Inventory Management in Reverse Logistics in FAW Co., Ltd

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Abstract

Recycling and remanufacturing returned goods are economically beneficial for companies since the cost of obtaining used parts is lower in many cases and selling price is close to that of a new product. This leads to decreased costs and thereby increased profits for the company. In addition, there are also great environmental benefits by keeping the structural integrity of a part; the energy used for disassembly and refurbishing is much lower than the energy required for raw material extraction and machining. Encompassing the returned goods makes the supply chain to closed loop supply chain, which is different from the traditional supply chain due to reverse logistics. A reverse flow of material is however usually more complex than a forward flow of parts and components from suppliers. This means that inventory management becomes critical and needs to be viewed from a new perspective.

The purpose of the report is to study FAW Co., Ltd’s inventory situation in reverse logistics. The report analysed the inventory management in the company, specifically focusing on one product as the instance Motor Engine LFTS-2000since it is in the maturity stage of product life cycle. Two scenarios were designed to consider how different parameters affect inventory levels in reverse logistics.

The report analysed how different parameters affect the inventory levels and minimum cost. With the increasing returned goods are processed, inventory levels and minimum cost will decrease correspondingly.

Keywords: FAW, reverse logistics, inventory management, closed loop supply chain.
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\[ n = Q_m (1 - r) \lambda DT \]
Equation 3 ...................................................................................................... 43
\[ = h s [Q m n T - 12 \lambda D n T^2 + n (n + 1) 2 r \lambda D T^2] \]
Equation 4 ...................................................................................................... 43
\[ C Q m, T, n = h s Q m - 12 \lambda D n T + n + 12 r \lambda D T + 12 h r r \lambda D T + C r f T + \]
\[ C r m r \lambda D + C m f + C m m Q m n T \]
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1 Introduction

1.1 Background

From the table below, Asia shows the strongest advance in car sales. Since 2010 Asia’s car sales have approximately 40% proportion of global market, and Chinese car sales reaches over 40% of Asia’s market. In North American market, Mexico becomes the significant factor to revival the market. There is a rapid growth of demand for crossover utility vehicles in Canadian market (Global Auto Report, 2013).

<table>
<thead>
<tr>
<th></th>
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<td><strong>Total Sales</strong></td>
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<td>1.59</td>
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<tr>
<td>United States</td>
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<td>11.55</td>
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<td>0.85</td>
<td>0.90</td>
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<td>Western Europe</td>
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<td>14.39</td>
<td>12.98</td>
<td>12.80</td>
<td>11.76</td>
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<td>3.33</td>
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<tr>
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<td>9.41</td>
<td>10.04</td>
<td>10.68</td>
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<td>India</td>
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<td>0.89</td>
<td>1.87</td>
<td>1.95</td>
<td>2.02</td>
</tr>
<tr>
<td>South America</td>
<td>1.64</td>
<td>2.52</td>
<td>4.27</td>
<td>4.47</td>
<td>4.72</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.94</td>
<td>1.57</td>
<td>2.69</td>
<td>2.64</td>
<td>2.84</td>
</tr>
</tbody>
</table>
Table 1 International Car Sales Outlook (millions of units)

China has been the largest market of automotive since 2008 and became the second largest producer since 2008. As Figure 1 illustrated, China automobile production reached 19,271,800 units in the first half year of 2012 which had a growth of 4.63% compared with the same period of 2011. Production of passenger cars increased to 15,523,700 units by 7.17%; the output of commercial vehicle fell to 3,748,100 units by 4.71% compared with the same period of last year. On the other hand, Chinese automobile sold 19,306,400 units which had a growth of 4.33% compared with the last year as Figure 2 shown. Passenger car sales reached 15,495,200 units increased 7.07%; commercial vehicle sales reached 3,811,200 units decreased 5.49% compared with the last year. However the automobile companies of Chinese brands lost a little market share compared with the same period of last year although sales amount had some growth in 2012. For instance, the market share of passenger cars decreased 0.38% year on year, and commercial vehicles decreased 0.72% of market share compared with the last year. Furthermore CAAM forecasted the demand for vehicles was approximately 20,800,000 units and automobile production would be approximately 18,300,000 units in 2013 which would surpass European Union and provide 24% supply of vehicles worldwide (CAAM, 2013).

![Figure 1 Output of Automobile in China (CAAM, 2013)](image_url)
Some big companies such as GE, IBM and 3M have developed a mature system of reverse logistics. They collect and recycle the returned goods for decreasing the loss generated by the return policy. Philips reduced the returned products by over 500,000 units and saved billions dollars through enhancing the management of returned goods since 1998. HP and Epson produced the cartridges which can be refilled. After Volvo disassembled the returned goods, some plastic and metal are sold, while some components were remanufactured for assembling the vehicles for secondary market. In China, reverse logistics has grew rapidly. Shanghai Baosteel recycled the disposal steel. Lenovo cooperated with APLL logistics for recalling and handling the returned goods.

First Automobile Works (FAW) founded in 1956 and locates in Changchun. In 1956, they produced the first truck in China, and in 1958 they produced the first passenger car and the first limo. Now they are one of largest automobile companies in China. FAW production sales exceeded 2,600,000 units in 2011 while production sales reached 2,645,000 which were almost flat compared with the last year.

FAW Car Co., Ltd is a subsidiary of First Auto Works and also a major company to develop its own-branded business. The company is responsible for development, manufacturing and sales of cars and their auto parts. FAW Car Co., Ltd founded on Jun.10, 1997 in Changchun, China, and went public on Shenzhen Stock Exchange on Jun.18, 1997. The registered capital of the company is 230 million dollars and the total assets are approximately 2.3 billion dollars. The company covers 3.17 million square meters and has 11701 employees. Current annual manufacturing capacity is 400,000 cars, 330,000 automotive engines and 520,000 automobile gearboxes. The company has the following major brands: Red Flag limousine, Besturn, Oley and so on.
From Table 2 shown, operation revenue and gross margin both reduced in the first half year of 2012 due to strong business competition in Chinese vehicle market, weak customer demand, low growth of market and decrease of sales amount and price.

Engine & Transmission manufacturing centre of FAW Car Co., Ltd. founded on Aug.17.2012, which covers 0.63 million square metres and has 2120 employees. The company is responsible for production management, production preparation, manufacturing and sales of automotive engines and automobile gearboxes. It has manufactured over 1.3 million automotive engines and over 3.5 million automobile gearboxes so far.

<table>
<thead>
<tr>
<th>Main business situation</th>
<th>Operation revenue</th>
<th>Operation costs</th>
<th>Gross margin</th>
<th>Operation revenue ratio</th>
<th>Operation costs ratio</th>
<th>Gross margin ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor industry</td>
<td>11.122 billion</td>
<td>9.322 billion</td>
<td>16.19%</td>
<td>-37.15%</td>
<td>-34.28%</td>
<td>-3.77%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main products situation</th>
<th>Operation revenue</th>
<th>Operation costs</th>
<th>Gross margin</th>
<th>Operation revenue ratio</th>
<th>Operation costs ratio</th>
<th>Gross margin ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle sales</td>
<td>10.169 billion</td>
<td>8.684 billion</td>
<td>14.6%</td>
<td>-39.85%</td>
<td>-36.6%</td>
<td>-4.39%</td>
</tr>
<tr>
<td>Spare parts sales</td>
<td>0.952 billion</td>
<td>0.637 billion</td>
<td>33.09%</td>
<td>-0.54%</td>
<td>5.7%</td>
<td>-3.95%</td>
</tr>
</tbody>
</table>

Table 2 Main Business Situation and Main Products Situation in the first half year of 2012

With the rapid development of automotive industry in China, reverse logistics attracts increasing attentions since it is beneficial for reducing cost for manufacturers and preserving the environment by increasing utilization of used products and parts. The Society of Motor Manufacturers and Traders suggested that sustainable development should be the ultimate goal of automobile companies in future (SMMT, 2001). The public also think the social responsibilities of companies include environmental responsibilities (SEITZ, 2003).

1.2 Objective

When products are in maturity of life cycle, their demand is relatively stable in the market and approximate to be represented by a constant. The constant can be predicted using historical information. Therefore manufacturers can use Economic Order Quantity model and its extended models to solve the problems regarding
inventory control. However in the reverse logistics case, the classical EOQ models cannot be applied on this problem due to the three following reasons. Firstly, the returned products and parts also have opportunity to be remanufactured to be good products to sell. Secondly the trade-off cost and inventory holding cost differ compared with the classical supply chain. Lastly, the cost changes due to where returned items are stored (Richter & Dobos, 2003). That is why a new model is needed to solve the problem of inventory control in reverse logistics. The objective in this report is to find the optimal inventory strategy compared with two situations: products return rate is stable and unstable.

1.3 Research Questions

This report aims to set up a mathematical model to describe the inventory control in reverse logistics in FAW Car Co., Ltd, and to discuss the difference of inventory strategies depend on whether the products return rate is stable. One type of auto engines is chosen as a test case for the study to find the optimal model for solving problems regarding inventory control in reverse logistics. The report designed two scenarios: one where the product’s return rate is stable and the other one where the rate is unstable. After applying the model in the two scenarios, the paper will assess the difference between the two results and why they differ. This assessment will be used to find the optimal solution, which can be applied in practice.

1.4 Project limitations

The models in the report are only applied under the condition of single cycle, which means the situation of multiple cycles is not considered. Multiple cycles are more common in practice, which requires order repeatedly and nonstop replenishment of inventory. Furthermore when setting up the model, lead time is not considered, and that means the lead time of manufacturing and remanufacturing the products is zero. Because inventory cost varies with the increase of the lead time, and this variation is unstable. The disposal of the returned parts and stock out are not considered either. Waste disposal reduces the utilization rate of returned parts and products, and if there is stock out, the inventory is not continuous any more. Lastly the report only researched the products which are in the maturity stage of life cycle since the demand is stable and predicted.

1.5 Structure of the report

Chapter 1 is the introduction of the report, which describes the outline of the report including background, objective, research questions, project limitations and structure of the report. Chapter 2 explains the methodology used in the report and addresses what is the approach for delivering the outcome. Chapter 3 introduces the theoretical framework of the report. Theoretical framework is the basis of the research since it
summarizes the past efforts and gives a comprehensive understanding of reverse logistics and inventory control. Chapter 4 explains the situation of inventory control and reverse logistics in FAW Car Co., Ltd. Chapter 5 analyse the data and information collected from Chapter 4. Two scenarios are designed to analyse the change of inventory levels and minimum cost depend on different parameters. Chapter 6 gives a conclusion of the report.
2 Research Design and Methodology

This report studies the inventory control in reverse logistics in FAW Car Co, Ltd. It is on the basis of literature review, interviews and case study.

2.1 Literature Review

Literature review is reading and evaluating the published articles, journals, books, reports and so on, which summarizes past efforts and gives insight and outsight of understanding inventory control in reverse logistics (Tranfield et al., 2003). A comprehensive understanding of topic is the basis of the research. Literature review combines rigour evidence regarding the research problem and provide a systematic understanding. Besides literature review is necessary to establish the problem and identify the connections with theory and practice. With the explosive growth of information, it is important to distinguish what has been done and what needs to be done. Furthermore a new perspective also can help the researchers to do an excellent research. With the literature review, the researchers can find what problem they interest in and identify the explicit purpose, which is critical to the research.

Numerous researchers do the research on closed supply chain and reverse logistics, but there is only a few to distinguish one from the other, which means there is no absolute difference between them. Meantime the researches regarding inventory strategies are in the maturity stage since inventory attracts a lot of attention from last century. In general the objectives of inventory management are to decrease the cost and increase the profit, and furthermore the efficient way to manage inventory is controlling the factors that affects inventory. Inventory management in reverse logistics is different from in traditional supply chain due to the returned parts and products.

In order to do a profound literature review, the sources of literature are involved with the books, journals and conference reports which are from Google Scholar, IEEE Xplore and MDH library. The key words when doing the research are primarily reverse logistics, EOQ, and inventory control.

2.2 Data Collection

The choice for the methods of data collection depends on the parameters to be measured, the source and the resources. The basic information and data regarding the company is collected from the annual statement since FAW is a public company. But the primary information which are used for models is gathered from interview the managers and observation of the workshop. Comparing with the secondary information, the primary information is new and reliable. The report takes open interviews instead of questionnaires. The open interviews are freer than
questionnaires and the important points are noted when talking for further analysis. In some cases, it is hard to organize and catch the key, but it is easy to find some problems not expected sometimes.

The managers and employees of Production Department and Logistics Department are interviewed about how is the reverse logistics and inventory management in FAW Co., Ltd, what are the issues in the inventory management and what are their opinions about inventory management in reverse logistics. After organizing the gathered information, the important parameters are picked up for setting up the models.
3 Theoretical Frameworks

This chapter introduces the theoretical framework in the report, and provide a knowledge regarding closed loop supply chain, reverse logistics and inventory management.

3.1 Closed Loop Supply Chain

Closed loop supply chain attracts increasingly attention due to the importance of remanufacturing the used products (Savaskan et al., 2004). Closed loop supply chain is a system creates large value. It saves cost and increases the profit for the company, while preserves the environment compared with the forward supply chain (Guide et al., 2003).

3.1.1 Forward Supply Chain

Forward supply chain is the process of implementing and controlling information and cash flows from purchasing raw materials, manufacturing intermediate goods and finished goods to deliver the products to customers through the selling network. It involves all parties for meeting customer requirements including manufacturing, transportation, distribution, sellers and supply chain management, which is also involved with all functions, such as raw material suppliers, manufacturer, warehouses, distribution centre and retailers. (Chopra et al., 2004)

3.1.2 Reverse Supply chain

Reverse supply chain is a newly subject from legal drives. Increasing governments require companies take responsibilities for dealing with the used product and components in order to preserve environment (Schultmann et al., 2004). There is no identical definition. Some authors think reverse supply chain is moving goods from customers for reusing or remanufacturing for capturing value or proper disposal. And some others advocate reverse supply chain is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics. On the other hand, in some areas it is also called reverse flow logistics, reverse distribution, closed loop supply chain systems and supply loops. In fact, there are not too many differences among all the kinds of the definitions since they are just defined according to the different subjects (Srikanth et al., 2006). Overall reverse supply chain is management of the returned goods.

3.1.3 Closed Loop Supply Chain

Closed loop supply chain is not only a simple combination of forward supply chain and reverse supply chain, which means it has its unique structure differs with the other types of supply chains. Except for the traditional supply chain’s functions, closed loop supply chain encompasses a set of activities: “production acquisition,
reverse logistics, test, sort and grade, remanufacturing/reconditioning and distribution and selling” (Guide et al., 2002). As shown in Figure 3, the forward supply chain is the traditional supply chain concerns the flow of products from the raw materials suppliers, manufacturer to the end customers. The reverse supply chain is caused by returns or recycles, and the end customers acts as suppliers in the reverse supply chain. After sorting out the collected products, the products can be reused will be moved to end customers through manufacturing and distribution. Defects and used or waste products are moving to manufacturer for reusing or remanufacturing or disposed after testing and sorting (Guide et al., 2002).

Figure 3 Closed Loop Supply Chain’s Structure

In 2006, Guide and Van Wassenhove defined closed loop supply chain as “the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with the dynamic recovery of value from different types and volumes of returns over time” (Guide and Wassenhove 2006). The definition has full understanding of supply chain management and evolves from the narrow understanding to a comprehensive understanding involved with remanufacturing (Atasu et al., 2009). Remanufacturing is the process of disassembly and recovery of used components and products to like-new quality standards and return them to market, so remanufacturing becomes the foundation of closed supply chain (Guide et al., 2000).

From the traditional view on closed loop supply chain, the major differences between forward supply chain and reverse supply chain is the different role of customers act. The customers are the ending in forward supply chain and act as suppliers of cores to the remanufacturing company and the beginning in reverse supply chain. Closed loop
supply chain is closed by remanufacturing (Krikke et al., 2004). However the customers are not only those simple roles and also they can be junk yards, brokers and even incurrence companies. It is important how to use the end customers serve in closed loop supply chain. Besides, evaluating the numbers and timing of returns and the quality of the used parts can also help the remanufacturer to improve reverse supply chain. So it is a challenge how to manage the relationships with suppliers and customers. The good relationships and communication with suppliers and customers provide the quick and accurate information to help manufacturer and remanufacturer to increase response time and reduce cost for satisfying the customer demands better. The relationships encompass “ownership-based, service-contract, direct-order, deposit-based, credit-based, buy-back and voluntary-based”. (Östlin et al., 2008)

Closed loop supply chain has high uncertainty because of reverse supply chain. In the reverse supply chain, it is uncertain with timing and quality of returned goods, what materials can be recovered and the demand of customer (Kumar et al., 2006). All of these factors have the obvious impact on demand management, inventory control and supply chain management. On the contrary, the forward supply chain does not have so much uncertainty, so the customer demand is clear and certain in normal case. In addition, reverse supply chain usually occurs when there are some problems with the products qualities or quantities since it is involved with remanufacturing the used product or parts. Therefore planning, implementing and controlling of reverse supply chain are quite complex (Karen et al., 2006). Besides, in most cases, the demands of collecting, inspecting and remanufacturing the used products and parts cannot meet the customer demands.

3.2 Reverse Logistics

3.2.1 The Definitions

James R Stock pointed out reverse logistics including returns, materials substitution, reused, disposal, recycles, maintenance and remanufacturing (Stock, 1992). In 1998, he elaborated reverse logistics as

“... the term most often used to refer to the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing.” (Stock, 1998)

In the above definition, Stock summarized most activities and functions of logistics in reverse logistics. Figure 4 illustrates the flow of major activities in reverse logistics.
3.2.2 Dimensions of Reverse Logistics

In the past decades, “Cradle-to-Cradle” is proposed as an ideal and radical concept emphasizes on recycling products and materials without quality deterioration. Reverse logistics is the process that companies produce new products using the used products, which is alike with “Cradle-to-Cradle” (Wiel et al., 2012). Reverse logistics can be classified as motivation, types of recovered items, return loop and types of sources of reverse logistics.

From environmental motivation, many governments issued some directives to regulate that companies should recycle some used products and components or waste components produced when manufacturing for friendly eco. For example, Environmental Department in European Commission issued a waste management policy to enforce companies should recycle or reuse several specific waste during manufacturing (European Commission, 2012). USA issued the Environment Protection Regulations 2009 for allocating the responsibilities for industrial waste and improving resource efficiency (United States Environment Protection Agency, 2009). China also issued Regulations on Management to Recovery and Treatment of Waste Electrical and Electronic Equipment in 2008. The regulations categorized the waste electrical
equipment and components, and emphasized the companies responsibilities (Ministry of Environmental Protection, 2008). On the other hand, companies retrieve some used products or components for remanufacturing and reusing so as to reduce cost and regain value on the basis of economical motivation. The key of this approach is selection of the used products and components to capture the gap between new products and used ones (Fargher, 1996). The perfect combination with two motivations make companies to obtain value as much as possible and also reduce negative effect on the environment to zero.

According to the types of recovered items, they are categorized as low-value materials, high-value spare components, packages and consumer goods. Low-value materials such as leftover scrap metal can be resold as raw materials of other productions. The benefits for recycling and reusing high-value components such as circuit board make manufacturers retrieve these components for remanufacturing or reusing meanwhile through the reverse supply chain. Packaging including glass bottles, plastic package and pallets can be returned quickly once the contents are delivered. Consumer goods are usually returned at the end of life cycle, but with the development of technology, especially fast consumer goods are also returned since they are outdating. (Fleischmann et al., 1997)

King, A. M., et al. divided return loop as reuse, repair, recondition, recycle and remanufacture. Reuse is the most convenient approach in the above five approaches. For example, glass bottles can be used directly after cleaning. Repair is the most common approach to extend the product’s life. It just restored the damaged products to work well even with losing some quality (Fleischmann et al, 1997), which cannot compare with remanufacturing and reconditioning. In most cases, people stop using products for two reasons: “functional obsolescence or fashion obsolescence” (King et al., 2005). Functional obsolescence means products failed physically and need to repair. By contrast, products go out just because people do not like their appearances any more or products are outdated no matter on function or appearance. Reconditioning is the intermediate approach between repairing and remanufacturing, because it requires reconditioning the failed products to a work condition and is expected to be inferior of the new product. All major components that failed will be rebuilt even including some ones that owners do not notice. However it is still the old products that cannot compare with the new one. Therefore reconditioned products cannot go to market as new products, but they can be sold to low-income family and social service (Renew, 2004). Different from the other form of reuse, remanufacturing is the only process that remanufactured products can be back to the market as original equipment remanufacturer performance with equivalent warranty as new product. The reason is the used products that are brought to remanufacturing site after carrying out complete disassembly, overhaul and replacement operations (Fleischmann et al., 1997). Electro-mechanical and mechanical products use remanufacturing since they have high relatives with both the market value and their original cost when recovery (King et al., 2005). Remanufacturing attracts a number of attentions since its unique characteristic in the past years. Lastly, recycling is the most mature stage in the all
return loops. The used products’ structures are not conserved in the process of recycling compared with remanufacturing. Recycling aims at preventing waste of potentially useful materials. Some discarded products are returned as raw materials such as aluminium stock out, which reduces efficiently waste and preserves the environment. However the quality of discarded products cannot be controlled which decrease the efficiency in some cases (Villalba et al., 2002).

Overall, reverse logistics encompasses two major products flow: returned products and waste materials. Waste material logistics is that the end customers return the used parts or products without value to the supplier, and collected, sorted, reprocessed, packaged, transported or stocked according to different requirements. Otherwise returns logistics encompasses repair of damaged products, returned products from customers due to complains, designs, sales problems and so on, and materials flows such as used packages and containers moved from customers to suppliers opposite to forward supply chain (Brook, 2001).

### 3.2.3 Reverse Logistics Activities

Figure 5 illustrates the basic flow of reverse logistic activities. Overall reverse logistics is a complicated process for increasing the value of products. Quantity, quality and time of arrivals of returns are all the parameters affect reverse logistics. Location of facilities should also be considered for reducing cost. (Srivastava et al., 2006)

Collection is the first and important step in reverse logistics, where products are sorted and collected according to the different types. Some of them, such as non-used products, packaging or waste may be transported to facilities for reusing or direct recovery, and some may be brought to the beginning of the supply chain for converging process. (Brook, 2001)

Inspection/testing and sorting may be implemented at the time of collection or afterwards. The quality of used products is uncertain, so inspection and sorting require skills based on used products conditions since sorting decisions affect remanufacturing cost (Srivastava, et al., 2006).

The products after inspection go to disassembly site where they are disassembled to used parts and non-used parts. Non-used parts with waste go to disposal site. Used parts are moved to remanufacturing site, repairing site or refurbishing site. After repairing and refurbishing process, these like-new products may go back to market or stocked as the part of inventory (Kim et al., 2006).

Some disposed products and components can be recycled for recovery and go back to supply chain as raw material again. The suppliers of disposed products and components are possible to be any nodes in supply chain, which means the products may be retrieved from customers, manufacturers and so on.
The used products or components which have no value or may pollute the environment should be disposed properly. Landfill and incineration are two major common methods of disposal, but they have possibility to pollute environment, mechanical treatments are the most common methods. Biological reprocess is eco-friendly method to decompose the organic matter through composting and digestion processes. Recycling used products reduce both costs for companies and effect on health and the environment (Brook, 2001). sorry, I didn’t find this book.

Figure 5 Flow Diagram of Reverse Logistics Activities (Srivastava et al., 2006)

European Commission issued Directive 2008/98/EC which defined the basic concept related to waste management. The directive explains the waste hierarchy and hierarchy ranks waste management options in order that different sorts of waste can be treated by the most effective methods (Pricce el., at, 2000).
3.3 Inventory Management in Reverse Logistics

3.3.1 The definitions of Inventory

Inventory plays a necessary role in operations of economy. With increasing studies, a number of researchers find that inventory is the crucial factor to determine the total cost and deliver time. Muckstadt and Sapra (2010) stated that the definitions of inventory should be categorized by different types as following: “anticipation stock, cycle stock, safety stock, pipeline stock, and decoupling stock”. For meeting future demands, anticipation stocks are created by a firm to complete customers’ orders, but in some cases, anticipation stocks are also created due to scarcities of raw materials or an expected rise in price of market. Tersine and Richard (1998) say cycle stocks are created to meet customers’ demand because of the cycle of the incoming supply of inventory. Hartman and Media consider that cycle stock is to fulfill regular sales orders through a selling cycle. After selling some portion of items, cycle stock will be replenished by some new items to maintain certain quantity in case there is no enough stock to meet customer demand, and hence cycle stock is part of on-hand inventory. The main function of cycle stock is to prevent stock out. Stock out represents loss of sales and a failure of inventory management. It does not only bring out monetary failure, but it also causes dissatisfaction of customers and even loss of customers. However reckless increasing cycle stock will lead to rise of storage costs and shipping costs, which is also an outcome that company keeps avoiding in inventory management. Therefore many companies want to reduce cycle length in order to reduce cycle stock, but reducing cycle stock means the growth of the number of cycles, and meantime company also increases the possibility of stock out. In
consequence, safety stock is carried to prevent undesirable stock out and sustain the service level for customers. Murray stated that safety stock is usually a tool to make sure companies have enough materials and items in storage for covering some unexpected and unforeseen accidents, such as fluctuating customer demand, damage in the warehouse, delay of shipping, quality issues found in production, forecast accuracy and variability in lead times (Murray, 2012). Some managers just use gut feeling or hunches to determine safety stock, which leads to poor performance. Kings (2011) considered that mathematical approaches could help companies to determine more accuracy safety stock, furthermore balance the contradiction of maximizing the service level and minimizing inventory cost. The ideal and perfect situation is zero-inventory. Zero-inventory represents completing customer requirements and also no inventory waste. Hann and Yamamoto (1999) found that if a company wanted to reach zero-inventory, it depended on supplier, technology, product and customer. When all these factors work well, it is possible to achieve to zero-inventory.

Muckstadt and Sapra (2010) state that pipeline stock begins from the time when goods are ordered until goods are ready to be received by customers, which means goods in pipeline stock stay in company’s distribution chain. The quantity of pipeline stock is equal to expected demand over lead time times the length of lead time. Harris found that pipeline inventory is the solution for the poor performance because of lags between decisions and ramifications other than gut feeling and intuitive decisions of determining stock. When managers make decisions, they should consider not only future needs, but also what they received, which is called Little’s Law. Cachon and Terwiesch (2006) state that pipeline inventory always exists no matter how fast work on a flow unit. In addition, Little’s Law also shows the best way to reduce pipeline inventory is reducing flow time since reducing flow rate is not desirable. According to Cachon and Terwiesch, decoupling inventory is the inventory between process steps, and it is also known as buffer. For downstream, buffer acts a resource of supply comes from upstream, and it can absorb variations between process steps due to different flow rates. Insufficiency of buffers may result in disruption between process steps from upstream to downstream. In other words, decoupling stock is another form of safety stock for ensuring manufacturing process work smoothly and constantly. Furthermore buffer is also a way to prevent breakdowns.

### 3.3.2 Objectives of Inventory Control

Starr et al. (1962) claimed that inventory control was that companies determined inventory, lead time, quantity of order and so on based on customer demand and the goals of companies. If companies want to make inventory strategies, there are some problems to be solved such as how long to check quantity of stock, when to replenish stock, how many goods to be ordered and so on. Uncontrollable factors in inventory system are customer demand and order lead time, while controllable factors are order quantity and when to order. The aim of inventory control is ensuring continuity of supply chain and handling uncertainty of customer demand according to appropriate inventory strategies and methods of inventory control.
3.3.2 Factors Affecting Inventory Control

Demand

Because demand is fluctuating and unstable, it is difficult to match demand (Cachon and Terwiesch, 2006). When demand occurs, warehouse should send some goods out, and hence demand is output of inventory system (Ehrhardt et al., 1987). Cachon and Terwiesch (2006) stated that in the short term inventory could be determined according to historical information or investigation and analysis based on sales in the market.

Figure 6 illustrates some types of demand. Among them, the most common type is constant demand. Warkertin et al. (2003) stated that the expansion of production with constant demand has no impact on costs and resource prices, even though demand is fluctuating in different stages of life cycle. On the other hand, the demand of products is discrete, not continuous. For example, a consumer decides which store to buy a refrigerator, a consumer decides which brand to buy, or a consumer decides which type of equipment to buy. All these choices are discrete and disordered (Hanneman, 1984). In addition, cyclic demand means some products’ demand is responded to season or shows peak over time, such as air-conditioning (Haltiwanger et al., 1984).

Moreover there are deterministic demand and random demand according to demand quantity, demand rate and demand mode. Suverajeet (1994) states that for deterministic demand, demand is usually viewed as constant, such as demand quantity for some type of component in assembly line in one working day. Random demand is unstable in terms of demand quantity since it is easier to be affected by some factors outside system.

![Constant Demand Diagram](image1)

![Discrete Demand Diagram](image2)
Supply

The stock needs to be replenished time to time due to depleted items. In some cases suppliers or manufacturers, sometimes resellers or even distributors help buyers to determine inventory, which means vendors keep watch on buyers’ inventory levels and prepare resupply in advance, even before orders from buyers. That is called vendor-managed inventory. Therefore stock replenishment is controllable since vendors make their own decisions about order quantity, shipping and timing (Waller et al., 1999). Replenishment may be instantaneous or non-instantaneous. In contrast to traditional supply chain, information moved from downstream to upstream in vendor-managed inventory, which reduces carrying cost and minimizing stock out situations (Çetinkaya et al., 2000).

Cost

Too much inventory may increase inventory costs, while too little inventory may not fulfil customers demand. One of inventory objectives is obtaining appropriate quantity of materials, consuming goods and finished products in right place and right time. There are five types of inventory costs as following: unit cost, order cost, setup cost, holding cost and shortage cost.

Unit cost

Walters (2008) says unit cost is the price of one unit of items suppliers charge to buyers. In general, unit cost is total cost spent on purchasing divided by number of items, but in practice, it is difficult to gain the accurate unit cost because there are several suppliers to sell the goods at the same time or suppliers sell different goods in different conditions. However unit cost is useful since it provides the information from the perspective of cost. It helps companies to know the actual cost spent on the items and identify improving the cost efficiency.

Order cost

Order cost occurs when companies placing orders to suppliers. It includes a fixed cost and a variable cost. Fixed cost remains the same no matter how many orders to be placed. It usually involves with the cost of facilities and maintenance cost of the
system related to process purchasing orders. In contrast, variable cost varies depended on the number of orders to be placed. It is important since it can show the actual cost spent on orders. It is involved with the whole process of placing orders including preparation of placing orders, creating orders, reviewing inventory levels, receiving orders, checking items when receiving them from suppliers and preparing and processing payments (Murray, 2012).

Setup cost

Setup cost in inventory occurs to get ready to process orders. It also encompasses two components: fixed cost and variable cost. Fixed cost includes the cost spent on equipment to manufacture products or disassembly used products for remanufacturing. On the other hand, variable cost includes personnel cost, material cost and so on (Business Maxims, 2011).

Holding cost

Holding cost represents the money of holding items in stock or holding inventory. It relates to quantity of inventory and is caused by logistics activities such as inventory control, package, disposal and so on. It is concerned with tied-up money, storage space, loss, handling, administration and insurance (Walters, 2008).

Shortage cost

Shortage cost occurs due to failure to meet customer demand and is not affected by the length of time that keep customer waiting (Petrovic et al., 1999). Walters (2008) states that shortage cost is not measured which means it is inherently inaccurate and misleading. Companies are willing to prevent potential shortage by carrying stock since shortage causes loss of customers and loss of future sales.

**Approaches of reviewing inventory**

There are two approaches to check inventory levels: periodic physical inventory and cycle counting.

Periodic physical inventory is the process of reviewing physical inventory of all items kept in stock at specific intervals during tax or calendar year. Tagaras et al. (2001) says that periodic physical inventory method is simple and effective to compute and implement to manage inventories due to uncertainty. REM (1998) states that this method requires plenty of manpower and should be conducted while business suspends operating.

Rossetti (2001) says that cycle counting method is a popular solution that allows company count a number of items kept in stock in some areas. It includes random sample cycle counting, ABC cycle counting and process control cycle counting. Random sample cycle counting reviews the random samples from the population of inventory instead of review all items kept in stock. ABC cycle counting method
categorizes the population of inventory as three levels according to Pareto principle. Process control cycle counting method picks up those items easy to count. This method is controversial in theory due to its biases.

### 3.4 Inventory Control in Reverse Logistics

The aim of reverse logistics is decreasing the inventory of returned products and parts as soon as possible and reducing the cost of inventory in reverse logistics through turning the returned products and parts to reusable products and parts which maximizes the values of returned parts and products. Therefore, that decreases tied-up money on inventory of returned products and parts and retrieve the value of returned products and parts as soon as possible.

Compared with the traditional inventory system in supply chain, the most different thing is adding one extra supply resource to adding one reverse supply chain in reverse logistics. Inventory in reverse logistics becomes more complicated because of returned parts and products. The goods in stock does not only encompass new finished products and also returned products and parts. Therefore, there are two kinds of supply resources which means returned parts and products can be regarded as supply resource except purchased parts and materials for manufacturing new products.

After collecting, inspecting and sorting the returned parts and products, those that cannot be reused will be disposed, and those that can be reused will be recycled or remanufactured for capturing value which means they will be sent to process as the form of supply resource.

The process of remanufacturing is commonly done by the original manufacturer since it requires the information of products structure and high techniques. In consequence, traditional process and remanufacturing process are combined to a hybrid system.
Collecting returned parts and products is driven by supply rather than market demand in forward supply chain, so it is not often controlled by the company. As a result, there is high uncertainty in quantity, time and quality of returned products and parts which is why inventory in reverse logistics is highly uncertain. For instance, the company is only passive to receive returned parts and products from customers other than collecting the returned parts and products initiatively. The ration of collecting some kind of parts is random. The quality of returned products and parts is unknown before inspecting which leads to uncertainty of lead time.
4 Empirical Findings

This chapter is the information collected from the interview, website and annual report related to FAW Co., Ltd. The data and information is also for further analysis.

4.1 General Information

The company pays more attention to reverse logistics than before, and it changes the logistics system several times for improving supply chain. However reverse logistics is still in the initial phase. The company is trying to establish a completed recycling system.

4.2 FAW Car Company’s Forward Supply Chain

4.2.1 Procurement

After receiving orders from customers, the company starts to do production planning according to customer demand. In FAW Car Corporation, they buy materials and components from overseas suppliers mostly in form of Completely Knocked Down. Overseas suppliers pack the components and materials in the distribution centre overseas after receiving orders from the company, and then components and materials are delivered to the company by trains or shipping. The most components and material come from Japan. There are around 1500 sorts of components and materials, and over 50% of them are in form of CKD.

Since the competition is increasing in automobile industry, the company should reduce the cost of purchasing materials and components for more profit. Therefore domestic procurement becomes more and more. The domestic suppliers of FAW Car Company are more than 70 and distributed in Tianjin, Changchun and so on.

The inspection plays an important role after receiving components and materials since it determines the quality of products. If there are defected or disqualified components and materials, the company usually send them back to suppliers and reorder the components and materials they need. After inspection and acceptance, the components and materials will be in stock respectively.
4.2.2 Suppliers

The forward supply chain is divided to three parts as Figure 9 shown. The first part is supply. Specifically there are three types of supply as following: batch supply, sequential supply and milk run. Batch supply is the most common type, which means the suppliers deliver the materials to the manufacturers on the basis of orders.
Sequential supply means the suppliers deliver the materials to the manufacturers according to the production sequence on the assembly line, and hence sequential supply requires the accuracy of information for avoiding that the materials from suppliers cannot be used in production line. Furthermore, buffer is the essential solution for avoiding abnormal situation, such as delay of delivery and wrong materials. Milk run is a concept from Japan that is delivering the goods collected from multiple suppliers to the customers directly which means there is no handling in the process. In FAW Car Co, trucks transport goods to manufacturers after collecting the materials from suppliers according to schedules and routes, and then go back to suppliers for next around with the empty case, which formulates a circle as shown in Figure 10. Using milk run as the type of transportation, the company considers the distance among the suppliers, loading capacity of suppliers and the roads condition as the determined factors when they determine the routes of transportation. On the other hand, there are some suppliers far from the manufacturer, so the company sets up transit station for shortening cycle time, improving the ability to handle unforeseen circumstances, put the goods from different ways together and increasing loading capacity. Milk-run requires the cooperation with the suppliers and the departments in the company.

4.2.3 Production Line

The company has one production line including 9 machine lines and 3 assembly lines, which manufacture 3 different sorts of automotive engines. The production lines can manufacture different automotive engines according to customer demand, which increase the manufactures’ quick reaction capacity to market. Production line encompasses four parts: operators, objects, components and stations.
As Figure 11 shown, production line is on the basis of equipment, and equipment is essential factor for completing logistics system and information flow. The equipment is functional entity which is able to complete assignments, such as machine tool and fixture. Logistics system is the movement of materials including raw materials, semi-finished goods and tools. In the process of manufacturing automotive engines from raw materials to finished products, there is only a small portion of time spent on assembly line, whereas the most time is spent on stock and transportation. Dispatch and monitor constitute production control system. Dispatch aims at allocating and managing resources, while monitor aims at completing real time monitoring of production line for collecting information of quality control.

Manufacturer use distribution centre and basket centre to deal with the goods transported from suppliers. Distribution centre covers an area of 27000 square meters where containers are unpacked. The goods are processed according to their sizes. Usually there are two types between goods-big and small which means big size goods and small ones are stored in the different zones. Distribution centre is divided to four areas: unpacking area, SLT storage area, GLT storage are and KLT storage area. Basket centre covers an area of 18000 square metres for delivering the goods by hand carts. There are big and small baskets on the hand carts for picking and sorting different goods. Basket centre is divided to Storage Area I, Storage Area II, Storage Area III, where goods are all placed at set-position for improving the efficiency of picking and sorting.
4.3 FAW Car’s Reverse Logistics

FAW founded a subsidiary which is constituted by seven logistics centres run by third party in 2002. The subsidiary aims at providing sorts of components for all stations of FAW, which can improve the performance of customer services. The logistics centres are located in Beijing, Guangzhou, Jinan, Wuxi, Chengdu, Xian and Changchun, which can cover the whole supply of China as shown in the following figure. The logistics centres are relatively independent run by third parties, but they also share the resources and information and are controlled by headquarter in Changchun. Theses logistics centres operate according to the process standards made by headquarter, moreover they need to accept management surveillance and direction from headquarter for assuring the quality of services.

![Diagram showing locations of logistics centres]

The company collects waste and scrap vehicles and components. The returned components are more common. Furthermore waste and scrap vehicles is usually disassembly to components to remanufacture for the convenience of transportation and storage. FAW outsources the function to a subsidiary of FAW. The process of reverse logistics is illustrated as Figure 13.
Figure 14 The Process of Reverse Logistics in FAW Car Co.

The company facilitates the human costs through outsourcing the reverse logistics to the third party and is beneficial for centralized management of returned components reducing intermediate steps due to professional services provided by third parties. Furthermore the inventory levels are decreased.

**4.4 Inventory in FAW Car Co.**

**4.4.1 Inventory System**

The inventory system is on the basis of information provided by central centre in Changchun as shown in Figure 14. Central centre will make plans after receiving information from suppliers, and then send the information to dispatch centre in Changchun and Beijing respectively. Dispatch centre also deliver the information to all warehouses for arranging the movements of materials. In the system, all the information are transferred free and bidirectional, and hence the system is highly efficient.

The system emphasizes on the control of central centre in Changchun, and strengthens the cooperation of warehouses through setting up dispatch centres in Changchun and Beijing, which reduces inventory cost thereby producing an efficient supply chain.

Moreover central centre in Changchun is responsible for the whole purchasing of materials and managing the inventory system. Specifically, dispatch centre in Changchun is responsible for domestic purchasing, while dispatch centre in Beijing is responsible for overseas purchasing.
Figure 15 Inventory System

4.4.2 Inventory Management in FAW Car Co.

Beipin Department is one of seven functional departments in FAW Car Co., which is responsible for procurement, allocation, storage, sales, distribution, information system management and analysis of information and data.

The department is responsible for purchasing materials from upstream suppliers and supplying materials to downstream logistics centres. Furthermore the department is also responsible for calculating, evaluating and analysing all kinds of data and parameters for meeting the requirements of distributors, stations and logistics centres. Logistics centres need to prepare data and information for Beipin Department. On the other hand, they also take charge of providing the parts to downstream distributors and stations and assisting local stations for services regarding with the parts and components. The stations have a certain amount of inventory of spare parts provided to end customers directly. If they have extra needs, they will send request to local logistics centres. Figure 15 shows the process of inventory system among manufacturer, suppliers and 4S shops.
Figure 16 Inventory System

There are three main steps of inventory management in FAW Car Co. first of all, dealers and customer services send the request of demands of parts and components to local logistics centre, and then logistics centre send all the information received to Beipin Department for purchasing. After that, Beipin Department uses the information and data for sales forecast, and then they make plans based on the combination of forecast and inventory levels of spare parts.

Generally the parts are classified according to ABC analysis. There are three groups of parts. The department place order to suppliers according to demand of the parts in Group A, and suppliers will deliver the parts to warehouses in 1-2 days. Generally, the parts from suppliers are unpackaged, and hence the parts need to be packaged after inspection. In general packaging is manual operations, while moving and storage require forklifts. Lastly, Beipin Department send the parts to logistics centres according to requests from centres after second packaging. Order cycle is twice per month for logistics centres.

According to Figure 9, manufacturer workshop is divided to four workshops: Punch, Welding, Painting and Assembly. Every workshop has independent unloading, moving and storage areas for receiving materials. The frequency of receiving materials is basically the same. Punching workshop has slightly higher frequency than the others. Parts in the warehouses are classified to Group A, Group B and Group C according to ABC Analysis. The key parts are in Group A, whose order quantity is 2/3 of Group B and 1/2 of Group C. The parts from foreign countries and from other
places of China are in Group A and Group B respectively, while common parts are in Group C.

ABC Classification is the most common classification method in inventory management. Annual amount of money spent equals unit price times annual quantity of parts consumed. Then sort the annual amount of money from high to low. The parts that tie up the most money and have high importance are classified in Group A. this group requires more attention and accurate order point and quantity. By contrast, the parts that tie up the least money and have low importance are classified in Group C. This group just needs to replenish inventory after stock counting at intervals. The management for Group B is intermediate. Table 2 shows details.

<table>
<thead>
<tr>
<th>Group</th>
<th>Proportion of Types of Parts</th>
<th>Proportion of Money Tied Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10%</td>
<td>70-75%</td>
</tr>
<tr>
<td>B</td>
<td>15-20%</td>
<td>20-25%</td>
</tr>
<tr>
<td>C</td>
<td>70-75%</td>
<td>5-10%</td>
</tr>
</tbody>
</table>

Table 3 The Situation of Group A, B and C in inventory

The demand of spare parts is another important parameter affects ABC Classification. According to Pareto Analysis, spare parts can be classified as following three groups: In Group X, the parts need to be replenished highly frequently, and vice versa. Based on previous experiences, Group X should include approximately 90% spare parts.
<table>
<thead>
<tr>
<th>Parts No.</th>
<th>Unit Price (Yuan)</th>
<th>Inventor Quantity</th>
<th>Cumulative Proportion</th>
<th>Stock's Cost (Yuan)</th>
<th>Cumulative Proportion</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 500400-JA</td>
<td>44401.5</td>
<td>2</td>
<td>0.02%</td>
<td>88803</td>
<td>8.32%</td>
<td>A</td>
</tr>
<tr>
<td>2 F6AZ2001CA</td>
<td>706.5</td>
<td>81</td>
<td>0.86%</td>
<td>57226.5</td>
<td>13.69%</td>
<td>A</td>
</tr>
<tr>
<td>3 3106016-KN1</td>
<td>476.38</td>
<td>113</td>
<td>2.04%</td>
<td>53830.94</td>
<td>18.73%</td>
<td>A</td>
</tr>
<tr>
<td>4 053911023A</td>
<td>1187.8</td>
<td>45</td>
<td>2.51%</td>
<td>53451</td>
<td>23.74%</td>
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<tr>
<td>5 F5LY12029A</td>
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<td>74</td>
<td>3.27%</td>
<td>49050.16</td>
<td>28.34%</td>
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</tr>
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<td>9</td>
<td>3.34%</td>
<td>44289.54</td>
<td>32.49%</td>
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<td>7 034903016W</td>
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<td>39294.37</td>
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<td>5187.7</td>
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<td>3.79%</td>
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<td>4.24%</td>
<td>342640.8</td>
<td>74.96%</td>
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<td>32947.2</td>
<td>78.05%</td>
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<td>11728.92</td>
<td>79.15%</td>
<td>A</td>
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<td>23610.34</td>
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</tr>
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<td>23162.46</td>
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<td>A</td>
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Table 4 The Classification of Spare Parts

Table 3 shows the classification of 25 random spare parts of Besturn according to ABC Classification. The total inventory quantity is 9619, and total stock’s cost is 1066932 Yuan. The parts whose inventory quantity is less than 20 are in Group Z; the
parts whose inventory quantity is between 20 and 40 are in Group Y; the parts whose inventory quantity is more than 40 are in Group Z.
5 Analysis

When products are in the maturity stage of life cycle, the demand is relatively stable, and hence the demand quantity approximates a constant. The constant can be obtained using the historical data and information of sales. Therefore the company can use classical EOQ and extensions for determining inventory issues of the products in the maturity stage. However in the closed supply chain, classical EOQ cannot solve the inventory issues since the returned items are also included.

In this report, products return rate is considered as an important parameter which has an impact on inventories. In addition, holding cost rate for the returned items is separated. Refurbished and remanufactured products are not the same quality and price as the new ones. Secondly the cost for refurbishing and remanufacturing is lower than producing new ones. Therefore holding cost for returned items is smaller than the one for new items.

5.1 Inventory Management if Products Return Rate is Stable

Because of the limited quantity of returned items and the cost for remanufacturing, the cost will increase if the company starts the process of remanufacturing when they receive one returned item every time. Therefore the company remanufactures returned items at intervals, which means the quantities of returned items are random.

5.1. Notation and Assumptions

λ_D the demand rate, where λ_D is a constant.

r products return rate, where 0<r<1.

h_r the cost for holding the returned items in warehouse within unit time.

h_s the cost for holding the available items in warehouse within unit time, with h_r<h_s.

Q_m the quantity of producing the products in a cycle.

T the cycle of remanufacturing.

nT the cycle of manufacturing.

C_{f_m} the fixed cost for producing the new products.

C_{m} the variable cost for producing unit quantity of products.

C_{f_r} the fixed cost for remanufacturing the returned items every time.

C_{r} the variable cost for remanufacturing unit quantity of returned items.
In addition, the following assumptions are used in this chapter.

1) The model only applies when there is the single one kind of product, and the company organizes cycle counting.

2) The demand from customers is continuous, which means $\lambda_D$ is a constant.

3) There is a proportion of products which are returned, which means $0 \leq r \leq 1$.

4) The returned products and parts take batch remanufacturing, and the cycle is $T$. Moreover it is supposed that the production cycle is $nT$.

5) Returned product and parts can all be remanufactured, moreover remanufactured products have the same value as the new ones and they can sold out, which means disposable issues will not be considered.

6) There is no lead time for remanufacturing.

7) There is no stock out, and replenishment is instantaneous.

5.1.2 Mathematical Formulation

Based on the assumptions, the returned products and parts require a cycle to be remanufactured, so in a cycle, the quantity of available items after remanufacturing is $r\lambda_D T$. Figure 16 shows the inventory level of available items.

![Figure 16 The Inventory Level of Available items](image)

According the above assumptions, the total cost in the whole system encompasses the holding cost of available parts, the holding cost of returned parts and products, the cost for remanufacturing the returned parts and products and the cost for producing the new products. At the beginning of every remanufacturing cycle, there are always the products from the last remanufacturing cycle for sales due to continuity of inventory system. The quantity of these products is $r\lambda_D T$. 
According to the above assumptions, the inventory level at time \( t \) is:

\[
I(t) = Q - (j-1)\lambda_D T - [t - (j-1)T]\lambda_D + r\lambda_D nT = Q - \lambda_D t + r\lambda_D nT
\]

**Equation 1**

where \((j-1)T \leq t < jT, j = 1,2,...,n\)

There is no stock out in a manufacturing cycle, which means replenishment is instantaneous when the stock is zero, so \( I(nT) = 0 \), which also means

\[
I(nT) = Q - \lambda_D nT + r\lambda_D nT = 0
\]

**Equation 2**

Consequently,

\[
n = \frac{Q}{(1-r)\lambda_D T}
\]

**Equation 3**

Moreover the expected holding cost of available parts in a manufacturing cycle is

\[
h_s \int_0^n (Q - \lambda_D t + r\lambda_D nT)dt
\]

\[
= h_s \left[ \int_0^T (Q - \lambda_D t)dt + \int_T^{2T} 2r\lambda_D Tdt + \cdots + \int_{(n-1)T}^{nT} nr\lambda_D Tdt \right]
\]

\[
= h_s \left[ Qm T - \frac{1}{2} \lambda_D n^2 T^2 + \frac{n(n+1)}{2} r\lambda_D T^2 \right]
\]

**Equation 4**

Because the average inventory level of returned parts is \( r\lambda_D T/2 \), the expected holding cost of returned parts in the whole manufacturing cycle is \( h_r r\lambda_D T/2 \). The average cost for remanufacturing the returned parts in the whole cycle is \( C_r^f + C_r^m r\lambda_D T \), so the average cost for remanufacturing returned parts in \( nT \) cycles is

\[
\frac{c_r^f}{T} + C_r^m r\lambda_D. \text{ In addition, the average cost for manufacturing the new products is}
\]

\[
\frac{c_m q_m + c_m^f}{nT}
\]

According to the above analysis, the average total cost in the inventory system is

\[
C(Q_m, T, n) = h_s \left[ \frac{Q_m}{2} - \frac{1}{2} \lambda_D nT^2 + \frac{n+1}{2} r\lambda_D T \right] + \frac{1}{2} h_r r\lambda_D T^2 + \frac{c_r^f}{T} + C_r^m r\lambda_D + \frac{c_m^f q_m + c_m^m q_m}{nT}
\]

**Equation 5**

Replace \( n \) in Equation 5 with Equation 4, so
\[ C(Q_m, T, n) = \frac{1}{2} h_s [Q_m + r \lambda T] + \frac{1}{2} h_r r \lambda D T + C_f r \lambda D + (1 - r) \lambda D C_m^f \]

\[ + (1 - r) \lambda D C_m^m \]

Equation 6

The objective function of the question is

\[ \min C(Q_m, T) = \frac{1}{2} h_s [Q_m + r \lambda D T] + \frac{1}{2} h_r r \lambda D T + \frac{C_f}{T} + C_m r \lambda D + \frac{(1 - r) \lambda D C_m^f}{Q_m} \]

\[ + (1 - r) \lambda D C_m^m \]

Equation 7

The first partial derivative should be zero for obtaining the optimal solution, so

\[ \frac{\partial C(Q_m, T)}{\partial Q_m} = \frac{1}{2} h_s - \frac{(1 - r) \lambda D C_m^f}{Q_m^2} = 0 \]

Equation 8

\[ \frac{\partial C(Q_m, T)}{\partial T} = \frac{1}{2} r \lambda D (h_s + h_r) - \frac{C_f}{T^2} = 0 \]

Equation 9

The Hesse matrix of Equation 7 is

\[ H = \begin{bmatrix} \frac{\partial^2 C(Q_m,T)}{\partial^2 Q_m} & \frac{\partial^2 C(Q_m,T)}{\partial T \partial Q_m} \\ \frac{\partial^2 Q_m^2}{\partial^2 C(Q_m,T)} & \frac{\partial^2 C(Q_m,T)}{\partial T^2} \\ \frac{\partial Q_m}{\partial Q_m} & \frac{\partial^2 C(Q_m,T)}{\partial Q_m \partial T} \\ \frac{\partial^2 C(Q_m,T)}{\partial Q_m \partial T} & \frac{\partial^2 C(Q_m,T)}{\partial^2 T^2} \end{bmatrix} \]

Equation 10

The second partial derivative of Equation 7 is

\[ \frac{\partial^2 C(Q_m, T)}{\partial^2 Q_m^2} = \frac{2(1 - r) \lambda D C_m^f}{Q_m^3} \]

\[ = \frac{2 C_f}{T^3} \]

\[ = 0 \]
\[
\frac{\partial^2 C(Q_m, T)}{\partial^2 T^2} = 0
\]

Therefore the Hesse matrix is

\[
H = \begin{bmatrix}
\frac{2(1-r)\lambda_D C_m^f}{Q_m^3} & 0 \\
0 & \frac{2C_r^f}{T^3}
\end{bmatrix} = \frac{2(1-r)\lambda_D C_m^f}{Q_m^3} + \frac{2C_r^f}{T^3}
\]

Equation 11

where 0<r<1, so 1-r>0

According to the above conditions, H>0, consequently primitive function is positive definite function. As a result, \( C(Q_m, T, n) \) is strictly convex function, and the objective function has the unique minimal value.

The optimal solution of objective function can be obtained by the first partial derivative-Equation 8 and 9.

\[
Q_m^* = \sqrt{\frac{2(1-r)\lambda_D C_m^f}{h_s}}
\]

Equation 12

\[
T^* = \sqrt{\frac{2C_r^f}{(h_s + h_r)\lambda_D r}}
\]

Equation 13

According to Equation 12, the optimal quantity of producing the products is positive correlation with the fixed cost for producing the new products and demand rate, while negative correlation with the cost for holding the available items in warehouse within unit time. Furthermore if the returned products and parts increase, the optimal quantity decreases correspondingly since utilization rate of returned goods is far less than new materials. In practice, the quality of remanufactured products is not as good as the new products. If their prices are the same, customers prefer the new products. The strength of remanufactured products is still low cost.

According to Equation 13, the optimal time of cycle is positive correlation with the the fixed cost for remanufacturing the returned items every time, while negative correlation with the cost for holding the returned items in warehouse within unit time and the cost for holding the available items in warehouse within unit time. However the time of cycle narrows correspondingly with the increase of products return rate.
The more returned products are input to the process of remanufacturing, the less is inventory level, and hence the time of cycle reduces.

5.1.3 Case Study
Motor Engine LFTS-2000 is used as example to prove the theory.

\[ \lambda_D = 108 \text{ units/day}, h_r = h_s = 110.6 \text{ yuan per unit/day}, \]

\[ C^f_m = 519.13 \text{ yuan per unit, } C^m_m = 10741.57 \text{ yuan per unit}, \]

\[ C^f_r = 319.3 \text{ yuan per unit, } C^m_r = 572.2 \text{ yuan per unit}. \]

If it is supposed that \( r=0.05, r=0.1, r=0.15, r=0.2, r=0.25 \), and substitute them in Equation 12 and 13, the following figure shows how products return rate affects inventory levels.
Overall if demand is stable and also a constant, the quantity of the returned parts will increase with the growth of the rate of returned items sent back to the company, and optimal quantity of products and optimal cost decrease in the unit cycle. Besides since the products are in the maturity stage of life cycle, so the unit cost for remanufacturing the returned parts is lower than the unit cost for manufacturing the new products. Moreover in the condition that remanufactured products is the same as the new products, the more the returned parts quantities, the less the new products to be produced. Meantime the cost will also reduce. In consequence, the inventory cost will decrease and the profit will increase.

In this case, stable products return rate means that remanufacturing is at constant intervals. To some degree, that shows some features of scale effect. The increasing quantity of returned products and parts causes the fall of cost. In practice, the returned products and pars just possess a very small proportion of selling products, and hence the quantity of returned goods for remanufacturing is small correspondingly. However the quantity will grow after accumulating in the inventory at intervals. The storing the returned goods causes holding cost, but the cost is rather small compared with the cost for starting the process of remanufacturing. Therefore the cost drops with the growth of products return rate correspondingly as shown in Figure 18.

5.2 Inventory Management if Products Return Rate Is Not Stable

In practice, the returned parts and products are affected by a lot of factors, so it is ideal that products return rate is stable. Actually the rate is distributed statistically.

5.2.1 Notation and Assumptions

$h_r$  the cost for holding the returned items in warehouse within unit time.
The cost for holding the available items in warehouse within unit time, with \( h_t < h_s \).

The quantity of producing the products in a cycle.

The quantity of accumulative returned items.

The end time of remanufacturing the returned items the \( j^{th} \) time, where \( T_0 = 0 \).

The cycle of manufacturing, where \( n \) is positive integer.

The fixed cost for producing the new products.

The variable cost for producing unit quantity of products.

The fixed cost for remanufacturing the returned items every time.

The variable cost for remanufacturing unit quantity of returned items.

The inventory level at time \( t \).

The arrival time of the \( j^{th} \) returned item.

In addition, the following assumptions are used in this chapter.

1) The demand from customers is continuous, which means \( \lambda_D \) is a constant, and the process of collecting the returned items and the process on demand are independent.

2) Returning parts and products is random, and it follows Poisson distribution with the parameter \( \lambda \). Because the products are in the maturity stage, \( \lambda < \lambda_D \).

3) Returned product and parts can all be remanufactured, moreover remanufactured products have the same value as the new ones and they can be sold out, which means disposable issues will not be considered.

4) After the returned items are accumulated to a certain quantity, they will be in the process of remanufacturing.

5) There is no lead time for remanufacturing and manufacturing.

6) There is no stock out, and replenishment is instantaneous.

### 5.2.2 Mathematical Formulation

The time is random since the quantity of returned items is random. Therefore the problem of the model is finding the quantity \( Q_m \) which minimizes the total cost in the unit time and the quantity of accumulative returned items - \( Q_r \). Based on the above assumptions, the inventory level of available parts and the returned items are illustrated as following figures.
The total cost in the inventory system includes the holding cost of available parts and the returned items and the cost for producing the new products. At the beginning of every remanufacturing cycle, there are always the products from the last remanufacturing cycle for sales due to continuity of inventory system. The quantity of these products is $Q_r$.

According to the above assumptions,

$$E(S_j) = \frac{j}{\lambda}$$

Equation 14

The holding cost of available parts in the cycle is

$$I(t) = Q_m - \lambda_D T_{j-1} + (j - 1)Q_r - \lambda_D (t - T_{j-1}) + Q_r = Q_m + jQ_r - \lambda_D t$$

Where $T_{j-1} \leq t \leq T_j, j = 1, 2, ..., n$
Equation 15
Every time the returned items are accumulated to \( Q_r \), they will be remanufactured, and the interval is
\[
\Delta T = T_j - T_{j-1} = \frac{Q_r}{\lambda}
\]

Equation 16
So \( T_j = \frac{jQ_r}{\lambda} \) where \( j = 1, 2, ..., n \)

Equation 17
Because there is no stock out, replenishment is instantaneous when inventory level is zero, which means \( I(T_n) = 0 \),
\[
I(T_n) = Q_m + nQ_r - \lambda_D \frac{nQ_r}{\lambda} = 0
\]
In consequence,
\[
n = \frac{\lambda Q_m}{(\lambda_D - \lambda)Q_r}
\]

Equation 18
The expected inventory level in the whole cycle is
\[
E[I(t)] = \int_{0}^{T_n} (Q_m + jQ_r - \lambda_D t) \, dt
\]
\[
= \int_{0}^{T_n} (Q_m - \lambda_D t) \, dt + \left( \int_{0}^{T_1} Q_r \, dt + \int_{T_1}^{T_2} 2Q_r \, dt + \ldots + \int_{T_{n-1}}^{T_n} nQ_r \, dt \right)
\]
\[
= \int_{0}^{T_n} (Q_m - \lambda_D t) \, dt + \sum_{i=1}^{n} \int_{T_{i-1}}^{T_i} iQ_r \, dt = Q_m T_n - \frac{1}{2} \lambda_D T_n^2 + \frac{n(n+1)}{2} (T_i - T_{i-1}) Q_r = Q_m T_n - \frac{1}{2} \lambda_D T_n^2 + \frac{n+1}{2} T_n Q_r
\]
Therefore the expected holding cost of available parts in the cycle is
\[
E(C^h_5) = h_s [Q_m T_n - \frac{1}{2} \lambda_D T_n^2 + \frac{n+1}{2} T_n Q_r]
\]
Equation 19
Because the returned items need to be accumulated to enough quantity $Q_r$ to be remanufactured, the expected holding cost of returned items between two remanufacturing process is as following

$$h_r E[(\Delta T - S_1) + (\Delta T - S_2) + \cdots + (\Delta T - S_{Q_r})] = h_r \left[ E(Q_r \Delta T) - \sum_{j=1}^{Q_r} E(S_j) \right]$$

$$= h_r \frac{Q_r}{2\lambda} (Q_r - 1)$$

Therefore the expected holding cost of returned items in the whole cycles is

$$E(C_h^r) = nh_r \frac{Q_r}{2\lambda} (Q_r - 1)$$

Equation 20
The cost for remanufacturing the returned items in the whole cycles is

$$E(C_r) = n(C_r^f + C_r^m Q_r)$$

Equation 21
The cost for manufacturing the new products in the whole cycles is

$$E(C_m) = C_m^f + C_m^m Q_m$$

Equation 22
As a result, the total cost of inventory system in the unit time is

$$E[C(Q_m, Q_r, n)] = \frac{E(C_h^g) + E(C_h^r) + E(C_r) + E(C_m)}{T_n}$$

$$= h_s \left[ Q_m - \frac{1}{2} \lambda_b T_n + \frac{(n + 1)}{2} Q_r \right] + \frac{1}{2} h_r (Q_r - 1) + \frac{\lambda C_r^f}{Q_r} + \lambda C_r^m$$

$$+ \frac{C_m^f + C_m^m Q_m}{T_n}$$

Substitute the $T_n$ in the above equation with the equation 17 and 18
The objective function of the question is

$$\min E[C(Q_m, Q_r)]$$

$$= \frac{1}{2} h_s (Q_m + Q_r) + \frac{1}{2} h_r (Q_r - 1) + \frac{\lambda C_r^f}{Q_r} + \frac{(\lambda - \lambda) C_m^f}{Q_m} + (\lambda_D - \lambda) C_m^m$$

Equation 23

The first partial derivative should be zero for obtaining the optimal solution, so

$$\frac{\partial C(Q_m, Q_r)}{\partial Q_m} = \frac{1}{2} h_s - \frac{(\lambda_D - \lambda) C_m^f}{Q_m^2} = 0$$

Equation 24

$$\frac{\partial C(Q_m, Q_r)}{\partial Q_r} = \frac{1}{2} (h_s + h_r) - \frac{\lambda C_r^f}{Q_m^2} = 0$$

Equation 25

The Hesse matrix of Equation 23 is

$$H = \begin{bmatrix} \frac{\partial^2 C(Q_m, Q_r)}{\partial Q_m^2} & \frac{\partial^2 C(Q_m, Q_r)}{\partial Q_r \partial Q_m} \\ \frac{\partial^2 C(Q_m, Q_r)}{\partial Q_r \partial Q_m} & \frac{\partial^2 C(Q_m, T)}{\partial Q_r^2} \end{bmatrix}$$

Equation 26

The second partial derivative of Equation 23 is

$$\frac{\partial^2 C(Q_m, Q_r)}{\partial Q_m^2} = \frac{2(\lambda_D - \lambda) C_m^f}{Q_m^3}$$

$$\frac{\partial^2 C(Q_m, T)}{\partial Q_r^2} = \frac{2\lambda C_r^f}{Q_r^3}$$
\[
\frac{\partial^2 C(Q_m, Q_r)}{\partial Q_m \partial Q_r} = 0 \\
\frac{\partial^2 C(Q_m, Q_r)}{\partial Q_r \partial Q_m} = 0
\]

Therefore the Hesse matrix is
\[
H = \begin{bmatrix}
\frac{2(\lambda_D - \lambda)C_m^f}{Q_m^3} & 0 \\
0 & \frac{2\lambda C_r^f}{Q_r^3}
\end{bmatrix} = \frac{2(\lambda_D - \lambda)C_m^f}{Q_m^3} \ast \frac{2\lambda C_r^f}{Q_r^3}
\]

Equation 27

where \( \lambda_D > \lambda \), so \( \lambda_D - \lambda > 0 \)

According to the above conditions, \( H \succ 0 \), consequently primitive function is positive definite function. As a result, \( C(Q_m, Q_r) \) is strictly convex function, and the objective function has the unique minimal value.

The optimal solution of objective function can be obtained by the first partial derivative-Equation 24 and 25.

\[
Q_m^* = \sqrt{\frac{2(\lambda_D - \lambda)C_m^f}{h_s}}
\]

Equation 28

\[
Q_r^* = \sqrt{\frac{2\lambda C_r^f}{h_s + h_r}}
\]

Equation 29

According to Equation 28, the optimal quantity of producing the products is positive correlation with the fixed cost for producing the new products and demand rate, while negative correlation with the cost for holding the available items in warehouse within unit time. Poisson parameter \( \lambda \) means the quantity of returned goods in the unit time. If \( \lambda \) increases, the optimal quantity decreases correspondingly since utilization rate of returned goods is far less than new materials.

According to Equation 29, the optimal the quantity of accumulative returned items is positive correlation with the fixed cost for remanufacturing the returned items every time, while negative correlation with the cost for holding the available items in warehouse within unit time and the cost for holding the returned items in warehouse within unit time. However the quantity grows correspondingly with the increase of \( \lambda \).
The more returned products, the more is the quantity of accumulative returned items.

5.2.3 Case Study

The above case data is still used in this case, and the parameters are showed as following:

\[ \lambda_D = 108 \text{ units/day}, h_r = h_s = 110.6 \text{ yuan per unit/day}, \]

\[ C_m^f = 519.13 \text{ yuan per unit}, C_m^m = 10741.57 \text{ yuan per unit}, \]

\[ C_r^f = 319.3 \text{ yuan per unit}, C_r^m = 572.2 \text{ yuan per unit}. \]

If it is supposed that \( \lambda = 10, \lambda = 20, \lambda = 30, \lambda = 40, \lambda = 50 \), the following figure shows how \( \lambda \) affects the inventory levels:

![Figure 22 How \( \lambda \) affects inventory levels](image_url)
As the above two figures illustrate, if the demand remains the same, the quantity of the new products reduce with the growth of returned items, and the minimum cost in the system also decreases. Because the products are in the maturity stage of life cycle, the demand is stable, and meantime if no differences between the new products and the remanufactured products, the quantity of the remanufactured products increase with the growth of the returned items.

With the growth of returned products and parts, the cycle of remanufacturing obviously narrows, and the numbers of remanufacturing increase.
The remanufacturing cost grows with the increase of returned goods, but the remanufacturing cost is smaller than manufacturing cost. Besides it is supposed that remanufactured products are the same as the new ones. Therefore the total cost falls with the growth of returned goods since the new products to be produced also drops correspondingly. It is beneficial for the company from the aspect of cost management.
6 Conclusions

The returned parts and products are excluded in the traditional inventory models. But nowadays the company are facing the returned parts and products, and also reverse logistics attracts a lot of attentions. The report takes the inventory system in FAW Car Co., Ltd as instance to study their inventory system. In FAW Car Co., Ltd, the cost of inventory encompasses the cost for reverse logistics except ordering cost, holding cost and stock out cost. The cost for reverse logistics consists of the cost for transporting, holding and remanufacturing the returned parts and products. The inventory can be replenished by placing orders to suppliers and also the returned parts and products.

This report analyses inventory levels in two different situations. The first one is under the condition that products return rate is stable, and the second one is under the condition that products return rate is unstable. From the two case studies in Chapter 5, the optimal quantity of producing products and minimum cost both fall with the growth of returned goods whatever scenario is, which means that remanufacturing is beneficial for the company.

In practice, the products return rate is unstable and unpredictable. Moreover the products return rate is lower than 10%. If products return rate is higher than10%, the company will dissatisfy the customers demand and face the loss of customers. The models can help the company find an explicit view to make decisions regarding dealing with the returned parts and products.
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