MASTER

Determining the customer order decoupling point for a global supply network

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Determining the Customer Order Decoupling Point for a Global Supply Network

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Abstract

In this master thesis, we conduct a research on the Customer Order Decoupling Point(CODP) determining for a global supply network at Company A which would like to change the local production to global production. The products we studied are revolving doors and barriers. The products with small demand volume, large variance and variety should be MTO as previous researches. However, a demand aggregation rule is applied to conquer the difficulty. In the process of data collection, we found that the data of revolving doors is not as detailed as the data of barriers. Thus, we applied two analytical models to determine the CODP for two type of products, respectively. 0-1 integer linear programming is used to determine the CODPs for revolving doors, and Markov chain and Queueing theory is applied to locate the CODPs for barriers. We considered both the local production and global production in the model. Transportation cost and finance cost are involved in the global models. The results provide minimal total costs and shorter production time solutions. The influences of demand characteristics, holding cost, setup cost, leadtime, backorder cost and processing rate ratio on the CODP determining support the previous research. The influences of product value, global production, manufacturing cost between two factories, transportation cost and customer order fulfillment delay cost on the CODP positioning provide rules of the CODP determining.

Keywords: customer order decoupling point, supply chain, 0-1 integer linear programming, Markov chain, queueing theory.

Preface

This thesis presents the result of my master graduation project in Business Information System at Eindhoven University of Technology. This research project has been carried at Company A in the Netherlands. I have conducted a challenging project for which I have learned at lot in the last seven months. I would like to thank several people who supported me during the project.

First of all, I would like to thank my first supervisor from the university, dr. A. Chocklingam. I appreciate your patience of hearing from my thinking. You inspire me when I face difficulties. Your critical suggestions help me better understand the project. You let me learn the attitude to solve problems initiatively instead of holding back. Moreover, I would like to thank my second supervisor dr. Z. Atan for checking details in my model and providing me professional advises in the supply chain field.

From Company A I would like to thank my supervisors Mr. M. Dingerdis and Mr. H. Picavet. The data collection is difficult because multi factories and departments are involved in. During the process, you offer me much help to coordinate different resources. You ensure that the inputs are correct. Meanwhile, I would like to thank my colleagues H. Groot, M. Koning, D. van Beusekom for helping me understand the production and B. Dammers and M. de Graff for letting me know products well, and T. Stork for guiding me in the Beijing factory.

Finally, I would like to appreciate my parents and friends. You always support my decisions and make my master life unforgettable.

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Executive Summary

we conduct a research on the Customer Order Decoupling Point(CODP) determining for a global supply network at Company A. The Customer Order Decoupling Point (CODP) is the boundary between make-to-order (MTO) and make-to-stock (MTS). The decoupling point(DP) (Sun et al., 2008; Perona et al., 2009), the order penetration point(OPP) (Olhager, 2003, 2010; Teimoury et al., 2012), the delay product differentiation(Jewkes and Alfa, 2009; Hsu and Wang, 2004) and the product customization postponement (Feitzinger and Lee, 1997) are used as the same concept in some researches. The most popular techniques to solve the CODP determining problem are analytical models and frameworks.

Company A is a leading company in the security doors production industry which designs, produces and supplies security door system to meet its worldwide markets. We analyzed five product families which are grouped into two sorts of doors, revolving doors and barriers. There are three factories, the Netherlands factory, the China factory and the USA factory. The Netherlands factory produces all five product families, and the China factory produces two type of barriers, and the USA factory produces one type of barriers. As the company grows, it faces three challenges:

- Isolated production and sales;
- Unpredictable demand;
- Unshared materials during production.

To deal with the challenges and to double sales, the company aims to determine CODPs in the supply network for product families which optimize the total cost subject to reasonable customer leadtime.

As the demand volume is small and demand variance is large, we aggregated the demand and found the most popular configurations as the standard configurations.

Because the data of barriers are not as detailed as the data of revolving doors, we built up two models. We had the processes of revolving door production and the labor cost and material cost in each step. Therefore, we can calculate the relevant cost based on the labor cost and material cost. A step can be either MTO or MTS, and then a variable valued 0 or 1 is suitable to represent the two choices. We applied 0-1 integer linear programming in the revolving door model. However, we do not have the data about the processes of barriers. The pre-production is finished by suppliers, and assembly do not go in details. Most of important, we do not obtain the material cost in each step even if we know processes. The states of the customer order number and the semi-finished product number changes always exist, thus we can describe states with Markov chain. Hence, we apply Markov chain and Queueing theory in the barrier model.

The objective is to determine the optimal CODP to minimize the total cost. Thus, the cost structure of the models is important. We consider the setup cost, holding cost, stock-out cost, asset specificity cost in the revolving door model, and holding cost, asset specificity cost, customer order fulfillment delay cost in the barrier model. In the global production, we consider transportation cost and finance cost in both models. After run the models, we found solutions for each configurations.

To understand how different factors affect the determination of CODP, we did sensitivity analysis. After did sensitivity analysis, we had some findings which reveal the CODP positioning rules.

The demand characteristics were studied by scholars and they are the most important factors. The larger demand volume results in the CODP going downstream. The larger relative demand variance leads to the CODP going upstream. The inventory cost moves the CODP upstream, while the effect of stock-out cost does not make effort on the CODP determining in the research. In the global production, the CODPs move upstream compared to the local production. The result also shows that the first factory should be the factory with smaller production cost in the global production.

This thesis extend the CODP determining and the factors which influence the CODP positioning in the global production and provides recommendations for the company.

The company should make effort to modularize production. First of all, the company is able to maximize the number of standard components. Second, the modules can be produced separately. Third, the production problems and quality problems are easier to be diagnosed. Fourth, it is efficient in dealing with small demand volumes.

The products with larger demand volume have priorities to execute the CODP strategy. Besides the products we analyzed, if there are some other products that have large demand volume, their CODPs should be changed with priority. The products whose configurations are easier to be aggregated should also be prioritized.

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Chapter 1

Introduction

It is an advantage for a company to be able to quickly respond to the market and also provide wide product variability to customers. Make to stock(MTS) is a strategy that allows a company to quickly respond to customers, but it incurs risks to have a high inventory cost and a low customization. Make to order (MTO) can provide more customized products to meet the customer preference, but the response time is longer compared to MTS strategies. Thus, the Customer Order Decoupling Point(CODP) positioning becomes a very important research topic.

The CODP separates the MTS and the MTO strategies. The upstream of the CODP follows the MTS strategy, while the downstream follows MTO strategy. A correct CODP determination contributes to lower inventory cost and allows the company to fulfill customer orders quickly and provide a wide range of products as well. Many scholars come up with the same concepts such as the decoupling point(DP) (Sun et al., 2008; Perona et al., 2009), the order penetration point(OPP) (Olhager, 2003, 2010; Teimoury et al., 2012), the delay product differentiation(Jewkes and Alfa, 2009; Hsu and Wang, 2004) and the product customization postponement (Feitzinger and Lee, 1997). According to the difference of the CODP position, there are many manufacturing situations. As the CODP goes downstream, the manufacturing situations may be named as engineer to order, make to order, assemble to order and make to stock(Olhager, 2010; Giesberts and van der Tang, 1992). The most popular approaches to analyze the determination of the CODP are through the use of analytical models and frameworks.. We would like to benefit from a framework which is suitable for a realistic situation, and find a more precise solution based on analytical models as well.

The graduation project is a cooperation project with Company A, which is a revolving door and security lane manufacturer. It has a whole supply chain from manufacturing to sales. Company A transformed from a local company to a global company in the last a few decades, and plays a leading role in the industry. However, during the processes of globalization, the current supply chain strategy, pure MTO, makes it harder to meet demand as well as before. The strategy elongates the response time so that orders may not be fulfilled on time in the busy time, and some of customers cannot accept the long leadtime. Therefore, to double sales, and to take advantage of strengths in the three factories, Netherlands factory, China factory and the USA factory, determining suitable CODPs for a global supply network is on the agenda.

We determined the CODPs for two main sorts of doors: revolving doors and barriers. The common characteristics of the two doors are complex production processes and unpredictable demands. The production processes may be different for different configurations. The number of configurations in each product family is big, while the demand volume for each configurations is small and unstable, so it is difficult to forecast. It is a challenge to determine the CODPs. Based on Olhager (2003)'s research, the products with small demand volume and big variance should be MTO. Thus, we dedicate ourselves to detect a better solution.

During the processes of data collection, we found that the degree of data accuracy is different for revolving doors and barriers. The data of revolving doors are more accurate than that of barriers. The most important difference is that we do not have the processes of barriers and the manufacturing costs in each steps, so we can not analyze the barrier CODPs based on precise production processes. The input differences make a big difference on the analytical models of revolving doors and barriers.

We determined the CODPs for revolving doors with 0-1 integer linear programming. Linear programming is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships (Wikipedia). When the value of all unknown variables is 0 or 1, it is named 0-1 integer linear programming. There are two states for each production unit in different steps: MTS or MTO, which is the same as binary variable 0 or 1. Thus, it is suitable to apply 0-1 integer linear programming. The positions between MTS step and MTO step are looked as the CODPs. Note that it is possible to have multi-CODPs in this model. The relevant costs are inventory cost, stock-out cost, setup cost and so on. Also, the components produced in the MTS system may not suitable for the demand in the MTO system because of demand variance; thus it yields loss. We will consider the loss into the model as well.

We analyzed the CODP positioning for barriers with Markov chain and queueing theory. Because the production processes are unknown, we regard the processes as a whole, and hence we cannot use integer linear programming for our analysis. However, we can find states of customer arrival and semi-finished product arrival, thus we can apply Markov chain and queueing theory in the model. The CODP location is measured as the percentage of completion. The inventory sizes at the CODPs are also decided. The relevant costs are inventory cost, asset specificity cost and customer order fulfillment delay cost. No matter which model we use to analyze the CODP positioning, the objective is to minimize the total cost.

In the project, we solved the questions:

- How to conquer the small demand volume and big demand variance?
- How to deal with the process complexity?
- How to find the optimal CODPs for revolving doors with 0-1 integer linear programming?
- How to determine the optimal CODPs for barriers with Markov chain and queueing theory?
- How to gain insight from the results?

The remainder of this thesis is organized as follows: Section 2 provides a description of the company, followed by the problem definition in Section 3. Then we describe the literature review in Section 4. Section 5 contains an input analysis of the data involved in the models. We describe the models of revolving doors and barriers in detail in Section 6, and then do verification and validation in Section 7 to make sure that the models work correctly. Section 8 provides the results of different doors which include the CODP positioning, production time and the total cost. After that, we do sensitivity analysis on parameters to go insight of the results in Section 9. Section 10 concludes the paper.

Chapter 2

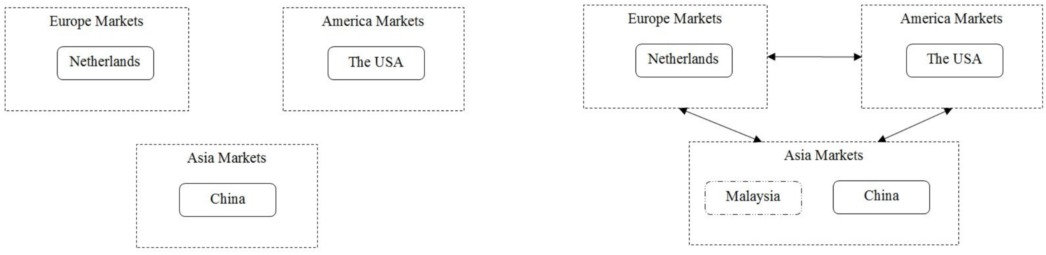
Company Description

In this chapter, background information of Company A is provided with a general overview of the company. First, a description of the company is given, followed by a introduction of the product families involved in the thesis. After that, the factories in the Netherlands, China and the USA are explained.

2.1 The Company

Company A focuses on door systems, security access and advanced door care. The company has built a worldwide distribution network in the last few decades. It has factories in China, the Netherlands and the USA. It delivers a broad range of innovative, high quality entrance products and services that meet customers needs for efficiency, security and aesthetic design all round the world.

At present, the distributors accept customer orders, and then send the orders to factories. After a factory finishes the production, they deliver the orders to customers. In some cases, the factories accept orders directly since they are not linked to any distributors. Moreover, each factory is isolated. They supply their local markets. However, in the next few years, the distribution centers will be constructed in the Netherlands, China, the USA and Malaysia. To take advantage of experienced workers, the distribution centers in China, the Netherlands and the USA will be near the factories or even in the factories. A strong relationship will be built between factories and distribution centers. The current supply network and further supply network are displayed in Figure 2.1.



(a) The current supply chain

(b) The futher supply chain

Figure 2.1: The Current Supply and the Further Supply

2.2 Product Families

Five product families are considered in this project.They are Revolving door 1 (RD1), Revolving door 2(RD2), Barrier 1(B1), Barrier 2 (B2) and Barrier 3(B3). RD1 and RD2 are revolving doors, and B1, B2 and B3 are barriers.

Revolving doors A revolving door typically consists of three or four doors that hang on a central shaft and rotate around a vertical axis within a cylindrical enclosure. Revolving doors are energy efficient as they prevent drafts, thus preventing increases in the heating or cooling required for the building(Wikipedia). We consider a door as a product unit.

Figure 2.2: Revovling Door

Barriers Barriers consists of at least one basic unit. A basic unit has a master and a slave. The master with control units is able to control the slave. Several intermediates may be present based on customer requirements. An intermediate is also regarded as a product unit.

Figure 2.3: Barriers

2.3 Factories

Company A consists of three factories. They are Netherlands factory, China factory and the USA factory.

Netherlands factory Netherlands factory is formed for the European markets. Occasionally, Chinese customers may order parts from Netherlands factory because of customers requirement. This factory mainly produces revolving doors, but some barriers are also produced. RD1, RD2, B1, B2 and B3 are produced in Netherlands factory. The development and research department is in the Netherlands factory, so the strength of the factory lies in producing doors that require complex technology.

Distributors are located in France, Germany, Spain, United Kingdom, etc. Customers order the products by contacting distributors. After the distributors send the order to Netherlands factory, the planning department schedules the production. Then the production department starts producing to fulfill customer orders.

China factory China factory is formed for the Asian markets. More than 90 % of the orders come from mainland China. The rest of orders are from neighboring countries such as Hong Kong, Thailand, Malaysia, etc. The emphasis for this factory is placed on the production of barriers. B1 and B2 are produced in the China factory. The strength of the Beijing factory is the low labor cost, so the labor-intensive products are better suited for producing in the Beijing factory.

The Sales Department of China factory is responsible for accepting orders from customers. Then the operation process is similar with that of China factory. The planning department schedules the orders first, followed by the Engineering Department which creates the Bill of Material. After that, the purchasing department procure raw material or components from the warehouse and suppliers. Production starts after all necessary parts are ready. Finally, the products are delivered to customers.

The USA factory The USA factory is formed for the American markets. The products in the USA are more standard, and the production line allows mass production. Thus, the USA factory is suited for manufacturing the large demand volume products. B3 is produced in the USA factory.

The operation method of the USA factory is the same as that of the Netherlands factory. Distributors accept orders, followed by materials procurement, scheduling, production and delivery.

Chapter 3

Project Definition

3.1 Challenges

The company's size boomed in the last few decades; however, because its rapid growth, the current model begins restricting the development. We have already mentioned that the supply chain strategy is MTO. Though it helps reduce the inventory cost, the long leadtime is harder to be accepted by customers. If the company keeps the current supply chain structure and operation method, it may have less advantages compared with its competitors. Furthermore, in the process of market expanding, customer demands increase dramatically. If the company can't prepare products or semi-finished products in advance, it is possible to have difficulties in production coordination in the busy time. In fact, the company loses some orders in the busy time which was told by a manager. Therefore, the current situation forces a change in the supply chain. However, when making a strategy for the expansion, three challenges have to be dealt with. They are isolated production and sales, unpredictable demand and unshared materials.

3.1.1 Isolated production and sales

The whole production processes of a product occur in a factory. For example, an order from Europe market is seldom produced in the USA. Instead, it is only produced in the Netherlands factory, resulting in insufficient usage of strengths in different factories. As we mentioned in the last chapter, the strength of Netherlands factory is the high-tech-intensive ability, and the strength of China factory is the labor-intensive ability, and the strength of the USA factory is the high production capacity. Hence, if the processes with high-tech requirement are produced in Netherlands factory and the rest of processes are produced in China factory, the strengths of different factories can be taken advantage of.

In addition, its sales is also isolated. Each factory is just responsible for its own market. The China factory doesn't produce RD1 and RD2, so the demand of the two products in the Asian Market is hard to meet. Except the product families we study, other products in the company face the similar situation. Thus, potential demand is lost.

3.1.2 Unpredictable demand

The classes in a product family are large while the demand for each class is small so that the demand is hard to forecast. Take RD2 as example. We investigated the history demand data in Netherlands factory from 2010 to 2012. If we look the products with different product number, diameter, height under canopy(HUC), canopy size and finish as different products, there are 119 classes. The highest demand for a product in the RD2 family is only 11 units in the past three years (see Table 3.1). The similar situation also occurs in other product families.

The unpredicted demand triggers the long customer leadtime and inefficient capacity. The company follows the MTO strategy because they scarcely prepare components in advance. The CODP is at the beginning of supply chain, resulting in the long leadtime. Owning to the unpredicted demand, the production volume is not constant. In the busy time period, the capacity is insufficient. In the idle time period, the utilization of capacity is low. The usage of capacity is inefficient.

Table 3.1: An example of RD2 classes and the demand

Product number	Diameter	HUC	Canopy size	Finish	Demand
1	1700	2300	200	304-K240	11
2	1700	2200	200	304-K240	8
3	1800	2595	300	VB6-EV3-A20	8
4	1800	2200	200	VB6-MX4-A20	8
5	1700	2200	200	Remarks 30%	6

3.1.3 Unshared materials

There are two categories of materials in each factory. One is standard components, and another is special components. The standard components such as screws can be used in different products, while the special components such as side frames can be only used in a certain configuration. The purchasing of the standard components follows (s, Q) strategy which is ordering Q quantity components when the inventory position is less than s components. However, the purchasing departments order the special components from suppliers after the factories accept orders because demand deviation may lead to material loss. For the revolving doors, the factories process some of the special components, which also costs time. The special components are scarcely shared among different configurations, so they are seldom prepared in advance. This means that the CODP is hard to move downstream.

3.2 Project Definition

The methods to shorten the customer leadtime are the capacity increasing and the CODP downstreaming. When the resource utilization is not that high, increasing the capacity is not reasonable. In addition, the workers need specific training for the production and equipment cost is high. Therefore, we prefer to move the CODP further down the production process. The upstream of CODP is MTS, so the production volume is large, and then the utilization goes up. Further, the shorter leadtime reduces the probability of order lost. On the other hand, the local basis production leads to insufficient product families in different factories. If we extend the production lines being able to produce all products, the cost(large plant area and more equipment etc.) is higher. Therefore, if each factory is responsible some product families and ships the semi-finished products to distribution centers to assemble, all manufacturing sites are able to offer whole product families. Considering the CODP downstreaming, the upstream of CODP can be set in a factory, and the downstream of CODP can be set in another factory or distribution centers.

In conclusion, the objective of the project is to determine a CODP in the supply network for product families which optimizes the total cost subject to reasonable customer leadtime with these functional requirements:

- Meeting at least 95% of customer orders.
- The total cost of the new strategy is no more than the total cost of the current strategy.

However, the inventory cost increases if part of supply network follows MTS; the transportation cost and finance cost increase if the local production is transfered to global production. If the cost including inventory cost, transportation cost and finance cost is higher than the original one, the feasibility of redesigned strategy should be analyzed to determine if the new strategy is actually better than the original one. Moreover, the MTS in the upstream of CODP requires precise demand forecasting. The unpredictable demand is a big challenge to solve this problem.

3.3 Project Scope

To develop such a methodology for determining the CODP in a global supply network, clear project boundaries need to be set. These are summarized below with clear explanation.

The products we investigate are B1, B2, B3, RD1 and RD2. We only focus on the production processes, so the behaviors of suppliers, distributors, the sales departments, the post-sales services are out of scope. We also don't consider the shipment and installation because no customizations are involved in the processes. Thus, the total production chain consists of 3 processes:

- Own component supply
- Subassembly
- Final assembly

Specifically, the components of barriers are purchased from suppliers directly, so the "Own component supply" is out of scope for barriers. Meanwhile, because the company hasn't decoupled "Subassembly" and "Final assembly", we regard them as one production unit. Therefore, the project scope is displayed in Figure 3.1.

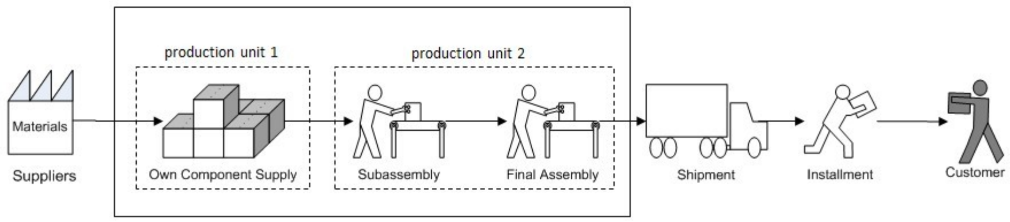


Figure 3.1: The Project Scope

Some important assumptions are made:

- There are always sufficient materials so that the process never starves.
- The company does not accept orders in the weekends and national holidays.
- Workers work 8 hours per day, 260 days per year.
- The overtime is not considered in the project.
- Machines never shut down and workers are never absent.
- The external environment is stable during the analysis period.
- The global production takes place between two factories.

3.4 Project Deliverables

The project deliverables are as follows.

- Analytical models to determine the optimum CODP.
- Relevant tools.
- Final report.

Before formulate the analytical model, we will investigate the natures of data. Appropriate assumptions will be made based on the natures. The model is applied to determine the optimum CODP.

Chapter 4

Literature Review

4.1 Concepts

The Customer Order Decoupling Point (CODP) is the boundary within a production process between make-to-order (MTO) and make-to-stock (MTS). The decoupling point(DP) (Sun et al., 2008; Perona et al., 2009), the order penetration point(OPP) (Olhager, 2003, 2010; Teimoury et al., 2012), the delay product differentiation(Jewkes and Alfa, 2009; Hsu and Wang, 2004) and the product customization postponement (Feitzinger and Lee, 1997) are used as the same concept in some researches.

The MTS is on the upstream of supply chain while the MTO is on the downstream. The MTS follows standard production and it is forecast-driven. Standardization is usually companied with high production-volume. Customization is the feature of MTO strategy, so it is customer-driven and the production-volume for each product is low. The product range of MTS is narrow. The supply chain type of MTS is physically efficient. The MTO product range is wide because customers' preference is various. Thus the supply chain type of MTO is market-response. Mass production reduces cost, so costs and productivity are used to evaluate the performance of MTS; however, high flexibility and short delivery time are regarded as a good MTO supply chain (Olhager, 2003, 2010; Fisher, 1997).

Table 4.1: Some important characteristics of MTS and MTO

Attributes	MTS	MTO
Product type	Standard	Special
Product range	Narrow	Wide
Demand	High volume, predictable	Low volume, volatile
Performance measurement	Cost, productivity	Flexibility, delivery lead times
Supply chain	Physically efficient	Market-repsonsive

According to different positions of CODP, manufacturing situations are classified into make-to-stock(MTS), assemble-to-order (ATO), make-to-order(MTO) and engineer-to-order(ETO) (Olhager, 2010; Giesberts and van der Tang, 1992). The ATO is on the downstream of CODP which is before assembly. The MTO is the manufacturing situation whose CODP is before fabrication and procurement. If the CODP is before the design and engineering stage, the downstream is ETO. MTS is after the CODP which directly faces customers.

Gunasekaran and Ngai (2005) and Chen et al. (2009) claimed a concept build-to-order(BTO) similar with the ATO. The BTO system integrates the upstream supplier of raw materials, the midstream manufacturer of components and the downstream distributor of finished goods(Chen et al., 2003).Build-to-order supply chain has global operations, so exchange rates, taxes, political stability and the resources and capacity of the assembly line should be addressed. Miemczyk and Howard (2008) applied the BTO supply strategy to manage a global auto company. As the

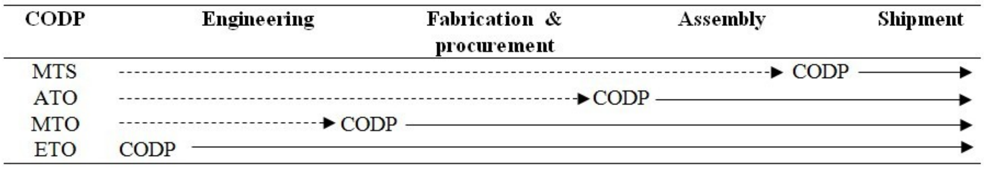


Figure 4.1: Different customer order decoupling points(Olhager, 2010)

program relates to extend local supply chains to a global supply network, positioning a CODP is determining the start point of BTO strategy. However, because researchers usually use the MTO to stand for all manufacturing situations, we also use the MTO to represent the BTO.

4.2 Performance measures

The CODP determination is to optimize a MTS-MTO hybrid strategy. It has the characteristics of MTS and MTO. To measure a supply network with the CODP, two important performance indicators should be taken into account: cost and customer delivery time.

4.2.1 Total cost

To minimize the total cost is the requirement of MTS strategy. Fisher (1997) defined a supply chain for functional products and innovative products, respectively. Functional products are fit for the MTS strategy and the main goal is cost control. Because the inventory at the CODP is an important operational problem, the inventory cost is a significant part of total cost and it occurs in the MTS strategy. Minimizing the total cost is the objective of supply network improvement in many researches (Arreola-Risa and DeCROIX, 1998; Sun et al., 2008; Kerkkänen, 2007; Perona et al., 2009; Rajagopalan, 2002; Teimoury et al., 2012; Akkerman, 2010; Gupta and Benjaafar, 2004). Normally a trade-off can be found among the composition of total cost. The most popular trade-off is holding cost and backorder cost. Backorder cost is the penalty cost when orders are not met on time. Thus, backorder cost potentially indicates another critical performance measure: customer delivery time. Under the situation where the backorder is considered, it is possible that the customer delivery time is not considered (Arreola-Risa and DeCROIX, 1998). The detailed cost structure will be discussed in Section 4.

4.2.2 Customer delivery time

The customer delivery time, or customer leadtime is on the basis of the requirement of MTO strategy. A pure MTO strategy has a longer leadtime than pure MTS strategy. Thus, a short customer delivery time represents a good customer response result. It has two dimensions: the length of customer delivery time and on-time delivery. Wang et al. (2010) minimized the leadtime of production and engineering when determining the CODP. Köber and Heinecke (2012b) used short delivery time as a positive indicator to measure supply chain with CODP. On-time delivery is a more common measurement. Sun et al. (2008) defined a upper bound for customer delivery time which means orders have been finished before due dates. Perona et al. (2009) applied the average of delay as one of indicators. Köber and Heinecke (2012b) also used on-time delivery to measure the results. The order completion delay (Teimoury et al., 2012) is the concept similar with on-time delivery.

4.2.3 Other performance measures

The average stock is to measure the stock level on the upstream of CODP. It strongly refers to holding cost, but more focuses on the physical capacity of warehouse. Köber and Heinecke (2012b) and Perona et al. (2009) measured supply chain via the inventory level. Teimoury et al. (2012) studied the quantity of semi-finished products which should be stored.

Furthermore, average products in order and number of product orders (Perona et al., 2009), flexibility (Fisher, 1997; Wang et al., 2010) are applied in some researches.

4.3 Strategical decisions

Soman et al. (2004)'s hierarchical framework has set the CODP determining at the strategical level. This section discusses what factors impact the MTS/MTO product classification and the CODP positioning, and how these factors act on determining the CODP. Note that some research classifies the products into MTS or MTO, while some studies locate the CODP within the production process of a group of products. Nevertheless, the factors involved are shared.

4.3.1 Cost structure

Total cost contains the costs which affect the value of total cost and the CODP determination. Material cost and operation cost indeed exist during manufacturing(Akkerman, 2010). As we mentioned in Section 3, holding cost and backorder cost are also relevant. Arreola-Risa and DeCROIX (1998) analyzed the conditions where MTO/MTS should be used, by keeping a balance between holding cost and backorder cost. Likewise, Sun et al. (2008) minimized the total cost by finding trade-off between inventory cost and stock-out. But the scholar also got about setup cost and asset specificity cost involved. When MTS, some components are processed in advance. If customers don't order the products using the components, the components loss is the asset specificity cost. Kerkkänen (2007) did a case study for a steel manufacturer. Considering the specificity of steel industry, if the manufacturer stored every types of steel, inventory cost increased; however, if the manufacturer stored only some basic types of steel, to cut the steel into a certain size, material loss was created. Rajagopalan (2002) utilized holding cost and setup cost. Teimoury et al. (2012) and Jewkes and Alfa (2009) located the CODP where to balance the customer order fulfillment delay cost, holding cost and the cost of disposing unsuitable items. The customer order fulfillment delay cost considers the time effect in the cost. Unsuitable item cost is the cost similar with the asset specificity cost.

In a global supply chain, more costs have to be considered. The transportation cost(Rao et al., 2000; Meixell and Gargeya, 2005; Teimoury et al., 2012) is important where build a supply chain, but Teimoury et al. (2012) did not apply the transportation cost in the CODP determination. Import tax and currency exchange loss(Meixell and Gargeya, 2005) are also special cost occurring in a global supply chain. We defined import tax and currency cost as finance cost.

4.3.2 Demand

In MTS the customer demand is determined through forecasting. The demand determines how orders meet customer's preference in MTO strategy. Fisher (1997) thought understanding the nature of demand was the first step to build a supply chain. Demand also plays an important role on CODP positioning. Three characteristics describe demand. They are demand volume, demand variance and demand variety.

Demand volume

Demand volume is the total number of demand for a certain product. The more one product is affected by a high demand, the more it makes sense to meet it via MTS, and vice versa(Perona et al., 2009). As demand volume goes up, the CODP goes to the downstream of supply chain (Teimoury et al., 2012). Wang et al. (2010) compared demand volume with production lot. If demand volume is not smaller than the least production lot, the product can be produced to customer order. Rajagopalan (2002) indicated that lower demand items should be MTO and higher demand items should be MTS, but the highest demand items were MTO.

Table 4.2: Cost structure on CODP determining

Cost	Literature
Material cost	Akkerman (2010)
Operation cost	Akkerman (2010)
Holding cost	Arreola-Risa and DeCROIX (1998); Sun et al. (2008) Rajagopalan (2002); Teimoury et al. (2012) Kerkkänen (2007); Jewkes and Alfa (2009)
Backorder cost	Arreola-Risa and DeCROIX (1998); Sun et al. (2008)
Customer order fulfillment delay cost	Teimoury et al. (2012); Jewkes and Alfa (2009)
Material loss	Kerkkänen (2007)
Setup cost	Sun et al. (2008); Rajagopalan (2002)
Asset specificity cost	Teimoury et al. (2012); Jewkes and Alfa (2009) Sun et al. (2008)
Transportation cost	Meixell and Gargeya (2005); Rao et al. (2000) Teimoury et al. (2012)
Finance cost	Meixell and Gargeya (2005)

Demand variance

Demand variance is a more important attribute than demand volume to describe demand because the predictable demand is more important where locate the CODP. The irregular demand will have an upstream effect on the CODP position(van Donk, 2001). Giesberts and van der Tang (1992) held the view that uncommon order size should be MTO. Sun et al. (2008) and Perona et al. (2009) agreed that greater demand variability led to MTO. Olhager (2003); Köber and Heinecke (2012a) stated the relative demand volatility(RDV) as one of two major factors affecting the CODP positioning. It is equal to the standard deviation divided by the average of the demand. If the RDV is low, the product is fulfilled from stock.

Demand variety

Product variety should be considered during BTO supply chain development (Miemczyk and Howard, 2008). Olhager (2003) pointed that a wide product range shifted the CODP to upstreams so customer delivery time became longer. The great finished product variety is an important characteristic in food industry CODP determining(van Donk, 2001).

4.3.3 Time

Though customer delivery time is a performance measure, it is also used as a decision variable in some studies. When the customer delivery time is longer, materials or components tend to MTO(Sun et al., 2008). Olhager (2003) and Köber and Heinecke (2012b) applied a ratio between production leadtime(P) and delivery leadtime(D). If the P/D is less than 1, that means delivery leadtime is longer than production leadtime, so it is better to use MTO.

The cost of setup time is represented as setup cost. In some cases, researchers use setup time instead of setup cost. If the setup time is long, MTS strategy is superior to MTO strategy(Rajagopalan, 2002).

4.3.4 Capacity

Rajagopalan (2002) presented that processing capacity available was a part of the MTS/MTO decision and the lot size function. The high processing rate can be regarded as the high capacity. The high capacity would improve the performance of MTS/MTO determining(Teimoury et al., 2012). The expected order completion delay decreases versus the processing rate growth. The expected number of semi-finished products also decreases because the customer demand is well-satisfied.

4.4 Operational decisions

Soman et al. (2004)'s hierarchical framework displayed the capacity co-ordination and scheduling & control at the tactical level and the operational level, respectively. These are operational decisions because they emphasize on the medium-term or the short-term operations. MTO order acceptance policy, due date policies for MTO products, lot sizes for MTS products, production volumes and sequence are determined in the operational decisions.

Soman et al. (2007) extended the framework with more details. His MTO-MTS short-term batch-scheduling heuristic focused on the incorporation of MTO and MTS items. The objective is to minimize the overall makespan and the product list(containing MTO and MTS items) follows the earliest due date. The inventory policy for MTS items is the order up-to S policy. Federgruen and Katalan (1999) designed interruption disciplines for MTO-MTS items which is about scheduling. Absolute Priority rules (preemptive-resume and nonpreemptive-resume) and Postponable Priority rules were compared. If the setup time is small, the preemptive priority is optimum, so MTO items are produced immediately when the order is placed. If the setup time is large, the Postponable priority is superior, so the MTO item will delay a certain time period before being produced.

On the aspect of order acceptance, Wang et al. (2011) thought if works-in-process(WIP) was smaller than the maximal WIP, the order would be accepted, otherwise rejected.

Inventory policy is an important part in the operation decision; however, in some researches, the optimum inventory level is analyzed when determining the CODP. For example, in Jewkes and Alfa (2009) and Teimoury et al. (2012)'s research, the optimum semi-finished goods inventory buffer size is determined in the objective function which also determines the CODP. The optimum semi-finished goods inventory buffer size is the inventory level at the CODP. Akkerman (2010) determined the number and composition of intermediate products in the CODP which assumed that CODP was determined before. They only got the optimum value, namely, the inventory level, but didn't offer a certain stock policy.

Silver et al. (1998) introduced four kinds of inventory policies: (s, Q), (s,S) with continuous review and (R,Q), (R,s,S) with periodic review. For the periodic review, it allows reasonable prediction of the level of the workload on the staff involved in, while the continuous review requires less prediction. Three categories items, A, B, and C, are mentioned. A items account 20 percent of the total number of items but make up 80 percent of the dollar sales volume. B items comprise roughly 30 percent of the items but represent 15 percent of the dollar sales volume. A items are fit for (s, S) and (R,s,S) policy, while B items are fit for (s,Q) and (R,S) policy. The optimum order quantity and optimum period review time can be estimated through EOQ. The base-stock policy is also a common policy.

Perona et al. (2009) linked the inventory policies with the CODP position. If the CODP is at the finished stage, the inventory policy can be (R,S) policy or monthly rolling based on the number of customer orders. The CODP at the finished stage means that the supply chain is pure MTS, so periodic review inventory policy with good prediction is cost-saving. If the CODP is at the intermediate stage, the inventory policy can be lot-for-lot or (R,S) policy. If the CODP is at the raw material stage, the inventory policy can be lot-for-lot or EOQ because of the sales volume.

4.5 Techniques

4.5.1 Analytical models

An analytical model pursues a monetary objective function. To minimize the total cost is the most common objective; however, the decision variables are different in certain problems.

Jewkes and Alfa (2009) and Teimoury et al. (2012) defined the cost as the function of the semi-finished goods buffer and the amount of processing to take place at the supplier. They calculated the optimal value with a direct search heuristic method. Assigning the amount of processing to take place at the supplier a range of value and fixing the semi-finished goods buffers help to find the smallest total cost.

Arreola-Risa and DeCROIX (1998) minimized the average cost per unit. The objective function is convex but not continuous, so the difference between two neighboring values is used to find the optimum value. When the difference is zero or the smallest, that is the optimum one.

Lagrange multiplier is one of the optimization methods. Rajagopalan (2002) minimized the inventory costs of the MTS items subject to a service constraint for MTO items. Wang et al. (2011) put the cost matrices and transition matrices as the inputs to the dynamic programming model for solving the Markov Decision Process model.

Akkerman (2010) used two mixed-integer linear programming(MILP) model to optimize the total cost of raw material costs and the mixing operation costs. Two boolean variables are in the cost function. If the raw material is used, mixing is necessary, the value of variables are 1, otherwise, they are 0. As one type of linear programming, relevant constraints have to be taken into account. Sun et al. (2008) applied the mixed-integer linear programming model as well. The researcher studied the multiple CODPs in a supply network, so the only boolean variable is to represent MTO/MTS decisions of components. As the CODP separates the MTS and MTO, this method is reasonable. In particular, it performs well when multi CODPs exist or the CODP is determined in a supply network. It is suitable for our project.

4.5.2 Simulation-based models

In Perona et al. (2009)'s research, the simulation-based model evaluated the performance and analyzed sensitivity. After created a framework, he compared the performance of pre-framework solution and post-framework solution through the simulation model, and tested the model with different input date. Köber and Heinecke (2012b) simulated the model on the view of System Dynamics. Thus, the negative or positive effects of performance measures can be found during simulation.

Wang et al. (2011) built the simulation model for the operational decisions with Flexsim. The replenishment policy, order admission control and so on were determined in the simulation model.

4.5.3 Frameworks

The assumptions of numerical solution limit their applicability to real cases though analytical models give important insights(Perona et al., 2009).Therefore, frameworks are necessary to solve some problems, especially for real cases. Frameworks are popular in certain industries or case studies, because scholars can make decisions according to the natures of industries or cases; however, general frameworks are also presented by some researchers.

Olhager (2003), Zaerpour et al. (2008),Perona et al. (2009) and Wang et al. (2010) designed frameworks for general situations. The Fuzzy theory and SWOT analysis are involved in Zaerpour et al. (2008)'s framework. Perona et al. (2009) grouped the products based on the number of customer orders, sales volume, the number of production order and production volume. Then made decisions for different groups. Wang et al. (2010) studied the CODP on three dimensions. The stages with customization attributes are the CODP candidates. After the candidates are mapped, the CODP can be determined by the position of the process map. Olhager (2003)'s framework is classical. The demand variance, processing time and delivery time are denoted as decision variables.

Olhager (2003)'s framework is used as the phase 1 in Köber and Heinecke (2012b)'s framework, which is designed for an agricultural machinery manufacturer. Then the Pareto rule and a simulation model are applied on phase 2 and phase 3, respectively. van Donk (2001) considered the market characteristics and process characteristics in his framework for food industry, and took a case as an example. Soman et al. (2004) also worked on the food industry but he focused on the hierarchical framework based on the frequencies of events. Kerkkänen (2007) emphasized on a steel mill. This specific framework studied the grade of steel based on the technical and market requirements, production volume, and feasibility criteria. The market requirements showed similarity with van Donk (2001)'s framework and the production volume had similarity with Perona et al. (2009)'s framework, because these factors are important on the CODP determining. Miemczyk and Howard (2008) classified four scenarios based on two dimensions: pull/push strategy and high/low growth as they are critical aspects on managing global auto operations.

4.6 Conclusions

The CODP separates the MTS and MTO and balances the total cost and the customer delivery time, which means that the performance of whole supply chain is improved. Therefore, determining the CODP is meaningful for a supply network. This paper investigates the variables of CODP determination and relevant techniques. For the performance measurements, the total cost and the customer delivery time are the most important indicators. The factors which impact the CODP positioning are cost structure, characteristics of demand, time and capacity, while the former three are more significant. Among the techniques, analytical models and frameworks are used more often to determine the CODP and relevant operational decisions, and the simulation-based model is more frequently applied to evaluate the performance.

To solve a real case, building a framework is a better choice because the framework can describe the real situation of the case better. However, an analytical model may be used as a part of framework. When we create a framework, multiple factors are considered such as demand and time, and the final objective is to optimize the cost and leadtime. After the CODP is determined, simulation-based model would not only offer the evaluation of supply chain performance, but can also be used for the sensitivity analysis. If some parameters affect the performance of supply chain much, we should deal with them carefully; otherwise, this may be a risk for the company.

Chapter 5

Input Analysis

The most important inputs in the project are demand, Bill of Material, processes and costs. The demand analysis is based on the history data from 2010 to 2012 in the three factories. The demand quantity below is the total demand in three years. The processes of revolving doors are from the Netherlands factory. According to the record in Netherlands factory, we have the BOM of revolving doors and barriers. The processes of B3 are from the USA factory, while the processes of B1 and B2 are missing because the Netherlands factory does not decouple the assembly process. The relevant costs are obtained from the three factories.

5.1 Demands

5.1.1 Characteristics

As we mentioned in Section 3, the demand volume is small while the demand variety is large (see 3.1). If we regard products with different configurations as different classes if they are in the same product family, there are 119 classes of RD2 and 108 classes of RD1 based on the history data from 2010 to 2012 in Netherlands factory. The biggest demand volume of a class in the RD2 family is 11 units, and that in the RD1 family is 15 units. Thus, the yearly demand is no more than 5 for all classes. Similar situations can be found in the barrier product families.

The demand variance is large. Take a product in the RD1 family as an example. If the product number is 1, the diameter is 1000 mm, the height under canopy (HUC) is 2200 mm, the canopy is 200 mm and the finish is RAL 9010 30%, we would find that one product was ordered in March 2010, four in June 2010, one in January 2011, six in December 2011, one in July 2012 and two in August 2012. In the rest of months, the demand volume is zero. No trend pattern can be detected in the history data.The similar situations can be found in other product families.

If we apply the framework created by Olhager (2003), the ratio of demand mean to demand variance is small, thus the products are supposed to MTO. See details in Section 4. The current situation is MTO and there is a belief that this can be improved if the CODP is moved downstream. If we draw a conclusion that the products should be MTO, it is against the belief. Hence, we aggregated the demands to conduct demand forecasting.

5.1.2 Aggregation Rules

The key principle is detecting the similarities in a product family so that the different products in a family can be aggregated together. Then the demand volume becomes larger. The most popular aggregated product is defined as standard unit. The customized products are the extension of standard unit through assembling add-ons. The steps of aggregation are as follows

- Figure out the most sensitive configurations.
- Aggregate the less sensitive configurations.

- Find the popular configurations.
- Decide the relative standard configurations.

5.1.3 Aggregation results

RD1

After discussed with the product manager, we defined the ceiling, profiles, canopy, dustcover, as standard modules while control panels, security systems, lighting, glass, finish, junctions were defined as add-ons.

The most sensitive configuration is diameter; namely, if the diameter changes, the whole product will change. Thus the most sensitive configuration should be fixed. The diameter with 1000 mm accounts for 65%, and the diameter with 1500 mm occupies 32.8%. The percentage of two diameters in total is 97.8%, so the rest value of diameters is not considered. The HUC can be aggregated. We can determine a standard height for HUC. If customers prefer a height which is lower than the standard height, we can cut the HUC to the preferred height. Similar rules can be applied in the canopy size. If the HUC is less than or equal to 2300 mm, it occupies 83.5% of the products with the 1000 mm and the 1500 mm diameters. If the canopy size is less than or equal to 300 mm, it accounts for 88.1% of that. Therefore, the standard configurations are:

- diameter=1000 mm, HUC=2300 mm, canopy= 300 with the total demand 174 which occupies 57.4%.
- diameter=1500 mm, HUC=2300 mm, canopy= 300 with the total demand 50 which occupies 16.5%.

The most important add-on modules are finish and security systems. When we analyze the data in all Circlock products, the percentage of normal steel finish is 89.7%,followed by the stainless steel finish(8.3%) and unfinished(2.3%). Because of the high occupation of normal steel finish, we will not take other finishes into account. The security system with weight sensors takes up 48.7% (147 units), while the rest(StereVision, one-zone contact mat, two-zone contact mat and so on) occupies 52.3%. Hence, the components and materials of the normal steel finish and the security system with weight sensors can be prepared in advance but assembled depending on customization.

RD2

After discussed with the product manager, we defined the ceiling, profiles, canopy, wings, pivot as standard modules while finish, security systems, matwell trim, lighting, glass,control panel, junctions were defined as add-ons.

The most sensitive configurations are the number of wings and diameter.The products with four wings occupies 91.23% while the product with three wings accounts for 8.77%, so we do not consider the three-wing products. The percentage of the diameter with 1600 mm is 15.9%, and that of the diameter with 1800 mm is 56.9%. The HUC which is less than or equal to 2300 mm seizes 73.9%. The canopy size which is less than or equal to 300 mm takes up 90.4%. Therefore, the standard configurations are:

- 4 wings, diameter = 1800 mm, HUC = 2300 mm, canopy = 300 mm with the total demand 134 which occupies 33.6%
- 4 wings, diameter = 1600 mm, HUC = 2300 mm, canopy = 300 mm with the total demand 44 which occupies 11.1%.

The aggregated results of RD2 are not as good as that of RD1. The total percentage(44.7%) is less than 50% which means a low level of standardization.

The most important add-on modules are finish and security systems. The percentage of normal steel finish is 74.4% in all RD2 products. The percentage of stainless steel finish is 23.3% in all

RD2 products. Because of the high occupation of normal steel finish, we will not take other finishes into account. The security system with weight sensors takes up 71.2%(284 units), while the rest occupies 29.8%. Hence, the components and materials of the stain finish and the security system with weight sensors can be prepared in advance but assembled depending on customization.

B1

The lane width and the frame length differentiate a B1 project. When the lane width varies, it is not only the width of glass changes, but also the drive and internal mechanical structure change, so the demand with different width and length cannot be aggregated.

Demand of the Asian Market The length with 1650 mm occupies 23.5%, and the length with 1946 mm takes up 70.1%. The rest values of length is neglected because of their small occupation. However, the width varies much. The width with 500 mm occupies 13.5%. The width with 600 mm takes up 29.1%. The percentage of the width with 550 mm is 15.2% and the percentage of the width with 650 mm is 13%. In total they cover 70.8%. The rest of 29.2% is hard to analyze owning to many variants.

Therefore, the popular configurations are:

- length = 1946 mm, width = 600 mm with the total demand 94 which occupies 17.4%.
- length = 1946 mm, width = 500 mm with the total demand 74 which occupies 13.5%.
- length = 1946 mm, width = 650 mm with the total demand 62 which occupies 11.5%.

We cannot find a dominating configuration in the Asian Market.

Demand of the European Market The checklist of B1 in Europe is different from that of in Asia. The frame height and length are fixed. Two standard options are in the width: 500 mm (56.7%) and 900 mm (18.8%). Therefore, the standard configurations are:

- width = 500 mm with the total demand 247 which occupies 56.7%.
- width = 900 mm with the total demand 82 which occupies 18.8%.

Demand of the American Market Similarly, B1 in the USA factory has two types: wide version (width = 900 mm) and normal version (width = 500 mm). Nevertheless, the demand quantity is not large.

- width = 500 mm with the total demand 16 which occupies 56.7%.
- width = 900 mm with the total demand 4 which occupies 18.8%.

The configurations in the European Market and the American Market are the same so the demands can be summed up .

B2

The important configurations to determine a B2 product are the lane width , the glass height and the frame length. The lane width and the frame length are sensitive configurations for barriers, so the demand of different width cannot be aggregated. However, the glass height more than 900 mm can be aggregated after discussed with the product manager. When the height is more than 900 mm, the top frame is different the height equal to 900 mm.

Demand of the Asian Market The length with 1375 mm, 1395 mm and 1946 mm occupies 24.9%, 42.4% and 24.9%, respectively. The height with 900 mm and more than 900 mm takes up 39.5% and 30.5%, respectively. The percentage of the width with 550 mm, 510 mm and 610 mm is 39%, 32.2% and 11.9%, respectively.

Therefore, the popular configurations are:

- length = 1395 mm, width = 510 mm, height = 900 mm with the total demand 24 which occupies 13.6%.
- length = 1395 mm, width = 510 mm, height > 900 mm with the total demand 23 which occupies 13%.
- length = 1395 mm, width = 610 mm, height > 900 mm with the total demand 21 which occupies 11.9%.
- length = 1375 mm, width = 550 mm, height > 900 mm with the total demand 43 which occupies 24.3%.
- length = 1946 mm, width = 550 mm, height = 900 mm with the total demand 21 which occupies 11.9%.

The situation is similar with the demand of B1 in the Asian Market. There is no dominating preferences of customers.

Demand of the European Market The percentage of the length with 1375 mm, 1390 mm and 1395 mm is 18.7%, 43.6% and 33.3%. The height with more than 900 mm occupies 81.9%, followed by the height with 900 mm (18%). The width with 550 mm has the biggest percentage(56.9%), while the width with 510 mm and 910 mm has smaller percentage (18.4% and 15.8%). It seems that the configuration with length = 1390 mm, heigh > 900 mm and width = 550 mm is the most popular one, but the width = 550 mm excludes the combination of length = 1390 mm and height > 900 mm.

Therefore, the standard configurations are:

- length = 1390 mm, height > 900 mm, width = 510 mm with the total demand 189 which occupies 22.2%.
- length = 1375 mm, height > 900 mm, width = 550 mm with the total demand 144 which occupies 16.9%.
- length = 1395 mm, height > 900 mm, width = 510 mm with the total demand 146 which occupies 17.2%.

Though some configurations such as length = 1390 mm, width = 550 mm and height > 900 mm is dominating, they cannot combine together. Finally, there is also no dominating configurations.

Demand of the American Market Four types of B2 are produced in the USA factory. The data on frame length is missing.

- height = 900 mm, width = 510 mm with the total demand 27 which occupies 43.5%
- height > 900 mm, width = 510 mm with the total demand 12 which occupies 19.4%.
- height = 900 mm, width = 910 mm with the total demand 8 which occupies 12.9%.
- height > 900 mm, width = 910 mm with the total demand 15 which occupies 24.2%.

The first version is the most popular one, but the volume is small.

B3

The most important two configurations are frame height and lane width. The product with different height and different width cannot be aggregated. Compared with B1 and B2, B3 is more standard.

Demand of the European Market The length with 1018 mm takes up 96.67%, and the width with 500 mm occupies 95.2%. Therefore, the standard configuration is:

- length = 1018 mm, width = 500 mm with the total demand 929 which occupies 93.6%.

Demand of the American Market B3 is also standard in the American Market. The frame length is always 1212 mm and the lane width is 500 mm. However, the demand is small which is 98 from 2010 to 2012.

Therefore, the standard configuration is

- length = 1212 mm, width = 500 mm with the total demand 98 which occupies 100%.

5.1.4 Distributions

Because the demand volume is small, if we study demand in month or quarter, the volume is too small to research. Thus, we use the yearly average demand as the demand in the next year. Though the demand might increase, it is difficult to forecast precisely the demand in the next year when demand variance is large. The possible distributions are Normal distribution and Poisson distribution according to different mathematical models.

In Table 5.1, product families perform different characteristics in different markets. The demand of B2 in the Asian and European Market still has large variety and small quantity after be aggregated. The demand of RD1, RD2, B1 and B3 in the European Market performs better. There are dominating configurations and the quantity is far more larger. The demand of B1 in the Asian Market has a medium size of volume.

Table 5.1: Demand summary

Product family	Market	Configuration(millimetre)	Yearly demand	Standard deviation
RD1	Europe	1. diameter=1000 , HUC=2300 , canopy= 300	57.7	7.02
		2. diameter=1500, HUC=2300, canopy= 300	16.7	7.02
RD2	Europe	1. 4 wings, diameter =1800 , HUC = 2300, canopy = 300	44.7	0.58
		2. 4 wings, diameter = 1600, HUC = 2300, canopy = 300	14.7	5.13
B1	Europe	1. width = 500 mm	82.3	27.4
		2. width = 900 mm	27.3	7.77
	Asia	1. length = 1946, width = 600	31.3	42.25
		2. length = 1946, width = 500	24.7	16.46
		3. length = 1946, width = 650	20.7	12.12
	America	1. width = 500	5.3	1.53
		2. width = 900	1.3	2.31
B2	Europe	1. length = 1390, height > 900, width = 510	63	68.79
		2. length = 1375, height > 900, width = 550	48	15.87
		3. length = 1395, height > 900, width = 510	48.7	48.52
	Asia	1. length = 1395, width = 510, height = 900	8	3.61
		2. length = 1395, width = 510, height > 900	7.7	5.51
		3. length = 1395, width = 610, height > 900	7	6.56
		4. length = 1375, width = 550, height > 900	14.3	8
		5. length = 1946, width = 550, height = 900	7	12.12
	America	1. height = 900, width = 510	9	3
		2. height > 900, width = 510	4	5.29
		3. height = 900, width = 910	2.7	3.06
		4. height > 900, width = 910	5	5.57
B3	Europe	1. length = 1212, width = 500	309.7	151.12
	America	1. length = 1212, width = 500	32.7	22.23

5.2 Bill of Material

Bill of Material indicates the relationship between materials and processes and the material quantity changing. It also helps us estimate the manufacturing cost in each step.

5.2.1 Revolving doors

The BOM records how materials are used in different machines in the company (See Figure 5.1 and Figure A.1). Usually, BOM displays the quantity relationship how materials are merged in different steps. However, in Company A, no components are merged before assembly. They are processed into certain sizes and shapes to prepare for assembly, so the material quantity do not change before assembly. How components change in the assembly is not recorded in the database because the company does not describe assembly in detail.

The BOM of coated revolving doors is different from that of stainless one. The names of blocks in the Figure 5.1 and Figure A.1 are the names of machines. The figures in the bracket means that the quantity of that material used. The figures without bracket is the number of materials used. Then we will see the components processing paths are complicated.

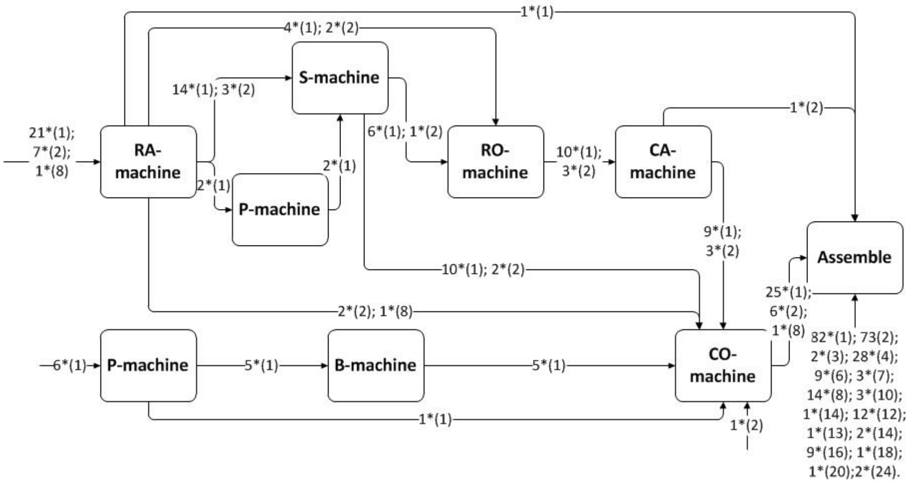


Figure 5.1: The BOM of RD1(coated version)

5.2.2 Barriers

The components of barriers are processed by suppliers and how components are used in the assembly is not recorded. The BOM only shows components used in the assembly but without detailed quantity relationship.

5.3 Processes

5.3.1 Revolvling Doors

The processes of RD1 and RD2 are the same; however, the components and configurations are different. See processes details in Figure B.1. Nevertheless, the demand of stainless steel is small and the electrical production is independent, hence we do not consider the paths of stainless steel doors and electrical production (See Figure 5.2). Note that the numbers are the index of each step.

Setup time, processing time and capacity are important factors to understand the processes. "Own component supply 1" and "Own component supply 2" are looked as set-up. In addition, "Own component supply 5", "Own component supply 6" and "Own component supply 8" are set manually, and tools are necessary to be change in the "Own component supply 4", "Own component supply 5" and "Own component supply 7". The company never record the setup time precisely. The technical chief advised the value of setup time for each step as 15 minutes. The details can be found in Appendix C.1. We assume that all processing time and setup time follow Exponential distribution. Specially, "Own component supply 1" and "Own component supply 2" do not have the setup time. However, they take place once a batch, so the processing time of these processes can be also regarded as the setup time.

5.3.2 Barriers

The processes of barriers only contain "Assembly". The processes of B3 can be found from the USA factory (See Figure 5.3). Unfortunately, the processes of B2 and B1 cannot obtained from the Netherlands factory. We hardly assume that the processes of B3 are similar with those of B2 ans B1. Moreover, we do not have the data how components assemble from the USA factory, which makes the manufacturing cost in each step hard to estimate. The missing processes and relevant data require us to apply a model different from the revolving doors. Thus, when we

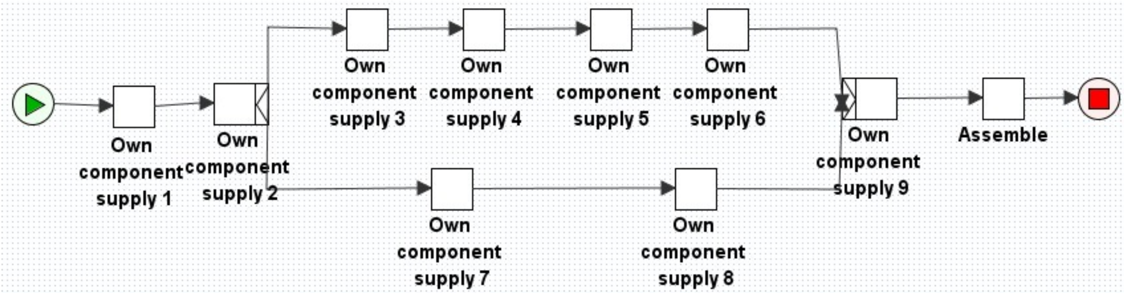


Figure 5.2: The Processes of RD1 and RD2

analyze barriers, we will regard the processes as an integration. The processing times of barriers can be seen in Table D.1.

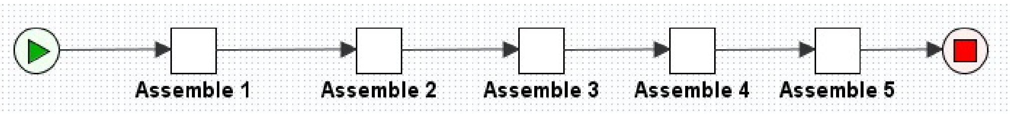


Figure 5.3: The Processes of B3

5.4 Costs

The costs in the revolving door model are not the same as the costs in the barrier model. The costs of revolving door model are setup cost, inventory holing cost, stock-out cost, and asset specificity cost. In the barrier model, the costs include inventory holding cost, asset specificity cost and customer order fulfillment delay cost. The processes of barriers do not have setup time, thus setup cost is zero. The stability condition ensures that the items never be stock-out, and then stock-out cost is also neglected. Because the barrier model does not have any constraints of leadtime, the customer order fulfillment delay cost is applied to realize time effect. More details can be seen in Chapter 6. To calculate the inventory holding cost, stock-out cost and asset specificity cost, the cumulative manufacturing cost has to be calculated first.

5.4.1 Manufacturing cost

The manufacturing cost is the cost of efficient production. We calculate the manufacturing cost in each step as:

$Manufacturing\ cost = Component\ cost + Labor\ cost$

If no new components are processed in that step, the manufacturing cost is equal to labor cost.

Revolving doors Because the China factory and the USA factory do not produce RD1 and RD2, we assume that the component cost are the same and the only difference is the labor cost.Though the costs of different configurations are a little different, we will neglect it because the cost deviation is small. Denote M_i as manufacturing cost(See Table 5.2).

Barriers Because there is only "assembly" in the processes, the manufacturing cost of barriers are calculated as the total manufacturing cost without specific manufacturing cost in different steps of the process.. The costs are separated into the cost per basic unit and the cost per intermediate. As the processing rates of barriers are the aggregated result of basic unit and intermediate processing rates, we will also aggregate the manufacturing costs. After we did statistics for the

Table 5.2: The manufacturing cost of revolving doors in the Netherlands factory(Unit: EUR/unit)

Doors	Own component supply 1 (M_1)	Own component supply 2 (M_2)	Own component supply 3 (M_3)	Own component supply 4 (M_4)	Own component supply 5 (M_5)
RD1	0.06	0.06	368.29	112.5	112.5
RD2	0.06	0.06	539.79	84.38	84.38
	Own component supply 6 (M_6)	Own component supply 7 (M_7)	Own component supply 8 (M_8)	Own component supply 9 (M_9)	Assemble (M_{10})
RD1	112.5	222.04	478.13	231.05	7322.99
RD2	56.25	237.56	84.38	231.05	6697.08

demand of barriers in the China factory, the number of basic unit is 178 and the number of intermediate is 341. The ratio is around 1/2. The data from the USA factory does not show details of basic unit and intermediate. Thus, we suppose one third of demand is basic unit and two thirds of demand is intermediate in the China factory and the USA factory. The manufacturing cost of barriers is already the average cost, and then we keep it as it is. Then we obtain the manufacturing costs(See Table 5.3).

Table 5.3: The manufacturing cost of barriers(Unit: EUR/unit)

	The USA factory	China factory	Netherlands factory
B1	0	7489.77	4226.16
B2	0	5371.56	6359
B3	4475.15	0	2745

5.4.2 Setup cost

When workers set up machines and tools, they spend time which would be used into efficient production. Thus, the setup cost is estimated as a sort of labor cost. The unit of setup cost is EUR/batch. The formula is:

$Setup\ cost = Setup\ time * Hourly\ labor\ cost$

The hourly labor cost in Netherlands factory is 56.25 EUR. The hourly labor cost in the USA factory is 67.71 USD, which is equal to 54.17 EUR (1 USD = 0.8 EUR). The labor cost of a worker in China factory is 25 CNY, which is equal to 3.13 EUR (1 CNY = 0.125 EUR), while the labor cost of an engineer is 35 CNY (4.38 EUR).

Revolving doors Because "Own component supply 1" and "Own component supply 2" happen once a batch, we look the whole processes as "Setup". After "Own component supply 2", the settings of "Own component supply 3", "Own component supply 4" and "Own component supply 7" change automatically, so the setup times are assumed as 0.001 (near 0).

Barriers Because only assembly is involved in the processes and no setup time is spent in the assembly, the setup costs are 0.

5.4.3 Inventory holding cost

Inventory holding cost is the cost to keep inventory in stock. To estimate the holding cost, we should know cumulative manufacturing cost because the holding cost is a rate of cumulative manufacturing cost.See Table 5.4 to find the cumulative manufacturing cost of revolving doors. About barriers, we define that the cumulative manufacturing cost is the cost from the beginning of assembly to the CODP. The manufacturing cost in other markets can be seen in Table E.1 and Table E.2. Denote the holding cost per unit per unit time in step i as h_i, r as the cost of having one euro an item tied up in the inventory for a unit time interval (EUR/EUR/unit time). Then,

$$CM_i = \sum_{j=1}^{i} M_j$$

if M_j are the manufacturing cost of ancestors.

$$h_i = r * CM_j$$

In the company, the inventory cost is estimated as 60 euro/m^2/month. According to the dimension of finished products, we can estimate the number of products being stored in a square meter, and then obtain the yearly inventory cost of a finished product. r is the yearly inventory cost of a finished product divided by its total manufacturing cost. The yearly inventory cost per finished product can be seen in Table 5.5.

Table 5.4: The cumulative manufacturing cost of revolving doors in the Netherlands factory(Unit: EUR/unit)

Doors	Own component supply 1 (CM_1)	Own component supply 2 (CM_2)	Own component supply 3 (CM_3)	Own component supply 4 (CM_4)	Own component supply 5 (CM_5)
RD1	0.06	0.11	368.41	480.91	593.41
RD2	0.06	0.11	539.79	624.17	708.54
	Own component supply 6 (CM_6)	Own component supply 7 (CM_7)	Own component supply 8 (CM_8)	Own component supply 9 (CM_9)	Assemble (CM_{10})
RD1	705.91	222.15	700.28	1637.24	8960.23
RD2	764.79	237.56	321.94	1317.78	8105.52

Table 5.5: The yearly inventory cost of a finished product(Unit: EUR/unit)

	RD1	RD2	B1	B2	B3
Yearly unit inventory cost	360	360	360	180	180

Revolving doors The output of "Own component supply 1" and "Own component supply 2" cannot be defined as production unit. Thus after execute these processes, there should be not inventory. The possible locations which have inventory are seen in Figure 5.4.

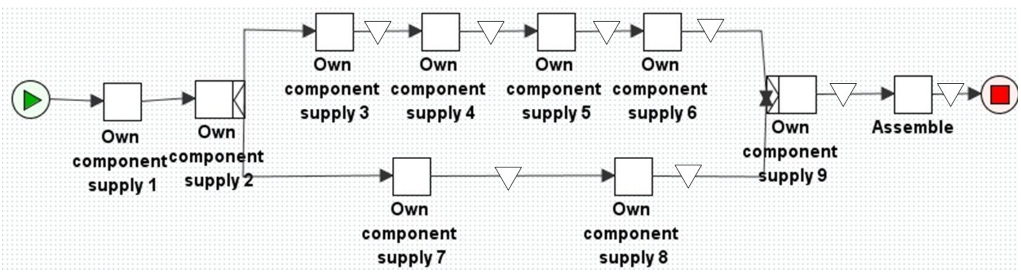


Figure 5.4: The inventory positions of the revolving door process are marked by triangles

Barriers Production units are not decoupled in the assembly. We look the CODP as the unique inventory location.

5.4.4 Stock-out cost

The stock-out cost is the cost that orders are not delivered on time. There are two sorts of stock-out: backlog and absolute loss. After some time delay, customers might accept or reject orders. If customers accept orders finally, it is backlog. If customers reject orders, it is absolute loss. To estimate the stock-out cost, we should know cumulative manufacturing cost because the stock-out cost is a rate of cumulative manufacturing cost. The stock-out cost is only applied in the revolving door model because of the requirement of model. Instead, we consider customer order fulfillment delay cost in the barrier model.

Denote p_i as the stock-out cost per unit per unit time in step i, b_i as the backlog cost in step i, l_i as the absolute loss cost in step i, γ as the probability of backlog, and $1-\gamma$ as the probability of absolute loss. Then the equation is:

$$p_i = \gamma(b)_i + (1-\gamma)l_i$$

Initially, we assign $0.5CM_i$ to b_i, $1CM_i$ to l_i, 0.8 to $Pr(b)$ and 0.2 to $Pr(l)$. However, we will vary the their values when do sensitivity analysis.

5.4.5 Customer order fulfillment delay cost

Customer order fulfillment delay is the time from accepting orders to delivering orders. The longer customers wait for their orders, the higher the customer order fulfillment delay cost is. The delay cost is only applied in the barrier model.

$$C_W = V\frac{8}{PT}$$

if the time unit is day because working hour per day is 8 hours. PT is the processing time. V is the product value.

5.4.6 Asset specificity cost

We define asset specificity cost as significant fixed investments that are unique to a particular transaction and cannot be redeployed easily for other applications or other products or other users without degrading productivity, yield or value (Sun et al., 2008). Once materials are deployed into a component or a product, it cannot be reused and the risk of loss becomes larger.The relative demand variance(RDV) affects asset specificity cost. Denote a_i as the asset specificity cost in step i per unit, σ as the standard deviation of demand, and μ as the mean value of demand. Thus we calculate the cost as:

$$a_i = CM_i\frac{\sigma}{\mu}$$

5.4.7 Transportation cost

All products are shipped by sea. The types of container are 40 DC(L*W*H = 12.01*2.33*2.38 m^3) and 40 HC(L*W*H = 12.01*2.33*2.69 m^3). Though the sizes are a little different, the cost are the same. We obtained the dimensions of product packages. However, the dimensions are the finished products. If we ship the semi-finished products, the dimensions are supposed to be smaller. The unit transportation cost of revolving doors in each step is calculated as

$$t_i = CM_i\frac{transportation\ cost\ of\ finished\ goods}{manufacturing\ cost\ of\ finished\ goods}$$

Table 5.6: The transportation cost (Unit: EUR/unit)

	The USA - China	China - The Netherlands	The Netherlands - The USA
Per shipment (40 DC/ 40HC)	3750.45	3279.99	2954.39
B1	117.19	99.94	92.32
B2	93.75	82	73.65
B3	44.64	38.07	35.17
RD1	301.62	266.5	240.41
RD2	313.34	276.75	249.62

5.4.8 Finance cost

Finance cost is the total cost of insurance and custom tax. It is only involved in the global supply chain context. After interviewed with a manager in the company, we will estimate the rate as 10%. Finance cost exists only under the global context. Denote f_i as the finance cost per unit in step i. Therefore,

$$f_i = 0.1 * CM_i$$

Chapter 6

Model Formulation

Because the data for barriers are not as complete as the data of revolving doors, the analytical models of the two doors are different. Due to insufficient data of the barrier production processes and the materials in each step, we analyzed the processes from a different viewpoint. To determine the CODP for revolving doors, we used 0-1 integer programming which cites the model in Sun et al. (2008), and to detect the optimum CODP for barriers, we applied Markov Chain and Queueing theory which cites the model in Jewkes and Alfa (2009).

6.1 Revolving doors

The costs we considered in the model are setup cost, holding cost, stock-out cost,and asset specificity cost as defined in Chapter 5. As the CODP goes downstream, the setup cost decreases because the number of setups in a MTS system is smaller than that of a MTO system and the stock-out cost decreases as well because orders can be planned in advance to avoid stock-out. The delay of a MTO system is longer than that of a MTS system, but we cannot know the delay before the CODP is determined in this model, thus the delay cost is not measured. The holding cost and the asset specificity cost increase. The unit holding cost increases in the downstream, thus with the same demand, the inventory holding cost increases. The semi-finished products are difficult to be redeployed in the downstream, and then the asset specificity cost goes up. Also , the transportation cost and finance cost are involved in the global model. The transportation of semi-finished products should be smaller than the finished products owning to smaller dimensions, and the finance cost of semi-finished products should also be smaller owning to the smaller product value, therefore transportation cost and finance cost increase as the CODP goes downstream.

Consequently, the setup cost and the stock-out cost cause the CODP to go downstream, and the holding cost, the asset specificity cost, the transportation cost and the finance cost cause the CODP to go upstream. According to these results, we expect to find a trade-off among all the costs.

6.1.1 Assumptions

Currently, RD1 and RD2 are only produced in the Netherlands factory. If we analyze the global production, the costs and processing time should be assumed in the model. After did fit testing for the demands, the demands follow Normal distributions.

- Demands follow Normal distributions.
- Each process has infinite production capacity.
- Orders follow the rule "first come first serve".
- The processing times in different factories are the same.

- The component costs in different factories are the same.
- A customer orders one product per order.

6.1.2 Notations

The following notation was used in the model:

1. Nodes, the number of steps in the production processes.
2. i, step index, $i \in Nodes$.
3. λ, the mean demand per time period.
4. σ, the demand standard deviation.
5. SS_i, the safety stock in step i. $SS_i = \lambda PT_i + z\sqrt{PT_i\sigma^2}$ after taking the safety stock into account.
6. PT_i is the production leadtime of step i.
7. I_i is the inventory cost of step i. $I_i = h_i \int_0^{SS}(SS - d)f(d)dd$ where h_i is the holding cost per production unit per unit time in step i, d is the demand volume, and $f(d)$ is the demand probability distribution.
8. O_i mean stock-out cost in step i. $O_i = p_i \int_{SS}^{+\infty}(d - SS)f(d)dd$ in the MTS system. p_i is the unit stock-out cost per production unit per unit time in step i. $p_i = \gamma b_i + (1 - \gamma)l_i$ where b_i is the backlog cost per production unit per unit time, and l_i is the absolute loss cost per production unit per unit time, and γ is the probability of backlog.
9. S_i, production setup cost. Denote K_i as the setup cost per order, and OI_i as the order interval. $OI_i = \sqrt{2K_i/h_i\lambda}$. Then $S_i = K_i/OI_i$ if it is MTS, and $S_i = K_i\lambda$ if it is MTO.
10. A_i represents asset specificity cost in step i. $A_i = CM_i\lambda\frac{\sigma}{\lambda}$, where CM_i is the cumulative manufacturing cost(in the first factory under the global context).
11. T_i stands for the transportation cost in step i. $T_i = t_i\lambda$ where t_i is the transportation cost per production unit.
12. F_i is the finance cost in step i. $F_i = f_i\lambda$, where f_i is the finance cost per unit which is equal to $0.1CM_i$
13. DT is the customer leadtime.
14. x_i is a boolean variable therefore its value is 0 or 1. $x_i = 1$ if step i is MTO, and $x_i = 0$ if step i is MTS. Then X $= [x_1, x_2, x_3, ...]$ is the variable vector.
15. $PT(\mathrm{X})$ is the production time of finished products. $PT(\mathrm{X}) = x_iPT_i$.

6.1.3 Basic model

Theoretically, "make-to-order" or "make-to-stock" describes components instead of processes. As the BOM is complicated and the number of materials is large, it is very difficult to track all of materials. Hence, we analyzed the processes instead of BOM. In the next, MTO/MTS refers to the components finished in different steps.

The features of production processes of revolving doors include large step numbers and existing steps in parallel. Hence, it is possible to have multi CODPs. The 0-1 linear programming is the methodology used to solve the possible multi CODPs situation. In this case, it is possible to choose either of two strategies for each step: MTS or MTO. The choice of strategy is viewed as a binary option. If the boolean variable times relevant costs is applied to minimize the total cost, the results will reveal which step should be MTS/MTO.

The relevant costs for both MTS and MTO are summarized in Table 6.1. Note that the basic model excludes transportation cost and finance cost.

Table 6.1: The costs involved in MTO and MTS

Symbol	Cost	MTO	MTS
S_i	Setup cost	$K_i\lambda$	K_i/OI_i
I_i	Inventory holding cost	0	$h_i \int_0^{ED}(ED-q)f(q)dq$
O_i	Stock-out cost	0	$p_i \int_{ED}^{+\infty}(q-ED)f(q)dq$
A_i	Asset specificity cost	0	$CM_i\lambda\frac{\sigma}{\lambda}$
Total cost	The sume of above costs	TC^{MTO}	TC^{MTS}

The total supply chain cost includes the cost of MTO and the cost of MTS. The objective was to minimize the total supply chain cost. Thus, the problem can be formulated as follows.

$$TC = min\sum_{i=1}^{10}(TC^{MTS} + x_i(TC^{MTO} - TC^{MTS}))$$

subject to $PT(\text{X}) \leq DT$, $x_{i+1} - x_i \geq 0$, $(x_2 - x_3)(x_2 - x_7) = 0$, $x_{11} = 1$.

$x_{i+1} - x_i \geq 0$ because when $x_i = 1$, x_{i+1} is impossible to be 0. MTO being at the upstream of MTS is infeasible. The up bound of i is 10 because there are 10 steps. x_{11} is a variable to ensure the constraint $x_{i+1} - x_i \geq 0$ make sense. The CODP cannot be just after "Own component supply 2" and the steps after "Own component supply 2" are MTO because "Own component supply 2" is the step to set machines. It is not meaningful to change settings of machine but do nothing in the next, thus $(x_2 - x_3)(x_2 - x_7) = 0$.

6.1.4 Global model

Global model takes transportation cost and finance cost into account. The products are produced in the first factory and then delivered to the second factory. The formula of transportation cost and finance cost calculation is displayed in Chapter 5. Transportation cost and finance cost execute on the boundary of MTS and MTO instead of all the MTS steps. The inventory cost, stock-out cost and asset specificity cost only exist in the MTS system. Hence, the unit holding cost, unit stock-out cost and unit asset specificity cost are the ratio of manufacturing cost in the first factory. Note that the labor costs of two factories are different, resulting in the difference of unit setup cost. MTS system takes place in the first factory, thus the unit setup cost is calculated based on the labor cost in the first factory. MTO system happens in the second factory, thus the unit setup cost is computed based on the labor cost in the second factory.

$$TC = min\sum_{i=1}^{10}(TC^{MTS} + x_i(TC^{MTO} - TC^{MTS}) + (x_{i+1} - x_i)(F_i + T_i))$$

subject to $PT(\text{X}) \leq DT$, $x_{i+1} - x_i \geq 0$, $(x_2 - x_3)(x_2 - x_7) = 0$, $x_{11} = 1$.

6.2 Barriers

We analyzed the CODP of barriers through two models. The first model was a basic model and the second model was the global context model. The basic model is the scenario that products are produced in one factory. The global context model is the scenario that barriers are produced in two factories. θ is the percentage of completion. The upstream of CODP processing rate to finish a whole product is μ. Meanwhile, the unsuitable item could be discarded owning to demand variance. The cost is the asset specificity cost which has been explained in Chapter 5. As θ goes up, the cost will also increase. $\phi(\theta)$ is the probability of unsuitable items discarded. Then $\phi(\theta) = b\theta$ where $b = \frac{\sigma}{\lambda}$. Because the factory only produces θ % of products, the MTS processing rate is $\delta\mu(1-\phi)/\theta$, where δ is the ratio of MTS processing rate to MTO processing rate. If the MTO production is in the same factory, $\delta = 1$. If the MTO manufacturing is in another factory, $\delta \neq 1$ but remains positive.

The customer order fulfillment delay might decrease as θ increases for the production time from the CODP is shorter, but it might increase if no suitable items are in stock. The number of semi-finished products in the CODP might go down as θ grows, because unit holding cost increases and we prefer to store less items. The number of unsuitable items is proportional to θ.

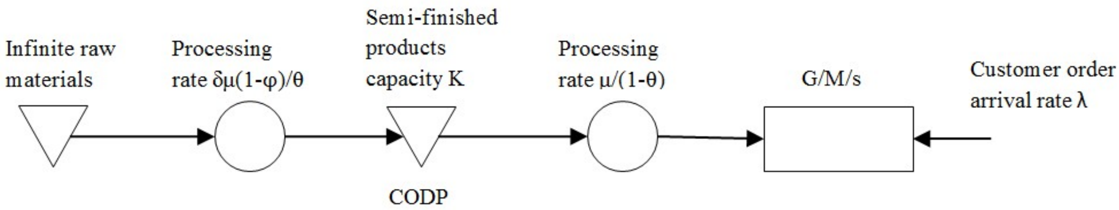


Figure 6.1: The CODP model of barriers

6.2.1 Assumptions

We applied Markov chain and Queueing theory to analyze the model. Some important assumptions are involved in. Because we only have the yearly demand of last three years, we cannot do any fit testing. Thus, we make assumptions for the demand distributions.

- The waiting space for customer orders is unlimited.
- Customer orders arrive at a Poisson rate λ.
- Customer orders are served on a first come first serve basis.
- Customer orders are processed at a Exponential rate μ.

6.2.2 Notations

The following notations were used for the mathematical formulation of the considered model:

1. i, the number of customers in the system waiting for a finished product.
2. j, the number of semi-finished product at the CODP.
3. θ, the percentage of completion.
4. K, the optimal storage capacity of semi-finished products.
5. μ, the processing rate of MTO.
6. δ, the ratio of the MTS processing rate to MTO processing rate.
7. λ, the customer order arrival rate.
8. V, the value of a finished product. If it is in the global context model, V_1 is the value of a finished product in the first factory and V_2 is the value of finished product in the second factory.
9. $V(\theta)$, the value per unit of semi-finished products(EUR/unit). $V(\theta) = V\theta$

10. $\phi(\theta)$, the probability of unsuitable items discarded.

11. C_U, the factor of cost of disposing an unsuitable item. The cost of disposing an unsuitable item per unit is $C_U V(\theta)$.

12. C_H, the factor of holding cost of a semi-finished product. The holding cost of a semi-finished product per unit is $C_H V(\theta)$.

13. C_W, the cost of customer fulfillment delay(EUR/unit/unit time). $C_W = V\frac{8}{PT}$ if the time unit is day because working hour per day is 8 hours. PT is the processing time.

14. C_T, the transportation cost of a finished product(EUR/unit).

15. C_F, the factor of finance cost. The finance cost per unit is $C_F V(\theta)$. It is fixed to 0.1.

16. $E(S)$, the expected number of semi-finished product.

17. $E(W)$, the mean customer order fulfillment delay.

18. $E(U)$, the expected number of unsuitable items.

6.2.3 Basic model

For the basic model, we considered the continuous time Markov chain $\{(i,j), i \geq 0, 0 \leq j \leq K\}$. See the state transition diagram in Figure 6.2. Because of the complicated state transition, we divided the diagram into blocks based on the number of customer orders, thus the number of blocks was infinite. Each block can transfer and only transfer the state between its neighbors and itself. When i increases by 1, the rate is λ. When i decreases by 1, the rate is b, where $b = \frac{\mu}{1-\theta}$. When the number of customer orders do not vary, that is the internal transition of a block and the rate is a, where $a = \frac{\delta\mu(1-\phi(\theta))}{\theta}$, and then we have the generator matrix Q. In the block, the states transfer with the change of the number of semi-finished product, resulting in the number of states in the block is $K+1$, namely, the dimensions of matrix B, A_0, A_1 and A_2 are $(K+1)\times(K+1)$.

$$\mathrm{Q} = \begin{bmatrix} \mathrm{B} & \mathrm{A}_0 & & & \\ \mathrm{A}_2 & \mathrm{A}_1 & \mathrm{A}_0 & & \\ & \mathrm{A}_2 & \mathrm{A}_1 & \mathrm{A}_0 & \\ & & \ddots & \ddots & \ddots \end{bmatrix}$$

where

$$\mathrm{B} = \begin{bmatrix} -(\lambda+a) & a & & & \\ & -(\lambda+a) & a & & \\ & & \ddots & \ddots & \\ & & & -(\lambda+a) & a \\ & & & & -\lambda \end{bmatrix},$$

$$\mathrm{A}_1 = \begin{bmatrix} -(\lambda+a) & a & & & \\ & -(\lambda+a+b) & a & & \\ & & \ddots & \ddots & \\ & & & -(\lambda+a+b) & a \\ & & & & -(\lambda+b) \end{bmatrix},$$

$$\mathrm{A}_2 = \begin{bmatrix} 0 & \mathbf{0} \\ \mathrm{I}b & \mathbf{0} \end{bmatrix}, \mathrm{A}_0 = \mathrm{I}\lambda.$$

Before analyzing the steady state, we made sure the Markov chain met the stability conditions. Let $\mathrm{A} = \mathrm{A}_0 + \mathrm{A}_1 + \mathrm{A}_2$. Then we know that A is a generator matrix with its associated stationary distribution $\pi = [\pi_0, \pi_1, \pi_2, ..., \pi_K]$. It is a $1 \times (K+1)$ vector because A refers to the number of

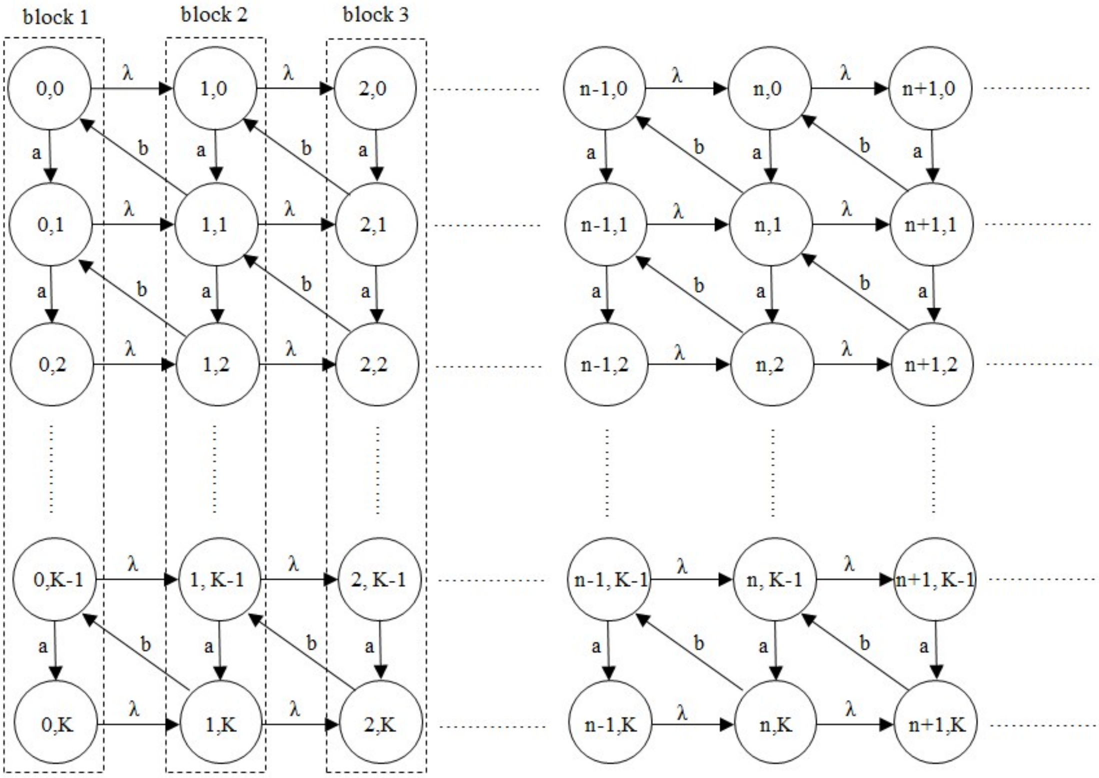


Figure 6.2: The State transition diagram of barriers model

semi-finished products. To calculate π, we had $\pi \mathrm{A} = 0, \pi \mathbf{1} = 1$. Let $\rho = \frac{\delta(1-\theta)(1-\phi)}{\theta}$ which is the ratio of MTS processing rate to MTO processing rate. Then $\pi = \frac{1-\rho}{1-\rho^{K+1}} \left[1, \rho, \rho^2, \rho^3, ..., \rho^K\right]$ (Kulkarni, 2011). To make the system stable, the MTO processing rate should exceed the customer arrival rate, and the MTS processing rate was to be higher than the MTO processing rate. The Markov chain was positive recurrent if $\pi \mathrm{A}_2 \mathbf{1} > \pi \mathrm{A}_0 \mathbf{1}$. Thus, we obtained the stability condition as $\lambda(1-\rho^{K+1}) < \frac{\mu}{1-\theta}\rho(1-\rho^K)$. After reducing, the stability condition became

$$\lambda < \frac{1-\rho^K}{1-\rho^{K+1}} \frac{\delta\mu(1-\phi)}{\theta}.$$

The steady state helped us determine the expected number of semi-finished products, the expected number of unsuitable items and expected customer order fulfillment delay. Let $\mathbf{x} = [\mathbf{x_0}, \mathbf{x_1}, \mathbf{x_2}, ...]$. The dimension of vector $\mathbf{x}$ is $1 \times \infty$ as the capacity of waiting space is infinite. The result was as follows

$$\mathbf{x}\mathrm{Q} = 0, \mathbf{x}\mathbf{1} = 1.$$

The number of customer orders changed one from $\mathbf{x_i}$ to $\mathbf{x_{i+1}}$. In the steady state, the "movement" in the space from $\mathbf{x_i}$ to $\mathbf{x_{i+1}}$ was constant according to the matrix geometric theorem. The movement is represented by R. We had as follows

$$\mathbf{x_{i+1}} = \mathbf{x_i}\mathrm{R}$$

Because of $\mathbf{x}\mathrm{Q} = 0$, $\mathbf{x_i}\mathrm{A}_0 + \mathbf{x_{i+1}}\mathrm{A}_1 + \mathbf{x_{i+2}}\mathrm{A}_2 = \mathbf{x_i}\mathrm{A}_0 + \mathbf{x_i}\mathrm{R}\mathrm{A}_1 + \mathbf{x_i}\mathrm{R}^2\mathrm{A}_2 = 0$, with $i \geq 1$, it can be reduced as

$$A_0 + RA_1 + R^2A_2 = 0.$$

The spectral radius of R written as $sp(R)$. Only if $sp(R) < 1$, the Markov chain was stable. R was calculated by the iterative approach given as

$$R(n+1) = -(A_0 + R(n)^2A_2)A_1^{-1},$$

until $|R(n+1) - R(n)|_{i,j} < \epsilon$ with $R(0) = \mathbf{0}$. In the boundary, the vector $\mathbf{x_0}$ was computed from $\mathbf{x_0}B + RA_2 = 0$. After being normalized, the equation became

$$\mathbf{x_0}(I - R)^{-1}\mathbf{1} = 1.$$

The mean number of customer orders in the system including the one being served was $E[L] = \sum_{i=0}^{\infty} i\mathbf{x_i} = \mathbf{x_1}\sum_{i=1}^{\infty} iR^{i-1}$. When i is big enough, R^i was near zero, so it can be neglected. After reducing the equation, we obtained

$$E[L] = \mathbf{x_1}(I - R)^{-2}\mathbf{1}.$$

Based on Little's Law, the expected customer order fulfillment delay was

$$E[W] = E[L]/\lambda.$$

The expected number of semi-finished products should be $\sum_{j=1}^{K} j * p_j$ where p_j is the probability of j semi-finished products are in stock. Then the expected number of semi-finished products in the system was as follow

$$E[S] = \mathbf{x_0}(I - R)^{-1}\mathbf{v}$$

where $\mathbf{v} = [0, 1, 2, ..., K]^T$.

Once an unsuitable item was discarded, the number of semi-finished item was always less than K, so the expected number of unsuitable semi-finished items discarded per unit time was the probability when the number of semi-finished item was less than K times the probability of unsuitable items times MTS processing rate. The number of semi-finished item can be expressed as follows

$$E[U] = (1 - Pr(j = K))\phi(\theta)\frac{\delta\mu}{\theta}.$$

The objective was to minimize the total cost to find the optimum θ^* and K^*. The following costs were involved:

- The expected costs of customer order fulfillment delay.
- The expected holding costs of semi-finished products.
- The expected costs of asset specificity.

Hence the objective function was

$$min_{\theta,K}TC(K,\theta) = min_{\theta,K}(C_UV(\theta)E[U] + C_HV\theta E[S] + C_WE[W]),$$

subject to

$$0 < \theta < 1.$$

The algorithm to optimize the total cost is:

1. Set the initial value of TC_{opt} as a large value.
2. Assign K as i. i is a positive integer.

3. Vary the value of θ from 0.01 to 0.99.
4. If $TC < TC_{opt}$, $TC_{opt} = TC$.
5. Set K as $i + 1$.
6. Repeat step 3, 4 and 5 until TC_{opt} is stable.

6.2.4 Global model

Under the global context, more costs should be taken into account. The main two costs were shipment cost and finance cost. If the CODP went upstream, the dimensions of products were small, the unit shipment cost was small because a container can load more items. Meanwhile, the finance cost was also smaller than that of the finished products because product value was smaller. Thus, both two costs are relevant to θ. In addition, the MTO and MTS processing rate, and the manufacturing costs in two factories might be not the same. Hence, δ might not be 1, and C_W should be delay cost in the second factory as $V_2\frac{8}{PT_2}$, where V_2 was the product value and PT_2 was the processing time in the second factory. Therefore, the objective function is:

$$min_{\theta,K}TC(K,\theta) = min_{\theta,K}(C_U V_1(\theta)E\left[U\right]+C_H V_1(\theta)E\left[S\right]+C_W E\left[W\right]+C_T\theta E\left[S\right]+C_F V_1(\theta)E\left[S\right]),$$

subject to

$$0 < \theta < 1.$$

The algorithm is the same as the basic model.

Chapter 7

Verification & Validation

7.1 Revolving doors

Two paths are in the revolving door processes. The first path is "Own component supply(OCS) 1 (i=1) - Own component supply 2 (i=2) - Own component supply 3 (i=3) - Own component supply 4 (i=4) - Own component supply 5 (i=5) - Own component supply 6 (i=6) - Own component supply 9(i=9) - Assemble (i=10)". The second path is "Own component supply 1 (i=1) - Own component supply 2 (i=2) - Own component supply 7 (i=7) - Own component supply 8 (i=8) - Own component supply 9(i=9) - Assemble (i=10)". When discussing the expected costs, figures were displayed in both Path 1 and Path 2. We would see how setup cost, inventory cost, stock-out cost, asset specificity cost and total MTS/MTO cost vary with i.

The inputs are: $\lambda = 50$, $\sigma = 5$; $M_i = 100$ if $i = 1, 2, ..., 9$; $M_{10} = 1000$; $K_i = 2.5$ where $i = 1, 2, ..., 10$; $h_i = 0.2CM_i$; $p_i = 0.8b_i + 0.2l_i$ where $b_i = 0.5CM_i$, $l_i = CM_i$; $t_i = 100\frac{CM_i}{CM_{10}}$; $DT = 15$. The leadtimes are in Table 7.1

Table 7.1: The production leadtimes

i	1	2	3	4	5	6	7	8	9	10
Step	OCS1	OCS2	OCS3	OCS4	OCS5	OCS6	OCS7	OCS8	OCS9	Assemble
Leadtime	2	2	2	2	2	2	2	2	2	5

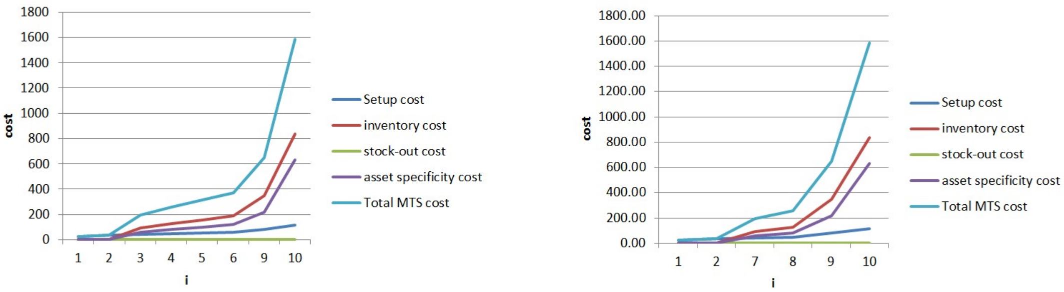
Figure 7.1 shows the relevant costs in the MTS system. As i goes up, all costs except stock-out cost go up in both Path 1 and Path 2. In the downstream of supply chain, the product value becomes larger, thus the unit holding cost increase. The leadtimes of each step except "Assemble" are 2 days, and then the safety stocks are the same. Therefore, inventory cost increases. The leadtime of "Assemble" is 5 days. To avoid stock-out, the safety stock is larger than other steps. Then we can see the inventory cost increases dramatically when $i = 10$. The increasing of asset specificity cost is similar because safety stock is consistent while the unit asset specificity cost increases. As the unit holding cost increases, order interval becomes smaller, resulting in the increasing of setup cost. Due to small probability of stock-out, the stock-out cost is near zero. All most of all costs have an increasing trend, thus the total cost also increases.

Figure 7.2 shows the relevant costs in the MTO system. In the MTO system, inventory cost, stock-out cost, asset specificity cost are zero. Hence the total cost is equal to setup cost. Setup cost is stable at the value of 125 euro. Because the setup times of each step are 0.25 hours, the setup cost should be stable.

When $i = 1$ and $i = 2$, the total MTS cost is smaller than the total MTO cost. As i increases, the situation reverses in both Path 1 and Path 2. The setup cost when $i = 1$ and $i = 2$ in the MTO system is not dominating to determine the CODP. Therefore, the point where two total cost curves across should be the CODP because we can obtain the minimal cost; namely, the CODP shold be after "OCS2 ($i = 2$)" and before "OCS4 ($i = 3$)" or "OCS7 ($i = 7$)". After run the model, we have the result as follow

$$X = [0, 0, 1, 1, 1, 1, 0, 1, 1, 1],$$

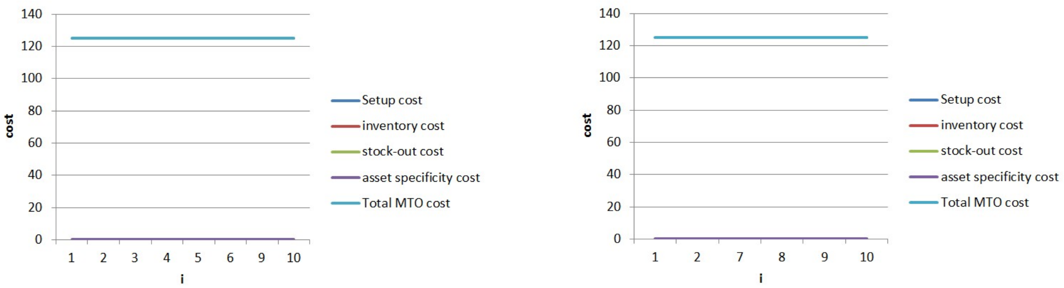
which is the same as our expectation. Therefore, the model shows correct situation and trend of reality.



(a) Expected costs on Path 1

(b) Expected costs on Path 2

Figure 7.1: The expected costs of MTS in the revolving door model



(a) Expected costs on Path 1

(b) Expected costs on Path 2

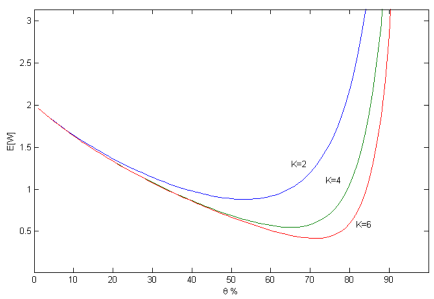
Figure 7.2: The expected costs of MTO in the revolving door model

7.2 Barriers

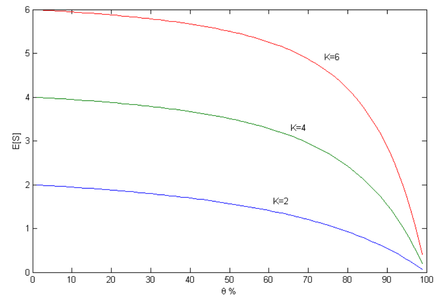
We are interested in seeing how K and θ affect the expected customer order fulfillment delay, the expected semi-finished products at the CODP and, the expected number of unsuitable items. The relationships between K, θ and relevant costs are also discussed. The inputs are: $\lambda = 0.5$, $\mu = 1$, $\phi(\theta) = 0.5\theta$, $\delta = 1$, $C_H = 0.2$, $C_W = 1$, $C_U = 1$, $C_T = 0.2$, $CF = 0.1$, $V(\theta) = \theta$.

As θ goes up, the expected customer order fulfillment delay slightly goes down and then dramatically goes up (Figure 7.3.(a)). When the CODP is at the very beginning, customers have to wait long time to get their order, so the fulfillment delay is long. When the CODP is near the end of the supply chain, the warehouse at the CODP cannot provide enough semi-finished products, therefore, the customer order fulfillment delay is long as well. The number of semi-finished products in the stock is relatively stable because the arrival rate of suitable semi-finished products is relatively stable. However, as the θ grows, the rate that the number of semi-finished products increasing 1 becomes smaller, which means that the number of semi-finished products is more difficult to increase, resulting in the number of semi-finished products keeps in a low level, so the inventory decreases(Figure 7.3.(b)).The percentage of completion increases, products have less possibilities to be customized, and then the loss of semi-products unable to meet the customer demand goes up. Thus, the number of unsuitable semi-finished products goes up(Figure 7.3.(c)).

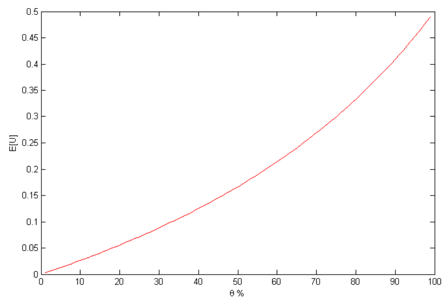
The increase of K contributes to more suitable semi-finished products, so customer order fulfillment delay is shorter(Figure 7.3.(a) & (b)). No matter how K changes, the rate of unsuitable items will not change, so no difference can be found with different K(Figure 7.3.(c)).



(a) Expected customer order fulfillment delay



(b) Expected number of semi-finished products

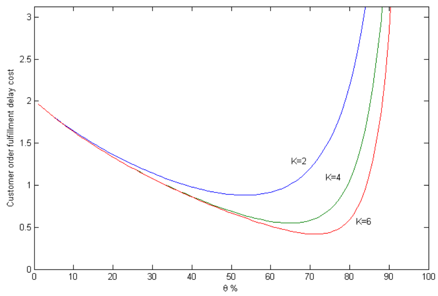


(c) Expected number of unsuitable items

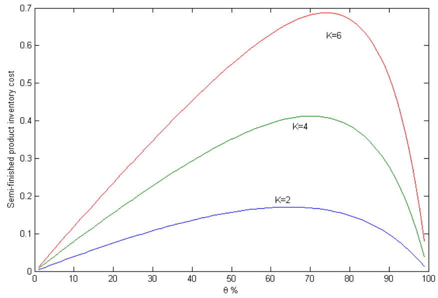
Figure 7.3: The expected numbers in the barrier model

After getting the expected numbers times unit cost, we obtain the relevant costs in the model. They are customer order fulfillment delay cost, semi-finished product inventory cost, asset specificity cost, transportation cost and finance cost. The unit cost of fulfillment delay is a constant in the basic model and changes slightly in the global model, so the trend of the cost should be almost the same as the trend of fulfillment delay(Figure 7.4.(a)). The expected number of semi-finished products decreases mildly when θ is not that big while the unit holding cost always increases with θ and K, so the aggregated result is increasing. When θ is big, the effect of semi-finished product number makes a bigger difference, and then the inventory cost goes down. The similar situation happens in both transportation cost and finance cost because the unit costs grow with θ and K, which is the same as inventory cost(Figure 7.4.(b), (d), (e)). The asset specificity cost always goes up because both the unit cost and the expected number of unsuitable items increase with θ.

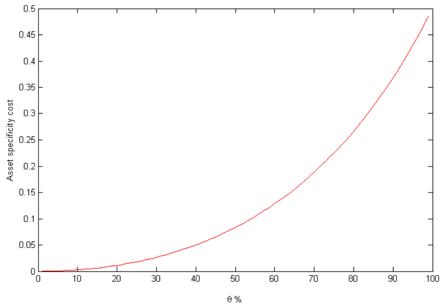
Because the unit fulfillment delay cost is big in our verification and validation input, the customer order fulfillment delay cost is dominating. Hence, after slight reduction, the total cost goes up significantly. The point before total cost goes up is the optimum cost(Figure 7.5). In conclusion, the model shows correct situation and trend of reality.



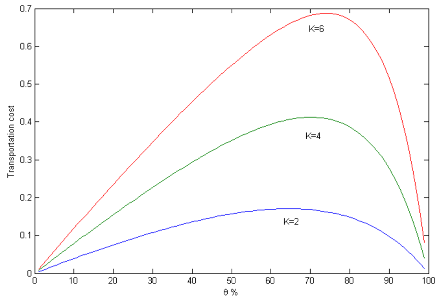
(a) Customer fulfillment delay cost



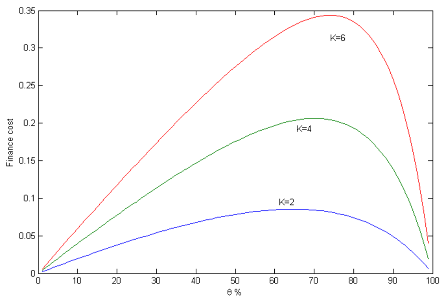
(b) Semi-finished products inventory cost



(c) Asset specificity cost per unit time



(d) Transportation cost



(e) Finance cost

Figure 7.4: The relevant costs in the barrier model

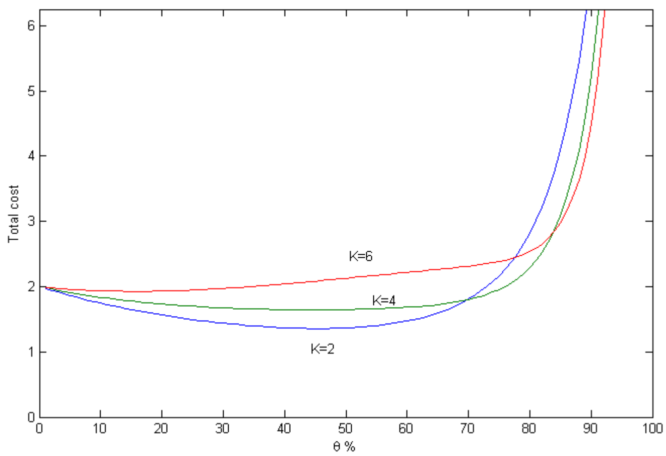


Figure 7.5: The total cost of barrier model

Chapter 8

Results

This chapter shows the results of revolving door model and barrier model. The results of revolving doors include the CODP position, production time and the total cost of each configurations. The results of barriers include the percentage of completion, optimal inventory level and the total cost. All configurations and their index mentioned below are from Table 5.1.

8.1 RD1

RD1 is only produced in the Netherlands factory. To discuss the CODP positioning, we assume that the products can also be produced in the China factory and the USA factory because the company plans to do like that. The expected demands are the same as in the European Market. The production time and customer leadtime are also the same. The company can produce CL locally as well as globally. There are three local Scenarios: producing in the Netherlands factory only, producing in the China factory only and producing in the USA factory only. There are six global Scenarios: producing in the Netherlands factory and then in the China factory and reversed, producing in the Netherlands factory and then in the USA factory and reversed, producing in the China factory and then in the USA factory and reversed.

8.1.1 Local production

Because we assume that the component costs and the demand in different markets are the same in the three factories, the difference is labor cost in the different factories for the same configuration. The demand volume and relative demand variance make a difference for the different configurations in the same factory.

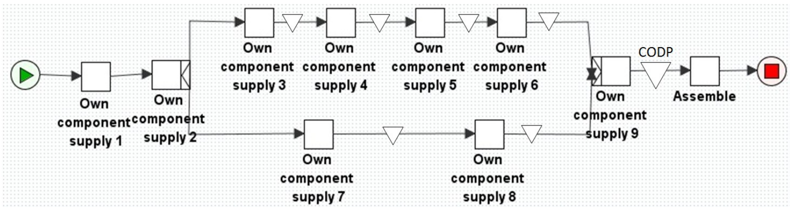
See Table 8.1. The CODP of configuration 1 is between "Own Component supply 9" and "Assemble" in the Netherlands factory and the USA factory, resulting in 5 days production time which shortens leadtime much. The CODPs of configuration 1 in the China factory are after Own Component supply 2 and after "Own Component supply 8". The leadtime is 20 days in the China factory which is 15 days ahead of original 35 days. The main reason making the CODP difference is that the setup cost in the China factory is small. Considering the sufficient capacity, MTO strategy minimizes the total cost in the China factory.

The CODPs of configuration 2 in the Netherlands factory and the USA factory are after "Own Component supply 2" and after "Own Component supply 7". The CODPs of configuration 2 in the China factory are after Own Component supply 2 and after "Own Component supply 8". The manufacturing costs of configuration 1 and configuration 2 are the same in the same factory. As a result of demand volume and relative demand variance, the CODP positioning of configuration 2 in the Netherlands factory and the USA factory is different from that of configuration 1. The effect of demand will be discussed in the sensitivity analysis.

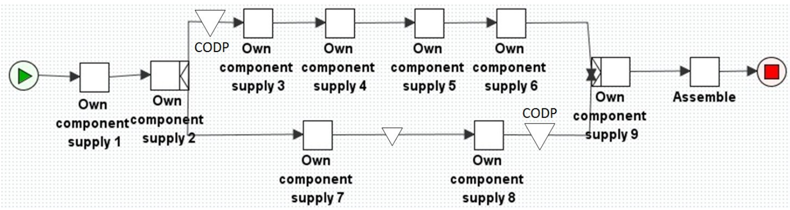
The CODPs of RD1 confifuration 1 and 2 can be seen in Figure 8.1.

Table 8.1: RD1 local production CODP determining results

Scenario	Configuration	X	PT(X)	TC^*
Netherlands	1	$[0,0,0,0,0,0,0,0,0,1]$	5	1907.04
	2	$[0,0,1,1,1,1,0,0,1,1]$	20	995.55
China	1	$[0,0,1,1,1,1,0,1,1,1]$	20	287.67
	2	$[0,0,1,1,1,1,0,1,1,1]$	20	131.67
The USA	1	$[0,0,0,0,0,0,0,0,0,1]$	5	1871.89
	2	$[0,0,1,1,1,1,0,0,1,1]$	20	965.41



(a) The CODP of RD1 confifuration 1 in the Netherlands factory



(b) The CODPs of RD1 confifuration 2 in the Netherlands factory

Figure 8.1: The CODPs in the revolving door processes

8.1.2 Global production

The patterns of the CODP position between the China factory and other two factories are simple. If the second factory is the China factory, the CODPs are after "Own Component supply 2" and after "Own Component supply 7" for both configuration 1 and 2 no matter that the first factory is at Netherlands or the USA. If the first factory is the China factory, the CODP goes downstream. The CODP of configuration 1 is before "Assemble" which shortens the leadtime to 5 days. The CODP of configuration 2 is before "Own Component supply 9" which shortens the leadtime to 8 days. The difference of leadtime is due to demand characteristics.

Let us look at the global production between the Netherlands factory and the USA factory. The CODP should be before "Assemble" for the configuration 1 when the first factory is the Netherlands factory or the USA factory. For the configuration 2, no matter which is the first factory, the CODPs are located after "Own Component supply 2" and after "Own Component supply 7".

8.1.3 Conclusion

Considering both Table 8.1 and Table 8.2, the best CODP strategy of RD1 should be as follows:

The first factory is the China factory so that the total cost is minimal. To meet the demands of the European Market, the semi-finished products are shipped from China to Netherlands. If the products are with configuration 1, they should be shipped after "Own Component supply 9"; if the products are with configuration 2, they should be delivered before "Own Component supply 9" based on our results. However, in the real situation, both CODPs being before "Own Component supply 9" might be better because the production leadtime of "Own Component supply 9" is not long but "Own Component supply 9" is easier to be customized. To fulfill the demands of

Table 8.2: RD1 global production CODP determining results

Scenario	Configuration	X	PT(X)	TC^*
Netherlands - China	1	[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]	20	471.71
	2	[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]	20	267.41
China - Netherlands	1	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	1002.41
	2	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	8	871.54
Netherlands - The USA	1	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	2066.16
	2	[0, 0, 1, 1, 1, 1, 0, 0, 1, 1]	20	1187.62
The USA - Netherlands	1	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	2028.46
	2	[0, 0, 1, 1, 1, 1, 0, 0, 1, 1]	20	1107.5
The USA - China	1	[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]	20	472.42
	2	[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]	20	268.02
China - The USA	1	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	1005.52
	2	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	8	865.16

the Asian Market, the CODPs of both configuration 1 and 2 should be after "Own Component supply 2" and after "Own Component supply 7". To meet the demands of American Market, the products are shipped from China to the USA. For configuration 1, the products should be shipped after "Own Component supply 9"; for configuration 2, the products should be delivered before "Own Component supply 9". Figure F.1 shows the CODPs in the processes.

8.2 RD2

Similar with RD1, RD2 is also produced in the Netherlands factory only. To analyze the CODPs of RD2, we do the same assumptions. The RD2 CODP positioning has 9 Scenarios as well.

8.2.1 Local production

When configuration 1 is produced in the Netherlands factory and the USA factory, the CODP is before "Assemble" with the leadtime 5 days. However, when configuration 1 is produced in the China factory, the CODPs are after "Own Component supply 2" and after "Own Component supply 7". The leadtime in the China factory is 20 days. The labor costs are different in the three factories, resulting in the CODP location difference. No matter in the Netherlands factory or the USA factory configuration 2 is produced, the CODPs are after "Own Component supply 2" and after "Own Component supply 8" with the leadtime 20 days. The reason why the CODP of configuration 2 goes upstream compared with that of configuration 1 is smaller demand volume and larger variance. The CODPs of configuration 2 in the Beijng factory are after "Own Component supply 2" and after "Own Component supply 7" with the leadtime 20 days.

Table 8.3: RD2 local production CODP determining results

Scenario	Configuration	X	PT(X)	TC^*
Netherlands	1	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	1259.25
	2	[0, 0, 1, 1, 1, 1, 0, 0, 1, 1]	20	844.48
China	1	[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]	20	216.37
	2	[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]	20	100
The USA	1	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	1235.91
	2	[0, 0, 1, 1, 1, 1, 0, 0, 1, 1]	20	8017.68

8.2.2 Global production

When the first factory is in China and the second factory is one of the other two factories, the CODPs are in the downstream of supply network for both configuration 1 and configuration 2. The CODP of configuration 1 is before "Assemble" with the leadtime 5 days, and the CODP of configuration 2 is before "Own Component supply 9" with the 8-day leadtime. When two factories are reversed, the CODPs go upstream significantly. The CODPs are after "Own Component supply 2" and after "Own Component supply 7" in Scenario "the USA-China" for both configuration 1 and 2 and in Scenario "Netherlands-China" for configuration 1 with the 20-day leadtime. The CODP is after "Own Component supply 1" in Scenario "Netherlands-China" for configuration 2 with the leadtime 25 days.

When the first factory is the Netherlands factory and the second factory is the USA factory, the CODP of configuration 1 is before "Assemble" with the leadtime 5 days; the CODPs of configuration 2 is after "Own Component supply 2" and after "Own Component supply 8" with the leadtime 20 days.

When global production happens in the USA factory first and then in the Netherlands factory, the CODP of configuration 2 is before "Assemble" with the leadtime 5 days, while the first CODP of configuration 2 is after "Own Component supply 2" and the second CODP of configuration 2 is before "Own Component supply 9" with the leadtime 20 days.

Table 8.4: RD2 global production CODP determining results

Scenario	Configuration	X	PT(X)	TC^*
Netherlands - China	1	$[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]$	20	265.06
	2	$[0, 1, 1, 1, 1, 1, 1, 1, 1, 1]$	25	112.63
China - Netherlands	1	$[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]$	5	682.57
	2	$[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]$	8	728.73
Netherlands - The USA	1	$[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]$	5	1432.3
	2	$[0, 0, 1, 1, 1, 1, 0, 0, 1, 1]$	20	864.06
The USA - Netherlands	1	$[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]$	5	1406.27
	2	$[0, 0, 1, 1, 1, 1, 0, 0, 1, 1]$	20	882.46
The USA - China	1	$[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]$	20	284.43
	2	$[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]$	20	159.64
China - The USA	1	$[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]$	5	686.37
	2	$[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]$	8	723.98

8.2.3 Conclusion

Integrated the results in Table 8.3 and Table 8.4, the best CODP strategy is as follows:

The production should start in the China factory. To meet the demands in the European Market, the semi-finished products should be shipped to Netherlands. The configuration 1 should be shipped after "Own Component supply 9" and the configuration 2 should be delivered be before "Own Component supply 9". Considering the flexibility of products, though shipment before "Own Component supply 9" cannot reach the minimal total cost for configuration 1, it might be better because "Own Component supply 9" is easy to be customized. To meet the demands in the Asian Market, the CODPs of configuration 1 should be after "Own Component supply 2" and after "Own Component supply 7", and the CODP of configuration 2 should be after "Own Component supply 1". To fulfill the demands in the American Market, the semi-finished products should be delivered from China to the USA. The strategy is the same as the strategy in the Netherlands factory. Figure F.1 shows the CODPs in the processes.

8.3 B1

B1 is produced independently in the Netherlands factory and China factory, so we will optimize the CODP in four scenarios: production in the Netherlands factory only(Netherlands), production in the China factory only(China), production in the Netherlands factory first and then China(Netherlands-China), production in the China factory first and then Netherlands(China-Netherlands). The first two are determining the CODP for current situation, and the last two are locating the CODP for a global supply network. Though there are demands in the American Market, we do not have the manufacturing costs in the USA factory and can hardly forecast the cost, so we will ignore the demands in the American Market. However, we will analyze it in the sensitivity analysis. The processing rate in both Netherlands and China is 2.4 units per day.

8.3.1 Local production

Scenario 1: Netherlands Even if we will plan the global supply network strategy, the local production in the Netherlands factory or China factory is necessary to analyze because the factories should meet the local demand. The order arrival rate of configuration 1 is 0.32 unit/day in the European Market. The optimal result can be seen in Table 8.5. The optimal K and θ are 1 and 0.6, respectively, because the total cost (1897.1 EUR) is the smallest. Thus, the CODP should go downstream. The order arrival rate of configuration 2 is 0.12 unit/day, and the optimal $K = 1$ and $\theta = 0.1$ with the total cost 1227.8. The CODP goes upstream significantly.

Table 8.5: The B1 configuration 1 optimal K and θ in Scenario 1

K	θ	$TC(K, \theta)$
1	*0.7*	*1897.1*
2	0.6	2127.2
3	0.3	2511.2
4	0.0	2572.1
5	0.0	2580.6

Scenario 2: China The order arrival rates of configuration 1, configuration 2, configuration 3 are 0.12 unit/day, 0.1 unit/day, 0.08 unit/day, respectively. The optimal results can be seen in Table 8.6. The CODP of configuration 1 is in the middle of the supply chain, while the CODPs of configuration 2 and 3 are relatively downstream.

Table 8.6: The B1 optimal K and θ in local production

Scenario	Configuration	K^*	θ^*	$TC(K^*, \theta^*)$
Netherlands	1	1	0.7	1897.1
	2	1	0.1	1227.8
China	1	1	0.4	2819.1
	2	1	0.6	2577.1
	3	1	0.7	2405.8

8.3.2 Global production

Scenario 3: Netherlands-China It shows what situation is under global context. Products are first produced in the Netherlands factory first and then shipped to China, so the demand arrival rate should be the demand in the Asian Market. In addition, the transportation cost and finance cost will affect the CODP position. In Table 8.7, the CODPs remain in the positions while the total costs increase compared with local production in the China factory.

Table 8.7: The B1 optimal K and θ in global production

Scenario	Configuration	K^*	θ^*	$TC(K^*, \theta^*)$
Netherlands - China	1	1	0.4	2670
	2	1	0.7	2365.4
	3	1	0.8	2164.4
China - Netherlands	1	1	0.1	2555.6
	2	1	0.0	2342.7

Scenario 4: China-Netherlands The optimal results in Scenario 4 are quite different. θs are very small. Hence the CODP is at the beginning and materials for one unit product are in stock.

8.3.3 Conclusion

The costs of Scenario 3 are lower than those of Scenario 4, so under a global context, the initial factory should be the Netherlands factory. The costs of Scenario 3 are also lower than those of Scenario 2. This means that the global strategy is superior to local production in China. Hence, the strategy for B1 would be initialize production in the Netherlands factory. In order to meet the demand in the European Market, one semi-finished product with 70% of completion (configuration 1) and 10% of completion (configuration 2) is stored in the warehouse. In order to fulfill the demand in the Asian Market, one semi-finished product with 40%, 70% and 80% of completion, respectively, is stored in the warehouse. Figure F.2 shows the CODPs in the processes.

8.4 B2

B2 is produced independently in the Netherlands factory and China factory; so similarly, we will also optimize the CODPs in four scenarios. The scenarios are the same as those of B1. The demands in the American Market are ignored because of the same reason as B1. The processing rate in both Netherlands and China is 2.4 units per day. The customer order arrival rates and b are calculated from Table 5.1.

8.4.1 Local production

Scenario 1: Netherlands The CODPs of configuration 1 and configuration 3 are at the upstream of supply network because $\theta = 0.1$. The number of semi-finished products in the CODP is 1. While the CODP of configuration 2 is in the middle of the supply network and the inventory is still 1.

Scenario 2: China The situations in the China factory are not as ideal as those in the Netherlands factory. The CODPs are at the beginning of the supply chain. Materials for only one product are stored in the warehouse.

8.4.2 Global production

Scenario 3: Netherlands-China The CODP positions are the same as those of local production in the China factory. The inventory levels are also 1.

Scenario 4: China-Netherlands The percentages of completion are 0 for three configurations. Compared with local production in the Netherlands factory, the CODPs go upstream.

Table 8.8: The B2 optimal K and θ in local production

Scenario	Configuration	K^*	θ^*	$TC(K^*, \theta^*)$
Netherlands	1	1	0.1	1736.1
	2	1	0.4	1629.7
	3	1	0.1	1694.7
China	1	1	0.0	1046.6
	2	1	0.0	1046.6
	3	1	0.0	1045.3
	4	1	0.0	1057.6
	5	1	0.0	1045.3

Table 8.9: The B2 optimal K and θ in global production

Scenario	Configuration	K^*	θ^*	$TC(K^*, \theta^*)$
Netherlands - China	1	1	0.0	1055.7
	2	1	0.0	1055.7
	3	1	0.0	1054.4
	4	1	0.0	1066.8
	5	1	0.0	1054.4
China - Netherlands	1	1	0.0	1766
	2	1	0.0	1722.4
	3	1	0.0	1724.3

8.4.3 Conclusion

θs in two global models are all 0. It is not reasonable to ship raw materials to the second factory and then produce because we can purchase the raw materials in the second factory. Hence, the global strategy is not suitable for B2. The best strategy would be to produce independently for local markets. In the Netherlands factory, the CODPs are at 10%, 40% and 10% of completion and one semi-finished item is stored in the warehouse. In the China factory, materials for one finished product are stored in advance. Figure F.3 shows the CODPs in the processes.

8.5 B3

B3 is produced independently in the Netherlands factory and the USA factory. We will also optimize the CODPs in four scenarios. The scenarios are similar to those of B1 and B2. They are: Netherlands only, the USA only, Netherlands-the USA, the USA-Netherlands. The processing rates in both Netherlands and the USA are 2.4 units per day. The customer order arrival rates and b are calculated from Table 5.1. Only one configuration is considered, so we make a summary for all scenarios in Table 8.10.

Table 8.10: The B3 optimal K and θ

Scenario	K^*	θ^*	$TC(K^*, \theta^*)$
Netherlands	3	0.5	3976.7
The USA	2	0.8	2991.5
Netherlands - The USA	2	0.9	2652
The USA - Netherlands	2	0.4	5155.6

8.5.1 Conclusion

The cost of Scenario 3 is lower than the cost of Scenario 2, so global production starting at the Netherlands factory is better than the local production in the USA factory. However, the global product starting in the USA factory is not better than the local production in the Netherlands factory because of higher cost. Thus, the best strategy would be to start production in the Netherlands factory. To meet the demands in the European Market, the CODP is in the middle of the supply chain (50% of completion) and 3 semi-finished items are prepared in advance. To meet the demands in the American Market, the CODP is at the end of the supply chain(90% of completion), and 2 units of semi-finished products are stored. Figure F.4 shows the CODPs in the processes.

8.6 Conclusion

In Chapter 3, we mentioned two functional requirements.

- Meeting at least 95% of customer orders.

When calculated the safety stock in the revolving door model, we applied 1.65 to meet the 95% service level. In the barrier model, the stability condition ensure that the stock-out never occurs, thus the service level can be regarded as 100%. Therefore, both models meet at least 95% of customer orders.

- The total cost of the new strategy is no more than the total cost of the current strategy.

After we got the global production cost, we compared it to the local production cost. If the global production cost is higher than the local production cost, we would keep the local strategy. For example, B2 follows local strategy.

In conclusion, the results meet the functional requirements well. The results are the best solutions based on current inputs and assumption.

Chapter 9

Sensitivity Analysis

9.1 Revolving doors

In this part, we will analyze how parameters affect X, the vector of 0/1 variables. The demand characteristics makes a difference in the CODP positioning according to many scholars' research, thus we will detect how demand volume and relative demand variance affect the CODP locating. If the leadtime is short, to avoid long delay, the CODP should be in the downstream, hence leadtime also plays a part. The relevant costs such as setup cost, production value (manufacturing cost), holding cost and backorder cost also have influence on the CODP determination. In addition, because the probability of backorder is supposed instead of applying the real data, the probability of backorder is also going to be discussed. In the global production ,the effect of transportation and finance cost will be analyzed.

The inputs are: $\lambda = 50$, $\sigma = 5$; $h_i = 0.2CM_i$; $p_i = 0.8b_i + 0.2l_i$ where $b_i = 0.5CM_i$, $l_i = CM_i$; $t_{10} = 100$; $DT = 15$; $labor\ cost_1 = 20$. The leadtimes, processing times, setup times and component costs are in Table 9.1 and the optimal result X = $[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]$ with the $leadtime = 11\ days$ and $TC = 1720.1$. When varying values of one parameter and retain others, we obtained a couple of new results. The original results are displayed in italics.

Table 9.1: The leadtimes, processing time, setup times and component costs in the sensitivity analysis

Step	OCS1	OCS2	OCS3	OCS4	OCS5	OCS6	OCS7	OCS8	OCS9	Assemble
i	1	2	3	4	5	6	7	8	9	10
Leadtime (day)	2	2	2	2	2	2	2	2	2	5
Processing time (hour)	0	0	2	2	2	2	2	2	2	10
Setup time (hour)	2	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Component cost (euro)	0	0	100	100	100	100	100	100	100	1000

9.1.1 Basic model

Demand volume and relative demand variance We vary the value of demand volume as 30, 40, 60, 70 and 80 and retain the other parameters. As the demand volume increases and the variance retains, the relative demand variance decreases. Thus, we can see how demand volume and relative demand variance work out with the volume changing in Table 9.2.

As the demand volume increases and the relative demand variance decreases, the CODP goes downstream with the production time decreasing and the total cost increasing. The larger demand volume yields the larger setup cost of MTO. To reduce the total cost, the CODP has to go downstream. It is obvious that the production time would decrease as the CODP moves backward. The demand volume increasing results in a smaller order interval, thus the setup cost of MTS per year increases. In addition, the number of items in each inventory location goes up, therefore the yearly inventory cost, stock-out cost and asset specificity cost increase. Hence, the total cost increases as the demand volume increases. In a word, the large demand volume contributes to the CODP moving backward, and the smaller relative demand variance has the same effect.

Table 9.2: Revolving door sensitivity analysis on demand volume and relative demand variance

Demand volume	Relative demand variance	X	PT(X)	TC
30	0.1667	[0, 0, 0, 1, 1, 1, 0, 1, 1, 1]	13	1083.7
40	0.125	[0, 0, 0, 1, 1, 1, 0, 1, 1, 1]	13	1471.28
50	*0.1*	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
60	0.0833	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1901.91
70	0.0714	[0, 0, 0, 0, 0, 1, 0, 0, 1, 1]	9	2038.25
80	0.0625	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	7	2142.55

In the Chapter 8, the relative demand variances of RD1 configuration 1 and 2 are the same (7.02) while demand volume of configuration 1 (57.67) is larger than that of configuration 2 (16.67), resulting in the CODP moving upstream in the Netherlands factory and the USA factory.

The relative demand variances of RD2 configuration 2 and RD1 configuration 2 are larger than those of configuration 1. Therefore, we can see the CODPs of configuration 1 are more in the downstream.

Customer leadtime Customer leadtime is the constraint for the model. As the customer leadtime goes down, to meet the constraint, the production time reduces. Meanwhile, the CODP goes downstream with the total cost increasing. As the CODP goes downstream, the inventory cost, stock-out cost and asset specificity cost increase, thus the total cost increases.

The length of leadtime plays a role on the time complexity reduction when the number of steps is large. In the model, the time complexity is $O(2^n)$ where n is the number of steps. In this case, the number of steps is 10. The original leadtime is 15 days, while the production time is 19 days if the CODP is before "Own component supply 1". Thus, x_1 and x_2 ("Own component supply 1" and "Own component supply 2") are always 0 which means MTS. Then the actual time complexity is $O(2^8)$ instead of $O(2^{10})$. If the number of steps is large, for example, 1000, while the constraint reduces the time complexity to $O(2^{500})$, it is much more efficient.

Table 9.3: Revolving door sensitivity analysis on customer leadtime

Leadtime	X	PT(X)	TC
20	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1
15	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
10	[0, 0, 0, 0, 0, 1, 0, 0, 1, 1]	9	1789.16
8	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	7	1946.26
6	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	2358.15
4	[0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0	3866.04

The customer leadtimes of RD1 and RD2 are 30 days. If the leadtime is shorter, it is obvious that the CODP would go downstream.

Labor cost We vary the value of hourly labor cost as 10, 30, 40 and 60 and keep the other parameters. Labor cost affects setup cost and manufacturing cost, and the manufacturing cost has influence on the unit holding cost, unit stock-out cost and unit asset specificity cost because the costs are a ratio of manufacturing cost. Therefore, the increasing of labor cost results in the increasing of total cost. The CODP goes downstream as the labor cost increase because the setup cost in the MTO increases significantly. To minimize the total cost, the CODP has to be backward.

The labor cost in the China factory is smaller than that in the Netherlands factory and the USA factory. Thus, the CODPs of RD1 and RD2 configuration 1 in the China factory local production are after "Own component supply 1", while the CODPs of RD1 and RD2 configuration 2 in the Netherlands factory and the USA factory local production is before "Assemble".

Table 9.4: Revolving door sensitivity analysis on labor cost

Labor cost	X	PT(X)	TC
10	[0, 0, 0, 1, 1, 1, 0, 1, 1, 1]	13	951.86
20	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
30	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	2370.97
40	[0, 0, 0, 0, 0, 1, 0, 0, 1, 1]	9	2960.34
60	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	7	4078.3

Setup cost ratio The setup cost in the revolving door model is estimated. Once the company has the accurate data, the setup cost should be modified. Thus, we should detect the setup cost effect. The setup cost ratios is defined as the modified cost divided the original cost. We vary the value of setup cost ratio as 0.5, 1.5 and 2 and retain other parameters. As the setup cost increases, the CODP goes downstream. The setup cost increases the MTO total cost by a large amount. Thus, we prefer to reduce the MTO part and increase the MTS part, and then the CODP moves downstream.

Table 9.5: Revolving door sensitivity analysis on setup cost

Ratio	X	PT(X)	TC
0.5	[0, 0, 0, 1, 1, 1, 0, 1, 1, 1]	13	978.96
1	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
1.5	[0, 0, 0, 0, 0, 1, 0, 0, 1, 1]	9	2251.67
2	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	7	2656.56

Processing time ratio We assume the processing times in different factories are the same. However, during the real production, the processing times may have deviations in different factories or even in the same factory. Processing time ratio is the ratio of new processing time to the original processing time. If the ratio is more than 1, the new processing time is longer than the original processing time. If the ratio is equal to 1, the new processing time and original processing time are equal. If the ratio is less than 1, the new processing time is shorter than the original one. Processing time affects the manufacturing cost so that also affect the inventory cost, stock-out cost and asset specificity cost in the MTS system. The longer processing time results in the higher manufacturing cost and the CODP going upstream for in the upstream the inventory cost, stock-out cost and asset specificity cost are smaller.

Component cost ratio We assume that the component costs in different factories are the same. However, in the real production this is unlikely. Similar with the processing time ratio, the component cost ratio is defined with the same rule. Because the component cost only affects the manufacturing cost which is the same as the processing time. Therefore, the component cost ratio performs similarly as the processing time on the aspects of CODP positioning and the total cost.

Table 9.6: Revolving door sensitivity analysis on processing time ratio

Ratio	X	PT(X)	TC
1.5	[0, 0, 0, 1, 1, 1, 0, 1, 1, 1]	13	1793.33
1	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
0.5	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1636.46

Table 9.7: Revolving door sensitivity analysis on component cost ratio

Ratio	X	PT(X)	TC
0.5	[0, 0, 0, 1, 1, 1, 0, 0, 1, 1]	13	1598.87
1	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
2	[0, 0, 0, 1, 1, 1, 0, 1, 1, 1]	13	1903.72
3	[0, 0, 0, 1, 1, 1, 1, 1, 1, 1]	13	2018.79

Holding cost factor The holding cost factor is varied as 0.1, 0.05 and 0.01 and other parameters are constant. The decreasing of holding cost factory leads to the CODP going downstream and the decreasing of the total cost. The smaller holding cost factor is, the smaller inventory cost is. Hence, even if the CODP is in the downstream, the total cost is not large. To optimize the total cost, the CODP goes downstream.

The holding cost factor of RD1 (0.042) is not significantly different for the holding cost factor of RD2 (0.045). Thus, the holding cost factors do not make a difference on the CODP locating.

Table 9.8: Revolving door sensitivity analysis on holding cost factor

Factor	X	PT(X)	TC
0.2	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
0.1	[0, 0, 0, 1, 1, 1, 0, 0, 1, 1]	9	1476.23
0.05	[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]	7	1261.5
0.01	[0, 0, 0, 0, 0, 0, 0, 0, 0, 1]	5	1002.73

Backorder cost factor The backorder cost is estimated as 0.5 of the manufacturing cost in the model. If we estimate the backorder cost with other methods, the value of backorder cost may be different. We would like to see how the backorder cost factor influences the CODP positioning and the total cost, thus we vary the value of the backorder cost factor and retain other parameters. As the backorder cost factor increases, the CODP position and the total cost do not change. We consider the safety stock when calculate the stock-out cost. Therefore, the probability of stock-out is small and the number of stock-out items is also small, resulting the small stock-out cost. Because the stock-out cost is too small, the CODP positioning and the total cost are not influenced.

Probability of backorder The probability of backorder is estimated as 0.8, and then the probability of absolute loss is 0.2. We vary the value of probability of backorder to gain insight about it in case the estimated value is updated. The results can be seen in Table 9.10. No differences can be found in the CODP positioning and the total cost as the probability of backorder changes. The reason is the same as the reason of backorder cost factor. The safety stock contributes to lower probability of stock-out and smaller number of stock-out items. Thus the small deviation of stock-out can be ignored.

9.1.2 Global model

The effect of global production Because of transportation cost and finance cost, the total cost increases in the global production. The CODP goes upstream in the global production. If

Table 9.9: Revolving door sensitivity analysis on backorder cost factor

Factor	X	PT(X)	TC
0.3	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1
0.5	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
0.7	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1
1	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1

Table 9.10: Revolving door sensitivity analysis on backorder probability

Probability	X	PT(X)	TC
0.8	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1
1	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1
0.5	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
0.4	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	11	1720.1

the CODP goes upstream, the transportation cost and finance cost are lower. Thus to minimize the total cost, the CODP goes upstream. However, even if the CODP forwards, the total cost still increases.

Table 9.11: The effect of global production in the revolving door model

Production	X	PT(X)	TC
Local	[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]	*11*	*1720.1*
Global	[0, 0, 0, 1, 1, 1, 0, 0, 1, 1]	13	1804.83

Labor cost ratio The labor costs in different factories are different. Labor cost ratio is defined as the ratio of the labor cost of the second factory to the labor cost of the first factory. The larger the ratio is, the larger the labor cost in the second factory is. When the labor cost in the second factory is smaller (ratio = 0.5), the CODP is in the upstream. When the labor cost in the second factory is larger (ratio = 1.5), the

Unit transportation cost The transportation cost is counted as euro per container, thus the number of items in a container is important. Because the number of items may change, unit transportation cost may also change during the real shipment. We vary the value of transportation cost as 50, 150 and 1700 and retain other parameters. The CODP moves downstream when the transportation cost is small. When the transportation cost is between 100 and 1700, the CODP does not move. When the transportation is large, the CODP goes upstream.

Table 9.12: Revolving door sensitivity analysis on labor cost ratio

Ratio	X	PT(X)	TC
0.5	$[0, 0, 1, 1, 1, 1, 0, 1, 1, 1]$	15	1001.27
1	$[0, 0, 0, 1, 1, 1, 0, 0, 1, 1]$	*13*	*1804.83*
1.5	$[0, 0, 0, 0, 0, 0, 0, 0, 1, 1]$	5	2626.11

Table 9.13: Revolving door sensitivity analysis on transportation cost

Transportation cost	X	PT(X)	TC
50	$[0, 0, 0, 0, 1, 1, 0, 0, 1, 1]$	11	1788.94
100	$[0, 0, 0, 1, 1, 1, 0, 0, 1, 1]$	*13*	*1804.83*
150	$[0, 0, 0, 1, 1, 1, 0, 0, 1, 1]$	13	1814.63
1700	$[0, 0, 0, 1, 1, 1, 1, 1, 1, 1]$	13	2005.8

9.2 Barriers

In this part, we will analyze how parameters affect K, θ and TC. In Chapter 4, we know that demand volume and variance difference relocates the CODP position, so we will vary the value of arrival rate(λ) and the ratio of demand standard deviation to demand mean(b). The later has an influence on the probability of unsuitable items(ϕ). Moreover, unsuitable item discarded cost, holding cost and delay cost also will be analyzed. In addition, under the global context, finance cost and transportation cost will change the CODP, and the ratio of processing rates between two factories are going to be discussed as well.

To do sensitivity analysis, we set the inputs as: $\mu = 2.4$, $\lambda = 1$, $b = 0.5$, $V(\theta) = 1000\theta$, $C_U = 1$, $C_H = 0.2$, $PT = 8$ so $C_W = 1000$, $C_T = 100$, $C_F = 0.1$. Then we have the optimal result: $K = 2$, $\theta = 0.3$, $TC = 591$. If it is under global context, the optimal result will be: $K = 2$, $\theta = 0.17$, $TC = 680.09$

9.2.1 Basic model

Demand volume Let us change the arrival rate to 0.6 and 1.8 and retain the other parameters, and then we obtain the results in Table 9.14. As the arrival rate increases, K, θ and TC increase. Demand increases, so more semi-finished items should be in stock in case the orders are not fulfilled on time. Workers are busy so so orders are delayed more often. The CODP goes downstream to avoid long time delay. Because K and θ increase, the holding cost and the asset specificity cost increase, so the total cost increase. K is sensitive to the demand volume, while the CODP is not that sensitive.

Table 9.14: Barriers sensitivity analysis on demand volume

λ	K^*	θ^*	$TC(K^*, \theta^*)$
0.6	1	0.29	499.85
1.0	*2*	*0.3*	*591*
1.8	3	0.4	879.7

As we have known, the CODPs of B2 in the China factory are all at the very beginning position($\theta = 0$). One of the main reasons is the small demand volume. Thus, if B2 is produced in the USA factory to meet the American demand, the CODPs should be also at the very beginning because of the small demand volume.

One of the company goals is doubling sales, so the CODP position will go downstream. Specially, if the arrival rate cannot meet the stability condition, the capacity should be expanded so that makes processing rate increase. See the stability condition in Chapter 6.

Relative demand variance To test how relative demand variance affects the results, we vary b as 0.1, 0.3 and 0.7 and remain the other parameters. Then we have the optimal results in Table 9.15. Relative demand variance has no influence on the number of semi-finished products (K remains 2), while θ changes significantly. As b decreases, θ goes up and $TC(K^*, \theta^*)$ goes down. b decreasing contributes to the lower probability of unsuitable items discarded, so the asset specificity cost decreases. To minimize the total cost, we prefer to have a smaller customer order fulfillment delay cost, so the CODP backward helps quick response to customers, and then θ increases. Because both asset specificity cost and delay cost go down, the total cost reduces. When the variance is small, the CODP location is more sensitive.

Table 9.15: Barriers sensitivity analysis on demand variance

b	K^*	θ^*	$TC(K^*, \theta^*)$
0.1	2	0.66	480.22
0.3	2	0.41	554.57
0.5	*2*	*0.3*	*591*
0.7	2	0.24	613.17

The bigger variance is, the more difficult it is to forecast demands. Hence, the products with big b drive the CODPs forward even if demand volume is big. For example, in the Asian Market, the demand volume of configuration 1 of B1 (0.12 unit/day) is bigger than that of configuration 2 (0.1 unit/day), while the relative demand variance of configuration 1 (0.99) is bigger than the of configuration 2 (0.666), so the CODP of configuration 1 ($\theta = 0.4$) is more forward than that of configuration 2 ($\theta = 0.6$). Although we do not analyze the production of B2 in the USA factory, the variances are big (0.99 for configuration 2, 3, 4), so the CODPs should be at the beginning position.

Product value We set the product value to 500, 1500 and 3000 and leave other parameters as they are. The optimal results are displayed in Table 9.16. When V is 3000, K decreases because holding cost is unacceptable to store 2 items, so higher product value leads to lower inventory level. θ reduces and $TC(K^*, \theta^*)$ increases with the product value growth. Product value influences holding cost and asset specificity cost because both of costs are a ratio of product value. The product value increasing adds the unit holding cost and the unit unsuitable item cost. To avoid high inventory cost and asset specificity cost, the CODP goes upstream. Due to high product value, the total cost increases. When the product value is small, the CODP position changing is more sensitive.

Table 9.16: Barriers sensitivity analysis on product value

V	K^*	θ^*	$TC(K^*, \theta^*)$
500	2	0.45	481.59
1000	*2*	*0.3*	*591*
1500	2	0.19	654.5
3000	1	0.01	712.5

The manufacturing cost of B1 in the China factory is higher, so the CODPs of B1 go upstream. It is an important reason besides demand volume and variance.

Holding cost factor The factor of holding cost is 0.2 initially. Let C_H be 0.01, 0.02, 0.1 and keep the other parameters, and then see how K, θ and TC change. The factor of holding cost decreasing indicates the holding cost per unit per unit time decreasing. As the holding cost per unit per unit time reduces, semi-finished products in the warehouse go up. The CODP goes backward and the total costs decreases. If the holding cost EUR/unit/unit time is small, we prefer to store more items, so K increases. When holding cost is small, to reduce delay cost, the CODP moves downstream. The total cost also decreases due to the decreasing of holding cost and delay cost. Even though the holding cost factor changes much, it is not much significant to move the CODPs, but K changes much.

Table 9.17: Barriers sensitivity analysis on holding cost factor

C_H	K^*	θ^*	$TC(K^*,\theta^*)$
0.01	4	0.44	446.74
0.02	3	0.42	460.53
0.1	2	0.35	531.29
0.2	*2*	*0.3*	*591*

In the barriers model, the holding cost is an estimated cost. If we obtain the exact holding cost, we can adjust the CODP position based on precise holding cost.

Customer order fulfillment delay cost We vary the value of delay cost as 300, 500, 1500 and 3000 and remain the other parameters, and then compare with the original value, we will see the effects in Table 9.18. K, θ and TC increase with C_W. When C_W is small, we are not afraid of long fulfillment delay, so k and θ are small in order to reduce holding cost and asset specificity cost. When C_W is big, customer order fulfillment delay cost becomes the dominating factor to minimize the total cost. Thus, K and θ increases to shorten customer response time. When customer order fulfillment delay cost is small, the CODP position is more sensitive, while K is more stable.

Table 9.18: Barriers sensitivity analysis on customer order fulfillment delay cost

C_W	K^*	θ^*	$TC(K^*,\theta^*)$
300	1	0.01	214.2
500	2	0.11	345.14
1000	*2*	*0.3*	*591*
1500	2	0.4	787
3000	3	0.6	1251.1

Customer order fulfillment cost has a strongly relationship with processing time and product value. When product value is fixed, the long processing time means the delay cost per unit time is low. The delay cost per unit time of B2 is lower than that of B1, so the CODPs of B1 are more backward.

9.2.2 Global model

The effect of global production Considering transportation cost and finance cost, the total cost increases to 680.09 and θ decreases to 0.17. K keeps 2. Thus, transportation and finance cost makes the CODP forward. Finance cost is a ratio of semi-finished product value, and transportation cost is low if θ is small, so to reduce the transportation cost and finance cost, the CODP should go upstream.

Unit transportation cost As the energy fee increases, transportation cost will also mount. Some extra costs such as file post during transportation will also make the transportation cost higher. Therefore, we assign 150 and 200 as the transportation cost per finished items, and then we obtain results in Table 9.19. The higher transportation cost results in the CODP going upstream, and the inventory level decreasing, and the total cost growth. The more percentage of completion is, the more transportation cost is; so to reduce the transportation cost, θ becomes small. We prefer to ship less items to warehouse when transportation cost is high, so K goes down. Though we want to minimize the transportation cost, the higher transportation cost yields higher total cost.

Table 9.19: Barriers sensitivity analysis on transportation cost

C_T	K^*	θ^*	$TC(K^*, \theta^*)$
100	*2*	*0.17*	*680.09*
150	2	0.14	694.25
200	1	0.12	701.37

Transportation cost does not make a difference on the CODP locating. Transportation cost is relatively low compared with product value. When the difference of delay costs per unit time between two factories are big, we prefer the global production and the starting point is the lower delay cost factory. It is better that B1 is produced in the Netherlands factory and then shipped to China because transportation cost is quite small when comparing with product value.

Processing rate ratio In our case, the processing rates in different factories are the same. However, the USA factory has a higher potential to upgrade the processing rate, so the processing rates may change. As we mentioned before, δ is the ratio of the first factory processing rate to the second factory processing rate. We have:

$$\delta = \begin{cases} < 1 \ if \ \mu_1 < \mu_2, \\ = 1 \ if \ \mu_1 = \mu_2, \\ > 1 \ if \ \mu_1 > \mu_2. \end{cases}$$

where μ_1 is the processing rate in the first factory and μ_2 is the processing rate in the second factory.

Therefore, we vary δ as 0.3, 0.5, 1.5 and 2 and keep other parameters unchanged. The higher δ results in lower K, higher θ and lower TC. When the first factory processing rate is smaller than the second one, θ tends to be small because the second factory can respond to customers even if the CODP is in the upstream. When the first factory processing rate is bigger, we prefer produce more in the first factory so that the second factory can respond to customers quickly. In this case, the first factory is easily to provide semi-finished products, so K goes down to minimize the holding cost. Meanwhile, the fulfillment delay cost decreases, so the total cost reduces.

Table 9.20: Barriers sensitivity analysis on processing rate ratio

δ	K^*	θ^*	$TC(K^*, \theta^*)$
0.3	2	0.07	699.59
0.5	2	0.12	688.57
1	*2*	*0.17*	*680.09*
1.5	1	0.25	652
2	1	0.28	631.81

9.3 Findings

9.3.1 Common rules

We did sensitivity analysis on both revolving door model and barrier model. We found some important common rules of the CODP positioning.

Demand characteristics The main demand characteristics we analyzed are demand volume and relative demand variance. ***The larger demand volume results in the CODP going downstream. The larger relative demand variance leads to the CODP going upstream.*** Rajagopalan (2002), Olhager (2003) and Teimoury et al. (2012)'s research results also support the rule.

Product value ***The higher product value causes the CODP going upstream.*** In the revolving door model, labor cost, processing time and component cost affect the product value. As labor cost, processing time and component cost increases, the CODP all go upstream. In the barrier model, the result shows the rule directly.

Holding cost factor ***The higher holding cost factor is, the more upstream the CODP is.*** If the factor is small, the effect of inventory will be also small. The rule is similar with the result of Arreola-Risa and DeCROIX (1998), Rajagopalan (2002) and Soman et al. (2004) which agreed that the high holding cost should be MTO.

The effect of global production ***The CODP goes upstream in the global production in the global production.*** It is owing to transportation cost and finance cost.

Manufacturing cost difference between two factories ***If the manufacturing cost of the first factory is smaller than that of the second factory, the CODP goes downstream, and vice versa.*** We should take advantage of the rule especially when the cost difference is large.

Transportation cost ***The higher transportation cost results in the CODP going upstream.*** However, if the transportation cost is small. the CODP will not be that sensitive.

9.3.2 Special rules

We can also find some special rules for revolving doors and barriers. The special rules existing is because the models of two doors are different. If the same models would be used for both types of products then the same rules may be shown to hold.

Setup cost ***The higher setup cost causes the CODP going downstream.*** The rule is displayed in the revolving door model. Soman et al. (2004) presented that the item with low setup cost should be MTO; namely, the CODP should go upstream when setup cost is low. Rajagopalan (2002) concluded that items with higher setup cost are likely to be MTS. Our result matches their research.

Leadtime ***The shorter leadtime contributes to the CODP going downstream.*** The rule is displayed in the revolving door model. Sun et al. (2008) drew the same conclusion.

Backorder cost and the probability of stock-out ***Backorder cost and the probability of stock-out do not have influence on the CODP positioning.*** The reason is that the safety stock is considered. If we do not take the safety stock into account, the result should be different. Arreola-Risa and DeCROIX (1998) stated that the low backorder cost should be MTO; namely, the CODP should go upstream. Therefore, the CODP might go upstream as the backorder cost decreases.

Customer order decoupling delay cost ***The higher the customer order decoupling delay cost is, the more downstream the CODP is.*** The rule is displayed in the barrier door model.

Processing rate ratio ***The larger processing rate ratio causes the CODP going downstream.*** The rule is displayed in the barrier model. Jewkes and Alfa (2009) discussed the capacity of supplier and indicated that the higher capacity of supplier lead to the CODP going downstream. The concept capacity of supplier is similar with processing rate, thus the rule matches the research of Jewkes and Alfa (2009).

9.3.3 Model simplification rule

When we analyzed the revolving door model, we found that there were two methods to simplify the model time complexity. As we discussed about the leadtime in the revolving door model, the constraint will reduce the time complexity. Moreover, the difference of the MTO total cost and the MTS total cost also plays a part on the simplification.

Leadtime The shorter leadtime causes the CODP going downstream. The production time may be longer than the customer leadtime. The longer part will never be MTO. Thus the time complexity reduces. The number of steps is n and the leadtime can cover the step i to n, and then the time complexity reduces from $O(2^n)$ to $O(2^{n-i})$.

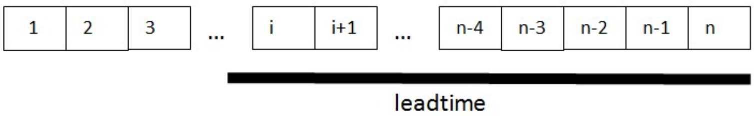


Figure 9.1: The leadtime to reduce time complexity

The difference of the MTO total cost and the MTS total cost When the MTO total cost is higher than the MTS total cost in step i, the step i is impossible to be MTO if we would like to minimized the total cost. The CODP determining is to find which step start to be MTO in the model. We take Figure 9.2 as an example. There are 10 steps in sequence. The MTS total cost always increases, while the MTO total cost fluctuates. In Figure 9.2, step 1, 2, 6, 7 and 8 are never MTO because the MTO cost is higher. The possible MTO steps are 3, 4, 9 and 10. Then the time complexity reduces from $O(2^{10})$ to $O(2^4)$. To generalize the rule, we have:

The possible MTO steps are always in the steps whose MTO total cost is smaller than the MTS total cost.

Hence, we can add a constraint before run the model such as "If $TC_i^{MTO} > TC_i^{MTS}$, x_i=0".

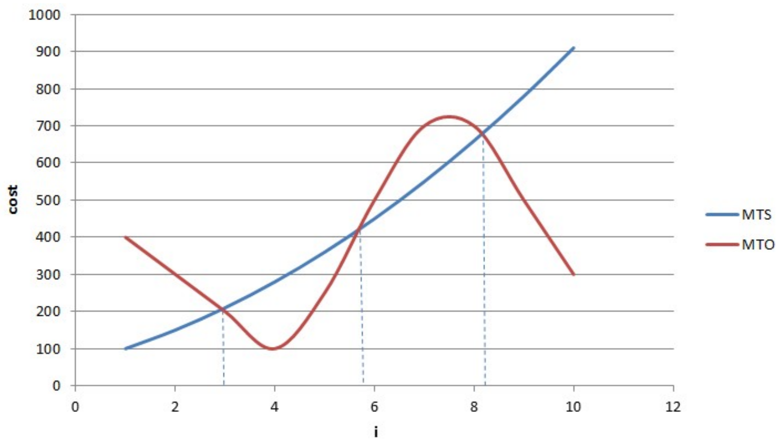


Figure 9.2: The leadtime to reduce time complexity

Chapter 10

Conclusions & Recommendations

The long customer leadtime, lost orders, doubled sales planning and global production requirement trigger Company A to consider determining the CODP for the global supply network, in order to optimize their production processes. The thesis provides the solutions for the products the company requests. According to the data, we applied scientifically supported methodologies to obtain the CODPs of products with different configurations. The demand aggregation rules make it possible to deal with the small demand volume and large variety. The application of 0-1 integer leaner programming and Markov chain and Queueing theory solved the problem of modeling two systems for which different amounts of data was available. After gain insight in the variables, we found the rules that affect the CODP positioning. We found the answers of the questions in Chapter 1.

- How to conquer the small demand volume and big demand variance?

To conquer the challenge, we managed to understand the configurations of the products. After interviewing with the product managers, we obtain the sensitive configurations which differentiate the products. Then we combined the nonsensitive configurations so that the demand volume becomes larger. We focused on the popular configurations because their demands are relative stable. That means a smaller demand variance.

- How to deal with the process complexity?

The production processes are highly relevant to configurations. The materials of finish differentiates the production processes much. When counting the number of different finish demand, we found that coated finish occupies the most of demand. Then we ignored the stainless finish. The criterion to simplify the process is the frequency of usage.

- How to find the optimal CODPs for revolving doors with 0-1 integer linear programming?

We aimed to minimized the total cost. The setup cost, holding cost, stock-out cost and asset specificity cost are included in the MTS system. The setup cost is included in the MTO system. A vector with binary variables is applied to describe the CODP determining. If a step is MTS, the value of variable is 0; if a step is MTO, the value of variavle is 1. After run the model in the excel, we found the optimal CODP position with the minimal cost.

- How to determine the optimal CODPs for barriers with Markov chain and queueing theory?

The objective is to minimize the total cost. We considered holding cost, asset specificity cost and customer order fulfillment delay cost in the model. The Markov chain played a role in calculating the steady states. The queueing theory helped us obtain the expected number of items in stock, the expected number of unsuitable items and the expected customer order fulfillment delay. After the cost function was convinced, we run the model with the algorithm, and then found the optimal CODP position.

- How to gain insight from the results?

We did sensitivity analysis on the parameters involved in the cost function. Thus, we can understand how parameters make a difference on the determination of CODP. The sensitivity analysis also provided rules of the CODP determining.

Our results are in line with results from literature and contribute to both the company and academical research.

10.1 Contributions

Contributions to the company

- We decided the standard configurations based on the demand volume.We accurately studied the products with different configurations. We offer suggestions of the standard production for the company.
- We offer solutions for the local production and global production. The basic model solved the local production and the global model dealt with the global production. We focused on different configurations which specified how to determine the CODP.
- Our solutions are able to deal with changes in the system. We analyzed the influence of different parameters on the CODP positioning. When data changes, we can forecast the CODP changing and take measures in advance.

Contributions to academical research

- We extend the CODP determination model under the global context. In the past researches, the analytical models were applied to solve local production because the scholars never considered the global factors in their model. Miemczyk and Howard (2008) presented a framework about Build-to-order supply chain management which is under the global context, but did not offer any quantitative analysis. We analyzed the CODP determining model under the global context and compared the difference of the CODP determining in the local production and global production. It is meaningful and innovative.
- We find rules to determine the CODP with quantitative methods which have not analyzed by other scholars. Demand characteristics, holding cost, setup cost, leadtime, backorder cost and processing rate ratio have been discussed by different researchers. However, product value, the effect of global production, manufacturing cost difference between two factories, transportation cost and customer fulfillment delay cost were seldom analyzed by scholars, especially the factors in the global production such as transportation cost. As the amount of research about the CODP determining in global production are not large, the findings are important.
- We find the rule to reduce the time complexity of revolving doors. According to the rule, the choice between MTO and MTS can be determined before we run the model. It is important when the data size is large. The algorithm improvement reduces the population size and increases the computation speed.

10.2 Recommendations

Recommendations for the company

- Make effort to modularize production. Hewlett-Packard is a successful case to modularize the products. One of Hewlett-Packard product design principles is that a product consists of independent modules. The relevant manufacturing processes should be also designed as different modules. There are four benefits of modularization production. First of all, a company is able to maximize the number of standard components. Second, the modules can be produced separately. Third, the production problems and quality problems are easier to be diagnosed. Fourth, it is efficient in dealing with small demand volumes.

- The products with larger demand volume have priorities to execute the CODP strategy. B3 is more suitable to change the CODP than B2 because of the larger demand volume of B3. Besides the products we analyzed, if there are some other products that have large demand volume, their CODPs should be changed with priority. The products whose configurations are easier to be aggregated should also be prioritized.
- The results should be re-evaluated after collecting more accurate data variables. We assume many data in the model such as the stock-out cost in the revolving door model. Hence the results have deviation with the real situation. To reduce the risks, it is necessary to re-evaluate.

Recommendations for the further research

- One of the assumptions in the revolving door model is that the capacity is infinite. In future research, the assumption can be relaxed to limit the capacity.
- Consider more factors which affect the CODP locating. If we really execute the solutions, more costs should be taken into account. For example, the company should redesign the production line and purchase resources to change the CODP. If the redesign cost is high, the company should be more cautious.
- Analyze the global production in more than two factories. We considered two factories in the production. As the development of the company, distribution centers will probably not be able to produce products, but final assembly may be performed at a local distribution center. Hence, the global supply network being complicated requests the analysis to include more production locations.
- The external environment is stable as our assumption. For example, the currency exchange rate and the taxes policy changing will influence finance cost, and the unit oil price increasing will affect transportation cost. Specifically, the currency exchange rate changes in different time period, thus the CODP positioning may be different in different time period.
- The scheduling problem of pure MTO items and MTS-MTO hybrid items is important. The MTS-MTO hybrid itmes occupy different percentage according to different configurations. For example, B3 configuration 1 takes up 95.2 % in the European Market, while RD2 standard configuration (configuration 1 and 2) only occupies 44.7%. Scheduling is important for the low percentage standard items. Because the production time of pure MTO items is longer than the hybrid items, pure MTO items should have priority, but the hybrid items may lose the advantage of short delay when many pure MTO items are in the head of queue.

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Appendix A

The BOM of stainless steel revolving doors

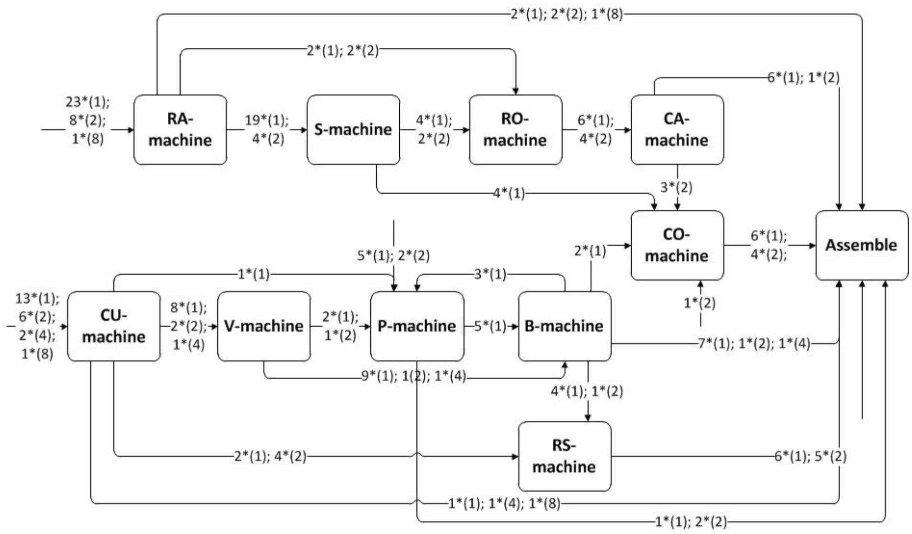

Figure A.1: The BOM of RD1(stainless steel)

Appendix B

The processes of revolving doors with stainless door paths

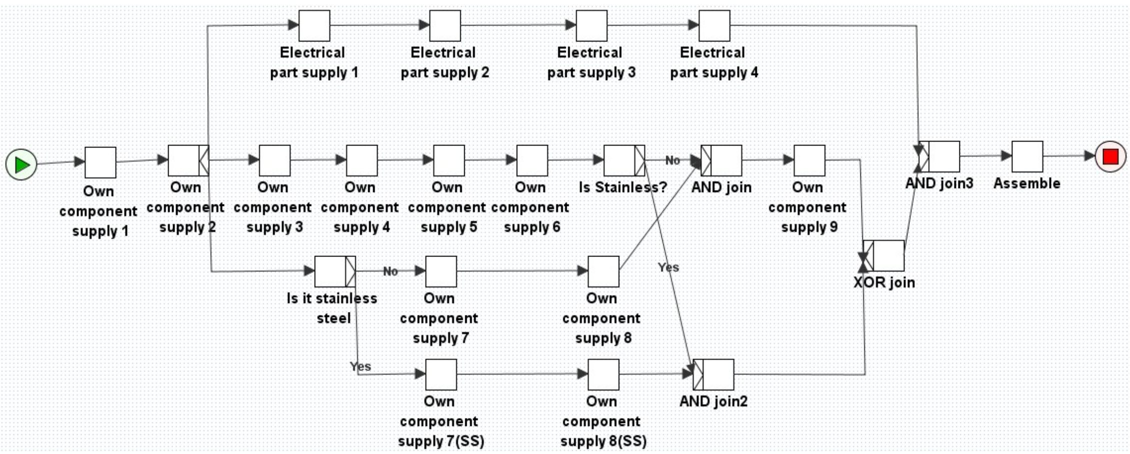

Figure B.1: The Processes of RD1 and RD2

Appendix C

The setup time, processing time, production leadtime and capacity of RD1 and RD2

Table C.1: The setup time(hour), processing time(hour) and capacity of RD1 and RD2

Items	Setup time	Processing time (RD1	Processing time(RD2)	Production leadtime	Capacity
Own component supply 1	0.001	5	4	8	1
Own component supply 2	0.001	1	0.75	3	1
Electrical supply 1	0.001	1	2	6	1
Electrical supply 2	0.25	4.5	4.5	3	2
Electrical supply 3	0.25	6	8	4	1
Electrical supply 4	0.25	3	2	6	1
Own component supply 3	0.001	2	3.5	6	3
Own component supply 4	0.001	2	1.5	2	3
Own component supply 5	0.25	2	1.5	2	2
Own component supply 6	0.25	1.5	1	2	1
Own component supply 7(Alu)	0.001	1.5	1.5	6	1
Own component supply 8(Alu)	0.25	1	1.5	8	2
Own component supply 9	0.25	1	1	3	1
Own component supply 7(SS)	0.001	1	1	6	1
Own component supply 8(SS)	0.25	8.5	13	8	1
Assemble	0.001	20.5	16	5	12

Appendix D

The processing time and processing rate of barriers

Table D.1: The processing time of barriers (hours)

	The USA	China	Netherlands
B1	0	8.23	6.33
B2	3.03	0	2.4
B3	0	17.33	13.33

The processing times of different products are different in different factories, while their processing rates are the same. It is 2.4 units/day.

Appendix E

Costs of revolving doors in the USA and China

The costs of revolving doors include manufacturing cost, setup cost, cumulative manufacturing cost, stock-out cost, inventory cost, asset specificity cost and finance cost. The main reason why the costs are different in different factories is the difference of labor cost in hour because we assume that the component cost are the same in different factories.

E.1 The costs in the USA factory

Table E.1: The cumulative manufacturing cost of revolving doors in the USA factory(Unit: EUR/unit)

Doors	Own component supply 1 (CM_1)	Own component supply 2 (CM_2)	Own component supply 3 (CM_3)	Own component supply 4 (CM_4)	Own component supply 5 (CM_5)
RD1	0.05	0.11	364.13	472.47	580.81
RD2	0.05	0.11	532.51	613.77	695.02
	Own component supply 6 (CM_6)	Own component supply 7 (CM_7)	Own component supply 8 (CM_8)	Own component supply 9 (CM_9)	Assemble (CM_{10})
RD1	698.15	219.96	680.41	1598.53	8846.64
RD2	749.19	234.44	315.70	1293.86	8022.32

E.2 The costs in the China factory

Table E.2: The cumulative manufacturing cost of revolving doors in the China factory(Unit: EUR/unit)

Doors	Own component supply 1 (CM_1)	Own component supply 2 (CM_2)	Own component supply 3 (CM_3)	Own component supply 4 (CM_4)	Own component supply 5 (CM_5)
RD1	0.00	0.01	262.05	268.31	274.57
RD2	0.00	0.01	353.87	358.57	363.26
	Own component supply 6 (CM_6)	Own component supply 7 (CM_7)	Own component supply 8 (CM_8)	Own component supply 9 (CM_9)	Assemble (CM_{10})
RD1	280.83	168.92	195.53	654.29	6113.43
RD2	366.39	157.88	162.58	706.9	6019.79

Appendix F

The results of the CODP determination

F.1 The results of RD1 and RD2

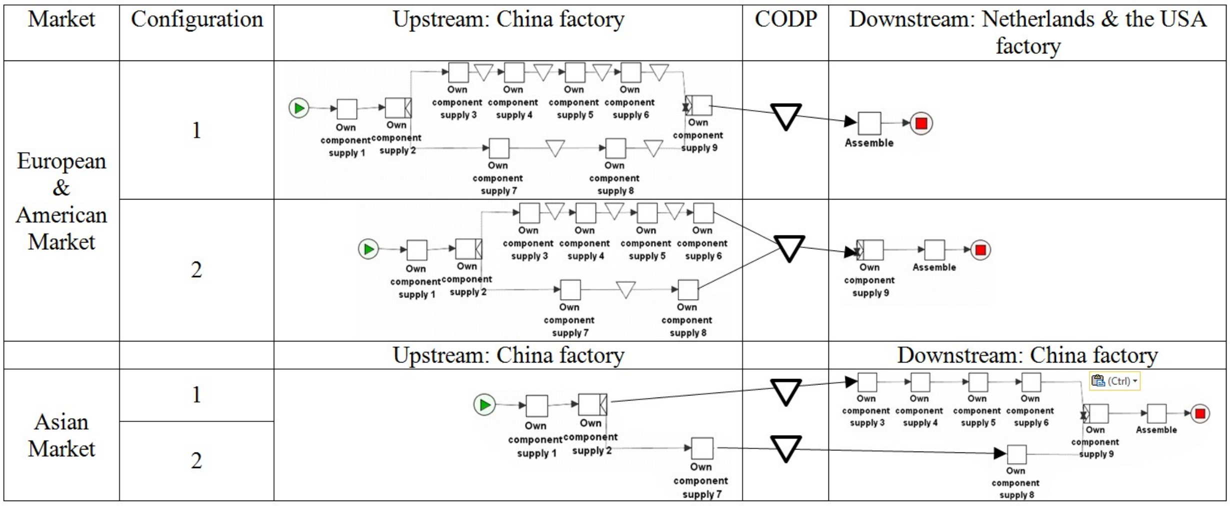

Figure F.1: The CODP determination results of RD1 and RD2

F.2 The results of B1

Market	Configuration	Upstream: Netherlands factory	CODP	Downstream: Netherlands factory
European Market	1	70%	▽	30%
	2	10%	▽	90%
		Upstream: Netherlands factory	CODP	Downstream: China factory
Asian Market	1	40%	▽	60%
	2	70%	▽	30%
	3	80%	▽	20%

Figure F.2: The CODP determination results of B1

F.3 The results of B2

Market	Configuration	Upstream: Netherlands factory	CODP	Downstream: Netherlands factory
European Market	1	10% ▽		90%
	2	40% ▽		60%
	3	10% ▽		90%
		Upstream: China factory	CODP	Downstream: China factory
Asian Market	1	▽		100%
	2	▽		100%
	3	▽		100%
	4	▽		100%
	5	▽		100%

Figure F.3: The CODP determination results of B2

F.4 The results of B3

Market	Configuration	Upstream: Netherlands factory	CODP	Downstream: Netherlands factory
European	1	50%	▽	50%
Market	Configuration	Upstream: Netherlands factory	CODP	Downstream: The USA factory
American	1	90%		▽ 10%

Figure F.4: The CODP determination results of B3