstances, techniques, and goals.

It is not immediately clear what mix of different suppliers and delivery modes will prove to be most beneficial in a given business situation because of varying performance between suppliers, e.g difference in reliability, prices, quality, and lead times. Reasons behind multiple-sourcing/delivery are many and it is of paramount importance to assess the combination of alternatives and not each offer alone when considering a combination of sources. An optimal replenishment policy cannot be achieved without an holistic view on operations and vast knowledge of the business situation and its underlying strategies.

In research, three main directions for multiple-sourcing/delivery can be presented:

- *Strategy*
- *Emergency-delivery*
- *Order-splitting*

Research conducted on strategic incentives focuses on e.g buyer-supplier relationships and risk-mitigation while emergency-delivery primarily provides different heuristics for triggering expedition of orders using deterministic lead-times in situations with risk of stock-out. Order-splitting is, apart from emergency-delivery, mostly performed simultaneously in the beginning of a replenishment-cycle between N-suppliers with potential benefits such as lowered effective lead times, lower safety- and cycle-stock.

3.1.1 Conducted research on Strategic reasons for multi-sourcing

Agent theory

The relationship between a buyer and supplier can be described with agent theory as previously done by Cachon (1999). This refers to each member in a party striving to achieving their own objectives driven by their own incentives. This can lead to opportunistic behaviour as a result of asymmetric information regarding e.g true costs. A way to mitigate the effects of the agency problem is by multiple-sourcing, however with varying results depending whether or not item "I" is considered being substitutable or not. Substitutable goods are often associated with low switching cost making low prices the primary tool of attracting customers which makes multiple-sourcing a suitable approach. This leads to inter-channel competition which keeps prices low, service high, and also enhances the buyers position in future procurements. It is a trade-off between hard-to-value-benefits and diseconomy of scale, ultimately depending on the buyers preferences and business situation.

Complex (harder-to-substitute) goods are often prone to agency problem and might be associated with high stock-out costs. This can be a reason for companies to vertically integrate, but that might not be possible due to various reasons. However, multiple-sourcing could be used to mitigate the effects of opportunistic behaviour if occasional emergency orders are needed. For example, assuming company A is using supplier B for both regular and expedited emergency orders. If A will ever need to use the emergency it gives supplier B more information regarding how much A is able to pay, assuming emergency orders are more expensive. Supplier B will most likely use this information for upcoming procurement to carefully stretch company A's willingness to pay(WTP) resulting in higher prices to meet with company A's ability to pay. For this reason it might be more beneficial for company A to turn to a supplier C for emergency deliveries even though the price might be higher short-term. This is done in order to keep procurement costs down with the primary supplier, thus more beneficial in a longer perspective.

Exchange rate volatility and switching costs

Multiple suppliers can also be used to offset fluctuating exchange rates. This gives companies operational flexibility when dealing with exchange rate risk. However, it is of great importance to adapt to each situation accordingly as there might be great costs associated with rearranging flows, greater than short-term winnings due fortunate exchange rates. An assessment of supplier capacity has to be made before deciding on rearranging fractions or full product flows. If not, there is a overwhelming risk of creating disruptions in the supply chain, e.g by depleting a new source, leaving the old supplier over-capacitated. Industries and their supply chains thrives on continuity and if treated as a spot-market there is an overwhelming risk of disrupting the continuity- and predictability. Kotabea et al. (2004) discusses domestic and global sourcing and the impacts of exchange rates and scattered operations. Furthermore Kouvelis (1999) discusses global management in operations and analyses the effects of exchange risk and switch over costs on operating policies. In situations with fluctuating exchange-rates a band of inaction can be considered as a strategy. The term refers to an interval for the exchange rate where no actions are being made. If the interval is exceeded it is assumed to be beneficial to swap to a more beneficial supplier instead. The width of the interval is depending on various of factors, e.g the exchange rate risk and switching costs.

Mitigating risk

Supply chain risk has been one of the main reasons as to why companies choose to diversify among their suppliers. Thorough research has been conducted in the field of risk management in logistics, e.g resilience versus disruptions (Zeng et al. 2009, Iakovou et al. 2010), financial risk management (Babich et al. 2012), operations- and insurance risk management (Dong and Tomlin 2012), and the tradeoff between reliability and unreliability in an global sourcing environment (Norman and Jansson 2004). These exposure depends on various of economic and business factors along with geographic positioning. This has been researched in theory(Babich et al. 2012, Tang 2006) as well as with empirical studies(Zeng et al. 2009, Wu and Choi 2005).

Firms operating in developing countries will have to cope with uncertainties that normally are assumed to run smoothly in developed countries.

This may include underdeveloped infrastructure, political risk, financial uncertainties, this might result in lower quality due difficulties managing operations. The number of suppliers also varies depending on what necessities has to be fulfilled when considering entering a state of partnership as multiple-sourcing is not equivalent to risk mitigation. Some industries require rigorous processes before suppliers can be certified to work with their products. This can act as a rather high threshold for businesses such as car manufacturing or aerospace industries (Babich et al. 2012).

3.1.2 Conducted research on emergency delivery models

Applying delivery modes in conjunction has been extensively researched starting 1961(Barankin, 1961) and has been been thoroughly researched since then. A realisation throughout the years is the complexity of the problem characterised by two or more suppliers/delivery modes. It might be necessary to circumvent complex structures and instead study a simplified problem as done by Moinzadeh and Nahmias(1988) with their inventory-on-hand tracking (Q_1, Q_2, s_1, s_2)-review policy. Later Moinzadeh and Schmidt (1991) presents a model where the trigger for an expedited order is based on the status and age of the outstanding order and current inventory level. Gallego et al. (2007) furthers their work by presenting a continuous review model with the ability to convert an already existing order to an expedited one at a cost if still within a predetermined time frame. The expedition service is targeted for customer requests and should not be interpreted as a general inventory system where orders are rushed on a regular basis. The objective of the model is to minimise holding, converting(expediting), purchasing and backorder costs. The primary benefits of using the model according to the authors is to create a basis for crafting contracts between retailer and supplier.

Johansen and Thorstenson (1998) analyses a similar problem similar to the work of Moinzadeh and Nahmias (1988). They also consider a continuous model but analyse two policies for triggering an expedited order. The first, more complex, policy is state-dependent and takes both stock-on-hand and time remaining on outstanding order in consideration when deciding whether or not to place a rushed order. The simpler approach focuses only on stock-on-hand. It is found that significant cost reductions can be achieved with an emergency delivery option. However, most of the cost reduction is accounted for using the simpler method.

Axsäter (2007) presents a model influenced by the work of Moinzadeh and Nahmias (1988) and Johansen and Thorstenson (1998) but extends the previous work by allowing more than one outstanding order and emergency lead-times larger than “very small”. Axsäter (2007) uses the techniques formulated in Zheng (1992) in order to determine the optimal Q and s. A disadvantage is the difficulties determining Q, s policy for regular orders. Axsäter claims his decision rule for regular/expedited orders can be applied in a more general sense than the previously conducted works.

Chiang and Gutierrez (1996) describes a periodic system(order-up-to-level) with multi-delivery modes. An indifference level is suggested and the expedition of an order is triggered if inventory is below said level to bring inventory up-to-level. A regular order is placed if above the indifference level. Tagaros and Vlachos (2001) work is similar, based on a periodic review system (order-up-to-level) but with two predetermined review positions. The regular order is based on inventory position and placed by the first review position and if stock-on-hand has fallen below a predetermined level at the emergency review point an expedited order will be placed. The expedited order is assumed to arrive in adequate time to cater to customers needs and raising the inventory to correct level before entering subsequent period.

Later works incorporate the idea of make-to-order (pull-system) by including both manufacturing production as well as transport lead-time in to models, thus using the latest information available in whether or not to rush orders. The expedition decision is thus made after goods have been produced, but prior to shipping. Chiang (2010) proposes a (Q, s, r)-review policy, meaning that inventory levels is being monitored continuously but with a static emergency review point, r, at the end of the manufacturer lead-time. If inventory level falls below this level fractions of the order can be expedited in order to “bump up” the inventory-on-hand, thus avoiding immediate stock-outs. Chiang (2010) argues for decreased complexity because no additional order is placed. The model operates under service-level constraints, both S1, and S2. This work differs from Chiang (2002) where the emergency-delivery triggers an additional expedited order under a S1-service-level constraint. Closely related to the work of Chiang (2010) is Groenevelt and Rudi (2003) which suggests a multi-sourcing model suggestion based on a periodic (r, S)-review which also is based on a make-to-order, pull-system. A decision regarding expedition is taken at the end of manufacturers lead-time. Jaine et al. (2010) concept is also based on a pull-concept and responds to Thomas and Tyworth (2006) critique regarding previous negligence of fixed costs and proposes an extended (Q, s)-policy for evaluating two possible deterministic freight modes, each with their own associated fixed costs. Veeraraghavan and Scheller-Wolf (2008) allows their work to order with two different suppliers while keeping track on two indices for order placing, using a near optimal "dual-index policy" heuristic. Sheopuri et al. (2010) continues their work resulting in further generalisation of the initial model. The work of Pérez and Geunes (2014) uses an slightly different expedition trigger. The regular shipment is considered being stochastic and is tracked. If not received at a certain predetermined time an additional order will be placed to "on top" of previous order to avoid stock-out . Thus applying a distinguishing "Wait-and-see-"-methodology. The authors tracks the inventory levels continuously with an ordinary (Q, s)-replenishment policy and it is assumed that stock-outs are extremely costly and backorders are not allowed, meaning that 100% of demand will be met.

3.1.3 Conducted research on order-splitting

Order splitting can serve different purposes and the studied articles have been sorted in 3 categories: Total cost analysis, Cycle stock reduction, and Effects on lead time. Primary focus lies in total cost.

Table 5. Order-splitting articles categorised according to primary objectives.

Total cost analysis	Cycle stock reduction	Effects on effective lead time
Sazvar et al. (2013)	Ryu and Lee (2003)	Kelly and Miller (2001)
Glock and Ries (2012)	Chiang (2001)	Ramasesh (1991)
Teimoury et al. (2011)	Ganeshan et al. (1999)	Kelle and Silver (1990)
Chiang (2010)	Chiang and Chiang (1996)	
Iakovou et al. (2010)	Lau and Zhao (1994)	
Burke et al. (2007)	Ramaseh et al. (1993)	
Ryu and Lee (2003)	Lau and Zhao (1993)	
Chiang (2001)	Ramasesh et al. (1991)	
Ganeshan et al. (1999)	Moinzadeh and Nahmias (1988)	
Chiang and Chiang (1996)		
Lau and Zhao (1994)		
Chiang and Benton (1994)		
Ramesesh et al. (1993)		
Lau and Zhao (1994)		
Ramasesh et al. (1991)		

Order-splitting refers to an replenishment order being simultaneously split instead of placing a single order. The possibility of order splitting has drawn attention among practitioners and academics for a very long time. Many studies with under assumptions suggests value propositions such as improved effective lead time, reduction of uncertainty, decreased risk of stock-out, decreased holding- and stock-out costs(Chiang and Chiang (1996), Chiang (2001), Kelle and Silver (1990), Kelle and Miller (2001), Thomas and Tyworth (2006)). Meaning that the savings from holding and shortage costs are potentially greater than the additional incremental costs followed by additional orders placed. The difference between single order and order splitting can be illustrated as in figure 4.

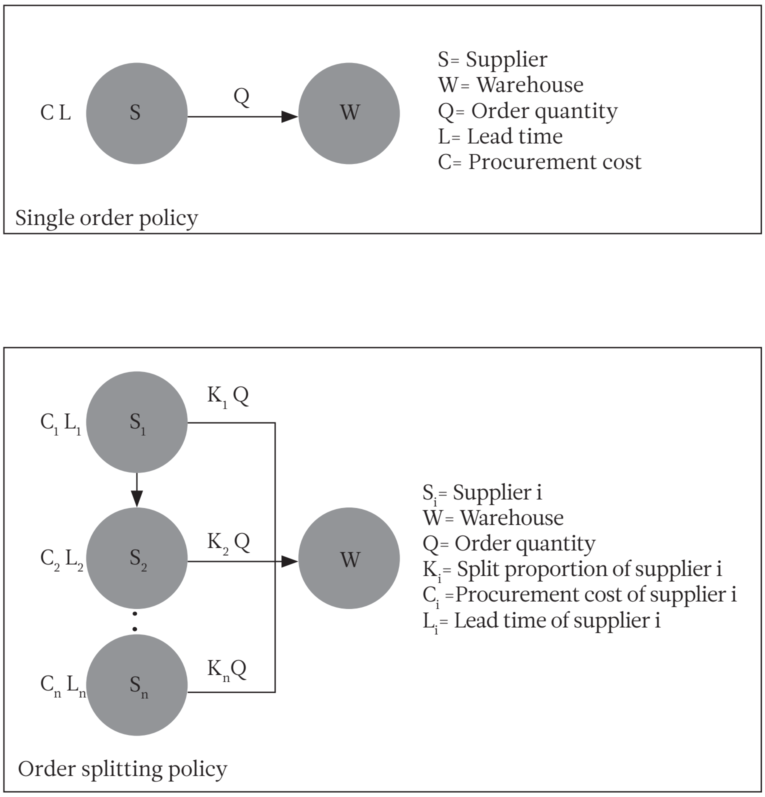

Figure 4. Single order policy versus order splitting policy

One of the first to analyse cost reductions associated with order-splitting was Ramasesh et al. (1991) applying a total cost perspective with focus on cycle-stock reduction and reduction of effective lead time using both identical as well as non-identical suppliers with quantities split even among suppliers. Demand is deterministic and the suppliers are assumed to have identical lead times. Back-order penalties per article and time unit are used. Later Ramasesh et al. (1993) extends previous work by adding non-identical lead times along with splitting portions. It is used to analyse lead time characteristics with purchase prices. The work of Lau and Zhao (1994) incorporates a model with both stochastic demand and lead time. The authors studies the impact of order-splitting done in purpose to reduce stock-out risk applying a total cost perspective. It is found that the major inventory cost reduction is due to cycle stock reduction rather than safety stock reduction. Chiang and Benton (1994) analyses a situation where the suppliers have identical characteristics regarding prices and lead time under normally distributed demand and shifted exponentially distributed lead times. The stock-out penalty is not dependent on the duration, as opposed to many other models. The authors suggest a service level constraint as a substitute to back-order penalties.

Chiang and Chiang (1996) presents a model in a JIT-fashion with a continuous-review policy with normally distributed demand, deterministic lead time, and with predetermined service levels. One supplier with multiple deliveries per order cycle is being considered. The conclusion of Chiang and Chiang's work is that inventory carrying cost can be significantly reduced when inter-arrival times are determined optimally.

Chiang (2001) continues with the same fundamental idea as Chiang and Chiang (1996) but applied in a periodic (r, S)-review environment. There is an optimal number of deliveries resulting in lowest total cost during each period, similar to Chiang and Chiang's previous work. However, the beneficial cost reduction in comparison to a single delivery mode is mostly because of reduction in cycle stock. Kelle and Miller (2001) has conducted similar research as Chiang and Chiang(1996) and Chiang(2001) but allows multiple suppliers for inter-arrival deliveries and instead focused on minimising the stock-out risk for strategically important items.

Ganeshan et al. (1999) further investigates the trade-off between supplier reliability and purchase prices using one reliable and one unreliable supplier. Using two suppliers, one reliable and one unreliable, where the latter has longer lead-time with higher variance but can offer discounts of purchase prices. Their work applies normally distributed demand as opposed to previous research conducted by Lau and Lau (1994) where deterministic demand was used. Dullaert et al. (2005) extends the work of Ganeshan et al. (1999) investigating the optimal mix of transport alternatives.

More recent works incorporates the idea of deteriorating goods where Jha and Shanker (2009) presents an optimised order quantity under a service level constraint in a single supplier, single vendor situation. Sazvar et al. (2013) extends this idea to a multi-sourcing environment using a continuous (Q,s)-model under stochastic demand. Unmet demand is backordered completely along with penalties. Empirical data regarding practical implementation is provided and show that the order-splitting policy is more attractive, especially when the lead times of the two considered suppliers are similar. If historical data is not available, fuzzy methodology is a possible approach. Teimoury et al. (2011) applies fuzzy queuing in their case study of SAPCO and results show that it is generally beneficial to split orders between suppliers.

Chandra and Grabis (2008) responds to the critical review given by Thomas and Tyworth (2006), who advocates economy of scale, and chooses to investigate how reduced lead time is accompanied by increased procurement costs and higher transport cost and how this affects the stockout risk. Glock and Ries (2012) considers sourcing a product from multiple suppliers using normally distributed demand and a continuous (Q, s)-review policy. The lead time of orders are assumed to vary linearly with size of batches and be non-stochastic. The authors investigate the interdependencies between risk of stockout during lead time and batch sizes.

Burke et al. (2007) analyses a single-product in a single period under demand uncertainty with multiple sourcing. It is found that single sourcing is the preferred method, but only with enough capacity and lack of diversification benefits, otherwise multiple-sourcing is preferred from a risk mitigation perspective. Iakovou et al. (2010) presents a one-period decision making tool made to capture the trade off between disruption risk and inventory policies in an unreliable dual-sourcing network.

3.2 Emergency delivery models - a closer inspection

The presented models(Table 6) were chosen to cover different types of replenishment combinations of regular/emergency ordering in different situations to show the reader how they operate, and under what circumstances service-levels constraints are used.

Table 6. Overview over the technical aspects of presented models

Emergency ordering	Demand	Leadtime(-Regular/ Emergency)	Replenish-ment(Reg-ular/Emer-gency)	Push/Pull logistic system	Backorder/ Ser-vice-levels
Tagaras and Vlachos (2001)	Normal, Erlang	Determin-istic/Deter-ministic	FOI/FOI	Push	BO
Pérez and Geunes (2014)	Determin-istic	Stochastic/ Determin-istic	FOQ/FOI	Push	BO
Moinzadeh and Nah-mias(1988	Normal/ Poisson	Determin-istic/Deter-ministic	FOQ/FOQ	Push	BO
Chiang (2010)	Poisson	Determin-istic/Deter-ministic	FOQ/FOI	Pull	SL
Chiang (2002)	Poisson	Determin-stic/Deter-ministic	FOQ/FOI	Pull	SL
Groenevelt and Rudi(2003)	CP	Determin-istic/Deter-ministic	FOI/FOI	Pull	BO
Jaine et al. (2010)	CP	Determin-istic/Deter-ministic	FOQ/FOI	Pull	BO

BO = Back-order penalties, CP = Compound Poisson demand process, FOI = Fixed order interval(Periodic), FOQ = Fixed order quantity(Continuous), SL = Service level constraint

No model with the review method FOI/FOQ was found

A realisation throughout the years of conducted research is the complexity of the problem characterised by two or more suppliers/delivery modes. It might be necessary to circumvent complex structures and instead study a simplified problem as done by Moinzadeh and Nahmias(1988). In their extension of the (Q, s)-model the inventory-on-hand is continuously tracked instead of the inventory position. If not, the model would be required to track the regular quantity, Q_1, and the expedited quantity, Q_2, along with the exact timing of the outstanding orders which is deemed too complex. The model is formulated as a (Q_1, Q_2, s_1, s_2) model. Two lead-times are defined, one regular and one expedited, as $0<L_2<L_1$ each associated with their fixed cost K_1 and K_2 if put to use. The cost of purchasing a unit is in a similar way expressed c_1 and c_2. When the reorder point s1 is reached, a regular fixed order quantity Q_1 will be ordered. If the regular order has not been received prior to the inventory-on-hand reaching the emergency reorder point s_2, an additional expedited order will be placed, but only if to arrive before the regular order. The primary objective of their work is to find order quantities and reordering levels in order to minimise total inventory costs based on cycle-stock reduction(Moinzadeh and Nahmias, 1988). The work of Moinzadeh and Nahmias has been a foundation for much other conducted research, because of how they circumvent initial problem. Since the work of Moinzadeh and Nahmias the very complex problem of tracking two outstanding orders has been brought up in the context of research since 1988 with no progress. This complex problem is essentially the core of the formulated problem and the solution/ replenishment policy is today unknown. A solution could potentially result in calculating service-levels while splitting orders. The policy would enable a buyer to set a predetermined level and reap the benefits of multiple-sourcing/ delivery for a single item "I". However, the complexity of the problem forces models to track inventory-on-hand after a regular order has been placed. This seem to result in a loss of service-level-constraints in research and back-order are being applied instead.

Tagaras and Vlachos (2001) presents a periodic (r,S)- review inventory system using a base-stock-policy in a push-logistic system. The model is featured with an additional order-type, an heuristic emergency replenishment option. Orders are being placed in two predetermined review times, regular and emergency, while the quantities are variable. Regular orders follows an order-up-to-S-policy and are placed periodically on inventory position and arrive after a non-stochastic lead time. Rushed orders can be placed at the emergency review time if the effective-stock is under the desired level in the end of an cycle(see Figure 5). The emergency replenishment is assumed to have shorter lead time at a higher cost. The authors considers their suggested model being an approximation and is claimed to be easy to put to practise due to simplicity. The authors show by the help of simulations that dual supply mode provides higher service level while keeping total stock to a minimum. However, it is unclear what service-level this is referring to. Assuming fill-rate, the expedited order would have have to be placed in adequate time and quantity, which in this case is set by the use of back-order penalties

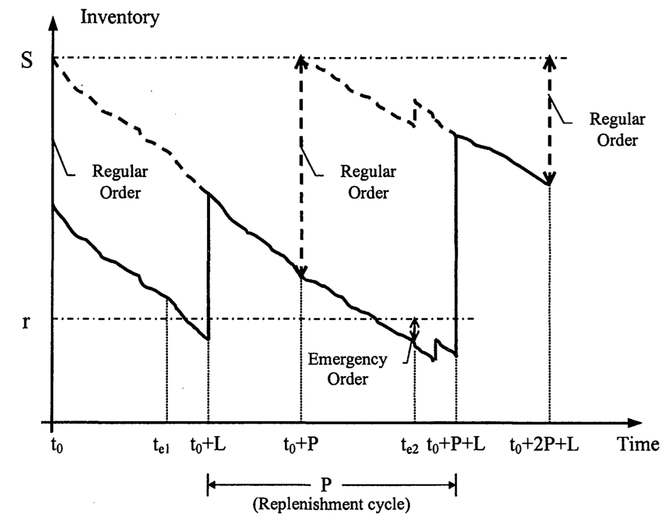

Figure 5. by Tagaras and Vlachos (2001) showing how their model operates.

P is the length of a replenishment cycle, L the regular lead time and L_e for expedited orders, where $L > L_e$. Period number is i, for i= 1, ..., n where S is the order up level and t_0 are the static review positions and $t_{e,i}$ represents the expedition review point. A regular order is placed at t_0 and will arrive at time t_0+iP+L. If inventory falls under predetermined expedition level, r, at time $t_{e,i}$ an emergency delivery will be triggered. The emergency point te, i can be placed in the interval $t_0 < t_{e,i} <$ iP-L_e. Depending on item "I"'s characteristics. This means that an earlier emergency review point can hedge against larger fluctuations and/or longer periods and a later placed emergency review will instead gather information for a longer time.
Three major assumptions are made, it is assumed that stock-outs are only possible in the end of an cycle. Secondly, it is also assumed that the expedited order is received prior to the end of the current replenishment-cycle to avoid stock-outs. Third and last assumption is regarding demand, which consists of Normal and Erlang distributions. The cost function consists of inventory holding cost, back-order penalties, cost of emergency supply, and assuming negligible fixed ordering costs. The authors have received critique for deriving optimal policies under restrictive assumptions (Gallego, 2007). As service-constraints are not applied, perhaps an emergency order-up-to-level can be defined. Having an upper bound for emergency-orders as a function of time would prevent too large orders from being placed in order to cater to the demand which later turns obsolete in some warehouse. Most models use the assumption that stock-outs are very costly under which additional stock-keeping is justified and catering to priority/backorder-penalty-approaches instead of service-level constraints. However, if not operating under this assumption[high backorder costs] new questions are raised. How much deviation from expected demand is financially viable? This question aligns with the question regarding how much a backorder costs. An indifference level could perhaps be applied in practise.
Chiang (2010) proposes a modified single-item (Q, s)-model with a stochastic demand, order quantity Q, and reordering level s(see Figure 6). Chiang emphasises the need for expedited shipments in practice and motivates an extension to an ordinary continuous model by implementing an additional operating parameter R. The model distinguishes itself by being adapted to a pull-system, taking manufacturer lead-time, M, in consideration. Chiang's work can thus be categorised as combination of a continuous and periodic review-system. The continuous (Q, s)-policy places an order at s, thus triggering the manufacturing lead time M. Meanwhile, if stock-on-hand falls below the rush-up-to-level-R a request for expedition is emitted and that fraction of the order will use the faster transport, G, while the rest of the order is sent by regular transport N. It is assumed that faster and more reliable transport comes with additional costs, i.e G<N with associated cost $c_N < c_G$

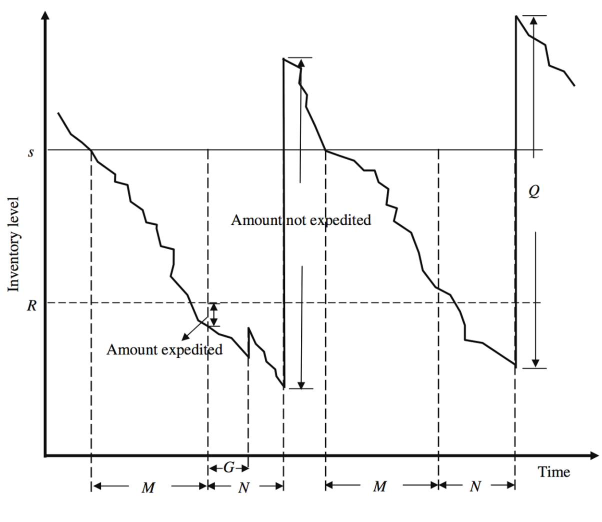

Figure 6. by Chiang (2010) showing how their model operates.

According to the results a firm can lower costs if manufacturing lead-time is long, expedition cost is low, demand variability is large, or the service-level is high. The average total cost per time unit is derived and minimised under service-level constraints. The service-level constraint is based on S1 or S2 under Poisson demand. Chiang(2002) used a similar approach, but instead of a fraction of an order an additional was placed and the S1-service-level was used under the assumption that demand is Poisson-distributed. Chiang(2010) provides tables of comparisons between the two approaches under different service-levels and values. Hypothetical results points to economical benefits for Chiang(2010) when service level is >95% for S1, and >99.9% for S2, while Chiang(2002) needs slightly higher S1 service-levels, >99.9%, to be profitable.
The expedited order serves as a fraction of the original and Chang argues for that it keeps the ordering complexity to a minimum because rushing a fraction of an order does not generate a new one, thus keeping outstanding orders to a minimum. How feasible this is in practise remains unclear. Assuming the originally placed order is Q_{tot} there will still be two outstanding quantities, regular Q_r and expedited Q_e when expedition is triggered. Considering that these two quantities will need packing, tracking, and to be sent by different means transportation the value proposition of simplified ordering-complexity can be questioned. Conversely, it might perhaps be even more work to give each placed order this much attention.
These works of Chiang are of interest for further inspection.

Groenevelt and Rudi (2003) presents a dynamic model based on a periodic (r, S)-review using a base stock inventory-policy made to simulate outsourcing to distant manufacturer to evaluate the potential of multi-sourcing among deliveries in a single echelon single item environment. The model takes the manufacturers production lead time, L_1, in to consideration(see Figure 7). At the end of L_1 the firm decides how much to deliver with the regular mode with lead time L_2 and how much to ship via the expedited mode with lead time l_2, as with previous work $L_2 > l_2$ and that associated costs are cexpedited>cregular. Regular order lead-time is therefor $L = L_1 + L_2$, and for expedited orders $L_e = L_1 + l_2$.

The model is somewhat of a mix between other works by incorporating the concept of a pull-system and allowing fractions of an order to be expedited, much alike Chiang (2010), under a two-position-review-location and exercising an review policy consisting of periodic approaches for both regular and expedited orders, like Tagaras and Vlachos (2001). The faster delivery mode is used as a hedge against stock-out when using the primary slower source, assuming that the replenishment periods are "quite long". Ordered goods are assumed to arrive in the end of the same replenishment period

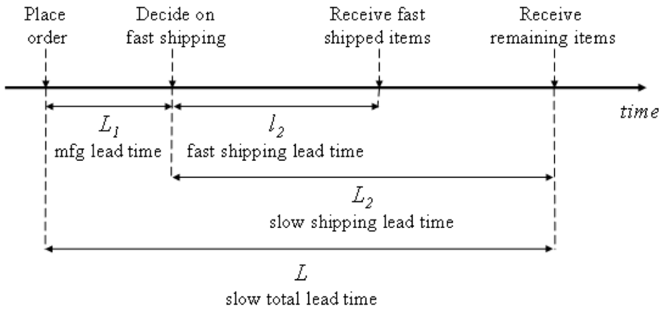

Figure 7. Graphic by Groenevelt and Rudi (2003) showing how their model operates.

Despite the similarities with Chang(2010) the model is not subjected to service-level constraints. The model tracks stock-outs and registers these as back-logs with associated cost, p. A linear unit holding cost is also being used. The authors show how to calculate optimal policies for single and dual-sourcing when the demand consists of a compound Poisson process. The issue of negative demand is avoided because the compound process is non-decreasing. Based on the assumption that the review periods are very long, this approach might be best suited for items that purposely do not have a service level. Keeping service-levels up for long periods of time can be very expensive as it implies keeping stock to achieve availability. In this case it might be better to use other measures of availability than S1 and S2. For example, the item might be delivered after a maximum of X days.

Jaine et al (2010) considers an extended (Q,s)-policy for evaluating two possible deterministic freight modes. The model is very much alike the approach by Chiang(2002), Axsäter (1990), and Zheng (1992). Jaine's model takes diseconomy of scale into consideration to a larger extent by including fixed costs depending on which freight mode being used. This can be interpreted as a response to the critique by Thomas and Tyworth (2006) who emphasises the need for economy of scale in modelling.

Orders are placed with a make-to-order manufacturer with manufacturing time L_1, and a decision regarding freight modes is based on the demand fluctuations incurred during the manufacturers lead time, L_1. The authors derive an expression for optimal reordering point and quantity that minimises cost with the help of back-order penalties. The inventory position is continuously monitored and when it drops to the reorder point, s, a batch of size Q is ordered by the manufacturer. This triggers the manufacturing lead time L_1 at the cost of K_1. After L_1 time units the order is ready to be shipped and be sent in two ways of transport.

i) Regular transport with lead time L_2 at the fixed cost of K_2 for each shipment
ii) Expedited transport with lead time l_2 with fixed cost k_2 and additional variable cost c_2 per unit shipped

The total leadtime is therefor $L = L_1 + L_2$ for the regular order and $l = L_1 + l_2$ for expedition. When the manufacturing is complete the order can be shipped by either of the two available freight modes, or split up between the two in any proportion. Holding costs are h per time unit for each physical unit and demand during stock-out is registered as backorders and receive a penalty cost p per time unit. The demand is expressed by a Poisson process, a non-decreasing stochastic process. There are no quantity discounts and holding costs are assumed to be linear.

Despite the approach being much alike Chiang(2002) a service-level constraint is not applied, even though it evidently is possible. Using back-order costs are, as previously mentioned, not feasible in practise. Applying fixed costs to different freight modes is an idea that advocates economy of scale, but for large scale use it will require much attention. Considering both these factors, the model could primarily be considered as a tool for analysing different theoretical services and not suitable for general purpose use.

Pérez and Geunes (2014) approaches the problem from a somewhat different angle than the other presented works. The authors assume deterministic demand and focus is put on the stochastic element on regular orders. The authors discusses the possibility of having two delivery options in a single echelon distribution situation. The objective of the model is to seek out the optimal reorder point and order quantity so that the average holding, ordering, and purchasing costs are minimised in the long run. These options represent different suppliers, or different delivery modes from a single supplier. One is being a slightly unreliable(stochastic) and considered a cheaper way of transport while the more expensive one being perfectly reliable(deterministic) but not necessarily used. The buyer does not permit shortages and may use two different transportations in each cycle and it is assumed that the uncertainty of the less reliable transportation is due to high utilisation of the mode while the more reliable shipping method is assumed to have excess capacity, capable of carrying any order.

Pérez and Geune's work is similar compared to previous presented work but with the difference that they focus on stochastic lead-time and places an expedited order "on top" if the regular one has not arrived at a predetermined point in the replenishment cycle. The model can use multiple delivery modes but with different associated cost, reliability, and lead time. An order-split is not conducted in the beginning of the period, but as stated previously, the expedited delivery mode might not even be used. Instead, a type of "wait-and-see" methodology is applied. The model is used in situations where stock-outs are extremely costly and a 100% service level is desirable, however, it is not clear which type of service-level this refers to. This could in practise lead to over-stocking items, i.e ordering too much to assure that demand is met. This is however justified under the assumptions that stock-outs are extremely costly, i.e item "I" is given the highest priority. This offsets the additional storage costs followed by over-stocking.

4 Discussion

4.1 Development in logistics noticeable in conducted research

Logistics has developed considerably throughout the years which is reflected in conducted research. Improvements such as categorisation techniques, real-time tracking with barcode-scanners, and radio frequency identification, all connected to software to facilitate the flow of information and execution of orders. These improvement can be put to use in conjunction with multi-sourcing methodology in a supply chain environment to find adequate inventory levels to minimise expected total costs. This development has led to more advanced analytical methods being considered in research along with more efficient solutions put to practise. It is possible to see differences between push- and pull methodology in research as well. Earlier works are primarily focused on a push system, where the supplier's goods are assumed to only need packaging and transport. Later works include a manufacturing lead-time, L_1, which corresponds to the additional lead time followed by a pull-system. This additional lead-time, L_1, is used to gather information by the "buyer" until the placed order has been produced. By doing this, it is possible to gather valuable information regarding the state of the system and the "buyer" can decide whether or not an expedited order will be needed.

However, some newer research models are used as tools to investigate the potential of certain services in a more theoretical purpose and might not suit the practical needs of simplicity and easy-to-implement which the business situation of Syncron calls for. These tools of analysis are often very niched, resulting in advanced analysis with little to no practical use other than academic excellence.
It is remarkable that so little focus has been put on the needs of the after-market despite the business potential, i.e addressing multi-sourcing modelling using service-levels. Although, more recent work suggests that service-level constraints in modelling is a direction worthwhile to be pursued.
When comparing single sourcing in a single echelon environment with multiple-sourcing it is clear that modelling with back-orders is preferred over service-levels. Both back-order penalties and service-levels can be used to optimise in the context of inventory management. Back-order penalties are convenient to use in models to calculate optimal results under various of assumptions. However, assessing the value of a back-order is very hard, if not impossible in practise. Conversely, working with service levels in practise is easier as these[levels] can be adjusted to match the characteristic of an item class, or item "I". They[service-levels] are, however, notoriously hard to calculate in a multi-sourcing context. There are significant differences between the analytical approaches. Service-levels are stochastic probabilities which, in Syncron's case, can be adjusted for different stages in a life cycle for inventory management, whereas back-orders are numerical penalties used to find optimal replenishment policies in a tailored/given instance of a problem.

This means that the back-order models presented in research-papers serves the purpose to suggest ideas and show that they work in theory. It is then up to a company to analyse their circumstances and put the underlying idea to practise. A researcher, Chi Chiang, focuses on the use of service-level constraints instead of back-order costs in modelling using stochastic demand and deterministic lead-times. This makes him of interest as he indirect advocates practical implementations. Chiang has published both order-splitting and emergency delivery papers and future works might be of interest for Syncron to follow. However,
The most interesting replenishment policy, calculating service levels based on two outstanding orders, is today unknown.

4.2 Emergency-delivery

The main objective for emergency deliveries is to provide operational flexibility. This means that a buyer can use a long lead-time "cheap" supply-source in order to cater for a part of a forecast or service-level and have a short lead-time "more expensive" second source in case of fluctuations in demand during the longer lead-time. Similarly the concept of expedition could be used in a pull-system to gather information during the manufacturing lead-time and if deemed necessary expedite orders in order to better match supply and demand. Researchers are mutually in an agreement that emergency-delivery policies generates more yield when used in the context of high demand volatility. This intuitively makes sense, as safety-stock is based on volatility in demand and length of lead-time.

No more than two options are being considered in emergency-deliveries, probably because of the complexity of the problem. The general assumptions for all of the emergency-delivery models, as characterised by Minner(2003). There exist multiple suppliers i, for i= 1, ..., n with associated purchase costs $c_1 > c_2 ... > c_n$ and lead-times $L_1 < L_2 < ... L_n$. This implies that lead-time is a function of cost and shorter more reliable lead-times can be achieved by higher payment. A fixed cost, K_i, is sometimes used to exercise the concept of diseconomy of scale. A backorder-penality, p, is used by a majority of the models which is triggered either once in the occurrence of an unmet demand, or per item and time unit.

Two models that operate under service-constraints have been found in the category. Both are operating under Poisson demand, a combination of FOQ/FOI-review, in a pull-system. The first(Chiang, 2002) uses the S1 service level constraints, whereas the second(Chiang, 2010) uses both S1- and S2 constraints. It is shown by simulation that the higher the service levels the more cost effective proposed policies. There are plenty of different emergency-delivery models, many of them mentioned in this thesis, but none which provides any validation of results from implementations in practise, not in comparison to other methods either(with the exception of Chiang). This is not surprising considering that the majority of the models operates by using back-order penalties, which are more or less impossible to determine in practise. Back-orders can be used to balance the holding costs versus the costs of stock-out. This leads to optimal solutions in theory but is to little use in practise other than highlighting ideas. The reason for this is that back-order costs depends on the characteristics of an item "I" in a specific situation, thus cannot be determined in a general way.

The presented models are a sample of how various of emergency-delivery models operates. A common assumption is that item "I" is considered high-priority when risk of stock-out is imminent and associated with high back-order costs. An extreme example is the work of Pérez and Geunes (2014) which, by their assumptions, circumvents the operational benefit of service-levels by placing order to meet with a service-level of 100%. However, there seem to be some confusion regarding what service-level is being used. As a service level of 100% implies infinite safety-stock(in theory), service-levels are used to adjust item I's availability according to stages in a life-cycle. This concept is the core of the after-service market. Therefor should most of these models be seen as suggestion that perhaps could be modified to use service-levels or simply applied to items that are purposely not subjected to service-level constraints. For example, the work of Tagaras and Vlachos (2001) represents a simple idea, two review points in a basic periodic order-up-to-level policy. These[review points] are optimally determined by the help of back-ordering penalties. The model could perhaps be modified to use the S2-service level, with an emergency-reordering point determined by monte-carlo simulations in order to "bump up" the inventory-on-hand if, for example, a large order is placed early in a cycle. It might also turn out that there is no use of applying service-levels to long lead-time items as maintaining service-levels(keeping stock) is too costly. It is then better to not keep safety-stock and perhaps base service in some other measure than S1 or S2.

4.3 Order-splitting

Order splitting is primarily done in a single item, single echelon system using a continuous review policy. A common direction in research of order-splitting is the analysis of the tradeoffs between single-source and dual- or multiple-sourcing. There are generally four categories of cost in consideration, which are: cost of placing an order, inventory holding costs(cycle, safety, and stock in transit), backorder cost, and purchase cost. Involving a new/an additional supplier is thus not considered being a financial burden other than increased ordering costs due to an additional order-split. Geneshan et al. (1999) and Chiang and Benton(1994) argues that transport cost is of paramount importance when deciding between single versus multi-sourcing, something being

overlooked in calculations.
The main objective of order-splitting has many times been how to come up with lowest expected stock levels and minimising back-orders by extensive statistical analysis regarding lead times in a just-in-time(JIT) manufacturing environment. Models that operates under service-levels constraints presents results based on lowered cycle- and safety stock(Chiang and Chiang, 1996) as a result of more frequent deliveries in a sole-sourcing environment. The same concept is extended to multiple-sourcing as well (Kelle and Miller, 2001). However, less effort has been put in to the effects of diseconomies of scale. It is quite surprising considering that the general problem in the category of order-splitting is formulated as an "order split between N-suppliers" with little paid attention to diseconomy of scale, increased procurement, and incremental cost increase having several suppliers involved. These supplier relationships also need time and effort to be kept alive and well in practise.

Similar to the critique first presented by Thomas and Tyworth (2006) much of the conducted research presents a reduction of cycle stock as the primary benefit of order splitting, from an average cycle stock of Q/2 to ((Q/n)/2). What is worth to emphasise is that an order-split in the beginning in a period still entails the same amount of goods in-transit and cycle-stock seen from a system perspective. This means that the remaining benefits of order splitting is the reduction in safety stock - which can be questioned as well. First, the possible savings from reduction in safety stock might not be as beneficial in practise as presented by hypothetical results operating on various assumptions from research papers. The field of order-splitting has a need for case studies of practical implementations to strengthen its value propositions, as pointed out by various critics. This makes the works of Teimoury et al. (2011) and Sazvar et al. (2013) interesting as it provides empirical validation to value proposition in the field of order-splitting. However, the former using a fuzzy-technique which differs considerably from "ordinary" methods and the latter focuses on deteriorating goods, quite different from industrial articles. Secondly, common assumptions among the models are independent lead time, which might not be true in practise(Minner, 2003). If not a valid, this could possibly distort the potential savings in safety stock reduction.

Order-splitting models tend to be used in the context JIT. Ultimately, JIT is a manufacturing concept where deliveries can be ordered in smaller batches to arrive "just-in-time" in production. This allows another dimension of control as manufacture forecasts consists of production schedules as opposed to the after-market where forecasts are based on distributions as breakdowns breakdown randomly.

Evidently, the value propositions of order-splitting can be somewhat questioned. An implementation could potentially entail more complex ordering routines with no additional yield other than over-arching strategic benefits, which can be achieved in other ways, see *Future research.*

4.4 Benefits, comments, and concerns

Being a buyer in a multiple supplier environment gives the possibility of using several potential suppliers and delivery modes to best suit the needs of a business. Depending on what items are being dealt with the benefits differ. If dealing with substitutable goods, it can be an efficient way to enhance a buyers position in upcoming procurement by creating inter-channel competition in a buyer-supplier-supplier triad. When dealing with harder-to-substitute goods agency problems could be mitigated by using emergency-delivery from an additional supplier despite higher short-term costs as to not diminish the buyer's negotiation position in long term procurements. In fact, there are so many different approaches that it is impossible to distinguish a general approach towards the multiple-sourcing/delivery. Each company has to assess their own needs accordingly. Whether the focus is characterised by strategy e.g risk mitigation(financial, insurance, disruptions), agency problems, or more direct monetary reasons followed by the benefits of order-splitting or emergency-orderings. Also, highly specialised businesses might not benefit by multi-sourcing due to very high switching costs such as steep learning curves, required certificates, or capacity issues. This means that multiple-sourcing has to be carefully assessed by management as it is a trade-off between diseconomy of scale and hard-to-value benefits unique for every business, implying that multiple-sourcing is not equivalent with risk mitigation and benefits. It is also of paramount importance to fully understand underlying assumptions and model calculations at hand before settling for a strategy. It is well documented in literature that the combination of weight, volume, and distance affects which approach is best suited for the task. These factors are not taken in to consideration in these models.

Order-splitting shows potential in theory, but can be questioned due to assumptions in calculations and the absence of practical validation of value propositions. A majority of the models are based on backorder-penalties except for the work of Chi Chiang who emphasises the need for service-levels, which is used his work. Chiang (2010) assumes Poisson distributed demand and that there is only "one" outstanding order, but fractions of it can be expedited. A combination of emergency delivery and order splitting, resulting in multiple delivery modes. Chiang (2002) is similar, and also assumes Poisson distributed demand and expedites an additional order. As soon as there are multiple outstanding orders the service-level constraint is replaced by back-order penalties in models. Additionally, there seems to be a confusion in the literature regarding the terminology, highlighted benefits in various of papers are "higher service-levels", not stated what type of service-level is being achieved.

An emergency-delivery model is a feasible approach towards the concept multiple-sourcing/delivery and can be used by a buyer to enjoy lower costs on a large portion of a total demand from item "I" while having the operational flexibility to respond quickly with expedited orders in case of fluctuations in demand, and to some extent substitute safety stock. If emergency-delivery or order-splitting are deemed not applicable in practise the idea of multiple-sourcing should not be rejected, but instead be reworked and approached from another angle. The over-arching strategic benefits for a "buyer" still applies and ought to be thought of as potential value propositions from Syncron to customers in the case of an multiple-sourcing/delivery service in the future.

4.5 Critique

Focus is primarily on fundamental ideas and various of value propositions among different techniques while scanning for models that might be of use in the after-market. The mathematics itself has not been a subject of analysis other than observing required inputs to models. This means that models with clever expressions might go unnoticed due to mathematical complexity and the amount of articles covered in the thesis. Also, enormous amounts of work has been conducted on the topic of multiple-sourcing/delivery when taking the three categories strategy, emergency-delivery, and order-splitting in consideration. The amount of papers on strategy are overwhelming and were never an object for a full mapping. This means that there are probably even more benefits and concerns associated with multiple-sources than presented.
Information is primarily gathered from peer-reviewed research papers available via Umeå University and are considered being highly trustworthy. However, the majority of the literature is strictly theoretical with little to no substantive empirical validation of various of the value propositions.

5 Future research

No model that caters to the needs of the formulated problem exist as of yet, however, it is clear that multiple-sourcing/delivery holds many potential benefits for a "buyer" from a strategic perspective. A multiple-sourcing service from Syncron could possibly approach the concept from an aggregate level by dividing different items-types in to groups and assign each group to a different supplier(B in figure 8) instead of splitting item I's demand, as has been researched in this thesis(A in figure 8).

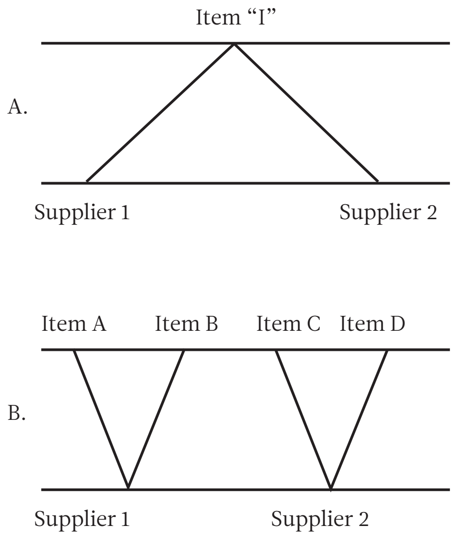

Figure 8. Two ways to achieve the strategic benefits of multiple sourcing/delivery

The new problem also seeks to simplify the supply-chain network by minimising the amount of suppliers that are needed. This could perhaps be formulated as an integer matching problem in a bipartite graph, assuming a single echelon system. For example, in figure 9 the objective would be to cover all the vertices on line V(articles) using a predetermined amount of vertices on the line W(suppliers). In this figure, two(out of possibly five) "active" suppliers are catering to the demand of the 4 selected articles. The idea is to have enough suppliers to reap the benefits of multiple-sourcing but as few as possible to advocate simplicity and economy of scale.

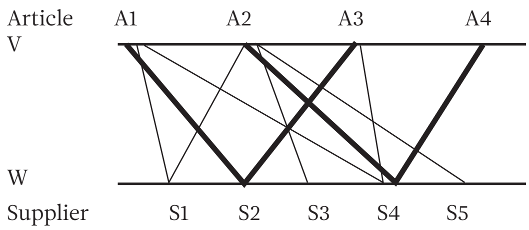

Figure 9. Illustration of the matching between different articles and suppliers. Unbold arcs are possible sources. Bold lines are selected "active" sources

Research shows extremely complex relationships in numerous dimensions covered in the category of strategy. Considering this, it might be a better idea to let the customers make sourcing decisions based on their given business situation and knowledge, i.e choosing the number of predetermined "active" suppliers in the matching-problem. This would both be simpler and more efficient than for Syncron to assess every customers' business situation along with their unique traits.
If solvable, the results of this problem might prove beneficial in practise as every relationship with a supplier requires time and effort and should be kept to a minimum. The problem can be modified to match distribution centres(DC) to suppliers as well, using the exact same methodology.

6 Conclusion

The concept of multiple-sourcing comes with many benefits especially under the concept of strategy. Multiple-sources/delivery increases the negotiation position for the buyer by creating inter-channel competition among suppliers and is used for risk mitigation versus e.g disruptions and agency problems. It is important to assess each situation accordingly as no business is subjected to the same internal and external environment implying that multiple-sourcing/delivery is not equivalent to benefits. Each supply source option has to be assessed in conjunction with an additional option in order to find an optimal replenishment policy for a given instance. It is essential that supply chains are not treated as spot-markets as there are considerable costs for redirecting flows of goods. The risks associated with swapping suppliers could be dealt with using a band of inaction. The broad spectre of strategic benefits should be thought of as customer value propositions for a multiple-sourcing service.

No general purpose multi-sourcing/delivery model which caters to the formulated problem has been found or seem to exist, as of yet. The increased complexity that comes with multiple outstanding orders seems to result in a loss of service-level control. Of the two categories order-splitting and emergency-delivery the former present questionable value propositions whereas the latter provides two models that operates under service-levels in pull-systems, which could be interesting for further inspection. A recommendation for Syncron is to keep using the same approach as today and possibly investigate the suggested matching problem instead.

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