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An investigation of rounding rules for Jula´s Supply Chain Management Systems

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Acknowledgments

This master thesis is the final part of the master program in Logistics and Transport Management. I am glad that I got the privilege and responsibility to analyze a practical issue for a real-world company.

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Abstract

Order picking is one of the warehouse operations that have the highest priority for improving warehouse efficiency. Without a systematic approach to assigning stock keeping units (SKUs) to appropriate storage locations, the efficiency of order picking causes additional material handling costs, as well as ineffective storage utilization in a warehouse. The rounding of orders to achieve a batch size is a common practice in warehouse operations to achieve efficiency. However, order batching has also been recognized as one of the causes of the bullwhip effect in the supply chain. Since there is limited academic study investigates the bullwhip effect connected with replenishment strategy, this thesis aims to find whether rounding rules can cause a consequence in the supply chain in terms of quantity distortion and changes in associated costs. The author chose Jula as a case company, used Excel VBA function simulated six rounding rules, made comparisons and reached the conclusion that, rounding rules cannot cause a significant change in quantity, however, rounding at a minimum rate and with more levels of packaging parameter registration have an effect of reducing the handling cost per order, ordering cost per piece and total cost per item per year. The author has also highlighted the areas for Jula to improve its supply chain performance.

Keywords: Replenishment, ERP, SCM, Bullwhip Effect, Order Multiple, Total Cost

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List of Abbreviations and Definitions

SKU	Stock Keeping Units
ERP	Enterprise Resource Planning
SCM	Supply Chain Management
SEK	Swedish Krona
DC	Distribution Center
ICM	Integrated Cargo Management
IT	Information Technology
MOQ	Minimum Order Quantity
CRP	Continuous Replenishment Programme
EPOS	Electronic Point of Sale
EDI	Electronic Data Interchange
IP	Inventory Position
ROP	Reorder Point
EOQ	Economic Order Quantity
KPI	Key Performance Indicator
UOM	Unit of Measure
VBA	Visual Basic for Applications
IoT	Internet of Things
BI	Business Intelligence
MRP	Material requirements planning
i.e.	In other words
RFID	Radio Frequency Identification

Table of Contents

1. Introduction

In this chapter, the author firstly introduces the background of this study, including a brief introduction of the targeted concept-bullwhip effect and the contemporary methods on how to mitigate the bullwhip effect within a supply chain. Afterward, two research questions and the research purpose are presented; finally, a statement of delimitation of the study is included at the end of this chapter.

1.1. Background description

Warehouse operations are critical in the context of supply chain management. They facilitate storage of products, ranging from raw materials to finished goods, between the upstream and downstream regions of a supply chain (Choy, Ho & Lee, 2017). Order picking is one of the warehouse operations that have the highest priority for improving the warehouse efficiency (De Koster, Le & Roodbergen, 2007; Chen, Wang & Xie, 2014). Especially, storage policy is a major element affecting the efficiency of the order picking process (Joe, Gan & Lewis, 2012). The main problem with storage location assignment is to assign incoming goods to storage locations in particular storage zones so as to minimize material handling costs while maximizing space utilization (Gu et al. 2007). Without a systematic approach to assigning stock keeping units (SKUs) to appropriate storage locations, the efficiency of order picking causes additional material handling costs, as well as ineffective storage utilization in a warehouse (Choy, et al., 2017).

The rounding of orders to achieve a batch size is a common practice in warehouse operations to achieve efficiency. However, it is recognized as a source of the bullwhip effect within supply chains (Potter & Disney, 2006). One of the main causes of additional costs within supply chains is the bullwhip effect (Lee et al., 1997). Bullwhip effect occurs when the variance of orders placed happens along a supply chain. Often, but not always, the distortion of order quantity increases variance (Potter & Disney, 2006). There are four major causes of the bullwhip effect have been recognized: demand signal processing- when amplification is introduced as a result of companies try to respond to the feedback loops and time delays (Forrester, 1961); order batching-where it is more economic for demand to be aggregated to acquire economies in either production or transport system (Burbidge, 1981); Gaming-this happens at times when there is a shortage in supply or delivery are missed, the actors in the chain are likely to order more as they perceive the supply is restricted (Houlihan (1987); pricing-where a company changes the price of a product in order to stimulate demand (Butman, 2003).

Thus, the uncertainty of demand, lead time and production schedule, as well as the demand information distortion are familiar challenges that many companies face. To mitigate the bullwhip effect, companies have relied on a combination of ERP (Enterprise Resource Planning), SCM (Supply Chain Management) and other specialized software packages, as well as their expertise to forecast sales and inventory(Stefanovic, et al., 2007). The continuous improvement of SCM and ERP is said to be an effective way of mitigating bullwhip effect since it accelerates information sharing and processes along the chain(Kamble, et al., 2015). And also, using of advanced technology as such Data Mining, which predicts customer demand and stock levels for various products located at various supply chain more accurately, is seen to serve as a guide to supply chain strategies (Stefanovic, et al., 2007).

Concerning the bullwhip effect that connected with push/pull strategy, most of the literature studying the impact of batching on bullwhip effect has claimed that batch sizes should be minimized as much as possible(Burbidge, 1981). However, for retailers, small order batches usually present high handling costs if a company uses traditional labor picking technique. For convenience transport and stock operations, many companies use rounding rules to reach an order batch. However, there is limited academic study investigates the rounding effect of batch sizes. The aim of this paper is to contribute to this endeavor. The author adopts the case study approach by choosing a Swedish retailer Jula as a case company, using the technique of rounding rule simulations to investigate the effect of rounding and try to find a best way to handle order batches in a retail setting, and gives overall recommendations on how to mitigate the bullwhip effect that is connected with its replenishment strategy.

1.2. Purpose of the thesis

In this thesis, the author investigates the push strategy caused effect within the internal supply chain for a retailer, namely, the caused effect by rounding rules from the perspectives of quantity distortion and changes in total costs by studying a case company Jula. The aim is to shed light for managers on how to manage order batches.

1.3. Research questions

In this study, investigations would be carried out to find if rounding has a positive effect on saving total cost, and which kind of rounding rule is the most favorable rules in terms of keeping bullwhip effect and total cost at a minimum. To serve the purpose of the study, the following research questions have been formulated:

RQ1: How does a rounding rule affect the supply chain?

RQ2: How should a retailer manage order batches in its supply chain operations?

1.4. Delimitation of the study

While bullwhip effect can occur multiple places of the supply chain (i.e. supplier, transport, inbound or outbound), this study only focuses on rounding rules caused bullwhip effect within the company´s supply chain. Also, the bullwhip effect can be manifested in many forms and many places, this study only focuses on quantity variance and total cost variance caused by rounding rules. The author uses simulations to imitate a company´s real operation on quantity rounding, however, the simulations used only aimed to find relationships between different rules and cannot be interpreted as absolute values.

2. Case Company

This chapter gives a brief introduction of case company Jula and provides a short background about the development of its information system, its order generation process and rounding rules which are the key elements that give rise to the problem of the case.

2.1. Company description

Jula AB is a family-owned company with a head office and central warehouse in Skara, Sweden. Jula offers creative home fixers and professionals a wide range of products at low prices via department stores. As of 2019 February, the company has approximately 3000 employees and a total of 99 department stores, 54 in Sweden, 33 in Norway and 12 in Poland. The company has been growing rapidly in both the number of department stores and the turnover in about 40 years period. As the latest figures are shown in the company´s website that, the 2017 company turnover was 6,5 billion SEK (€0,6 billion), with profit reaching 460 million SEK (€43,4 million), and the company´s equity ratio was 42% (2016).

Jula´s assortment has over the years been expended to include eight categories: tools and machines, buildings and paints. electricity and lighting, garden, leisure, car and garage, home and household. Most products are purchased directly from manufacturers all over the world so to ensure the low price. Over half of the goods are purchased from Asian suppliers which require Jula´s purchasing team to make forecast and place orders much more in advance. The lead time of Asian orders from the point of placing the order to arriving at the central warehouse is about 70 days to 120 days depending on the manufacture lead time. The lead time of products from other Europe countries is about 30 days and for Swedish products is about 7 days.

Jula owns one of the largest warehouses in Sweden, which area is up to 150,000 square meters and with a capacity about 220,000 pallets (Skaraborgslandstidning, 2018) (Skaraborg Logistic Center, 2013). Jula benefits from the geographical advantage of Skara and makes future expansion favorable. Skara lies 30km away from Falköping, which is the logistics center in the Skaraborg region. Each day, large volumes of goods are transported between the port of Gothenburg and the terminal in Falköping (Port of Gothenburg, 2016). With only one central warehouse, the DC (Distribution Center) supplies the replenishment for all 99 stores, with lead time 1-3 days for Sweden, 3 days for Norway and Poland.

2.2. Jula´s ERP and SCM systems

For managing products on such a scale, Jula has shown strong absorptive capability in terms of IT integration. Since 2006, Jula started using Movex/M3 by Infor as its business system. Until today Movex has gone through many upgrades and seamlessly connects and facilities the business operations through HR, Economy, Marketing, Business Development, Purchasing, Logistics, Customer service and IT.

Supply Chain as a core operation unit for Jula, relies heavily on the transparency and accuracy of information about products. Movex has provided Jula with the flexible integration platform that new systems can be installed quickly without disturbing the core business operations. However, after having continuous review of business process, development goals and existing IT systems, the management of Jula found that the functionality provided by Movex would not suffice to achieve the ambitious goals set by Jula for the warehouse, therefore they started a new system Relex solution for procurement in the summer of 2012 to reach better control and optimize product replenishment to its outlets and warehouse. Before launching Relex, planners made order planning manually with the help of simple tools such as Excel, which often caused too high or too low stock levels and affected customer service negatively. With the aid of Relex, orders are created automatically by Relex by using the sales and stock data from the day before the order creation date. Adopting of

Relex has helped Jula reduced human errors in order placing process, optimized stock levels and improved service level.

Besides Movex and Relex, Jula has also adopted the interface platform ICM (Integrated Cargo Management) system from Schenker to achieve better transparency of cargo. ICM is a cloud-based technology solution which enables Jula to follow up detailed cargo information and status from the moment order is placed to the moment goods are delivered and registered at their warehouse. With increased transparency of information, Jula gains better control of the whole supply chain operation.

Although Jula has demonstrated progress towards IT integration, the company has only a few such integrations, the existing interfaces are quite new, and they keep on searching improvement on their business system. For example, the ordering system Relex needs improvement on managing order multiples in a way that can take into consideration of handling costs of the distinct size of packages and keep the total inventory as low as possible.

2.3. Jula´s order generation process

For the inbound process, Relex generates the order quantity, which is based on the sales forecast, while the sales forecast is based on the historical sales record. For new items, they use the sales record of a reference item. The order quantity takes into account conditions such as lead time, demand, MOQ, package parameters, safety stock, on-shelf quantity, pending orders, maximum allowed units on the shelf. For the outbound process, the replenish quantity is based on the sales forecast for each store. Each item is associated with a replenishment level that is based on the product characteristics such as volume, demand, value, whether it is dangerous goods or if it is on a campaign. In general, the replenish level is based on the sales volume and item unit value and usually to be 7 days, 14 days, and 21 days of demand.

Relex adopts Continuous Replenishment Programme (CRP) which uses up-to-the-minute point of sale information through Electronic Point of Sale (EPOS) to find real-time demand and to pull product directly through the DC to the retail outlets. This CRP program synchronizes the flow of product and linked to the flow-through systems, which enables the company to get the right order proposal for both inbound and outbound operations. Warehouse, on the other hand, pick, pack and transport the goods according to the quantity proposed by Relex for each store.

The following provides an example of how Relex generates order proposal for one anonymous item to one of the outlet stores:

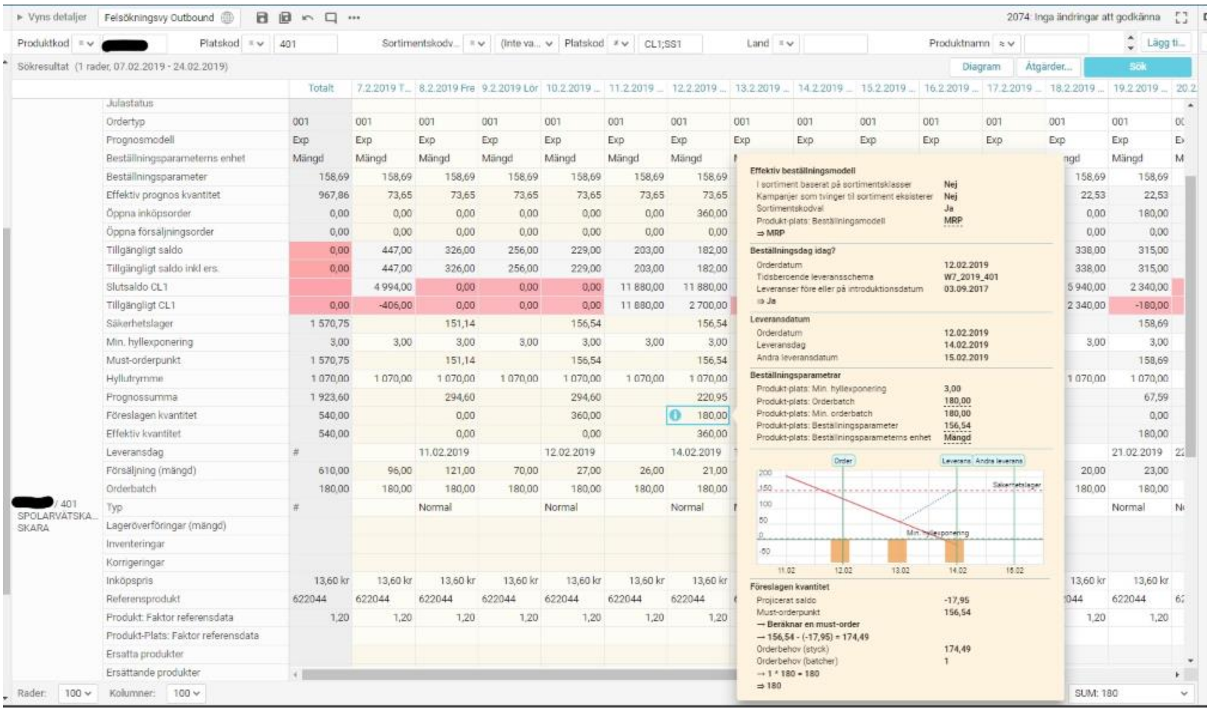

Figure 1 Example of outbound order generation process by Relex

The proposed quantity for this item on February 12, 2019, is 180 pcs. The pink box explains how 180 is generated by Relex:

The replenish level of this item is 158.69 pcs, daily sales forecast is 73.65 pcs, the first delivery date is in two days, which makes the total forecast during lead time 220.95 pcs (73.63 x 3 = 220. 95 pcs). The occurred actual sales during the lead time is 21 pcs, which makes the real time total forecast equals 220.95 - 21 = 199.95 pcs. The available stock position is 182 pcs, which makes the projected stock position in two days equals 182 - 199.95 = -17.95 pcs, with a must-order point 158.69, the needed order quantity is: 158.79 - (-17.95) = 176.74, because order multiple is 180, therefore, the proposed order quantity is 180 (the replenishment model will be further explained in chapter 3.4).

2.4. Jula´s rounding rule

When an item is being registered in a company´s system, among many item specifications, information such as retail unit, inner packing, outer carton, the pallet is registered in the number of sales units. The four levels of packaging are illustrated in figure 2. In this example, the order multiple is 10, as packing of 10 pcs is the nearest packing of the retail unit.

Figure 2 Four packaging levels at Jula (Internal Source)

For Jula, the rounding rule of order quantity is: if the fraction value of order quantity is 25% more than the order multiple, it rounds up to the nearest integer of the generated units of order multiple; if the fraction value is less than or equal to 25% of the order multiple, it rounds down to the nearest integer of order multiple. For example, when order multiple is 20, and the order quantity is 25, the generated units of order multiple is 1, since 25÷20 = 1.25 ; the fraction equals to 0,25, so the generated units of order multiple rounds down to nearest integer 1; however, if the order multiple is 20, while the order quantity is 26, the generated units of order multiple is 26 ÷ 20 = 1,3; since fraction 0,3 is bigger than 0,25, the generated units of order multiple round up to the nearest integer 2. So, the actual sending quantity is 20 (20 x 1 = 20) pcs when the order quantity is 25; while 40 pcs (20 x 2 =40) when order quantity is 26.

2.5. Case problem description

If applying a rounding rule, it can cause the order quantity to vary significantly from item to item, since order multiple of different items can vary significantly due to packaging. Order multiple, it can be any integer number from 1, 2, 3,4, and up to hundreds or thousands. A rule of thumb of 25% rounding rule raises the question of whether it is economic in terms of the total cost. Jula over the years has tried several times to get a proper way to handle order multiple for orders from the central warehouse to Department Stores. They have experimented different rounding rules, however, the results were not totally satisfying. Since the demand for same products varies across department stores, the solutions were either too general to apply for some department stores, or too detailed that it would be difficult to use.

In recent years, it is obvious that the number of picking rows increases markedly in the goods flow, which means increased costs for both the central warehouse and department stores for Jula. Therefore, Jula is in need to investigate the order multiple issues again and produce a solution which can both cater to the needs of different department stores and save the cost for warehouse operations.

3. Literature Review

In this chapter, literature reviews are presented as the theoretical bases for this study. Based on the research questions, the literature revolves around the basic concepts of inventory, EOQ model, total costs, inventory replenish models and inventory KPIs. Those concepts are relevant to the case study and provide a foundation for the analysis of the case.

Traditionally inventory management was considered as an essential part of business operations but not as a core strategy. With the trend of globalization and the advancement of Information Technology, logistics and supply chain management have caught extra attention in the last few years (Simchi-Levi, et al., 2008). In the retail industry, staying competitive requires offering a wide variety of products, and meet customer´s demand timely. Thus, keeping enough safety stock is a key strategy to keep a high service level. However, stock keeping is costly, and companies are beginning to understand that the cost of excess or unnecessary stock is going to have an impact on their bottom-line costs.

Although in the last two decades, the academic community has developed various models and theories to assist with the management of the supply chain, its applications are not familiar with the industry. In this literature review, we present a brief highlight of the state-of-art concepts models, solution methods and formulas that are relevant to this research.

3.1. Basic concepts of Inventory Management

There are many reasons for a company to decide to keep stocks of various products. The most important reason for holding the stock is to create a buffer between supply and demand. This is because it is always hard to predict demand even with advanced calculations. Other reasons include to keep down the cost by taking advantage of larger volume discounts, fulfil the minimum order quantity requirement, to account for seasonal fluctuations, to prepare for promotional sales, and to minimize delays caused by lead time uncertainty (Rushton, et al., 2017).

Inventories are categorized as in the form of raw materials, goods in process and finished goods that can be held at various places within a supply chain range from suppliers, factories, distribution channels, and retail stores (Ballon, 2004). Each type stands for tied up capital for a company until the goods being sold. Stocks make up a substantial portion of the business investment and must be well managed in order to maximize profits. It is observed that making use of proper inventory management practices is one of the ways to gain competitiveness. Good examples such as Wall-Mart, Dell and Amazon that they have excelled in supply chain innovation and have demonstrated how an efficient supply chain strategy can become a strong completive advantage for a company.

Simchi-Levi, et al., (2008) states that for many managers, effective supply chain management is synonymous with reducing inventory levels in the supply chain, while in fact, the purpose of effective inventory management in the supply chain is to have the correct inventory at the right place at the right time to minimize system costs while satisfying customer service requirements.

3.1.1. Push to Pull system

There are several forms of inventory systems, two systems that are popular and relevant to this research are: push and pull systems. The philosophy of pull systems is to draw inventory into the stocking location by the expected demand, and each stocking location is considered independent, the aim is to maximize the local control of inventories. While, push systems, goods are produced specially to order but not against forecast demand. This is because it takes into account the lead time involved in sourcing, manufacturing, shipping and so on. Especially in today´s retailing world, it is crucial to meet customer´s demand in time, therefore push systems are of great use for the retail industry. Push systems allocate production to stocking locations based on the unknown but estimated overall demand, the main purpose is to take advantage of the economies of scale.

Simchi-Levi (2008) described that with a pull-based supply chain, production and distribution are according to customer demand rather than a forecast. In a pull system, the company only react to specific orders instead of having inventory. This enables customer demand information flow faster to reach various supply chain actors. For example, a typical pull strategy is using POS data or EDI (Electronic Data Interchange). Thus, the pull system reduces lead time and inventory level at both suppliers and manufacturers and leads to a reduction in cost compared to traditional push strategy.

However, according to Simchi-Levi (2008) that a pull strategy is difficult to implement when the product lead time is long since the whole supply chain cannot react fast enough to respond to the customer demand. Also, if a system is not able to plan far ahead, it is difficult to take advantage of economy of scale in manufacturing and transportation.

Pure pull or push strategies are things of the past. Effective marketing strategy implementation demands careful coordination of marketing communication programs with sales strategy to maximize the value of the brand to both the retailer and the end customers, almost all marketing strategies are a mix of push and pull elements (Webster, 2000).

Daine, et al., (2011) argued that excessive accumulation of stock was considered as a problem of high importance which contributing to wasted activity, reduced stock value, reduced new sales opportunities and lowered the efficiency of the business in terms of both reduced revenues and increased activity costs, they suggested that the pull approach, which is a characteristic of Lean philosophy, would help to address problems in decision-making and other inefficiencies in the supply chain. Since the aforementioned issues were being adversely affected by the push approach as a company strive to reach high service level for the outlet. The pull strategy in Lean provides the autonomy of products being pulled by downstream consumers and not pushed by the upstream supply chain. The goal was to streamline the business process, accelerate the pace of innovation. Information sharing is one of the key strategies to counteract the bullwhip effect according to Lee & Whang, (1997). They pointed out that with information sharing, customer demand information delivered faster from downstream to upstream, which reduces lead time and gain better visibility of market demand.

3.1.2. Inventory costs

Three basic costs are associated with inventory: carrying or holding costs; ordering costs, and shortage costs.

Taylor & Russell (2011) defines the carrying costs are the cost of holding items in inventory, which can include facility storage such as rent lighting, insurance, etc.; material handling such as equipment; labor; record keeping; borrowing to purchase inventory such as interest on loans, taxes; product deterioration or obsolescence. It is common to assign the total annual carrying costs mentioned above onto a per-unit per time period basis. For example, a month or year. Carrying costs can also be expressed as a percentage of the value of an item or as a percentage of inventory value.

Ordering costs refer to the cost of actually placing an order associated with replenishing the stock of inventory being held. Usually, they are expressed as a dollar amount per order and the cost applies regardless of the size of the order. Costs incurred each time an order is made and can include the costs of raising and communicating an order, as well as handling, delivery, accounting, and auditing costs.

Shortage costs are also known as stockout costs which refers to the costs of not meeting a customer´s demand because of insufficient stock. Shortages can lead to loss of sales, profit, and reputation. Normally shortages occur because companies try to avoid high carrying inventory cost, therefore, carrying costs and shortage costs have an inverse relationship.

3.1.3. Inventory replenishment policy

The purpose of an effective inventory replenishment policy is to keep a proper balance between the cost of holding stock and a good service level. An inventory system controls the level of inventory by deciding how much to order and when to order. There are two major inventory policies: periodic(or fixed-time-period) review policy and continuous (or fixed -order-quantity) reorder policy.

Simchi-Levi, et al. (2008) distinguishes those two types of policies:

Continuous review policy: in which inventory is reviewed continuously and an order is placed when the inventory reaches a certain level, or reorder point. This type of policy is most appropriate when inventory can be continuously reviewed. For example, when computerized inventory systems are in use.

A graphical illustration of this model is shown in Figure 3. Note that this model assumes a constant demand d when the inventory position (IP) is reduced. When the IP touches the Reorder point (ROP), an order with fixed quantity Q is placed. The time between the moment of an order is placed and the moment of the order arrived is called lead time, which is also the time we have to wait for the order.

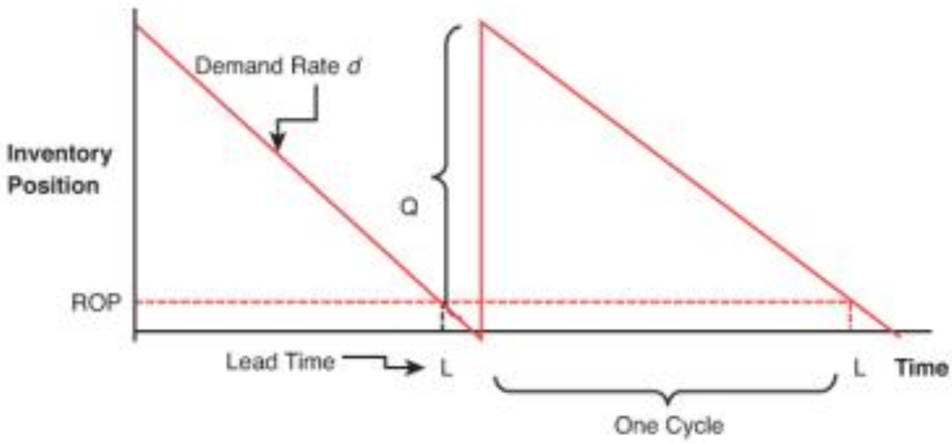

Figure 3 Continuous Review System

Source: (Simchi-Levi, et al., 2008)

In the classical version of continuous review model, Q is computed as the Economic Order Quantity(EOQ) which will be explained in section 3.2.

Periodic review policy: in which the inventory level is reviewed at regular intervals and a proper quantity is ordered after each review. This policy is more appropriate for when frequently a review of inventory is not convenient.

This model checked inventory levels at fixed time intervals marked as T in figure 4. This makes the order quantity vary based on the inventory position that each time checked. The system sets a target level, labeled as R. Inventory is checked every T interval, for example, every week or every odd week, and an order is placed to bring the inventory level back to R. The order quantity Q is dependent on how much inventory is in stock-the inventory position at time T:

Figure 4 Periodic Review System

Source: (Simchi-Levi, et al., 2008)

3.2. EOQ model

Economic Order Quantity (EOQ), sometimes expressed as Optimal Order Quantity, the traditional method of calculating EOQ is by using the classic square root formula, the Wilson formula. The formula attempts to estimate the best order quantity by balancing the conflicting costs of holding stock (holding costs) and of placing replenishment orders (ordering costs), which illustrated as in Figure 5.

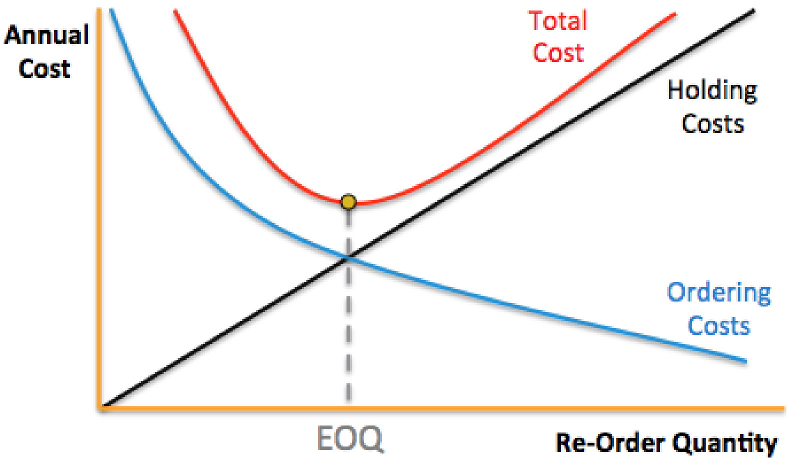

Figure 5 The economic order quantity (EOQ) principle

Source: (Rushton, et al., 2017)

Formula:

$$EOQ = \sqrt{\frac{2DS}{IC}} \qquad (3.1)$$

Where,

D- average annual demand, units

S-procurement cost per order, $/order

I- Carrying costs as a percent of product value, % per year

C-product value while in stock, equals purchasing price plus external and internal transport and handling costs, $ per unit

However, the EOQ formula is under a number of conditions and assumptions (Coyle et al., 1996), which are:

The demand (R) is known and constant

The order arrives in its entirety at once

The purchasing price per unit (C) is known and constant and not subject to the change of order size

The ordering cost is known and constant, for example administrating an order is independent, regardless of the ordering quantity and type of the order

No shortage is allowed

The equation provides sufficient accuracy in most instances, even though, in line with the restrictions of assumptions, it is a relatively rough estimation (Lumsden, 2007). However, when it is used in association with fixed point reorder system, and with safety stock provision, the EOQ is valid and can be applied to various products((Rushton, et al., 2017).

3.2.1. Safety stock

In most inventory models, the inventory for one item is featured of an equation: total system inventory = safety stock + cycle stock. Cycle stock is the on-hand inventory plus the inventory in-transit. Safety stock (denoted as SS hereafter) is calculated by the following equation:

$$SS = z\sigma\sqrt{LT + R} \tag{3.2}$$

Where,

z- the safety factor which is based on the probability of not stocking-out during a replenishment period (see Appendix 1)

σ- standard deviation of errors of forecasts over the lead time of replenishment

LT- average lead time for order replenishment

R- the amount of time for inventory review

Further expanded, if the errors of forecasts are unknown, it can be calculated by the following equation. Since the level of safety stock is depending on the variation of the demand during lead time, the formula reflects the combined effect of demand uncertainty and lead time uncertainty.

$$\sigma = \sqrt{L\left({S_d}^2\right) + d^2({S_{L_T}}^2)} \tag{3.3}$$

Where,

d – the average period of demand, units

S_d- standard deviation of demand (d)

S_{L_T} -standard deviation of lead time

3.2.2. Reorder point

Items are picked from the warehouse which means inventory will be reduced constantly. At a certain time, the inventory level declines to a predetermined level, the Ordering Point (OP). The inventory level at this point should cover the forecasted demand for the lead time, and the safety stock during an eventual deviation. The Ordering Point can be expressed as:

$$OP = LT*D + SS \tag{3.4}$$

3.3. Total cost

Under the EOQ model, two types of costs are added for a given period: the ordering cost during the period (TO) and the total cost of carrying a stock (TS), which can be expressed as:

$$TC = TO + TS \tag{3.5}$$

3.3.1. Ordering cost

For a demand of R during the period, D/Q times order should be placed. Thus, the ordering costs (S) occur D/Q times.

$$TO = \frac{D}{Q} * S \tag{3.6}$$

A wish to make small but frequent orders will automatically lead to high costs. On the contrary, a large order size can reduce the number of orders, to an extreme, make the order size equals the demand (D = Q) will keep the ordering cost to the minimum.

3.3.2. Carrying cost

A company´s operation is at the cost of its fixed capital that at least corresponds to an interest (I). Every item in stock is associated with a value (C), therefore, generate a capital cost is I * C. To calculate the capital cost for a period, the stock generated by the orders must be found. The generated order (Q) will be physically stored and gradually withdrawn by the demand (D). The outcome is that the average stock equals half of the order size (Q/2), which is illustrated in figure 6.

$$TS = \frac{Q}{2} * I * C \tag{3.7}$$

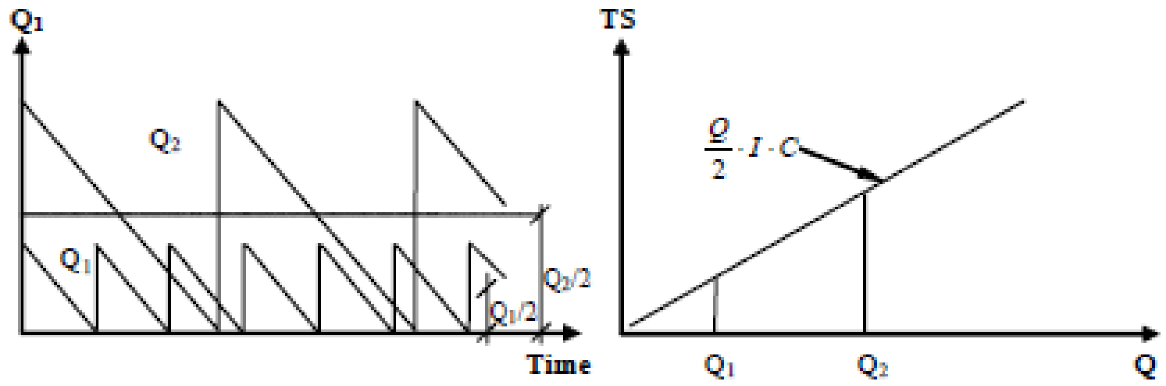

Figure 6 The average inventory level

Source: (Lumsden, 2007)

If the order size becomes smaller, which is usually preferred, the average stock decreases simultaneously. As a result, the carrying cost goes down. Therefore, an increase in the order size will reduce the ordering cost but increasing the carrying cost.

3.3.3. The total cost

With TO and TS explained, the TC can be expressed as:

$$TC = TO + TS$$

$$= D/Q * S + Q/2 * I * C \tag{3.8}$$

3.3.4. Total relevant cost

Under the model of reorder point, above cost equation is extended to include the cost of safety stock as well as the cost of out of stock, which can be expressed as:

$$TC = \frac{DS}{Q} + IC\frac{Q}{2} + ICr + k\,\frac{D}{Q}\sigma\, L_{(z)} \tag{3.9}$$

Where,

ICr - the capital cost of carrying safety stock

K – stock-out cost, $/unit

σ- standard deviation of errors of forecasts over the lead time of replenishment

$L_{(z)}$ - the standard loss function, i.e. the expected number of lost sales as a fraction of the standard deviation, hence, the lost sales = L(z) X σ_{DEMAND} (see Appendix B)[1].

Since this research investigates the relationship between different packaging levels to the total inventory cost, under the assumption that the service level should not be affected, therefore, we adjust the formula to not include stockout cost, which is to say, no stock out is allowed. The adjusted formula as:

$$TC = \frac{DS}{Q} + IC\frac{Q}{2} + ICr \quad (3.10)$$

3.4. Inventory replenishment models

With a few of the basics now covered, the following moves on to a discussion about inventory models. Among many models, three models are chosen based on their relevance to Jula´s operations.

3.4.1. Periodic review – replenishment level

For most of the distribution organizations, it is always helpful to know when an order (Q) will arrive. For example, for retailers, to know when an order arrive enables the planner to make a good forecast of product availability for the planned period and place next order in time so that suppliers can prepare for manufacturing the goods. The periodic review system means that the inventory will be reviewed at some predetermined time interval (t_p), for example, every Wednesday or every Thursday of odd weeks. At the time of review, if the current inventory level (Li) is below the predetermined replenishment level (S), an order of quantity (Q) is placed, which can be expressed as:

[1] z – the safety factor, is chosen from statistical tables to ensure that the probability of stockout during lead time is exactly 1 - α. (α =service level, this implies that the probability of stocking out is 1 – α

Q = S – Li (3.11)

The Q depends on the current inventory level, can vary each time when placing an order. The size of the Q under the ROP system should be equal to the economic order quantity or any other predetermined size such as minimum order quantity, or a filled package that is defined by the supplier. The relationships are illustrated in figure 7.

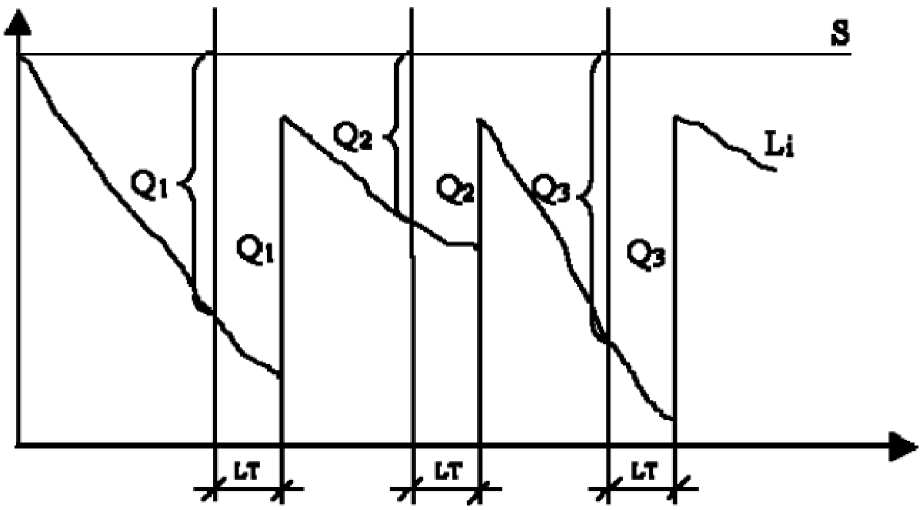

Figure 7 Inventory systems – periodic review (S) system

Source: (Lumsden, 2007)

With fixed time intervals, it spares the work to check inventory levels for the time between orders. However, the order size may vary to a great extent from time to time. For too small orders that the quantity is less than the economic order quantity, which makes it less economic. Also, the safety stock will increase because it is not only the safety stock needed for the lead time but also some extra to cover the uncertainty during the review period.

3.4.2. Periodic review with optimal batch size

To avoid ordering too small orders, a system of two levels (S, s) is designed to place only orders that are equal or bigger than the economic order quantity. Expressed by the formula:

Q = S – Li (Q > EOQ) (3.12)

Therefore, another level of s is included in this system to ensure Q > EOQ. This level is fined as:

s = S- EOQ (3.13)

The advantage of (S,s) system (see Figure 8) is that orders are placed with constant intervals and with a certain minimum order size which has to be over the economic order quantity. The disadvantage of this system is that the demand for too small orders will be pushed to the next review, which increases the time to receive the order. The longer the time it takes to receive the order, the more uncertainty it will have. Therefore, the safety stock also needs to be increased to cover the uncertainty under this system.

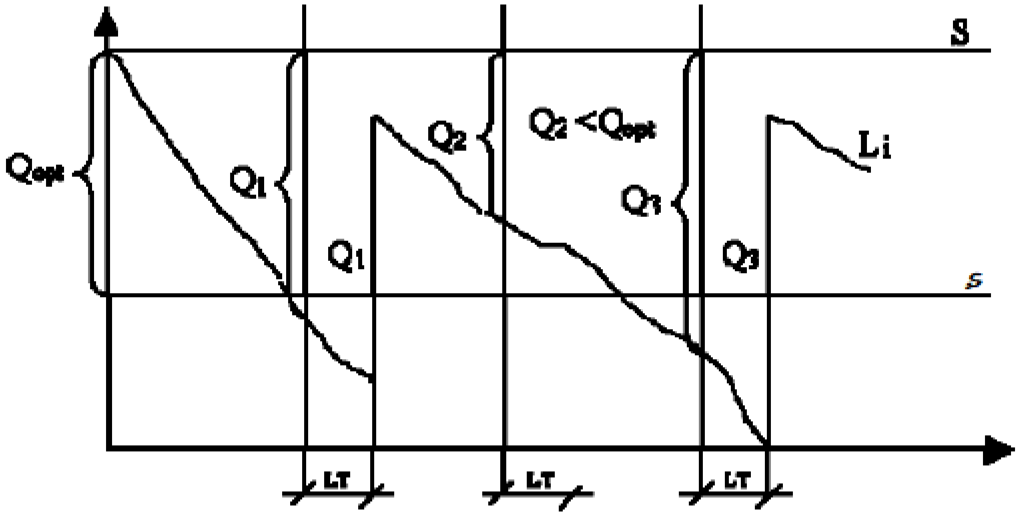

Figure 8 Inventory systems – periodic review (S,s) system

Source: (Lumsden, 2007)

3.4.3. Periodic review with simultaneous ordering point

One problem with the previous two systems is that orders will have to wait until review time to be placed. The periodic review with a simultaneous ordering point system is designed to place an order even before the review time as long as the current inventory level drops below the ordering point (as illustrated in Figure 9). This is especially for situations when the demand increases largely and makes the inventory drops to such low level that an order must be placed immediately before the stock goes reaches zero.

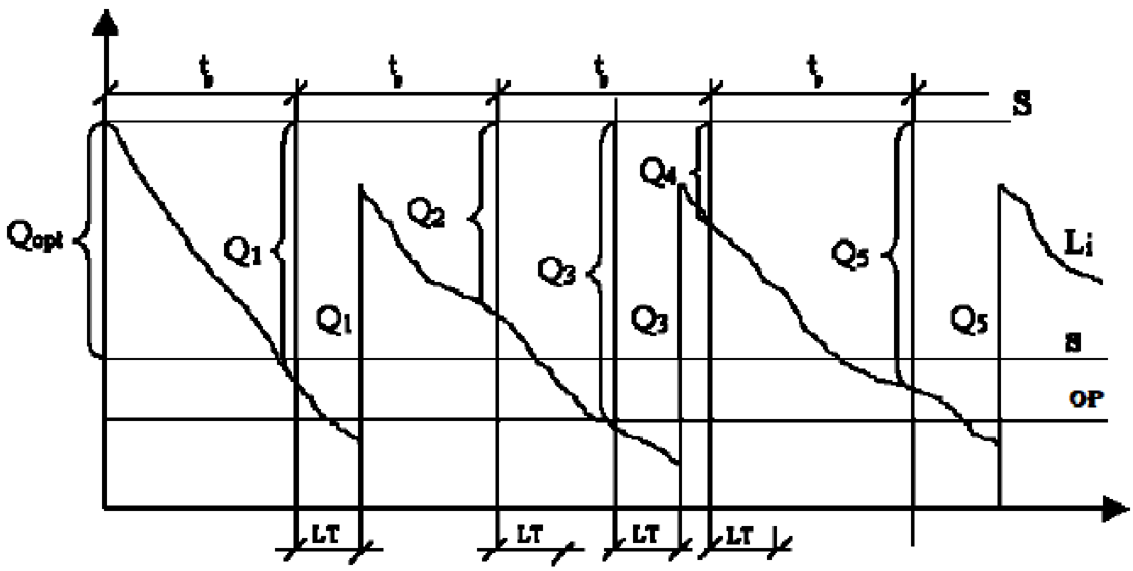

Figure 9 Inventory systems – periodic review with simultaneous ordering point

Source: (Lumsden, 2007)

The advantage of this system is that orders can be placed anytime as long as the inventory level touches the ordering point. The disadvantage is that the inventory levels will have to be checked and updated more often. The safety stock, on the other hand, will decrease dramatically since, without review time, the only uncertainty is associated with the lead time.

3.5. Inventory KPIs

A Key Performance Indicator (KPI) is a measurement of a company´s performance over time within an area toward a specific goal. There are plenty of standard KPIs to monitor the overall supply chain performance, among which some of the important ones include inventory turnover, cost of carrying inventory, service level, inventory accuracy, cycle time and so on.

Jula uses service level and inventory turnover as two key performance indicators, and cycle time is highly related to this research, therefore, those three concepts will be presented in this section.

3.5.1. Inventory turnover ratio

Inventory turnover ratio is defined as follows:

$$\text{Inventory turnover ratio} = \frac{\text{Annual sales}}{\text{Average inventory level}} \tag{3.14}$$

The definition indicates that a decrease in inventory level leads to a high inventory turnover ratio. A high inventory turnover ratio suggests a higher level of liquidity, lower risk of obsolescence and reduced tired up capital in inventory. Inventory turnover ratios vary across different industries.

3.5.2. Service level

The service level also mentioned as stock availability, a better way to express it is by the probability of not stocking out during the lead time. For individual items, the service level is computed as follows:

$$SL = \alpha = 1 - \frac{\sigma L_{(z)} D/Q}{D} = 1 - \frac{\sigma L_{(z)}}{Q} \tag{3.15}$$

Where,

σ - standard deviation of compound demand distribution, $\sigma = \sqrt{L\left({S_d}^2\right) + d^2({S_{L_T}}^2)}$

$L_{(z)}$ – partial expectation or unit normal loss integral

For multiple items on the same order, the service level is the combination of individual service levels as follows:

$$SL = SL_1 \text{ x } SL_2 \text{ x } SL_3 \text{ x } SL_n \tag{3.16}$$

3.5.3. Order cycle time

For warehouses, the timeliness of delivery operations needs to be assessed. For example, some companies would calculate in detail the time taken from receipt of order to final delivery. Thus, order fulfillment can be measured by the order cycle time or the actual lead time from the receipt of an order to its final delivery to the customer. For typical stock order, the time tied up with handling the order include:

- order receipt to order entry
- allocation for picking
- allocation for packing
- dispatch to final delivery

The purpose of presenting the concept of order cycle time is to provide the measurement of handling the cost for Jula case. Since their handling costs differ for goods of different packaging levels, using order cycle time helps to estimate the different level of handling costs.

4. Theoretical Framework

In this chapter, the author presents the theoretical concepts that are being used in this research. The theories used have helped the author´s thinking process and have been of great use when the results were analyzed.

4.1. Order Multiple

Order multiple is the quantity of the Order Quantity UOM (Unit of Measure), which often depends on the vendor pack, which can be the base unit, each, box or pallet. There are several levels in the hierarchy of packaging. The primary level is often referred to as "retail packaging" or “sales unit” which is the smallest Unit of Measurement that can be sold to a customer, for example, 1 pc. The secondary level often referrers to inner packaging, which holds a certain number of units that are in primary packaging, for example, 1 box which holds 12 pcs of toothbrushes, while sell packaging is per piece (pc). The third level refers to outer packing, which can be a carton which can contain a certain number of units that are in secondary packaging. The main goals of inner and outer packaging are to protect products and provide branding during shipping. The fourth level is a pallet, it is the most often used type by warehouses and in bulk shipments, consumers do not typically see this level of packaging (Benjamin, 2018).

To facilitate processing, standard UOM is commonly used for ordering, stocking, and shipping and invoicing. The standard UOM represents the most common UOM for an item and is the item´s smallest valid unit of measure. A standard pack UOM is used when items need to be shipped or stock consistently in packages of a specific size and type. For example, if one needs ship pens in boxes of 24, one can define a box as having 24 each, the 24 is the standard UOM or Order Multiple, and a box as the standard pack UOM (Kiefer & Novack, 1999). The standard UOM or Order Multiple is defined as the nearest level of packaging that contains the retail units, usually, it is the inner packaging units.

Quantity precision is an issue related with Order Multiples. It is a frequent practice that order quantity is rounded into whole numbers, say integers. Rounding rules are necessary which can help determine the direction in which fractional quantities are rounded so that calculations can result in whole numbers. There are two most commonly used round rules: one is nature round, which is when fractional values that are greater than or equal to 0,5 are rounded up to the nearest integer, and fractional values that are less than 0,5 are rounded down to the nearest integer; another one is roundup, which is when fractional values are always rounded up to the nearest integer. A company can decide the rounding rule themselves.

4.2. ERP and SCM integration

The arrival of a new industrial revolution(Industry 4.0) has transformed the relationship between stakeholders along an entire supply chain. The implementation of Industry 4.0 initiatives searches for, among many things, checking industrial processes, simulating, and optimizing production processes and increasing the agility of information flows (Moeuf, et al. 2017).

In order to increase the speed of information flows, Moeuf, et al. (2017) point that technologies such as cloud computing platforms, web interfaces, virtual reality, Big Data and IoT (Internet of Things) have been used to connect with enterprise production planning and control systems such as ERP and SCM. The integration of these technologies brings multiple benefits including optimized operations, enhanced collaborations between stakeholders, increased industrial efficiency and more flexibility in decision-making processes.

Enterprise Resource Planning (ERP) and Supply Chain Management systems (SCM) are common software tools that have been used in modern organizations. ERP systems help enterprises in automating and integrating corporate cross-functions such as inventory control, procurement, distribution, finance, and project management (Tarn, et al., 2003). SCM enables supply chain partners to work in close coordination through information sharing to ease supplier-customer interactions and minimize transaction cost (Lawrence, 1999; Premkumar, 2000; Lee and Whang, 2000). ERP and SCM work in a complementary fashion which often cause technical and organizational challenges (Bose, et al., 2008).

ERP and SCM systems and their integration efficient management of supply chains require continuous adjustments to achieve efficiency. In ERP systems, material, capacity and demand constraints are considered separately, while SCM systems consider all constraints simultaneously and develop a plan a higher quality plan more quickly (Bose, et al., 2008).

4.3. Application of Business Intelligence in Supply Chain Management

One of the crucial problems that Supply Chain Management facing is how to deal with a large amount of data and how to accelerate the processing of various transaction data and use it for improvements. This requires using business intelligence(BI) tools like data mining and data warehousing, to discover hidden trends and patterns in a large amount of data and eventually deliver derived knowledge to the business users via Web portals (Stefanović, et al., 2007).

The development of the internet and technology has made using Information Technology in SCM essential, most enterprises are using information systems such as MRP (Material requirements planning), ERP and so on. Some software has implemented SCM, including some optimization measures and decision support functions. Back in 2000, the supply chain management module in the system has not widely adopted data mining technology, while there is an increasing demand of such enterprise database usage (Chen, et al., 2000). Nowadays, data mining has become an indispensable tool in understanding customer needs, preferences, and behaviors, and used in pricing, promotion, and product development, but still, there are a lot of opportunities and applications of data mining even beyond the obvious, one of the potential areas is "Supply Chain Management" (Gopalappa, 2018).

In general, companies have relied on a combination of ERP, supply chain, and other specialized software packages, as well as their judgments, expertise to forecast sales and inventory. One of the realities for the manufacturing and retail industry is that no matter how developed a system is, the inevitable uncertainty in the chain creates a mismatch between demand and supply. Two key issues that plague Supply Chain Management are variation in demand and supply; variation in the promptness and extent of communication within the supply chain (Gopalappa, 2018). Companies face the common challenges of the uncertainty of demand, lead time and production schedule, and also the demand information distortion known as the bullwhip effect, make it even more difficult to plan and manage inventories (Stefanovic, et al., 2007). To overcome issues of SCM there is a need for an improved sales forecasting model which delivers reliable and efficient forecasting results (Kamble, et al., 2015).

Using data mining tools, it predicts customer demand and stock levels for different products located at various supply chain nodes more accurately; and ensures that each inventory point such as warehouse, the retail store has the optimal stock levels (Stefanovic, et al., 2007).

Data mining applies algorithms and produces patterns, which can be in the form of trees, rules, clusters, or a set of mathematical formulas. And further to be processed and become valuable information which can be used for prediction, reporting and as a guide to supply chain strategies (Stefanovic, et al., 2007).

5. Methodology

This part will describe the different steps that lead to the solution creation process. It provides the structure for the empirical data collection and can be used as the basis for the analysis.

5.1. Research design

This research is performed in a case study design. This implies that the detailed and intensive analysis of a single case that is studied because of its complexity or particular nature (Bryman & Bell, 2011). This case analyses a single retail company, Jula, and can be seen as a representative or typical case that exemplifies an average retail practice. Yin (2003) suggests that distinguishing the advantages and disadvantages of each research method depending on three conditions: (1) type of research question (2) control of investigator over the behavioral event (3) focus on contemporary and historical phenomena. Yin(2000) also indicates that when to focus on a contemporary phenomenon within a real-life context, questions of "why" and "how" are posed and the researcher has little control over events, the case study is the preferred strategy. Depending on the case, a case study can be a single case or multiple cases. For instance, a case can focus on one company or organization within an industry or multiple companies within that industry. In most cases, "why" forms the essential or central research questions in a case study, while "what happened "and "to what degree" complement the focal research question. In this sense, this thesis is, therefore, a single case study, as its focus is on a contemporary event of one company within an industry. A case study uses interviews, observations, and sometimes quantitative data as research methods.

There are three types of case studies: exploratory, explanatory and descriptive. An exploratory case study is usually a precursor to a detailed study intended to identify key research questions and hypotheses. An explanatory case study attempts to establish cause-consequence relationships between items of interest. A descriptive case study reveals issues of interest (Dube et al, 2003). The Jula case is explanatory in nature since it aims to find out the effect of rounding rules. To meet the goals and purpose of this study, three steps have been taken initially. At the first step, carrying out the literature review and theoretical framework provides the foundation of analysis, which includes both contemporary inventory knowledge and up-to-date supply chain improvements. The former helps the reader understands the process of Jula´s operation processes, while the later helps the author to identify the possible improvements for the case company with regard to the research question. At the second step, company data have been collected from unstructured interviews, multiple site visits and observations. Lastly, quantitative data analysis has been conducted by using excel calculations and scenario analysis.

5.2. Qualitative data collection

The qualitative data of this case study was collected by the author through participation in multiple meetings, reading of internal and external documentation, field notes, also through unstructured interviews of different personnel.

5.2.1. Unstructured interviews

The unstructured interviews have been conducted with several employees that have provided useful information for this thesis. There were multiple meetings taken place at Jula. Through the meeting with Jula´s supply chain manager, the author has gained a holistic view of the current situation of order multiple related issues. Through the meeting with the outbound planner, the author has gained information on outbound order generation process by learning their ERP and SCM systems. In addition, the site visits at Jula´s warehouse and outlet store offered major help in clarifying the impact of order multiple to different departments along the outbound process.

5.2.2. Observations

Observation is described to analyze situations, for the purpose of understanding the sample behavior (Marshall and Rossman, 1989). Bernard (1994) supports that the observations make it possible to collect several types of data to help the researchers to develop further research questions. For this study, participant observation method was used, where the researcher followed the people and activities involved in the phenomenon being researched. The purpose of using participant observation was to obtain a thorough understanding of the phenomenon and the causes, motives, effects of such phenomenon. According to Collis and Hussy (2014), the studied phenomenon must be observable within an everyday setting and the researcher should have access to the appropriate setting.

At the beginning of the thesis period, the author has practiced the replenishment/refill activity in one of Jula´s outlet stores and visited the central warehouse for getting familiar with the picking process. The data collected through the observation of Jula´s information systems, working flow, store and warehouse operations were used to construct the case description. They also helped relating the findings with the results obtained from quantitative analysis.

5.3. Pilot study and simulation data

A pilot study is a small-scale preliminary study that is frequently carried out before large-scale quantitative research for the purpose of saving time and money being used on an inadequately designed project (Thabane L.et al, 2010). Simulation data are generated by imitating the operation of a real-world process or system over time using computer test models (DeWitt Wallace Library, 2019). In this study, the author uses integer 1-4800 simulates the possible order proposal from DC to one store for one item. By using Excel VBA function to simulate six rounding rules, the author attempts to observe the effect of rounding rules in terms of quantity variance and ordering cost change.

5.4. Research limitations

According to Collis and Hussey (2014), the limitation in a study refers to the existed weakness that may affect the results. Firstly, due to the extensive number of items Jula has, it makes the analysis by using actual data less suitable for this thesis project. The author of this thesis attempts to solve the research question in a simple and easy to understand way by choosing Excel as an analysis tool. However, there are many approaches to solve this research question, for example by using algorithm or statistics analysis.

The author simulates proposed order quantity for an item from 1 to 4800 as base parameters to observe the consequences of different rounding rules. Since 1 to 4800 presents all possible order proposals for almost all Jula items. The rationale behind is that, it is assumed the demand of one of any Jula items of any store is between 1 and 200 pcs per day, with replenishing level from 1 to 24 days for all items, This makes possible order proposal quantity between 1 to 4800 for an unknown period (this is further explained in following paragraphs).

This simulation is used to compare the effects of six rounding rules since order quantity is the only variable that affects rounding results, therefore, all integer numbers between 1 to 4800 are used in the calculation. However, the analysis is based on a series of assumptions of variables, thus the numbers generated in the analyses results cannot be interpreted as absolute values, but only to reflect how much better or worse one rounding rule is compared to another.

Besides this, there are multiple places in the analysis simplified Jula´s real operation. For example, Jula´s replenish levels are different for different category of products based on volume and value specifications, usually are 7, 14 and 21 days. In the analysis, we use the replenish level of 24 days (21 days plus 3 days of transport lead time) for all products, this is to include all order quantity that might be proposed by Relex in its outbound order generation. Also, not all products in Jula have two parameters (order multiple, pallet) registered in the system, some products have only one packaging parameter, which can be either order multiple, inner packing, outer packing or even a pallet.

5.4.1. Reliability

Reliability refers to the absence of differences in the results as well as the accuracy and precision of the measurement if the research were repeated (Collis and Hussey, 2014). In this study, the author uses excel functions and calculations to reflect the relationship of six rules, since each rounding rule is associated with a fixed algorithm, repeating the test by using same parameters returns the same result, therefore, this approach could be considered feasible and accurate.

5.4.2. Validity

According to Leug (2015), validity measures the appropriateness of the study in relation to the research question, method, the research design, data analysis and if the results and conclusions are valid for the context. Bryman and Bell (2011) further distinguish the concept of validity into measurement validity, internal validity, and external validity.

Measurement validity examines whether the measures devised to assess a phenomenon and reflect accurately the phenomena that are supposed to be revealed. The measures of the concept should not fluctuate and ought to reflect the phenomena in a correct way. In this study, the Excel VBA codes correctly represent six rounding rules, the calculations of average picks, average ordering cost, and average quantity difference are straightforward results that can be used for comparison of six rounding rules.

Internal validity is concerned with the issue of causality. It examines whether a conclusion is caused by two or more variables (i.e. A causes B, fully or partly), can verify that the causality with a certain degree of certainty (i.e. it is A that is responsible for variation in B and not something else) (Bryman and Bell, 2011). The simulation of six rounding rules are derived from or in connection with Jula´s current situation, the analysis results explain the phenomena.

External validity can be termed as transferability, refers to whether the findings and results of a study can be generalized or applied to some other context beyond the specific research context (Bryman and Bell, 2011). The generalizability of this study is difficult to measure due to the fact that it lacks data on whether similar companies are having the same concern and whether they operate the same way as the case company does.

5.5. Model network and data

As mentioned in the company´s problem description, Jula has well-designed ordering system which generates orders based on sales forecast, while sales forecast is generated from the historical sales. However, the proposed order quantity does not consider different levels of handling costs associated with the packaging. Currently, some of Jula´s items have two packaging parameters been registered in its ERP and SCM systems, order multiple and pallet, and some of its items have only one parameter, which can be a parameter either from order multiple or pallet. The current rounding rule of 0.25, means that if the generated order quantity divides the order multiple, the fraction is larger than 25% of the order multiple, then quotient plus one; while, if the fraction is lower than or equal to 0.25, keep the quotient and abandon the remainder.

Since 25% rounding rule is just a rule of thumb, which could cause too high or too low volume received by each department store, and it doesn´t take into consideration of different handling costs associated with the different packages. Therefore, in this analysis, the author tries to find out if the current rounding rule of 0.25 is the best rule that is associated with the minimum total costs. Also, to reduce the handling cost, it is rational to pick the biggest possible packages than to pick multiple times of smaller packages. With only two levels (smallest and biggest) in Jula´s system, the picking technique barely considers a better option which is directly to pick an inner carton or outer carton to reduce the handling costs, since those parameters are not available in the system. In this analysis, the author tries to add two more parameters in between order multiple and pallet, which can symbolize inner carton (box) and outer carton (box), and to investigate the effect of it on the order quantity and total costs.

In order to find the best mechanic of picking packages, the author has assumed 6 rounding rules, two of the rules are based on Jula´s real situation. One is round at 25% for products with only one parameter, the other is round at 25% for products with two parameters. The author has used Excel Visual Basic for Applications (VBA) function coded six rules which simulate six distinct picking methods and compared them by calculating the average picks, average ordering cost per piece, average handling cost per order and average difference with original order quantity, so as to identify the best rule among assumed rounding rules.

The base parameter used in the calculation is the order quantity for each item per store. As for most of Jula items, the daily demand per item per store is within 1 to 200 pcs. The maximum replenish level is 21 days, plus 3 days of transport lead time, therefore, the needed order quantity per item per store per order will range from 1 to 200 x (21 +3) = 4800 pcs.

Excel uses order quantity from 1 to 4800 as a base parameter and extends to calculate the returned picks of each package level under 6 different rounding rules, and then extends to calculate the average picks, average ordering cost per piece, average handling cost per order and average difference with original order quantity.

5.5.1. Model assumptions

The analysis model investigates the rules of picking packages from DC to each store and their consequences towards handling costs and total inventory costs. It is based on below assumptions:

1. The order proposal generated by Relex for each store and each item is reliable and accurate.
2. Rounding rules are not subject to service level and demand variation.
3. The smallest packaging level allows to flow in the warehouse operations is order multiple. In Jula, order multiple can be an integer such as 1,2,3,4 up to 14, 120, 1270 and so on.
4. Four levels of packaging are assumed under four of the rules, the four packaging levels include order multiple, inner carton, outer carton, pallet. Not necessary one item has all 4 parameters.
5. Relex takes into account the maximum shelf units when giving an order proposal.

Since the analysis aims at only analyzing different rounding rules, therefore, it is assumed that the order proposal from Relex system is reliable and accurate. The service level goal of 97,5% is deemed to be constant when Relex generates order proposals; Also, Relex takes into account of both service level and demand variation when gives order proposal, therefore, rounding rules are not subjected to service level and demand variation, but only relying on the final proposed quantity.

Four levels of packaging are assumed under 4 of the rounding rules. However, not necessary one item has all 4 parameters available, if one level´s parameter is missing, just put a huge number i.e. 100000 in, then the rounding rule will skip picking the package of that level (this will be further explained in next section 5.5.2). However, in real practice, this can be improved by putting 0 or leaving as blank when one parameter is missing.

Order quantity proposed by Relex is based on replenishment model of periodic review with simultaneous ordering point (see Literature Review 3.4.3). Due to the development of Jula´s information systems, Relex has been able to take into constraints such as MOQ, maximum shelf units, minimum order value when giving order proposals. Therefore, in the simulation of rounding rules, such constraints will not be considered.

5.5.2. Six rounding rules

- **Rule 1 Adjusted exact pick**

Rule 1 assumes the ordering system enables 4 packaging levels: order multiple, inner box, outer box, and pallet. If one level´s parameter is missing, just put an enormous number i.e. 100000 in, the system automatically chooses the packaging level that is divisible by order quantity. This is because the picking rules are coded by Excel VBA function, when deciding to select the biggest possible packaging level, the excel calculates the integer part of (order quantity ÷ packaging level parameter), if the integer part is less than 1, then the system will skip to choose this packaging level but to choose a smaller level of packaging. Therefore, if one packaging level is not available, just to put 100000 in, the integer part will always be less than 1 and then the picking system will skip that level.

Based on the order quantity proposal by Relex, Rule 1 first adjust the quantity to the nearest multiple of order multiple, then it returns the unit value under each packaging level. For example, with Excel VBA function of Rule 1, it returns values in pinks cells as below:

Order Quantity	Qty adjusted	Order multiple	Inner box	Outer box	Pallet
		6	36	216	1296
37	42	1	1	0	0

When the order proposed is 37 pcs, Rule 1 first find the nearest multiple. In excel it uses formula = Ceiling (order quantity, order multiple) = Ceiling (37, 6)=42; then the system picks the packages from the biggest level to the smallest, until the total quantity matches the adjusted quantity.

Excel VBA code of Rule 1:

```
Function task1(height As Integer, standard As Range)

''''''''''''''''''''''

' adjusted exact pick

''''''''''''''''''''''

Dim box(1 To 4) As Integer

box(4) = Int(height / standard.Cells(1, 4))

height = height - standard.Cells(1, 4) * box(4)

box(3) = Int(height / standard.Cells(1, 3))

height = height - standard.Cells(1, 3) * box(3)

box(2) = Int(height / standard.Cells(1, 2))

height = height - standard.Cells(1, 2) * box(2)

box(1) = Int(height / standard(1, 1))

task1 = box

End Function
```

- **Rule 2 Round at 0.1 at order multiple**

Same as Rule 1, Rule 2 has four packaging levels, if one of the levels (except order multiple) is missing, just put 100000 in, then the system skips to pick that packaging level. When at the smallest level, order multiple, the quantity rounds at 0.1 which means when picking packages, from big to small, the remainder is not enough for one order multiple, but bigger than 10% of the order multiple, then the number of picked units in this level plus one; if the remainder is less than or equal to 10% of the order multiple, cut out the remainder and return the number of units can be wholly picked by the order multiple. For example:

Order quantity	Order multiple	Inner box	Outer box	Pallet
	6	36	216	1296
71	6	1	0	0

When order quantity is 71, the system picks the biggest packaging level that is divisible by the order quantity, that is inner box 36, the remainder is 71-36=35; the system now picks a smaller level, order multiple, it will be 35 ÷ 6 = 5.83, since it rounds up by 0.1, the units picked in this level will be 6.

Excel VBA code of Rule 2:

```
Function task2(height As Integer, standard As Range)

''''''''''''''''''''''''''''''''''''''

' smallest level round at 0.1

''''''''''''''''''''''''''''''''''''''

Dim box(1 To 4) As Integer

box(4) = Int(height / standard.Cells(1, 4))

height = height - standard.Cells(1, 4) * box(4)

box(3) = Int(height / standard.Cells(1, 3))

height = height - standard.Cells(1, 3) * box(3)

box(2) = Int(height / standard.Cells(1, 2))

height = height - standard.Cells(1, 2) * box(2)

box(1) = Int(height / standard.Cells(1, 1))

height = height - standard.Cells(1, 1) * box(1)

If height > standard.Cells(1, 1) * 0.1 Then

box(1) = box(1) + 1

End If

task2 = box
```

End Function

- **Rule 3 Round at 0.25 at order multiple**

Like Rule 2, Rule 3 rounds at 0.25 at the smallest packaging level, order multiple. For example, under Rule 3, the picked units of each packaging levels are:

Order quantity	Order multiple	Inner box	Outer box	Pallet
	6	36	216	1296
97	4	2	0	0

Compare: but under **Rule 2**, the results are:

Order quantity	Order multiple	Inner box	Outer box	Pallet
	6	36	216	1296
97	5	2	0	0

Excel VBA code of Rule 3:

```
Function task3(height As Integer, standard As Range)

''''''''''''''''''''''

' smallest level round at 0.25

''''''''''''''''''''''

Dim box(1 To 4) As Integer

box(4) = Int(height / standard.Cells(1, 4))

height = height - standard.Cells(1, 4) * box(4)

box(3) = Int(height / standard.Cells(1, 3))

height = height - standard.Cells(1, 3) * box(3)

box(2) = Int(height / standard.Cells(1, 2))

height = height - standard.Cells(1, 2) * box(2)

box(1) = Int(height / standard.Cells(1, 1))

height = height - standard.Cells(1, 1) * box(1)
```

```
If height > standard.Cells(1, 1) * 0.25 Then

box(1) = box(1) + 1

End If

task3 = box

End Function
```

- **Rule 4 Round at 0.5 at order multiple**

Rule 4 like Rule 3, instead of round at 0.25, it rounds at 0.5 at order multiple.

For example, under Rule 4, the picked units of each packaging levels are:

Order quantity	Order multiple	Inner box	Outer box	Pallet
	6	36	216	1296
104	5	2	0	0

Compare it with the results under **Rule 3 (round at 0.25)**:

Order quantity	Order multiple	Inner box	Outer box	Pallet
	6	36	216	1296
104	6	2	0	0

Excel VBA code of Rule 4:

```
Function task4(height As Integer, standard As Range)

''''''''''''''''''''''''''

' smallest level round at 0.5

''''''''''''''''''''''''''

Dim box(1 To 4) As Integer

box(4) = Int(height / standard.Cells(1, 4))

height = height - standard.Cells(1, 4) * box(4)

box(3) = Int(height / standard.Cells(1, 3))

height = height - standard.Cells(1, 3) * box(3)
```

```
End Function

box(2) = Int(height / standard.Cells(1, 2))

height = height - standard.Cells(1, 2) * box(2)

box(1) = Int(height / standard.Cells(1, 1))

height = height - standard.Cells(1, 1) * box(1)

If height > standard.Cells(1, 1) * 0.5 Then

box(1) = box(1) + 1

End If

task4 = box
```

- **Rule 5 Round at 0.25 at order multiple with two levels**

Rule 5 simulates Jula´s current rounding rule with two parameters: order multiple and pallets, and quantity round at 0.25 on order multiple. For example, under Rule 5, the picked units are :

Order quantity	Order multiple	Pallet
	6	1296
104	18	0

Compare it with the results of Rule 2 (rounds at 0.25 on order multiple), put parameters in inner box and out box as 100000 will make the rule the same as rule 5. The results are the same.

Order quantity	Order multiple	Inner box	Outer box	Pallet
	6	1000000	1000000	1296
104	18	0	0	0

Excel VBA code of Rule 5:

```
Function task5(height As Integer, order As Integer, pallet As Integer)

''''''''''''''''''''''''''

' current rule, round at 0.25 at order multiple
```

''''''''''''''''''''''''''

```
Dim box(1 To 2) As Integer
box(2) = Int(height / pallet)
height = height - pallet * box(2)
box(1) = Int(height / order)
height = height - order * box(1)
If height > order * 0.25 Then
box(1) = box(1) + 1
End If
task5 = box
End Function
```

- **Rule 6 Round at 0.25 with one level**

Rule 6 is similar as Rule 5, instead of 2 levels, Rule 6 has only 1 parameter at place. Rule 6 simulates Jula´s current rounding rule for products that have been registered with only one parameter. For example,

Order quantity	Order multiple
	4
25	6

Compare it with the results under Rule 5 (round at 0.25 at order multiple with 2 levels):

Order quantity	Order multiple	Pallet
	4	14
25	3	1

Excel VBA code of Rule 6:

```
Function task6(height As Integer, order As Integer)
''''''''''''''''''''''''''
```

```
' current rule, round at 0.25 at order multiple one level
''''''''''''''''''''''
Dim box(1 To 1) As Integer
box(1) = Int(height / order)
height = height - order * box(1)
If height > order * 0.25 Then
box(1) = box(1) + 1
End If
task6 = box
End Function
```

6. Analysis and Results

This chapter first explains the variables used in the calculations, then a brief description of the calculation steps in presented, and finally the results developed from the base scenario is developed in the end.

The methodology outlined in the previous chapter was used to conduct the analysis. As mentioned before, the calculations run under a series of assumed variables and the results are only used to observe the relationships of six rules and cannot be interpreted as absolute values, still some of the test variables been used are based on an estimated input from real-world practice, such initial handling cost of 10 SEK per order, and most used order multiples such as 1,2,3,4 to 14, as well as 1248.

The analysis will focus on three aspects:

- Key variables used in the analysis and their effect on handling costs and total costs
- Scenarios models for the effect on the number of picks and handling costs and average ordering cost per piece
- Sensitivity analysis of key variables

6.1. Key variables

There are a number of key variables used in the analysis. In order to compare the consequences of six rounding rules, a base scenario of an assumed item #123456 has been used under all six rounding rules. The item has four levels of parameters available for Rule 1 to Rule 4, and two levels of parameters for Rule 5 and one level for Rule 6. The smallest packaging (order multiple) is 6 pcs, inner box is 36 pcs, the outer box is 216 pcs and one pallet is 1296 pcs. The handling cost of each packaging level is assumed to be the same in the base scenario, it is 10 SEK per package, no matter what size it is. The inputs of the base scenario are shown in table 1.

	Order multiple	Inner box	Outer box	Pallet
L: Packaging sizes (L1-L4) (PCS)	6	36	216	1296
H: Handling cost per package level(H1-H4) (SEK)	10	10	10	10
N: Initial ordering cost (SEK)	5			

Table 1 Base Scenario Assumptions

Variables:

L: Packaging sizes:

It includes four levels of packaging, order multiple, inner box (carton), outer box (carton), and pallet. If the parameter of one level is missing, put in 100000 for calculation convenience, however, in real practice, the VBA code of this part could be improved by putting 0 or leave as blank if one parameter is missing, which makes less confusion for the user.

H: Handling cost per package level:

Each level of packaging is associated with a cost. It is assumed that handling of bigger packages costs more than the handling of smaller packages, because of the forklift or other equipment or tools used. However, in practice, Jula doesn´t have a detailed specification of handling costs per package level, but a general cost of 17 SEK per handling disregard of package sizes. Therefore, the same rate of handling cost is set for all packaging levels in the base scenario.

N: Initial ordering cost:

The initial ordering cost is the assumed fixed ordering cost associated with placing one order, regardless of the ordering quantity and type of the order.

6.2. Calculation steps

Here gives a brief description of the calculation steps:

1. Return picked units of each packaging level for all six rounding rules

In Excel, the column (column A) that associated with order quantity from 1 to 4800 will serve as the base parameter for all calculations (see Appendix 1). By using the Excel VBA function, the picking units associated with each packaging level are calculated automatically under six rounding rules.

2. Calculate the total picks, the total ordering cost per piece, total handling cost per order and the total quantity difference with proposed order quantity for all six rounding rules.

- Total picks = sum of picked units under each packaging level. The total number of picks is an indicator of labor insensitivity which has been recognized by Jula.
- Total handling cost per order = initial cost + handling costs of all levels of packages (each level is associated with a cost).
- Ordering cost per piece = Total handling cost per order / Total order quantity.
- Total quantity difference is the total picked quantity under a rounding rule compared with the original order quantity.

3. Calculate the average picks, average ordering costs and the average quantity difference for all six rounding rules, since using the average rather than the total values gives more direct comparison results among six rules.

6.3. Comparison results based on the base scenario

Based on the above steps, the average results of six rounding rules are shown in table 2. And the comparison results of total picks, order cost per pc, total handling cost per order and average quantity difference of six rules are illustrated by figure 10-13.

Rounding Rule	Rule Description	Average picks (times)	Average ordering cost per pc(sek)	Average handling cost per order(sek)	Average difference with original order quantity (pcs)
Rule 1	4 levels, Adjusted exact pick	8,7	0,1	97,0	2,5
Rule 2	4 levels, Round at 0,1 on order multiple	9,5	0,1	105,2	2,5
Rule 3	4 levels, Round at 0,25 on order multiple	9,4	0,1	103,6	1,5
Rule 4	4 levels, Round at 0,5 on order multiple	9,4	0,1	100,2	-0,5
Rule 5	2 levels, Round at 0,25 on order multiple	103,5	0,7	1045,0	1,5
Rule 6	1 level, Round at 0,25 on order multiple	400,2	1,7	4013,3	1,5

Table 2 Comparison results based on Base Scenario

Figure 10 Total Picks of Six Rules

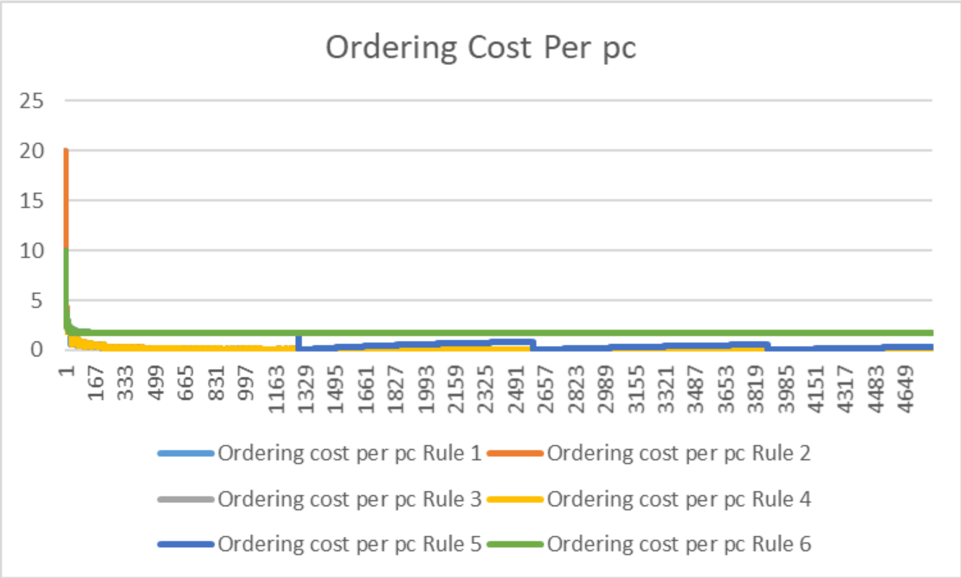

Figure 11 Order Cost Per pc of Six Rules

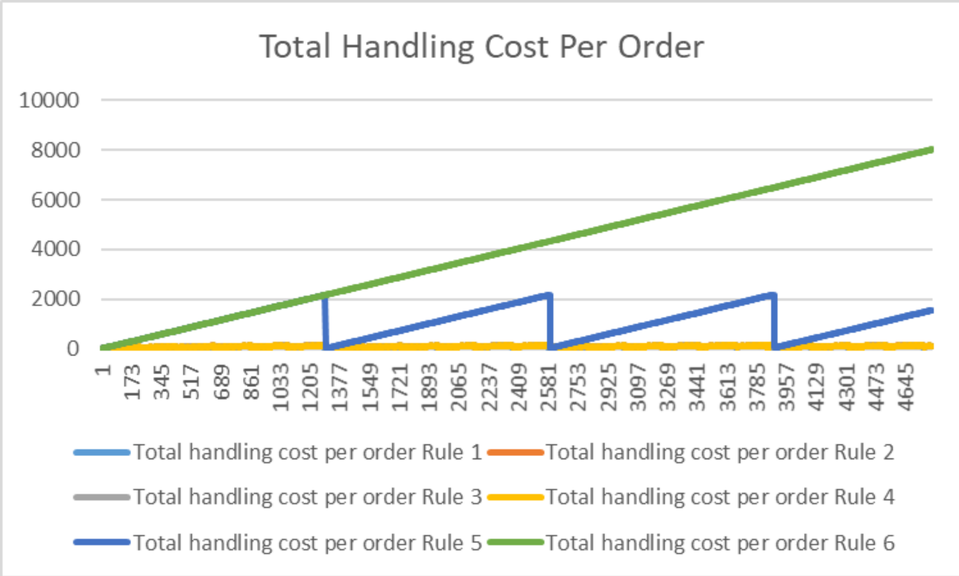

Figure 12 Total Handling Cost Per Order of Six Rules

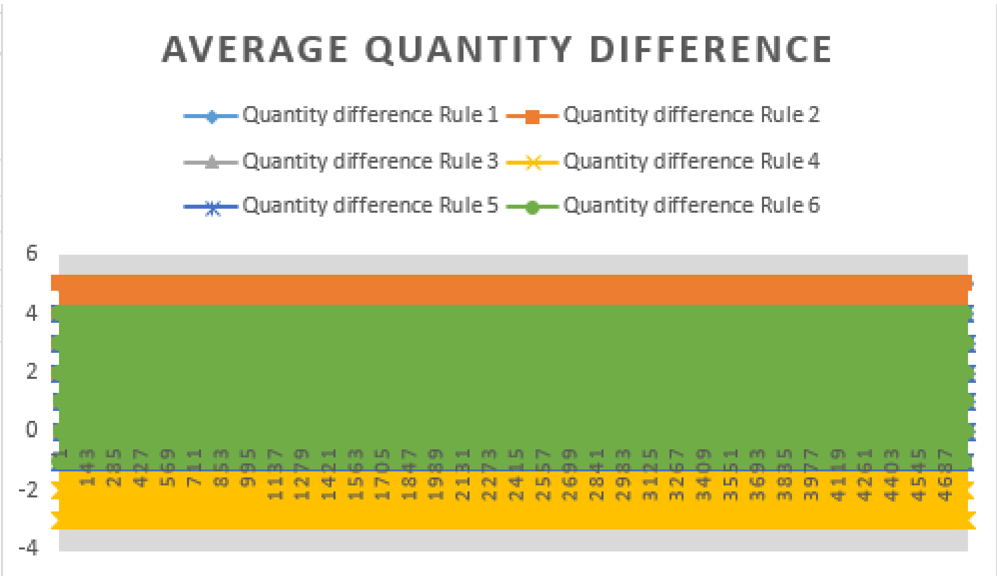

Figure 13 Average Quantity Difference of Six Rules

From table 2, it is observed that Rule 4 is associated with a negative quantity difference compared with original order quantity, which means that under Rule 4, the picked quantity is likely to be less than the originally proposed quantity, in such a case, it is likely to affect the service level negatively, therefore, Rule 4 should be excluded from consideration in real practice.

Comparing the rest of five rules, it is observed that rule 1 and rule 2 cause slightly higher quantity variance than Rule 3, 5, and 6 does. However, the caused quantity difference is marginal, as seen in figure 13. Therefore, the quantity caused the bullwhip effect can be considered as not significant. However, Rule 5 and Rule 6 are associated with much higher handling cost per order because, with only one or two levels of parameters, the average picks are much higher than with four levels of parameters. From the base scenario, the average handling cost per order is about 4 times higher under Rule 6 than under Rule 5, while the same cost under Rule 5 is about 10 times higher than that of under Rule 1, 2 and 3.

Implications on Total Cost

As presented in Literature Review 3.3.4, the Total Relevant Cost under reorder model can be expressed as TC = $\frac{DS}{Q}$ + IC$\frac{Q}{2}$ + ICr + k $\frac{D}{Q}\sigma\, L_{(z)}$, since only Rule 4 is associated with a negative quantity difference (an average -0.5 pcs), the stock out cost can be omitted. Therefore, the Total Relevant Cost, which is also the Total Cost can be expressed as:

$$TC = \frac{DS}{Q} + IC\frac{Q}{2} + ICr$$

Since rounding rules don´t affect demand D, inventory carrying cost I, product value C and safety stock r, therefore, the rounding rule caused the change of Total Cost can be expressed as:

$$\Delta TC = TC' - TC = \frac{D\Delta S}{\Delta Q} + IC\frac{\Delta Q}{2}$$

The total cost effect of changing Rule 6 to Rule 5

By observing the table 2, from Rule 6 to Rule 5, the average ordering cost changes from 0.7 to 0.1 SEK per pc, this makes ΔS =0.1/0.7= 0.14, while order quantity change from 1.5 to 1.5, this makes ΔQ = 1.5/1.5=1,

$$TC' = 0.14\,\frac{DS}{Q} + IC\frac{Q}{2} < \frac{DS}{Q} + IC\frac{Q}{2} = TC$$

Therefore, changing Rule 6 to Rule 5 has an effect of reducing Total Cost at an item level, which is to say, if Jula changes its product registration from one parameter to 2 parameters, it has an effect of reducing the Total Cost.

The total cost effect by changing Rule 6 to Rule 3

From Rule 6 to Rule 3 simulates Jula keeps its rounding rule of 0.25 but changes from 1 packaging parameter to 4 packaging parameters. From table 2, the average ordering cost changes from 1.7 to 0.1 SEK per pc, this makes ΔS = 0.1/1.7=0.06; while order quantity change from 1.5 to 1.5, this makes ΔQ = 1.5/1.5=1.

Therefore,

$$TC' = 0.06\,\frac{DS}{Q} + IC\frac{Q}{2} < \frac{DS}{Q} + IC\frac{Q}{2} = TC$$

Which is to say, changing Rule 6 to Rule 3 also has an effect of reducing Total Cost at an item level.

Comparing above 2 scenarios, it is observed that the Total Cost associated with changing Rule 6 to Rule 3 (change from 1 level to 4 levels) is lower than the Total Cost associated with changing Rule 6 to Rule 5 (change from 1 level to 2 levels), because

$$0.06\,\frac{DS}{Q} + IC\frac{Q}{2} < 0.14\,\frac{DS}{Q} + IC\frac{Q}{2}$$

Therefore, it confirmed that adding more parameters will lead to reduced total inventory cost.

The total cost effect by changing Rule 5 to Rule 3

Similarly, changing Rule 5 to Rule 3 simulates Jula keeps its rounding rule of 0.25 but changes its parameter registration from 2 levels to 4 levels. The average ordering cost changes from 0.7 to 0.1, while order quantity change from 1.5 to 1.5, this leads to a similar cost effect as by changing Rule 6 to Rule 5 (from 1 level to 2 levels):

$$TC' = 0.14\,\frac{DS}{Q} + IC\frac{Q}{2} < \frac{DS}{Q} + IC\frac{Q}{2} = TC$$

The total cost effect of changing Rule 5 to Rule 1

Similarly, from Rule 5 to Rule 1, the average ordering cost changes from 1.7 to 0.7, this makes ΔS= 0.7/1.7=0.41 while the order quantity change from 1.5 to 2.5, this makes ΔQ =2.5/1.5=1.7, with combined effect:

$$TC' = \frac{0.41DS}{1.7Q} + 1.7\ ICQ = 0.24\frac{DS}{Q} + 1.7\ ICQ$$

With Q as a denominator, the TC´can either increase or decrease. In order to find the condition where TC´ decrease, assume TC´ < TC, which means:

$$0.24\frac{DS}{Q} + 1.7\ ICQ < \frac{DS}{Q} + IC\frac{Q}{2}$$

$$0.24\frac{DS}{Q} - \frac{DS}{Q} < 1.7\ ICQ - IC\frac{Q}{2}$$

Where find $$Q < 0.79\sqrt{\frac{DS}{IC}}$$

From the equation, it is seen that there is a possibility of reducing the total cost by changing the rounding rule from Rule 5 to Rule 1(from two levels to adjusted exact pick). However, the quantity has to meet certain requirements. Which is to say, the cost-saving effect is more obvious when products with high demand and/or with low product value. However, due to the limitation of the thesis scope, the exact quantity in relation to demand, as well as carrying cost and product value will not be included in this thesis.

In sum, it is observed that increasing of parameters registration is associated with reduced total inventory cost; the more parameters added, the less total cost it will be.

6.4. Sensitivity test

6.4.1. The sensitivity of order multiple and magnification rates

The most frequent order multiples for Jula products are 1,2,3,4,…..14, 24, 42, 108,120, 144, 240, 1248 and so on, however, big parameters such as 108, 120, 144 or 1248 are usually being registered with only one level in the system. Since the research question is concerning of how to handle small order multiples, therefore, the most commonly seen order multiples such as 1, 2, 3 and up to 12 are used to test the results. Figure 14 is an illustration of how packaging parameters are being registered in Jula´s ERP and SCM systems.

Produktkod	OB	Batch fp	Batch krt	Batch pll ut
006789	14,00	0,00	1,00	14
006825	1,00	0,00	1,00	12
006788	14,00	0,00	1,00	14
006940	1,00	0,00	1,00	14
006860	108,00	0,00	108,00	108
000804	16,00	0,00	2,00	16
007134	6,00	0,00	1,00	6
006945	1,00	0,00	1,00	0
006464	8,00	1,00	1,00	8
001180	3,00	0,00	1,00	3
006821	1,00	0,00	1,00	1
325027	7,00	0,00	1,00	7
004545	1248,00	0,00	24,00	1248
006790	1,00	0,00	1,00	4
004489	1,00	0,00	1,00	2
715064	36,00	0,00	1,00	36
006941	1,00	0,00	1,00	8
709138	12,00	0,00	12,00	144
715204	44,00	0,00	44,00	44

Figure 14 Illustration of Jula´s packaging parameters registration in Relex system

Since packaging parameters in real-world vary from products to products, it is difficult to test all combinations. The author chooses order multiple 1,2,3 and 14 in a combination of different magnification rate to observe the results. Magnification rate is the multiple between sizes, in the real world the magnification rates between four packaging levels can vary, in this test, the author uses a fixed rate of 2 and 12 to simulate small and big differences between sizes. The test sizes are shown as following:

Order Multiple	Second level parameter	Third level parameter	Pallet	
1	2	4	8	Magnification rate 2
1	12	144	1728	Magnification rate 12
2	4	8	16	Magnification rate 2
2	24	288	3456	Magnification rate 12
3	6	12	24	Magnification rate 2
3	36	432	5184	Magnification rate 12
14	28	56	112	Magnification rate 2
14	168	2016	24192	Magnification rate 12

The test sizes can be grouped into 4 scenarios:

- small order multiple with a small magnification rate

- small order multiple with a big magnification rate
- big order multiple with a small magnification rate
- big order multiple with big magnification rate.

Results of the above test sizes are shown as following:

1. Test sizes: 1, 2, 4,8

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	301,1	1,3	3021,3	0,0
Rule 2	4 levels, Round at 0,1 on order multiple	301,1	1,3	3021,3	0,0
Rule 3	4 levels, Round at 0,25 on order multiple	301,1	1,3	3021,3	0,0
Rule 4	4 levels, Round at 0,5 on order multiple	301,1	1,3	3021,3	0,0
Rule 5	2 levels, Round at 0,25 on order multiple	303,1	1,3	3041,3	0,0
Rule 6	1 level, round at 0,25 on order multiple	2399,5	10,0	24015,0	0,0

2. Test sizes: 1, 12, 144, 1728

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	17,0	0,2	180,1	0,0
Rule 2	4 levels, Round at 0,1 on order multiple	17,0	0,2	180,1	0,0
Rule 3	4 levels, Round at 0,25 on order multiple	17,0	0,2	180,1	0,0
Rule 4	4 levels, Round at 0,5 on order multiple	17,0	0,2	180,1	0,0
Rule 5	2 levels, Round at 0,25 on order multiple	810,9	5,2	8119,4	0,0
Rule 6	1 level, round at 0,25 on order multiple	2399,5	10,0	24015,0	0,0

3. Test sizes: 2,4, 8,16

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	151,1	0,7	1521,3	0,5
Rule 2	4 levels, Round at 0,1 on order multiple	151,6	0,7	1525,6	0,5
Rule 3	4 levels, Round at 0,25 on order multiple	151,6	0,7	1525,6	0,5
Rule 4	4 levels, Round at 0,5 on order multiple	151,6	0,7	1520,6	-0,5
Rule 5	2 levels, Round at 0,25 on order multiple	153,6	0,7	1545,6	0,5
Rule 6	1 level, round at 0,25 on order multiple	1200,0	5,0	12015,0	0,5

4. Test sizes: 2, 24, 288, 3456

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	15,7	0,2	166,9	0,5
Rule 2	4 levels, Round at 0,1 on order multiple	16,2	0,2	171,8	0,5
Rule 3	4 levels, Round at 0,25 on order multiple	16,2	0,2	171,8	0,5
Rule 4	4 levels, Round at 0,5 on order multiple	16,2	0,2	166,8	-0,5
Rule 5	2 levels, Round at 0,25 on order multiple	716,6	3,8	7175,8	0,5
Rule 6	1 level, round at 0,25 on order multiple	1200,0	5,0	12015,0	0,5

5. Test sizes: 3, 6, 12, 24

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	101,1	0,5	1021,3	1,0
Rule 2	4 levels, Round at 0,1 on order multiple	101,7	0,5	1027,1	1,0
Rule 3	4 levels, Round at 0,25 on order multiple	101,7	0,5	1027,1	1,0
Rule 4	4 levels, Round at 0,5 on order multiple	101,7	0,5	1023,8	0,0
Rule 5	2 levels, Round at 0,25 on order multiple	103,7	0,5	1047,1	1,0
Rule 6	1 level, round at 0,25 on order multiple	800,2	3,4	8015,0	1,0

6. Test sizes: 3, 36, 432, 5184

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	16,0	0,2	170,1	1,0
Rule 2	4 levels, Round at 0,1 on order multiple	16,7	0,2	176,7	1,0
Rule 3	4 levels, Round at 0,25 on order multiple	16,7	0,2	176,7	1,0
Rule 4	4 levels, Round at 0,5 on order multiple	16,7	0,2	173,3	0,0
Rule 5	2 levels, Round at 0,25 on order multiple	800,5	3,4	8015,0	1,0
Rule 6	1 level, round at 0,25 on order multiple	800,2	3,4	8015,0	1,0

7. Test sizes: 14, 28, 56, 112

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	22,6	0,1	235,6	6,5
Rule 2	4 levels, Round at 0,1 on order multiple	23,3	0,1	242,9	5,5
Rule 3	4 levels, Round at 0,25 on order multiple	23,1	0,1	241,5	3,5
Rule 4	4 levels, Round at 0,5 on order multiple	23,1	0,1	238,6	-0,5
Rule 5	2 levels, Round at 0,25 on order multiple	25,1	0,2	261,4	3,5
Rule 6	1 level, round at 0,25 on order multiple	171,6	0,7	1727,1	3,5

8. Test sizes: 14, 168, 2016, 24192

Rounding Rule	Rule Description	Average picks	Average ordering cost per pc	Average handling cost per order	Average difference with original order quantity
Rule 1	Adjusted exact pick	11,1	0,1	121,4	6,5
Rule 2	4 levels, Round at 0,1 on order multiple	12,0	0,1	129,6	5,5
Rule 3	4 levels, Round at 0,25 on order multiple	11,8	0,1	128,2	3,5
Rule 4	4 levels, Round at 0,5 on order multiple	11,8	0,1	125,3	-0,5
Rule 5	2 levels, Round at 0,25 on order multiple	171,7	0,7	1727,1	3,5
Rule 6	1 level, round at 0,25 on order multiple	171,6	0,7	1727,1	3,5

The best rule Rule 1, Adjusted exact pick

From the above tests, it is observed Rule 5 and Rule 6 which simulate Jula´s current parameter settings are associated with high handling cost per order and high ordering cost per piece in all scenarios. Although the effect is more obvious with higher order multiples. The best rule observed is Rule 1, Adjusted exact pick, which is associated with the lowest handling cost per order and lowest ordering cost per piece.

Marginal effect on quantity change

It is also observed that along with the increasing of order multiple, the quantity difference increase slightly under all six rounding rules. The quantity difference increases from 0 to 6.5 along with the increase of order multiple from 1 to 14, but the quantity difference can be considered marginal compared to the order quantity used in the calculation(from 1 to 4800).

Big order multiple, big magnification rate

By observing the results, it can be seen that big order multiple with big magnification rate is associated with the lowest handling cost per order and ordering cost per piece among all 4 grouped scenarios.

6.4.2. The sensitivity of initial cost and handling cost per packaging level

Since initial cost and handling cost are objective existence, and Jula doesn´t have a cost specification regarding those two costs, therefore, it makes less sense to conduct the sensitivity test of those two costs. However, the handling cost per packaging level and initial costs are variables that might affect the results. The sensitivity test of cost per packaging level can use the same method as used in testing the sizes of 4 packaging parameters by using magnification rates. The initial cost sensitivity can be tested by increasing or decreasing in a series of percentages and observe the results change. Nevertheless, as mentioned previously, the sensitivity test of those two kinds of variables doesn´t match the problem description of Jula case, therefore, it will not be further analyzed in detail in this thesis.

7. Conclusions and Recommendations

In the final chapter, some concluding remarks and recommendations have been provided for Jula based on the analysis in previous chapters and some suggestions have been made for further research.

7.1. Conclusions

In this thesis, the author builds a model to simulate the picking mechanic of assumed 6 rounding rules in warehouse operations. The simulation of rounding rules is to verify the case company´s concern on whether rounding rule can cause a consequence in the supply chain, and if so, what kind of rounding rule is the best option for the handling of small order multiples. The simulation has two folds purpose: one is to verify rounding at which rate is the best option; the other is to verify whether increasing packaging parameters has a consequence on cost. The analysis serves the aim of improving Jula´s current Supply Chain System Relex and to find the best way to manage order multiples.

To answer the first research question: how does rounding rule affect the supply chain? The conclusions based on the simulation indicate that Rule 1, Adjusted exact pick with four levels is the best rounding rule among all assumed rules. Since rounding at a minimum rate is related to the lowest total cost. Also, increasing the levels of packaging parameter registration in the ordering system has a positive effect on cost saving at per item level. Thus, increasing levels of parameters lead to lower ordering cost per pc, lower handling cost per order and lower total inventory cost per item per year.

The simulations also found that rounding rules cause extremely marginal quantity discrepancy compared with original order quantity, thus the bullwhip effect can be considered insignificant except for Rule 4 which is associated with a negative quantity difference.

To answer the second research question: How should a retailer manage order batches in its supply chain operations? The author found that big multiple, big magnification rates between 4 packaging sizes are associated with less total costs, therefore, it is recommended to avoid registering too small order multiples, and the quantity gap between sizes should be as big as possible.

7.2. Recommendations

Based on the results of this project, it is recommended that Jula ought to register more packaging parameters in their ERP and SCM systems since order picking from more packaging levels has the potential to bring down the total inventory costs at an item level. Therefore, it is suggested that Jula should register 4 levels of packaging parameters for new items, while gradually update the existing product which with only one or two parameters into 4 parameters.

For setting the parameters, it is recommended to register parameters with big order multiple, and/or big magnification rate(s) between packaging levels. By adopting the 4 levels parameter picking mechanic, the system will automatically choose a bigger parameter for stores that have higher demand while choosing a smaller parameter for stores with low demand.

Furthermore, there are many more areas for Jula to focus on in order to improve its supply chain performance. First, Jula ought to seek continuous improvement in its system´s forecasting function, since forecasting accuracy is the primary factor that affects total costs. Secondly, keeping good control of fixed costs and to avoid excess stock of high-value items are going to help Jula limit the total inventory costs. Thirdly, an improvement in Jula´s ERP and SCM systems integration is an important aspect to improve the information sharing and accelerate the operation process, which helps to mitigate bullwhip effect along the chain. Fourthly, Jula uses service level and inventory turnover as two KPIs, however, in order to measure the handling cost per order, order cycle time can be used as an additional KPI for warehouse performance. Finally, innovative technologies such as RFID, data mining are potential tools for Jula to use to boost its industry performance in the future.

7.3. Further research

The results in this thesis are based on a simulation model, which was only able to explain the relationships between assumed rules and the consequences of them. The results provide insights on how rounding rules work and what are the consequences for rounding rules for a company. The conclusion was able to give a general way of how to set up parameters, however, the study could be continued by using a sample or actual company data, and to provide a concrete number in cost saving. Also, the analysis was not able to provide a concrete guide on how to set up a parameter to match different store´s demand, but a general direction of the sizes sitting. It is recommended to conduct analysis in this direction in further research.

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Appendix

A- Partial simulation data of six rounding rules

Partial simulation data Rule 1

Need Order quantity	Quantity adjusted by multiple	Order multiple	Inner box	Outer box	Pallet	Total picks Rule 1	Ordering cost per pc Rule 1	Total handling cost per order Rule 1	Quantity difference Rule 1
		6	36	216	1296				
1	6	1	0	0	0	1	15	15	5
2	6	1	0	0	0	1	8	15	4
3	6	1	0	0	0	1	5	15	3
4	6	1	0	0	0	1	4	15	2
5	6	1	0	0	0	1	3	15	1
6	6	1	0	0	0	1	3	15	0
7	12	2	0	0	0	2	4	25	5
8	12	2	0	0	0	2	3	25	4
9	12	2	0	0	0	2	3	25	3
10	12	2	0	0	0	2	3	25	2
11	12	2	0	0	0	2	2	25	1
12	12	2	0	0	0	2	2	25	0
13	18	3	0	0	0	3	3	35	5
14	18	3	0	0	0	3	3	35	4
15	18	3	0	0	0	3	2	35	3
16	18	3	0	0	0	3	2	35	2
17	18	3	0	0	0	3	2	35	1
18	18	3	0	0	0	3	2	35	0

Partial simulation data Rule 2

Need Order quantity	Order multiple	Inner box	Outer box	Pallet	Total picks Rule 2	Ordering cost per pc Rule 2	Total handling cost per order Rule 2	Quantity difference Rule 2
	6	36	216	1296				
1	1	0	0	0	1	15	15	5
2	1	0	0	0	1	8	15	4
3	1	0	0	0	1	5	15	3
4	1	0	0	0	1	4	15	2
5	1	0	0	0	1	3	15	1
6	1	0	0	0	1	3	15	0
7	2	0	0	0	2	4	25	5
8	2	0	0	0	2	3	25	4
9	2	0	0	0	2	3	25	3
10	2	0	0	0	2	3	25	2
11	2	0	0	0	2	2	25	1
12	2	0	0	0	2	2	25	0
13	3	0	0	0	3	3	35	5
14	3	0	0	0	3	3	35	4
15	3	0	0	0	3	2	35	3
16	3	0	0	0	3	2	35	2
17	3	0	0	0	3	2	35	1
18	3	0	0	0	3	2	35	0

Partial simulation data Rule 3

Need Order quantity	order multiple	inner box	outer box	pallet	Total picks Rule 3	Ordering cost per pc Rule 3	Total handling cost per order Rule 3	Quantity difference Rule 3
	6	36	216	1296				
1	0	0	0	0	0	5	5	-1
2	1	0	0	0	1	8	15	4
3	1	0	0	0	1	5	15	3
4	1	0	0	0	1	4	15	2
5	1	0	0	0	1	3	15	1
6	1	0	0	0	1	3	15	0
7	1	0	0	0	1	2	15	-1
8	2	0	0	0	2	3	25	4
9	2	0	0	0	2	3	25	3
10	2	0	0	0	2	3	25	2
11	2	0	0	0	2	2	25	1
12	2	0	0	0	2	2	25	0
13	2	0	0	0	2	2	25	-1
14	3	0	0	0	3	3	35	4
15	3	0	0	0	3	2	35	3
16	3	0	0	0	3	2	35	2
17	3	0	0	0	3	2	35	1
18	3	0	0	0	3	2	35	0

Partial simulation data Rule 4

Need Order quantity	Order multiple	Inner box	Outer box	Pallet	Total picks Rule 4	Ordering cost per pc Rule 4	Total handling cost per order Rule 4	Quantity difference Rule 4
	6	36	216	1296				
1	0	0	0	0	0	10	10	-1
2	0	0	0	0	1	5	10	-2
3	0	0	0	0	1	3	10	-3
4	1	0	0	0	1	5	20	2
5	1	0	0	0	1	4	20	1
6	1	0	0	0	1	3	20	0
7	1	0	0	0	1	3	20	-1
8	1	0	0	0	2	3	20	-2
9	1	0	0	0	2	2	20	-3
10	2	0	0	0	2	3	30	2
11	2	0	0	0	2	3	30	1
12	2	0	0	0	2	3	30	0
13	2	0	0	0	2	2	30	-1
14	2	0	0	0	3	2	30	-2
15	2	0	0	0	3	2	30	-3
16	3	0	0	0	3	3	40	2
17	3	0	0	0	3	2	40	1
18	3	0	0	0	3	2	40	0

Partial simulation data Rule 5

Need Order quantity	Order multiple	Pallet	Total picks Rule 5	Ordering cost per pc Rule 5	Total handling cost per order Rule 5	Quantity difference Rule 5
	6	1296				
1	0	0	0	5	5	-1
2	1	0	1	8	15	4
3	1	0	1	5	15	3
4	1	0	1	4	15	2
5	1	0	1	3	15	1
6	1	0	1	3	15	0
7	1	0	1	2	15	-1
8	2	0	2	3	25	4
9	2	0	2	3	25	3
10	2	0	2	3	25	2
11	2	0	2	2	25	1
12	2	0	2	2	25	0
13	2	0	2	2	25	-1
14	3	0	3	3	35	4
15	3	0	3	2	35	3
16	3	0	3	2	35	2
17	3	0	3	2	35	1
18	3	0	3	2	35	0

Partial simulation data Rule 6

Need Order quantity	Order multiple	Total picks Rule 6	Ordering cost per pc Rule 6	Total handling cost per order Rule 6	Quantity difference Rule 6
	6				
1	0	6	10	10	-1
2	1	0	10	20	4
3	1	1	7	20	3
4	1	1	5	20	2
5	1	1	4	20	1
6	1	1	3	20	0
7	1	1	3	20	-1
8	2	1	4	30	4
9	2	2	3	30	3
10	2	2	3	30	2
11	2	2	3	30	1
12	2	2	3	30	0
13	2	2	2	30	-1
14	3	2	3	40	4
15	3	3	3	40	3
16	3	3	3	40	2
17	3	3	2	40	1
18	3	3	2	40	0

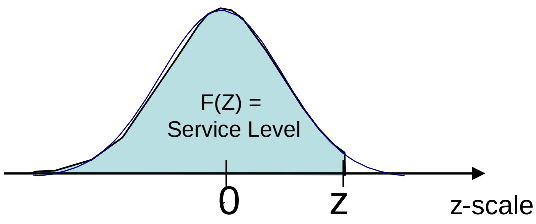
B- Z-Table

Z-Chart & Loss Function

F(Z) is the probability that a variable from a standard normal distribution will be less than or equal to Z, or alternately, the service level for a quantity ordered with a z-value of Z.

L(Z) is the standard loss function, i.e. the expected number of lost sales as a fraction of the standard deviation. Hence, the lost sales = L(Z) x σ_{DEMAND}

Z	F(Z)	L(Z)	Z	F(Z)	L(Z)	Z	F(Z)	L(Z)	Z	F(Z)	L(Z)
-3.00	0.0013	3.000	-1.48	0.0694	1.511	0.04	0.5160	0.379	1.56	0.9406	0.026
-2.96	0.0015	2.960	-1.44	0.0749	1.474	0.08	0.5319	0.360	1.60	0.9452	0.023
-2.92	0.0018	2.921	-1.40	0.0808	1.437	0.12	0.5478	0.342	1.64	0.9495	0.021
-2.88	0.0020	2.881	-1.36	0.0869	1.400	0.16	0.5636	0.324	1.68	0.9535	0.019
-2.84	0.0023	2.841	-1.32	0.0934	1.364	0.20	0.5793	0.307	1.72	0.9573	0.017
-2.80	0.0026	2.801	-1.28	0.1003	1.327	0.24	0.5948	0.290	1.76	0.9608	0.016
-2.76	0.0029	2.761	-1.24	0.1075	1.292	0.28	0.6103	0.274	1.80	0.9641	0.014
-2.72	0.0033	2.721	-1.20	0.1151	1.256	0.32	0.6255	0.259	1.84	0.9671	0.013
-2.68	0.0037	2.681	-1.16	0.1230	1.221	0.36	0.6406	0.245	1.88	0.9699	0.012
-2.64	0.0041	2.641	-1.12	0.1314	1.186	0.40	0.6554	0.230	1.92	0.9726	0.010
-2.60	0.0047	2.601	-1.08	0.1401	1.151	0.44	0.6700	0.217	1.96	0.9750	0.009
-2.56	0.0052	2.562	-1.04	0.1492	1.117	0.48	0.6844	0.204	2.00	0.9772	0.008
-2.52	0.0059	2.522	-1.00	0.1587	1.083	0.52	0.6985	0.192	2.04	0.9793	0.008
-2.48	0.0066	2.482	-0.96	0.1685	1.050	0.56	0.7123	0.180	2.08	0.9812	0.007
-2.44	0.0073	2.442	-0.92	0.1788	1.017	0.60	0.7257	0.169	2.12	0.9830	0.006
-2.40	0.0082	2.403	-0.88	0.1894	0.984	0.64	0.7389	0.158	2.16	0.9846	0.005
-2.36	0.0091	2.363	-0.84	0.2005	0.952	0.68	0.7517	0.148	2.20	0.9861	0.005
-2.32	0.0102	2.323	-0.80	0.2119	0.920	0.72	0.7642	0.138	2.24	0.9875	0.004
-2.28	0.0113	2.284	-0.76	0.2236	0.889	0.76	0.7764	0.129	2.28	0.9887	0.004
-2.24	0.0125	2.244	-0.72	0.2358	0.858	0.80	0.7881	0.120	2.32	0.9898	0.003
-2.20	0.0139	2.205	-0.68	0.2483	0.828	0.84	0.7995	0.112	2.36	0.9909	0.003
-2.16	0.0154	2.165	-0.64	0.2611	0.798	0.88	0.8106	0.104	2.40	0.9918	0.003
-2.12	0.0170	2.126	-0.60	0.2743	0.769	0.92	0.8212	0.097	2.44	0.9927	0.002
-2.08	0.0188	2.087	-0.56	0.2877	0.740	0.96	0.8315	0.090	2.48	0.9934	0.002
-2.04	0.0207	2.048	-0.52	0.3015	0.712	1.00	0.8413	0.083	2.52	0.9941	0.002
-2.00	0.0228	2.008	-0.48	0.3156	0.684	1.04	0.8508	0.077	2.56	0.9948	0.002
-1.96	0.0250	1.969	-0.44	0.3300	0.657	1.08	0.8599	0.071	2.60	0.9953	0.001
-1.92	0.0274	1.930	-0.40	0.3446	0.630	1.12	0.8686	0.066	2.64	0.9959	0.001
-1.88	0.0301	1.892	-0.36	0.3594	0.605	1.16	0.8770	0.061	2.68	0.9963	0.001
-1.84	0.0329	1.853	-0.32	0.3745	0.579	1.20	0.8849	0.056	2.72	0.9967	0.001
-1.80	0.0359	1.814	-0.28	0.3897	0.554	1.24	0.8925	0.052	2.76	0.9971	0.001
-1.76	0.0392	1.776	-0.24	0.4052	0.530	1.28	0.8997	0.047	2.80	0.9974	0.001
-1.72	0.0427	1.737	-0.20	0.4207	0.507	1.32	0.9066	0.044	2.84	0.9977	0.001
-1.68	0.0465	1.699	-0.16	0.4364	0.484	1.36	0.9131	0.040	2.88	0.9980	0.001
-1.64	0.0505	1.661	-0.12	0.4522	0.462	1.40	0.9192	0.037	2.92	0.9982	0.001
-1.60	0.0548	1.623	-0.08	0.4681	0.440	1.44	0.9251	0.034	2.96	0.9985	0.000
-1.56	0.0594	1.586	-0.04	0.4840	0.419	1.48	0.9306	0.031	3.00	0.9987	0.000
-1.52	0.0643	1.548	0.00	0.5000	0.399	1.52	0.9357	0.028			



***Z* & *L(z)* for special service levels**

Service Level F(z)	*z*	*L(z)*
75%	0.67	0.150
90%	1.28	0.047
95%	1.64	0.021
99%	2.33	0.003