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An Approach to Capacity Planning of Distribution Warehouses for X-Firm

By Karen Puspasari

Supervisors:

Dr. ir. L.L.M. van der Wegen

Dr. ir. J.M.J. (Marco) Schutten

Sonia D. P. Chandra, STP, MSc.

Management Summary

Introduction

X-Firm is known as an innovative company that manufactures and markets high quality foods and beverages. X-Firm started with only one manufacturing facility and distribution warehouse at Site I. To deal with the promising market developments, X-Firm expanded to Site II in 2013, and has decided to execute the second expansion plan, i.e., adding a new production plant at Site II and opening a manufacturing facility at Site III in 2015. X-Firm has made a capacity plan for the second expansion based on experience and common sense, but they are a bit doubtful about the result. X-Firm wants to validate their current capacity plan with another capacity plan that takes into account a scientific approach in its calculation. Therefore, the main objective of this research is:

"To find an approach to come up with a capacity plan for X-Firm's distribution warehouses."

Method

X-Firm's management requires the solution capacity plan to take into account: the expected demand growths that are directly given by management (i.e., 15% for brand category A2 and 8% for other brand categories), the probability of no stock out occasion (P_1) for C items that represents a fill rate (P_2) of 97%, the current fixed delivery route for retailer allocation, and the current multi drop list for distributor allocation. To meet the research objective and the requirements from management, we develop a capacity plan based on a conceptual framework (i.e., Figure 4.3-1 on page 56) that can support management in capacity planning. The conceptual framework consists of 2 major phases: (I) data preparation, and (II) capacity planning based on customer allocation. We use the (R, s, nQ) inventory policy in our solution approach that is similar to X-Firm's current inventory policy, apply the ABC classification, and determine the safety factor and safety stock based to the customer service approach: P_2 of 97% for the A and B items and P_1 of 95% for the C Items. We determine the total initial capacity in 2013 based on the expected on-hand stock for regular products and the maximum on-hand stock for the seasonal products using seasonality index (i.e., an integer number that shows how many times the demand in pallets of SKU_i maximally increases during seasonal periods compared to the average demand). We allocate a retailer to a distribution warehouse according to the fixed delivery route and a distributor according to total demands per site and the multi drop list. Our 2 preferences to decide whether the solution is feasible are to have a higher fraction of customer demand at Site II and to let the insufficient capacity occur at Site II rather than at Site I. For performance measurement, we determine the inventory turnover ratio (ITR), days of inventory (DOI), total operational costs, and total relevant costs. We structure the capacity plan in such way that it is adaptable and extendable in terms of adding or deleting SKUs, parameters, or assumptions.

Results

There are two results of the solution approach: the first and improved solution capacity plans. The capacity plan of the first solution meets our second preference (i.e., to let an insufficient capacity occurs at Site II), but this capacity plan is not feasible, since the needed capacity at Sites I and II is imbalanced, i.e., there is 52% of remaining capacity at Site I (2,254 pallet positions) and 24% of insufficient capacity at Site II (919 pallet positions) in 2014 (see Table 5.1-17 on page 73).

We improve the first solution by relaxing the distributor allocation, i.e., using customer's relative travel distance to Sites I and II and swapping the location of multi drop list of M06 that has the most distributors in the list, and this gives a feasible solution. From the improved solution capacity plan, there is insufficient capacity of 30 pallets positions in 2015 and 459 pallet positions in 2016 at Site II, while Site I has a remaining capacity of 603 pallet positions in 2015 and 59 pallet positions in 2016. Table 5.2-4 on page 76 presents the improved solution capacity plan of X-Firm's distribution warehouses in 2014 - 2016. The new storage warehouse at Site III requires 88 pallet positions in 2015 and 96 pallet positions in 2016. We estimate that there are 10 inventory movement trips per day between Sites I and II in 2013 and 2 inventory movement trips per day from Site III to Site I and from Site III to Site II in 2015.

Based on the performance measurement, the solution has an aggregate ITR of 14.11 and an aggregate DOI of 22 days. In comparison with X-Firm's current performance, our solution underperforms in terms of aggregate ITR, aggregate DOI, and total operational costs, because the solution capacity plan yields a larger numbers of pallets. By implementing our solution approach, the operational costs increase 19.9% compared to the X-Firm's current operational costs in order to improve the service level from 92.5% (i.e., the actual service level in 2013) to 97% (i.e., the targeted service level). According to the sensitivity analysis (see Table 1), we find that there is a trade-off between the service level and the total operational costs. Thus, to have a higher service level, X-Firm has to hold more inventories and spend more in the total operational costs, because the inventory holding costs increase.

Table 1. Sensitivity analysis

Service Level	Fill rate (P_2)	Prob. no stockout occasion (P_1)	Expected number of pallets needed *(in pallets)*	Total Demand 2013 *(in pallets)*	ITR	DOI	Total Operational Costs	Compared to 92% SL of each appoach, Total Operational Costs Increases by		Total Relevant Costs
								X-Firm's Approach	Solution Approach	
98%	98%	95%	5,900	77,878	13.20	23	€ 855,833.50	26.3%	23.3%	€ 2,760,104.50
97%	97%	95%	5,519	77,878	14.11	22	€ 812,723.35	19.9%	17.1%	€ 2,592,028.66
96%	96%	95%	5,231	77,878	14.89	21	€ 780,136.15	15.1%	12.4%	€ 2,466,707.86
95%	95%	95%	5,000	77,878	15.58	20	€ 753,998.50	11.3%	8.6%	€ 2,362,429.74
94%	94%	95%	4,793	77,878	16.25	19	€ 730,576.45	7.8%	5.3%	€ 2,270,010.86
93%	93%	95%	4,625	77,878	16.84	18	€ 711,567.25	5.0%	2.5%	€ 2,196,671.82
92%	92%	95%	4,470	77,878	17.42	18	€ 694,029.00	2.4%	-	€ 2,128,575.26
92%	-	-	3,670	77,878	21.22	15	€ 677,745.61	*X-Firm's current performance & capacity plan*		

Recommendations

The basic recommendation is to implement the step-by-step approach of the solution capacity planning in our conceptual framework using the historical demand of last year to check the capacity plan in 2015 and the following years. The SKU master data need to be updated regularly, since it is one of the inputs of capacity planning. The solution capacity planning is intended for strategic or tactical purpose only. The calculation of the safety factor k_i according to the fill rate (P_2) using the Solver add-in in Excel can be automated by using Excel VBA to make it less time consuming. If later the number of seasonal product significantly increases, the real seasonality index should be used to obtain a more precise result of the required capacity for seasonal products. The insufficient capacity in 2016 can be solved by extending the capacity at Site II by at least 500 pallet positions or to rent an external warehouse near Site II during the seasonal period or to occupy the excess capacity in the storage warehouse at Site III.

For further research, the total relevant costs approach and the transportation costs of customer delivery can be considered to determine the real total operational costs. The total transportation costs of customer delivery per customer can be used to optimize the customer allocation using a mathematical programming approach. The current fixed delivery route and multi drop list need to be reviewed according to the demand size and order behavior of each distributor (i.e., day of order, order frequency per month, etc.). The real production capacity can be taken into account in the future capacity planning to obtain a capacity plan that is more representative to X-Firm's real situation.

“Wisdom and knowledge will be the stability of your times,

And the strength of Salvation;

The fear of the LORD is His treasure.”

- Isaiah 33 : 6 (NKJV) -

Preface

Having capacity planning topic as my graduation assignment is actually 'a dream come true'. I have wanted to carry out research in capacity planning since I finished working on the capacity plan for X-Firm's distribution warehouses on its first expansion four years ago. At that moment, even though our team was able to come up with a good capacity plan based on our common sense and experience, I knew intuitively that there are better ways to make a sound capacity plan if we would have more knowledge in this area. Two years later in 2012, I had the opportunity to continue my study in the Industrial Engineering and Management program, with specialization Production and Logistics Management (PLM), which has provided me with all the knowledge that is very useful for doing my desired research in capacity planning. Here, I proudly present you my MSc. thesis, not only as an accomplishment of my graduate study at the University of Twente, but also as a sincere contribution to solve a practical problem in X-Firm.

There are many people who played their role to make this thesis complete. I thank them all. In particular, I like to thank the people below.

In the first place, I would like to express my highest gratitude to Jesus Christ - my God, for guiding my life and giving me the opportunity to study overseas, to live in the Netherlands, to travel to many countries in Europe, and to have many other wonderful experiences within these two years. *Ad maiorem Dei gloriam.* Second, I sincerely thank Leo van der Wegen and Marco Schutten for all their guidance, substantive feedback, fruitful ideas, and discussions. I do appreciate all the time they spent for proof-reading and for all the colorful marks that they wrote on my drafts to correct my grammatical errors, missing articles, and poor sentence structure. It is very motivating to know that someone spends time to read and gets involved in my work with such care. Third, I thank Sonia Chandra for fully supporting me to carry out this project in X-Firm and for spending some of her very busy time to read and give critical feedback on my approach and reports. Her comments enriched my research and kept me busy to think how this research would be useful in practice. I also thank my co-workers in X-Firm who have enthusiastically supported me with the data and the orientation during my field work in X-Firm. In particular, I thank Danny Williams Wongso, for very speedily providing most of the data that I needed, and Renaldy Kumoro and Andreas Didit, for spending their time to cross-check my work regarding the current situation and giving useful comments. Fourth, I thank all my international friends, my friends from the Indonesian Student Association (PPIE) and the International Christian Fellowship in Enschede (ICF-E) for the great time we have spent together during these two years. Being with them made me feel at home far away from home.

Finally, I thank my family and my best friends in Indonesia for their never-ending care and prayers that enabled me to go this far to make my dreams come true. There may not be enough words to express how blessed I am to have their love in my life.

Contents

Chapter 1 Introduction

In today's competitive market globalization, supply chain practice has become more and more complex. Rapid changes in business such as an increasing number of product variants, increasing capacity needed for production and storage, more suppliers and buyers geographically spread over the world, and more barriers in traffic and physical infrastructures, have challenged organizations to continually evolve their supply chain to meet their customers' demands. Nowadays, having an excellent and effective supply chain has inevitably become a competitive advantage in those evolving organizations. Supply chain excellence aims at delivering responsive and reliable service to fulfill the customers' demand. Meanwhile, organizations must be effective in managing their resources to deliver the desired service level.

To cope with today's dynamic market change, considering facility expansion at a certain point in time is one option. Company management has to perform capacity planning to calculate how much additional capacity in which facility is required for the expansion. The output of capacity planning is a capacity plan. The late Benjamin Franklin once said, "If you fail to plan, you are planning to fail". A successful implementation of a sound capacity plan is required to help an organization to achieve an excellent and effective supply chain. However, capacity planning is not a straightforward process. There are a lot of interrelated aspects along the supply chain that management has to carefully oversee.

This report describes a case study of making a capacity plan at a food company in Indonesia. This research study, as a completion part of the Master program Industrial Engineering and Management at the University of Twente, aims to aid this company in formulating a sound capacity plan. Due to a confidentiality issue, we call the company X-Firm.

This chapter is organized as follows. First in Section 1.1, we give a brief company profile of X-Firm. Section 1.2 describes the problem that X-Firm faces while making a capacity plan. Sections 1.3 and 1.4 provide the motivation and the scope of the research. Then, we elaborate on the research objective, questions and approach in Section 1.5.

1.1 Company Profile

X-Firm is known as an innovative company that manufactures and markets high quality foods and beverages under reputable and leading brands. X-Firm's manufacturing facilities, distribution warehouses, and research and development facilities are located at 2 separate places: Site I and Site II. In 2015, X-Firm also prepares to have another facility at Site III. Figure 1.1-1 shows the location map of these facilities.

Figure 1.1-1. X-Firm's manufacturing facilities: A. Site I, B. Site II, and C. Site III

According to its production plants, X-Firm currently has 5 different product types: ready to drink (RTD), powder type I, powder type II, powder type III, and other non-RTD. Besides manufacturing the products at its own production plants, X-Firm also outsources some production to several companies in different cities. Therefore, X-Firm has numerous product variants. These days, 175 Stock Keeping Units (SKUs) are sold in the Indonesian local market and more than 200 SKUs are exported to more than 30 countries worldwide.

The finished products are distributed via 4 distribution channels: export buyers, national distributors, retailers (modern outlet), and direct selling to the end customer. An export buyer is a foreign business partner who distributes X-Firm export products solely in the export destination country. A national distributor is a local business partner who distributes X-Firm local products to traditional markets and retailers in a certain region. A retailer is a shop or modern outlet, such as supermarket, convenience store, hypermarket, etc., whose sales orders are covered by X-Firm directly or by national distributors. In particular to serve its local market, X-Firm uses national distributors and retailers as its main distribution channels.

To show its commitment as a leader in service and quality management, X-Firm has obtained the International Standards Organization (ISO) certification for manufacturing in 1994, for distribution in 1997, and for its laboratory services in 2001. X-Firm's management commits itself to deliver a 97% service level to its customers and aims for cost effectiveness.

1.2 Problem Description

In the last 5 years, X-Firm has a progressive growth in demand and promising market developments. The existing manufacturing facilities can hardly fulfill the demands. To maintain their positive achievements, management of X-Firm decided to expand its manufacturing facility by opening a new site and adding production plants and warehouses. This section explains the stages of X-Firm's manufacturing facility expansion from the beginning of its operation until the year 2015 and the related problems in each expansion. In three separate subsections, we describe X-Firm's manufacturing facility at Site I, the first facility expansion to Site II in 2013, and the planning for the second expansion at Site II and to open Site III in 2015.

1.2.1 Manufacturing facility at Site I

Since the beginning, X-Firm has a manufacturing facility located at Site I. This facility has been operating for more than 30 years. It contains 2 raw material warehouses, 4 production plants (i.e., for ready to drink (RTD), powder type I and type III, powder type II and type III, and other non-RTD), and 1 distribution warehouse. X-Firm also outsources some production to several companies in different cities.

All planning, production, and distribution processes were centralized at Site I. Each of those processes can be explained as follows. First, a weekly production schedule is generated using traditional Manufacturing Resources Planning (MRP). Production planners manually adjust the production schedule based on historical demand data, experience, common sense, and intuition. The product types define where production will take place.

Once production is done, finished products are sent to and stored in a distribution warehouse. An incoming sales order triggers the order picking by the first expired first out (FEFO) dispatching rule. After picking, the prepared products are ready to be delivered to the customer. As a key performance indicator, X-Firm commits to deliver a 97% service level to its customers.

1.2.2 First expansion: Manufacturing facility at Site II

In 2010, all of the facilities at Site I were almost fully utilized, especially the distribution warehouse. There was no more space available at Site I that could be used to extend the warehouse capacity. After considering several alternative solutions for the capacity problem regarding its long term business plan and financial condition, management of X-Firm decided to open another manufacturing facility at Site II in 2011. This new manufacturing facility consists of 1 distribution warehouse, 1 production plant for powder type I and type III, and 2 raw material warehouses. All the planning and design processes of this new facility were carried out from 2011 until the first semester of 2012. The construction and building processes were carried out until the first semester of 2013. Finally, in the second semester of 2013, the manufacturing facility at Site II started its operation.

The planning, production, and distribution process in this new formation of dual manufacturing facilities can be explained as follows. All of the production planning is still centralized at Site I. X-Firm produces 84 SKUs at Site I, 71 SKUs at Site II, and 20 SKUs at outsourcing companies.

Production of powder type I is entirely moved to Site II to comply with the new quality standard required by the government. Besides powder type I products, the new plant can also produce powder type III products. Production of powder type II and type III, RTD, and other non-RTD takes place at Site I. The production department replenishes finished products of each SKU to the distribution warehouse at the same manufacturing site. Almost all outsourced products are sent to and stored at Site II due to the lack of capacity at Site I.

Major changes have occurred in both distribution warehouses. After considering several options of customer order delivery, X-Firm management decided to allocate each customer to one of both distribution warehouses taking into account its nearest location and its historical demand. This customer allocation aims at minimizing the transportation costs and balancing the workload in both distribution warehouses. Thus, each distribution warehouse serves different customer orders.

As every customer can order all X-Firm's SKUs but not all SKUs are originally available at each site, the inventories of these 2 distribution warehouses become highly correlated. Consequently, X-Firm has to maintain the SKUs availability in each distribution warehouse by doing daily replenishment between both distribution warehouses. These operational changes solve the warehouse capacity problem, but on the other hand the execution is very complicated and has become a bottleneck in the supply chain. Figure 1.2-1 describes the inventory movements between these two manufacturing facilities.

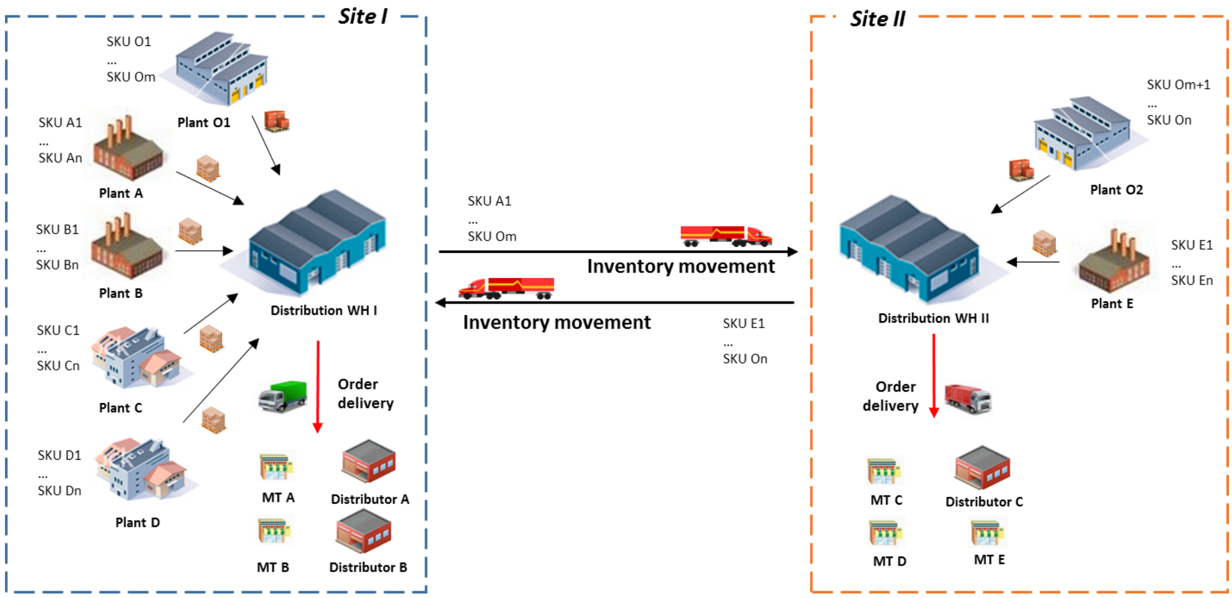

Figure 1.2-1. X-Firm inventory movements between distribution warehouses

1.2.3 Second expansion: New plant at Site II and manufacturing facility at Site III

Due to a progressive growth in demand and promising market developments, X-Firm management has decided to again expand its production capacity at Site II by adding 1 new plant for powder type II production in 2013. Later in the beginning of 2014, X-Firm also decided to open 1 new manufacturing facility at Site III. This coming manufacturing facility will have 1 production plant for RTD products and 1 storage warehouse. From this new storage warehouse, X-Firm can replenish the finished products to the distribution warehouses at Site I and Site II. Since these new plants are expected to run in the second semester of 2015, X-Firm calls these projects as the second expansion. Figure 1.2-2 shows the expected inventory movements between these 3 manufacturing facilities in 2015.

In the meantime, X-Firm management faces the biggest challenge in reviewing the capacity plan of the existing and new warehouses. With 3 manufacturing facilities in the coming years, capacity planning becomes more complicated. A lot of variables have to be considered to make a sound capacity plan, i.e., the given forecast, demand history, Days of Inventory (DOI), production capacities, and correlation between the distribution warehouses and the costumer allocation.

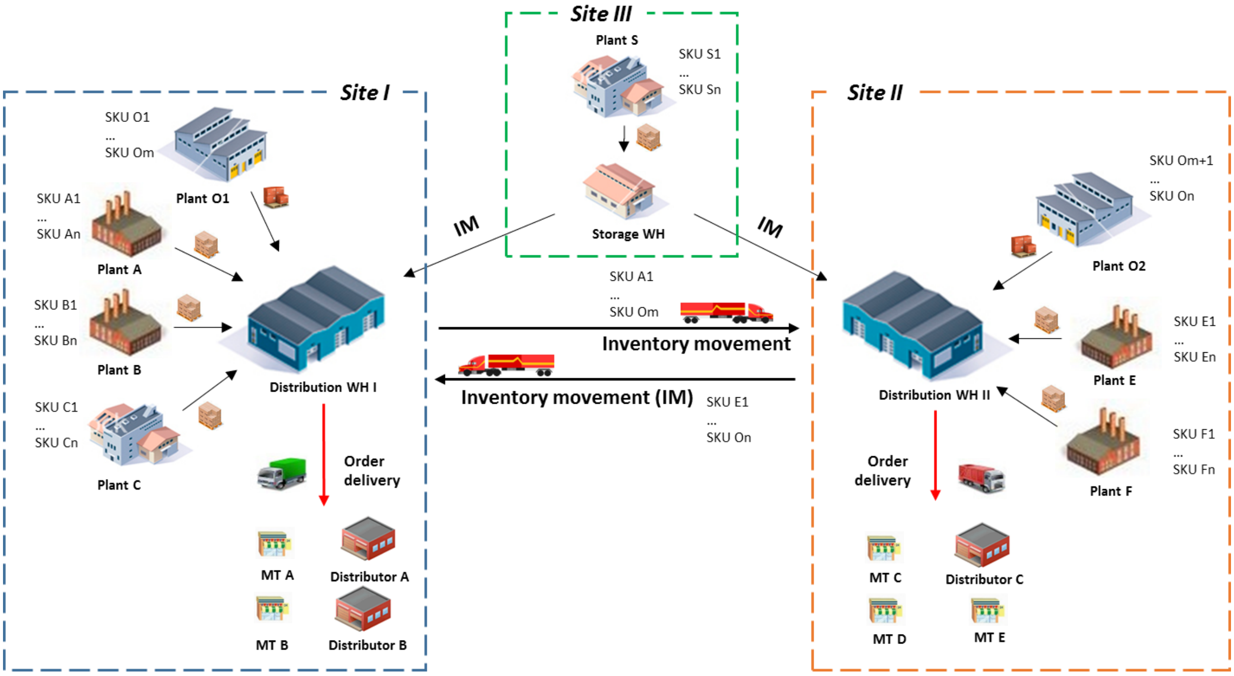

Figure 1.2-2. The X-Firm expected inventory movements in 2015

1.3 Research Motivation

To deal with the promising market developments, X-Firm decided to execute the second expansion plan (i.e., adding new production plants at Site II and opening a manufacturing facility at Site III) in 2015. Learning from the first expansion experience, X-Firm wants to have a better capacity plan, especially for their distribution warehouses. This time X-Firm has to consider more variables related to 3 different manufacturing facilities. This makes capacity planning based on experience and rationalization of the current process more difficult.

A good capacity plan is essential for X-Firm, because it can decrease the total operational costs of distribution warehouses needed to match the available capacity and the perceived demand by optimizing the warehouse utilization, replenishment strategy and customer allocation. Note that the improvement of the capacity plan needs to fulfill the committed customer service level of 97%.

1.4 Research Scope

The background of this research is that X-Firm wants to have a better capacity plan for their distribution warehouses before the second expansion runs. X-Firm management has calculated the capacity needed for this expansion based on previous planning experience and rationalization of the current process, but they are a bit doubtful about the results. To get an understanding about the quality of the calculated capacity plan, this plan has to be validated with another capacity plan that takes into account a scientific approach in its calculation.

To get a better input for the capacity plan, we need to determine the growth forecast for the next 3 years, look for a more reliable replenishment strategy, and look further on the costumer allocation. Because of the high amount and complexity of data, which turns to be too detailed for the management, decision support for developing a capacity plan is needed. In this research, we investigate how to help management to make a better capacity plan. We only focus on the existing 2 distribution warehouses and 1 new storage warehouse at Site III. We also focus our study primarily on local products, because it contributes the majority of inventory in X-Firm's distribution warehouses. The capacity planning for the production facility, the production scheduling in detail, and the decisions regarding warehouse layout are beyond the scope of this study.

1.5 Research Objective, Questions and Approach

Since there are a lot of aspects along the supply chain that management has to carefully oversee while considering capacity expansion, it becomes harder to make a comprehensive capacity plan for the distribution warehouses. Therefore, the aim of this research is to help X-Firm's management in constructing a sound capacity plan, which can be used as critical input for better decision making. Because capacity planning is a dynamic process, X-Firm expects to have an adaptable capacity plan for future use. From this background, our research objective is:

"To find an approach to come up with a capacity plan for X-Firm's distribution warehouses."

From this objective, we derive four main research questions and divide each question into sub research questions. The overview of this research is as follows:

Chapter 2: Context Analysis

RQ 1. What is the current situation at X-Firm?

Before going into detail on capacity planning, first we need to examine X-Firm's current performance. As stated before, X-Firm commits itself to deliver a 97% service level to its customers and aims for cost effectiveness. The first target 97% service level means that the target fill rate is 97%. In relation with capacity planning, we specify cost effectiveness as minimizing total operational costs of distribution warehouses (i.e. inventory costs, and transportation costs from Site I to Site II and vice versa) needed to match available capacity and perceived demand. X-Firm does not include the transportation costs for customer order delivery, since it is not under the responsibility of the logistics department. From these targets, we derive 2 performance indicators: (1) service level to customer; and (2) total operational costs of the distribution warehouses. We compare these 2 performance indicators with the given targets to know the performance of the current system.

To provide the answer of RQ 1, we first need to know how X-Firm regularly organizes its planning activities. We examine which activities are related to capacity planning and gather the right information to create a capacity plan later on. Then, we also investigate how X-Firm calculates the required capacity plan related with the second expansion plan.

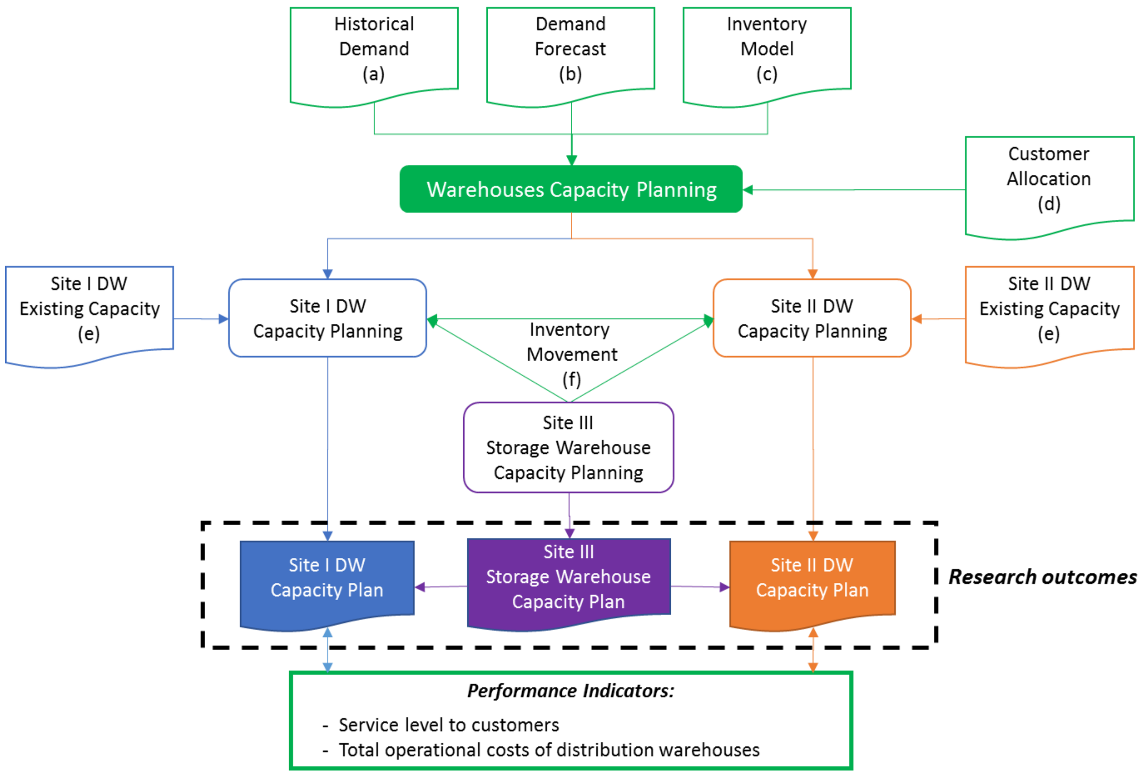

Figure 1.5-1. The scheme of the data collection process at X-Firm

Figure 1.5-1 shows the overview of data collection process at X-Firm to come to the current capacity plan for its distribution warehouses. The scheme leads us to the following sub-question.

SRQ 1.1 How does X-Firm perform with respect to its planning activities?

In this sub-question, we want to know what X-Firm's current service level is and how much total operational costs of X-Firm's distribution warehouses is. Besides checking on the performance indicators, we also look at related information as a prerequisite to make a capacity plan by observing on:

(a) How much is X-Firm's historical demand?
(b) How does X-Firm generate the forecast?
(c) Where does X-Firm produce each of its SKUs?
(d) What is X-Firm's inventories model?
(e) How does X-Firm allocate the customers to its distribution warehouses?
(f) How much capacity does each existing distribution warehouse have?
(g) How does X-Firm manage the inventory movements between its facilities?

From the problem description we recognize that a capacity plan for the second expansion has been calculated, but X-Firm is uncertain about the results. It means that X-Firm uses a certain approach to generate the capacity plan. Therefore, we introduce SRQ1.2.

SRQ 1.2 How does X-Firm calculate the required capacity plan for the second expansion plan?

To answer this second sub-question, we examine how the current capacity plan is created and note which criteria are used, e.g. which variables are taken into account and which are not, what assumptions are used, which tool is used for developing the capacity plan, etc.

In general, we answer RQ 1 and its sub-questions using the information obtained from X-Firm through its documentation (i.e., Standard Operation Procedures (SOP)), data mining (i.e., historical report and ORACLE database), observation and interview. We discuss all of those observations and the answer of RQ 1 in Chapter 2.

Chapter 3: Literature Review

RQ 2. What does the literature say about the measurement of inventory effectiveness, inventory management, allocation, and capacity planning for a situation such as X-Firm faces?

We answer this question by performing a literature study to get insight from the state-of-the-art theory related with this study. We discuss the literature study in Chapter 3. We create the following 6 sub-questions to show how we organize the literature study.

SRQ 2.1 What are the indicators to measure inventory effectiveness?

SRQ 2.2 What is known and considered as good inventory management in a distribution network such as X-Firm has?

SRQ 2.3 What is known about the modeling and solution methods for capacity planning?

After performing the literature study, we provide a summary and conclusion of the related theories that deliver the answer of RQ 2 and its sub-questions.

Chapter 4: Conceptual Design

RQ 3. What should a conceptual framework for X-Firm's capacity planning look like?

After examining X-Firm's performance given by the current planning activities and performing the literature study, we make a conceptual framework of capacity planning for X-Firm. We need this conceptual framework as our guideline in developing a solution approach. Before going further, first we want to know what specific requirements either from X-Firm's management that need to be taken into account while making a capacity plan. Therefore, we introduce the following SRQ 3.1.

SRQ 3.1 What requirements should be met by the capacity plan?

To answer this first sub-questions, we have to find:

(a) What outcome should the solution provide?
(b) What constraints should the solution take into account (e.g., certain regulation or procedures)?

Finally after answering SRQ 3.1, we have enough information to design an appropriate conceptual framework of capacity planning for X-Firm. This step leads us to the second sub-question in this part.

SRQ 3.2 What should the conceptual framework look like?

We answer this second sub-question by combining all the information we get from X-Firm's current planning activities, the knowledge gathered from literature study and insights from X-Firm's management. We discuss the observation of the requirements and the development of the conceptual framework in Chapter 4.

Chapter 5: Solution Test

RQ 4. What is the expected performance on the implementation of the solution approach?

To be able to answer RQ 4, we apply our solution approach based on the conceptual framework from Chapter 4 and evaluate the outcomes. First, we determine the solution capacity plan for the distribution warehouses at Sites I and II. Then based on the capacity plan for Site I and II, we can determine a capacity plan for the storage warehouse at Site III. Therefore, we introduce SRQ 4.1 and 4.2.

SRQ 4.1 What is the solution capacity plan for distribution warehouse at Sites I and II that is valid from 2013 until 2016?

SRQ 4.2 What is the solution capacity plan for the storage warehouse at Site III that is valid from 2015 until 2016?

To answer the first and second sub-question, we implement every step in the conceptual framework and determine each parameter that we mention in Table 4.2-1.

After knowing the capacity plans, we calculate the expected inventory movements between sites. Therefore, we introduce the third sub-question.

SRQ 4.3 How many trips of inventory movement are required per day with respect to the solution capacity plan?

Then, we discuss the performance measurement of the solution capacity plan to finalize our solution approach. This step lead us to the last sub-question in this part.

SRQ 4.4 What is the expected performance with respect to the solution capacity plan?

The goal of this sub-question is to compare the performance between the solution approach and the current approach. From the outcomes of the solution test, we will know how well X-Firm performs using this solution approach in terms of the inventory turnover ratio, days of inventory, and total operational costs of distribution warehouses needed to match available capacity and perceived demand.

We elaborate on the solution test and the discussion of the results in Chapter 5.

Chapter 6: Conclusions and Recommendations

In this chapter, we answer the main research question: *"How to obtain an approach to come up with capacity a plan for X-Firm's distribution warehouses?"* by aggregating the results of all research questions above that has to lead to the stated research objective: *"To find an approach to come up with a capacity plan for X-Firm's distribution warehouses."* We also recommend on further research in this chapter.

Chapter 2 Context Analysis

This chapter describes the current situation at X-Firm. It aims at setting a baseline performance of this research study. We first elaborate on the current performance of X-Firm in Section 2.1. To have a better understanding of how X-Firm obtains its current performance, we describe X-Firm's planning activities in relation with capacity planning in Section 2.2. As we can recognize from Chapter 1, a capacity plan for the second expansion has been calculated using a certain approach. We elaborate on how X-Firms generated their current capacity plan in Section 2.3. We mention critical remarks on X-Firm current situation in Section 2.4. To end this chapter, we draw a conclusion in Section 2.5.

2.1 Current Performance of X-Firm

In running their business, X-Firm's management commits itself to deliver a 97% service level to its customers and aims for cost effectiveness. The first target of 97% service level can be translated as a target fill rate of 97%. Fill rate is the fraction of demand that is fulfilled from physical stock in the warehouse (Hopp & Spearman, 2011). In relation with capacity planning, we specify cost effectiveness as minimizing the total operational costs of the distribution warehouses which are incurred to match the available capacity with the perceived demand. We use these targets against the performance indicators to know the system performance.

A performance indicator (PI) is a variable used to indicate the performance of a part or a whole system compared to an agreed target (Fortuin, 1988). From X-Firm's performance targets, we derive 2 PIs: (1) service level to customers; and (2) total operational costs of the distribution warehouses. The activity of measuring performance using PIs is called Performance Measurement (PM) (Lohman, Fortuin, & Wouters, 2004). In this study, the Production Planning and Inventory Controller (PPIC) department is responsible to monitor the service level and the logistics department is in charge of calculating the total operational costs of distribution warehouses. Subsections 2.1.1 and 2.1.2 explain the current performance of each PI.

2.1.1 Service level to customers

Service level agreement is "an agreement between the service provider and its customers quantifying the minimum acceptable service to customer"(Hiles, 2000, p.4). In this study, the service provider is X-Firm. The brand operation department of X-Firm has set the target of 97% service level and reviewed this target every year in the last quarter. This target SLA is then forwarded to the PPIC department.

X-Firm defines demand as all customer sales orders that have been inputted to the ERP system. Each sales order has its expected delivery date. Demand fulfilment depends on the availability of the physical stocks in the warehouse at the moment of order preparation (i.e., the order picking process) or just before the order needs to be delivered on the expected delivery date. It means that there is a possibility that the demand cannot be fully delivered. The fraction of demand that has been fulfilled and delivered to the customer in time is called delivered demand (d). On the other hand, the fraction of demand that could not be fulfilled is known as undelivered demand (u). X-Firm records every undelivered order as lost sales. In other words, an undelivered order will not be delivered when the physical stocks are ready later on. Therefore, we perceive the demand as follows

Eq. 2.1-1

$$Demand\ (D) = Delivered\ demand\ (d) + Undelivered\ demand\ (u)$$

After knowing the demand, X-Firm calculates service level based on demand value on an aggregate level as follows

Eq. 2.1-2

$$Service\ level\ (SL) = \frac{Delivered\ demand\ (d)\ per\ year\ (in\ Euros)}{Demand\ (D)\ per\ year\ (in\ Euros)} \times 100\%$$

From the given formulas, we deduce service level as the percentage of total value of customers' demand that X-Firm could fulfill compared to the total value of the whole customers' real demand. The PPIC department monitors this service level every month in aggregate (i.e., not on SKU level).

Figure 2.1-1 shows X-Firm's service level from 2011 to 2013. The additional green line is the target service level of 97%. From the chart, we observe that X-Firm's service level meets the target service level in 2011 (98.1%), but then it declines quite significantly in 2012 (94.9%) and becomes even lower in 2013 (92.5%).

Bad performances in the last 2 years occurred mainly because of a lack of production capacity at Site I and the distribution warehouse at Site I was fully utilized, since the first quarter of 2012. Those imperfect condition continued until the end of 2013. Moreover, when Site II was ready in the second semester of 2013, X-Firm faced another challenge. This new manufacturing facility could not directly operate smoothly, which is normal to happen in a new factory. A lot of adaptations were needed with regard to new team members, new production machines, and a new procedure for inventory movements between sites. The adaptation processes took until the end of 2013; after this, Site II could operate properly. Currently, X-Firm still works on improving their approach for inventory movements between sites.

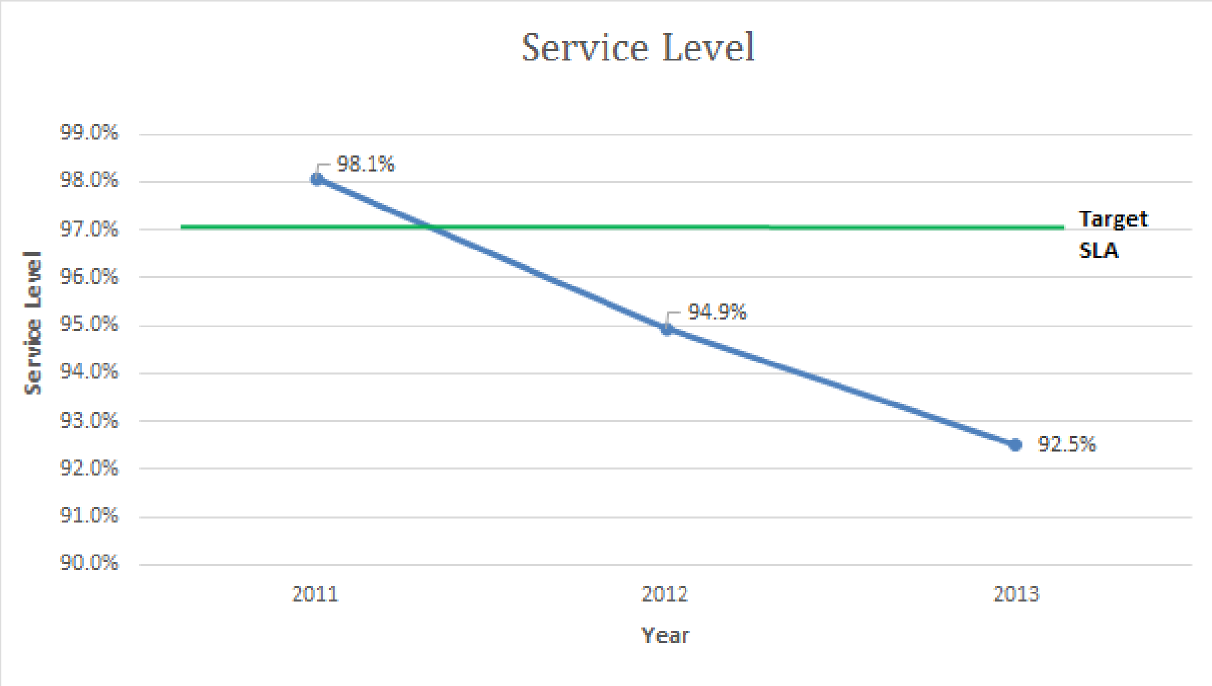

Figure 2.1-1. X-Firm's service level from 2011 to 2013 compared to the target SLA.

2.1.2 Total operational costs of distribution warehouses

X-Firm's logistics department calculates the total operational costs of distribution warehouses by adding up 2 cost components: replenishment costs and inventory holding costs. Inventory holding costs are incurred from storing products in the warehouse. Replenishment costs are incurred from the transportation costs of inventory movements between distribution warehouses at the two sites. X-Firm considers this approach as performance measurement, because these cost components are the biggest variable costs contributing to the operational costs of distribution warehouses. X-Firm does not include the transportation costs of customer order delivery, because the execution, budgeting, and cost control of customer order delivery is not under the responsibility of the logistics department, but under responsibility of the transportation department. Table 2.1-1 shows the total operational costs of X-Firm's distribution warehouses in 2013.

Table 2.1-1. Total operational costs of X-Firm's distribution warehouses in 2013

Costs component	Location	Total initial capacity I_m *(in pallets)*	Cost/day	Number of working day /year	Total costs/year
Inventory holding costs	Site I	1,722.95	€ 0.31	365	€ 194,951.79
	Site II	3,204.87	€ 0.31	365	€ 362,631.04
Replenishment costs	-	-	€ 397.89	302	€ 120,162.78
Total operational costs/year in 2013					**€ 677,745.61**

Regarding the inventory holding costs, the required number of pallets for storage capacity needed for each distribution warehouse is taken from X-Firm's current capacity plan, i.e., taken from Table

2.3-2 and Table 2.3-3 in Section 2.3. X-Firm charges same fixed holding costs[1] for Site I and II (i.e., € 0.31/pallet /day). Since X-Firm calculates the total inventory costs per year, the number of working days per year for carrying the inventory is equal to average number of days per year or 365 days. X-Firm uses this assumption, because they keep carrying the inventory when the warehouse is close on Sunday and on public holidays. The total inventory holding costs contribute 69% to the total operational costs per year.

Every day X-Firm proceeds on average 7 replenishment orders. X-Firm rents 2 built-up trucks and hires 2 drivers and 2 helpers for this purpose. The logistics department works 6 days a week. It is close on Sunday and on public holidays. Therefore, the number of working days per year to do the replenishment processes in 2013 is 302 days. The replenishment costs contribute 31% to the total operational costs per year. For cost effectiveness, X-Firm's management desires to minimize total operational costs of the distribution warehouses, especially the replenishment costs.

2.2 Information in Relation with Capacity Planning

During the field work at X-Firm, we observed the historical demand, forecasting process, inventory model, customer allocation process, and inventory movement process. We collected the information based on our scheme of data collection process that has been presented in Figure 1.5-1 in Chapter 1. We first begin with explaining product classification to describe how X-Firm classifies its products. Then in consecutive order, we elaborate on the data that we have collected.

2.2.1 Product classification

Product classification is important for informative purposes, such as for planning, monitoring, and reporting. Currently X-Firm has 175 Stock Keeping Units (SKUs) of local products and more than 200 SKUs of export products. X-Firm uses different production strategies for local and export products. Make to Stock (MTS) is the strategy for local products, while Make to Order (MTO) is the strategy for export products. In an MTS environment, forecasts drive the production of finished products, which later become stocks in the warehouse. Customer orders are fulfilled from this available inventory. In contrast to MTS, customer orders drive the production of finished products in an MTO environment. Inventory of MTO is stored upstream in the form of raw materials (Sabri & Shaikh, 2010). In this study, we focus on local products, because these mainly contribute to the inventory in X-Firm's distribution warehouses. Figure 2.2-1 describes the classification of X-Firm products including the number of SKUs for each brand category.

[1] X-Firm uses the fixed carrying rate (i.e., € 0.31/pallet/day) to calculate the inventory holding costs, but we prefer to call it as fixed holding costs, because the carrying rate has another meaning according to the literature.

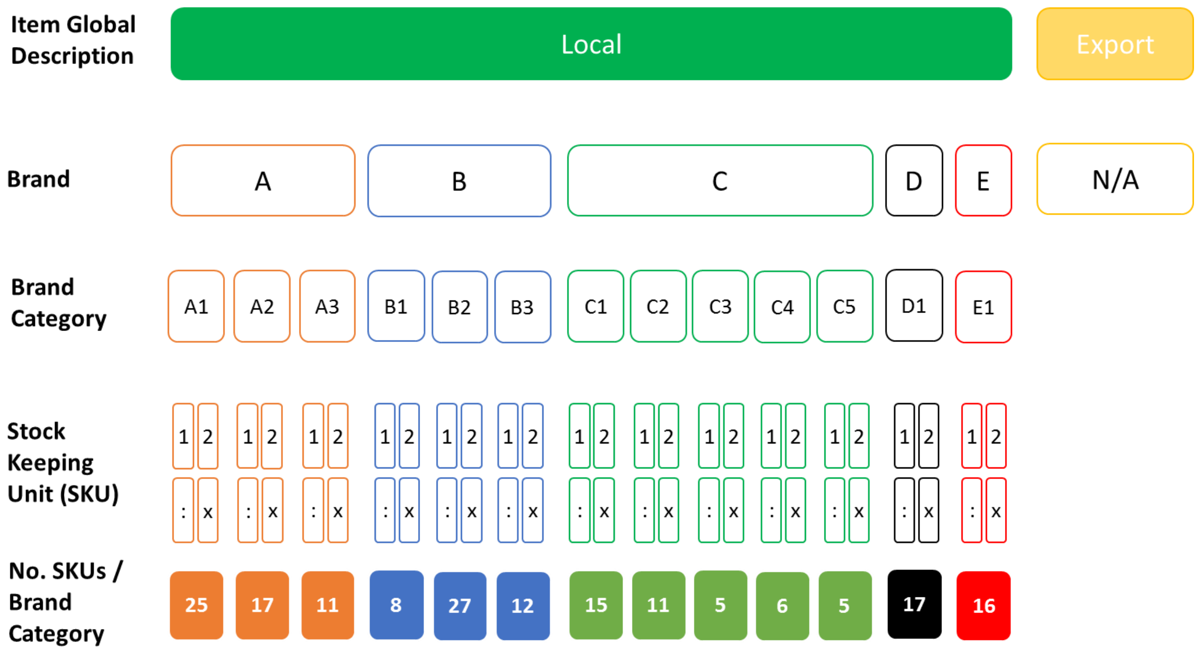

Figure 2.2-1. Classification of X-Firm's products including total number of SKU per brand category

X-Firm classifies its product in a hierarchical structure. This product hierarchy contains 4 levels, namely from the most general to the most detailed: item global description, brand, brand category, and SKU. There are 2 categories of the item global description: local and export. Here we look further on the local product category. Each brand has one brand category or more. Each brand category contains a number of SKUs. On the other hand, each SKU belongs to one brand category, one brand, and one item global description.

2.2.2 Historical demand

In Section 2.1.1, we have discussed at a glance how X-Firm defines its customers' demand. Demand is all customer sales orders that have been inputted to the ERP system. X-Firm generally uses historical demand in money value to monitor forecast error and as an input for forecasting to make a forecast for one year ahead. Historical demand is also needed as an input for capacity planning. In the context of capacity planning, we convert historical demand in money value to a quantity in cartons. Figure 2.2-2 shows the profile of X-Firm historical demand in the last three years.

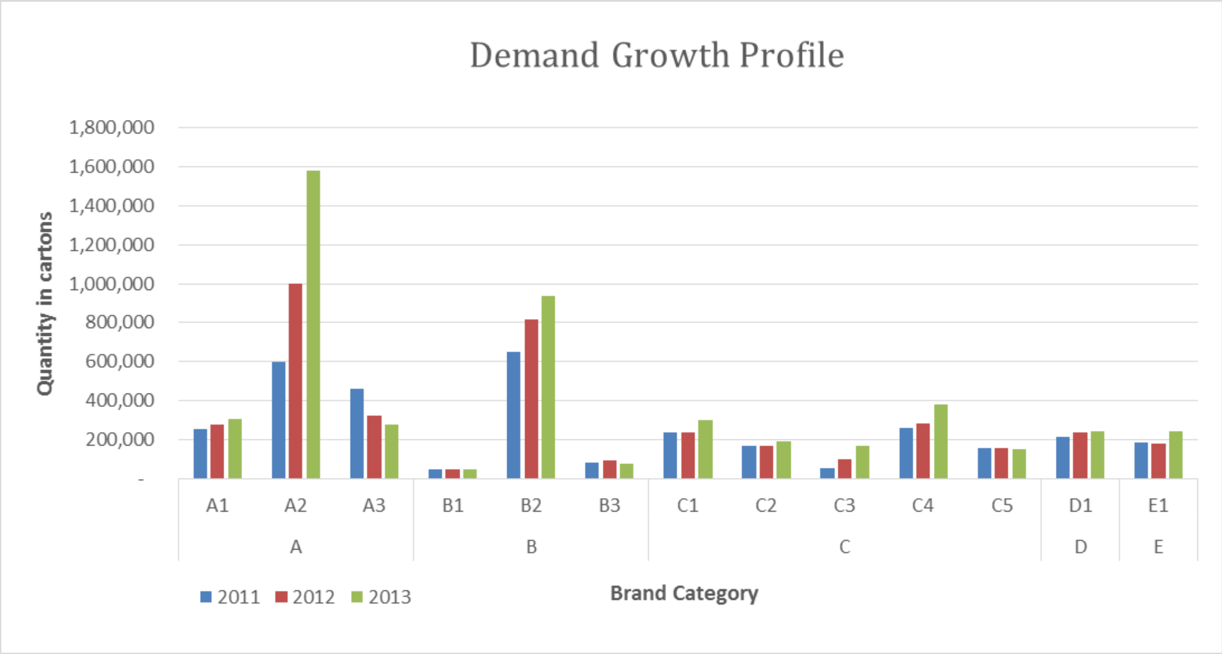

Figure 2.2-2. Profile of X-Firm's demand growth per brand category from 2011 until 2013.

This profile shows the variation of growth in demand quantity per brand category. Most of the brand categories have positive growth, but there are also some brand categories with no growth or even negative growth. Brand categories which have positive growth in demand quantity in the last 2 years are A1, A2, B2, C1, C2, C3, C4, and D1. Several brand categories with no growth or negative growth are A3, B1, B3 and C5. Brand category E1 has a negative growth in 2012, but it has a positive growth in 2013. Based on its quantity of historical demand, we can deduce that brand category A2 and B2 are X-Firm's backbone products. Overall, X-Firm's demand in quantity carton increases 16% in 2012 and 25% in 2013. Table 2.2-1 shows the quantity of historical demand and growth of X-Firm per brand category and overall.

Table 2.2-1. X-Firm's historical demand and growth per brand category

Brand Category	Historical Demand (in cartons)			Growth	
	2011	2012	2013	2012 to 2011	2013 to 2012
A1	252,490	278,777	308,593	10%	11%
A2	601,407	998,428	1,580,000	66%	58%
A3	458,915	321,674	275,122	-30%	-14%
B1	46,375	45,470	45,583	-2%	0%
B2	652,905	818,663	935,348	25%	14%
B3	85,009	95,311	77,655	12%	-19%
C1	235,197	238,413	300,200	1%	26%
C2	170,022	169,378	192,857	0%	14%
C3	55,556	98,104	165,781	77%	69%
C4	258,965	281,258	380,283	9%	35%
C5	155,577	156,330	149,644	0%	-4%
D1	212,243	234,753	244,044	11%	4%
E1	183,573	182,004	242,498	-1%	33%
Total/year	3,368,234	3,918,563	4,897,608	16%	25%

2.2.3 Forecasting

Forecasting is a process to make a projection of customer demand in the future by taking several parameters into account, such as trend of historical demand, company's target growth, marketing activity, business opportunity, human adjustment, etc. The output of forecasting is a forecast. Forecast is made per SKU on a monthly basis for a year period. X-Firm has 2 types of forecasts which are the beginning forecast and the rolling forecast. The beginning forecast is a fixed forecast that is published once at the beginning of the year and used for external business purposes (i.e., as target sales agreement with distributors and other business partners). The rolling forecast is a periodically revised forecast to adapt the condition of current situation (i.e., real customer demands, inventory level of the distribution warehouses, availability of production capacity, additional promotion program, etc.) and usually used for internal operational purposes.

The brand operation department under X-Firm's Marketing division is responsible for making and monitoring the forecasts. The beginning forecast for next year is published in the last quarter of the current year. The rolling forecast is monitored every month. The brand operation department revises the rolling forecast if it is necessary. In January, the value of the rolling forecast per SKU per month is exactly the same as the value of beginning forecast, but as the time goes on the values can be different due to some revisions in the rolling forecast. At the end of the year, the value of the rolling forecast is usually higher than the beginning forecast.

A forecast is very often inaccurate, especially in an MTS environment with its high demand uncertainty. The gap between the forecast and the actual demand is known as a forecast error (Fredendall & Hill, 2000). X-Firm calculates the forecast error as follows

Eq. 2.2-1

$$Forecast\ error\ (\%) = \frac{\sum_{i=1}^{n}(Rolling\ forecast_i\ - Actual\ demand_i\ )}{\sum_{i=1}^{n} Rolling\ forecast_i}$$

with n = number of SKUs.

X-Firm maintains its forecast error per month in the range of ± 20%. Knowing that a forecast is often inaccurate does not mean that it is unnecessary to have a forecast. X-Firm uses forecasts as a guideline for the procurement department to order raw materials, for the PPIC department to make a production plan, and for the sales department to sell the product in accordance with the given target sales.

2.2.4 Production location

At this point in time, X-Firm has 2 manufacturing sites with different type of production plants at each manufacturing site. Manufacturing Site I has 4 production plants (i.e., for RTD, powder type II, powder type III, and other non-RTD), while Site II has only one production plant (i.e., for powder type I and type III). X-Firm also outsources some production to several outsourcing companies.

Figure 2.2-3 shows the arrangement of X-Firm's production location with regard to its brand categories. X-Firm manufactures 84 SKUs from 10 brand categories on Site I. Brand category A1, A2, and B2 dominate the utilization of production plant at Site I. Even though Site II only has one production plant, it is responsible for producing 71 SKUs from 9 brand categories. Brand category C1, C2, D1, and E1 are almost equally utilizing the production plant at Site II. Besides manufacturing products in its own production plants, X-Firm has 20 SKUs from 5 brand categories which are produced in several outsourcing companies.

After production, the production department replenishes finished products of each SKU from the production plant to the distribution warehouse in the same manufacturing site. Due to the lack of capacity at Site I, almost all SKUs from outsourcing companies are sent and stored in distribution warehouse at Site II. Therefore, this arrangement of production location represents the arrangement of original SKUs stored in distribution warehouse at Site I and II.

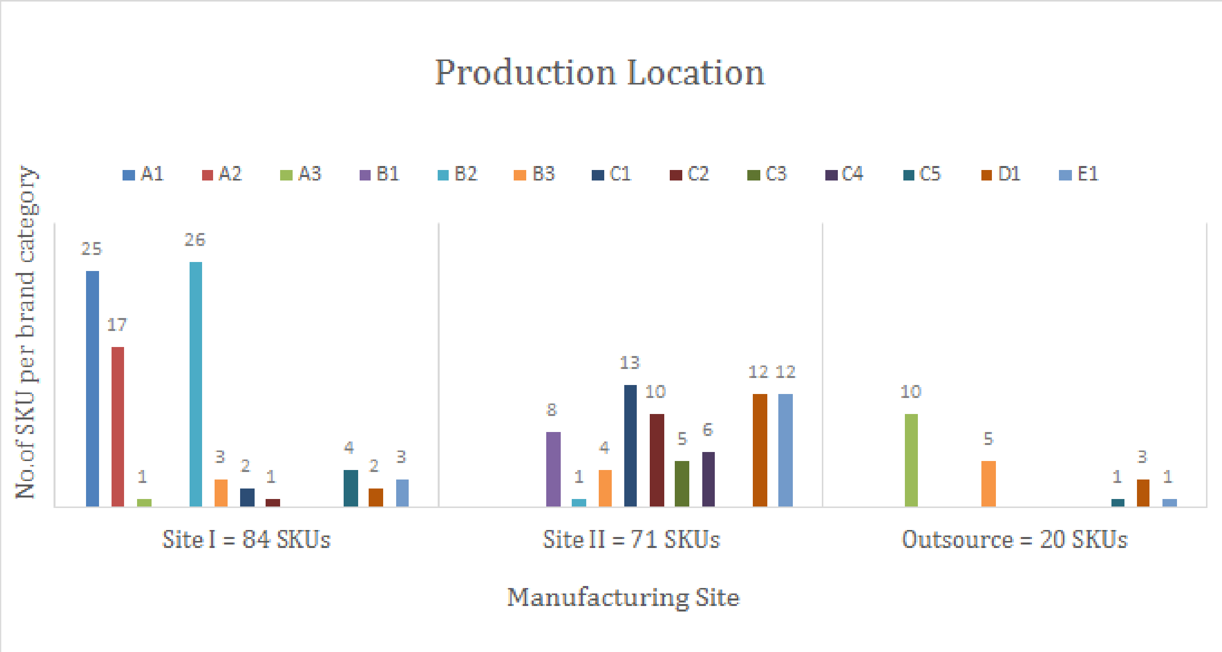

Figure 2.2-3. The arrangement of X-Firm's production location per brand category

2.2.5 Inventory control policy

After elaborating the historical demand and forecasting process, we now look into X-Firm's inventory control policy. In this study, we focus on the finished product inventory. The inventory control policy determines how frequent the inventory level should be reviewed, what level of safety stock should be maintained in the distribution warehouses, how much products should be ordered to the production department, and when the products should be replenished. Understanding X-Firm's inventory control policy is essential as an input for capacity planning improvement.

In general, the PPIC department is responsible to control X-Firm's overall inventories. Every Wednesday, production planners arrange a production schedule for the following week. During this production planning process, they check the overall inventories (i.e., raw materials, work in process inventories, and finished products). They first check on the inventory level of finished products, then continue with checking on the raw material and work in process inventories to decide on a final production quantity for each SKU.

The inventory level that the production planners take into account is the inventory position, which consists of physical stock on-hand and stock on-order minus committed demand. Stock on-order are the inventories that have been produced and will be replenished soon from the production department to the distribution warehouse. Committed demand are the inventories that have been booked by the system according to the customers' sales order. Thus, the Inventory Position (IP) of the distribution warehouse is calculated as follows

Eq. 2.2-2

$$Inventory\ Position\ (IP) = Physical\ \ Stock\ On\ Hand\ + Stock\ On\ Order - Committed\ Demand$$

X-Firm uses Days of Inventory (DOI) as a parameter to monitor the inventory level. X-Firm sets DOI of 10 days as the reorder point (s) for finished products. X-Firm calculates DOI by dividing the inventory position with the demand. For the demand, X-Firm uses an average daily demand of the last 2 weeks or 12 days (i.e., named as MAD12) that has been smoothed using certain fixed weights on each day. Each fixed weight is a certain real number between 0 and 1; the sum of all weights is equal to 1. The PPIC department sets those fixed weight based on their previous experience on demand monitoring. The formula for calculating DOI is as follows

Eq. 2.2-3

$$Days\ of\ Inventory\ (DOI) = \frac{Inventory\ Position\ (IP)}{Moving\ Average\ Daily\ Demand\ of\ the\ last\ 12\ days\ (MAD12)}$$

The process of production scheduling is as follows. If the aggregate inventory level of an SKU (i.e., by considering the IP of both distribution warehouses) is below 10 days, the production planners list this SKU on the draft production schedule. After checking all SKU inventory levels, they set the beginning production quantity of each SKU with DOI less than 10 days to order-up-to level of 20 days. X-Firm calculates the beginning production quantity as follows

Eq. 2.2-4

$$Beginning\ production\ quantity\ = (20\ days\ \times Current\ MAD12) - Current\ IP$$

Then to fix on a final production quantity of each SKU, they adjust the beginning production quantity by considering the availability of raw materials, production capacity, replenishment lead time (L), and lot size (Q) of each SKU. For each SKU, X-Firm has a specific replenishment lead time and lot size. The lead time and lot size can vary between SKUs.

X-Firm measures replenishment lead time in days. For SKUs that X-Firm produces internally, the replenishment lead time consists of production lead time and quality control lead time. The production lead time mainly depends on product type (i.e., powder type I and type III, powder type II, ready to drink (RTD), and other non-RTD) and the need of manual packing due to packaging customization (e.g., additional gusset for product in bottle for brand category A1, inner plastics packaging for brand category A2). The quality control lead time for microbiological checks normally is 3 - 4 days for non-RTD and 5-10 days for RTD products. Almost all SKUs needs quality control after production, except powder type II (i.e., brand category A1 and A2) and powder type III product (i.e., brand category B2).

For SKUs that X-Firm outsources to another company, the replenishment lead time is equal to the order lead time to the outsourcing company (i.e., it already includes the production lead time, quality control lead time, and delivery lead time from the outsourcing company to X-Firm). The order lead time is either 11, 33, or 66 days and it depends on the agreement between X-Firm and the outsourcing company. Figure 2.2-4 describes the replenishment lead time variation within each of X-Firm's brand categories.

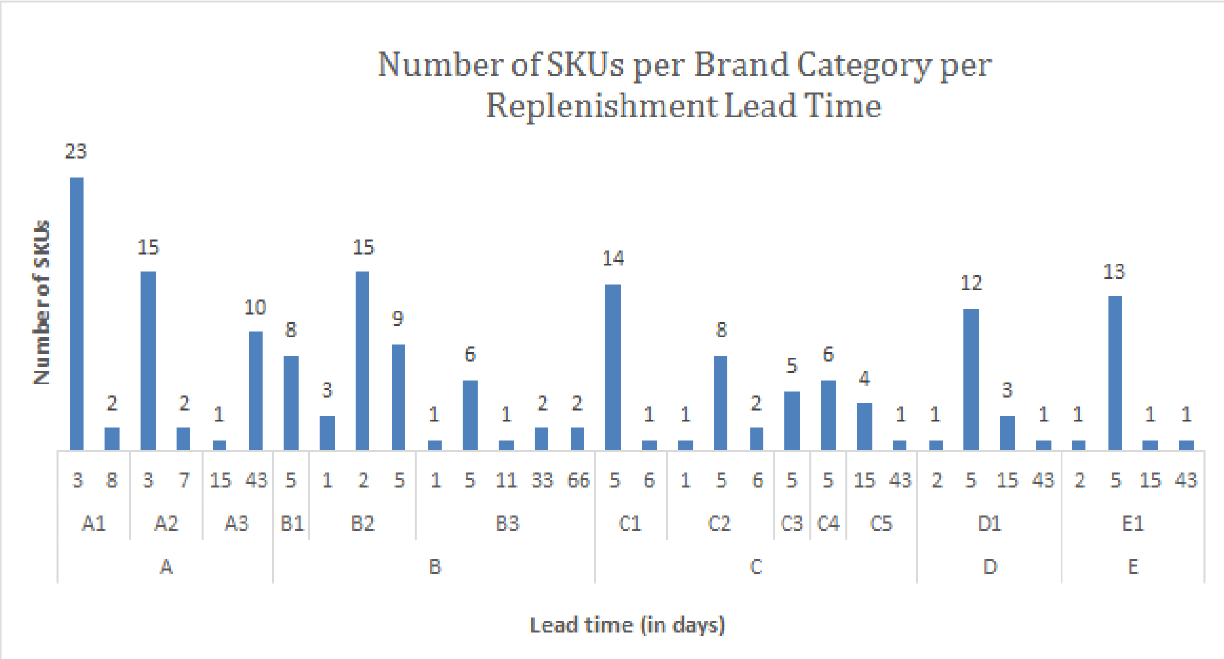

Figure 2.2-4. Replenishment lead time variation in each X-Firm's brand category.

The replenishment lead times of powder type II and powder type III products without microbiological test usually are 1 - 3 days. The replenishment lead times of powder type I and other non-RTD products that need microbiological test vary between 5 – 8 days. Ready to drink products (i.e., SKUs in brand category A3, C5, D1, and E1) have a long replenishment lead time between 12 – 16 days, because of an additional 7 days for incubation included in the production lead time and a longer time for microbiological test. As an exception, there are 2 RTD SKUs (i.e., in brand category A3 and D1) that have a replenishment lead time of 25 days due to other special treatments.

Note that if the storage warehouse at Site III runs in 2015, the replenishment lead time for the RTD products that will be produced at Site III is equal to 1 day, that is equal to the lead time for inventory movements from Site III to Sites I and II. It is because the production lead time and the long waiting time of incubation and microbiological test will be carried out at Site III and will not directly influence the replenishment time from Site III to Sites I and II. Later we consider the additional replenishment costs regarding the inventory movements from Site III to Sites I and II.

In general, X-Firm's production activity consists of 3 phases which are mixing, filling and packing. X-Firm records the lot sizes of finished products in cartons. Variation in lot size depends on the type of production process (i.e., batch or continuous) and packaging dimension. X-Firm applies a batch process for non-RTD products and a continuous process for RTD products. Packaging dimension can vary between SKUs based on product weight. Products in one brand category with the same item description, but different flavors usually have the same packaging dimension. We present the lot size variation in each brand category in Table 2.2-2.

Table 2.2-2. Lot size profile of each brand category

Brand Category	Lot Size (in carton)		
	Average	Std. Dev	CV
A1	132.39	58.67	0.44
A2	170.68	57.14	0.33
A3	883.73	227.14	0.26
B1	156.71	34.97	0.22
B2	251.67	138.03	0.55
B3	412.58	145.56	0.35
C1	194.90	58.49	0.30
C2	179.37	47.88	0.27
C3	104.00	17.93	0.17
C4	160.67	30.27	0.19
C5	1077.00	181.16	0.17
D1	258.71	111.37	0.43
E1	301.31	121.86	0.40

The lot sizes of X-Firm's SKUs are vary from 34 up to 1,258 cartons. Based on the coefficient of variation (cv), we can deduce that X-Firm has a dispersed lot size in every brand category. Generally, the lot sizes of RTD products (i.e., category A3 and C5) are larger than the lot sizes of non-RTD products. The coefficients variation of brand category D1 and E1 are relatively high, because X-Firm merges the RTD and non-RTD products in one brand category. Meanwhile, the high cv of brand category B2 is caused by the variation in packaging dimension (i.e., SKU with product weight 25g, 50g, 100g, 250g, and 500g). Figure 2.2-5 describes X-Firm's inventory control and production planning process.

Besides during production planning every Wednesday, production planners also monitor the inventory level of finished products every day and make a revision to the production schedule if it is necessary for operational settings. Since on tactical level X-Firm monitors its inventory weekly, therefore the review period (R) is equal to 7 days. Based on all information of X-Firm's inventory control and production planning process, we understand that X-Firm adopts a periodic review with fixed lot size (Q) or a (R, s, nQ) inventory control policy with specific production lead time (L) for each SKU.

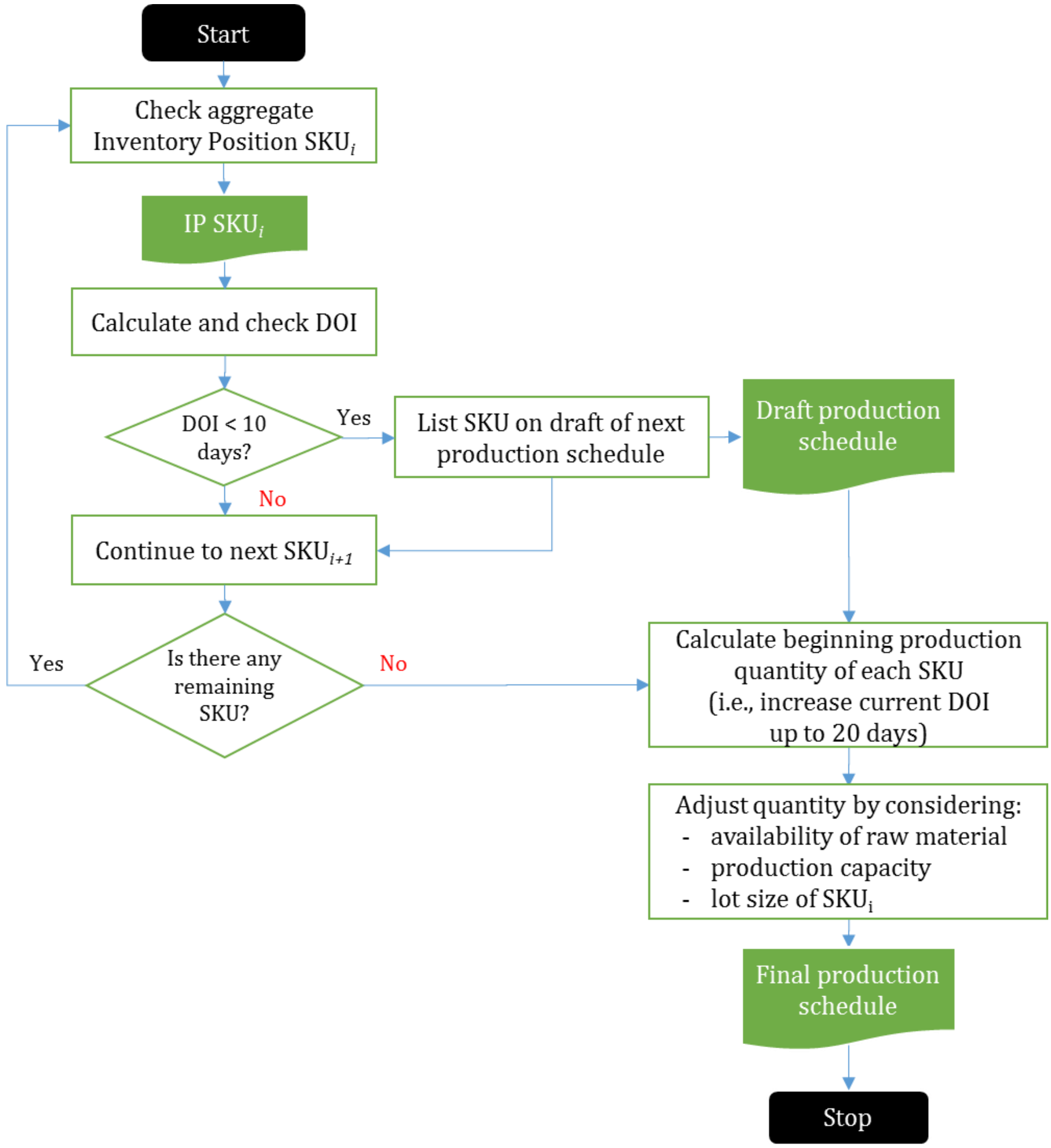

Figure 2.2-5. Flowchart of X-Firm's inventory control and production planning

2.2.6 Customer allocation

In general, X-Firm distributes its products via 4 distribution channels: export buyers, national distributors, retailers (modern outlet), and direct selling to the end customer. In particular to serve its local market, X-Firm uses national distributors and retailers (modern outlets) as its main distribution channels. Henceforth we refer to both of them as X-Firm's customers. Note that a retailer is a modern outlet which is located only in the area of Jabodetabek (i.e., Jakarta, Bogor, Depok, Tangerang, and Bekasi). Other retailers outside Jabodetabek are covered by national distributors.

At the beginning, the distribution warehouse at Site I served all customer orders. Then after having 2 distribution warehouses, X-Firm has allocated every customer to one of both distribution warehouses. The purposes of customer allocation are minimizing transportation costs by assigning all retailers to a delivery route and balancing the workload in both distribution warehouses. In 2014, X-Firm has 1,092 customers that consist of 230 distributors and 862 retailers. X-Firm uses different parameters to determine the allocation of national distributors and retailers. Table 2.2-3 shows the parameters and decision variable of the customer allocation.

Table 2.2-3. Parameters and decision variable of X-Firm's customer allocation process

Customer Category	Parameter(s)	Decision Variable
National distributor	• Multi drop point • Historical demand	Deliver from distribution warehouse at Site *m;* m = {I, II}
Retailer (modern outlet)	• Location	

X-Firm considers the multi drop point and historical demand to allocate a national distributor. A multi drop point is a joint distribution of 2 or more distributors in one province for which their orders need to be delivered using one expedition to minimize the transportation costs. X-Firm checks historical demand (i.e., last 3 months) to know by which manufacturing site the ordered products are mostly produced.

X-Firm has already set a list of multi drop points based on their previous delivery experience. X-Firm refers to this list to calculate the total historical demand of the distributors in each multi drop point. Then, X-Firm assigns each multi drop point to the distribution warehouse at a site where most of the total ordered products are produced. Therefore, every distributor in one multi drop point will have the same distribution warehouse to serve their orders.

To allocate a national distributor, X-Firm first checks the list of multi drop points. If this distributor is in the list, then X-Firm assigns it to the distribution warehouse at which site its multi drop point has been assigned. If this distributor is not in the list, then X-Firm checks its historical demand and assigns it to the distribution warehouse at a site where most of the ordered products are produced. After assigning all national distributors, X-Firm gets the total number of national distributors served by each distribution warehouse.

To allocate a retailer, X-Firm only considers its location. X-Firm assigns a customer's location to a fixed delivery route. X-Firm's transportation department sets the fixed delivery route based on region and number of outlets in that region. X-Firm uses this fixed delivery route to minimize the transportation costs by combining the delivery of customer orders in the same region using a bigger truck. Currently, there are 14 delivery routes set for Site I and 3 delivery routes set for Site II. After assigning a retailer to a delivery route, X-Firm directly gets the total number of retailers served by each distribution warehouse. Table 2.2-4 shows X-Firm's customer allocation for each distribution warehouse.

Table 2.2-4. X-Firm's customer allocation per distribution warehouses in each site in 2014

Customer Category	Site I	Site II	Total per Customers
National Distributor	184	46	230
Retailer (Modern Outlet)	759	103	862
Total customers per site	943	149	1,092

Most customers, both distributor and retailer, are served by Site I, because at the moment most production plants are located at Site I, while Site II has only one production plant. After the second expansion of Site II in 2015, X-Firm has to review this customer allocation to optimize the capacity of distribution warehouse at Site II.

2.2.7 Storage capacity of distribution warehouses

Currently X-Firm has 2 distribution warehouses, one at each manufacturing site. Both distribution warehouses have a rectangular shape. X-Firm uses pallet as a unit load in its warehouse. Pallets of finished products are placed either on block stack or 5-level static pallet racks. The layout setting of both distribution warehouses is quite similar.

Each distribution warehouse consists of 4 main functional areas: receiving, storage, picking, and staging. The purpose of each area based on the movement of finished products is as follows. Receiving is a block stack area to receive and check the compliance between the physical products and the delivery note of finished products from the production department. After checking and receiving, the pallet of finished product is moved to the storage area. Storage is an area to store finished products on 5-level static pallet racks until it is used to fulfill a customer order. This area occupies almost 80% of total pallet positions in the warehouse. X-Firm adopts a random location storage to store the products in the storage area. Picking is an area where all finished products (i.e., SKUs) are stored in a certain sequence on a limited numbers of pallet positions. Here is where the picking process of customer orders takes place. Due to a continuous order picking process, warehouse operators have to replenish a certain number of pallets from the storage area at certain point of time. After the picking process is done, pallets of prepared finished products are moved to staging. Staging is an area to store pallets of ready-to-be delivered customer orders temporarily before the pallets are loaded in a transportation truck. In this study, we focus on the storage capacity of the buffer stock.

For the second expansion, X-Firm plans to build one storage warehouse at Site III. This new storage warehouse consists of only 3 main functional areas: receiving, storage, and staging. It will have a maximum capacity of 2,500 pallet positions to store the RTD products. From this storage warehouse, a warehouse operator replenishes the RTD products to the distribution warehouses at Site I and Site II to fulfill customer orders. Table 2.2-5 shows the current storage capacity and possible extended capacity of both distribution warehouses and the future storage warehouse at Site III.

Table 2.2-5. Storage capacity of X-Firm's distribution warehouses.

Warehouse Location	Existing Storage Capacity (in Pallets)	Possible Extended Capacity (in Pallets)	Maximum Capacity (in Pallets)
Site I	4,302	-	4,302
Site II	3,802	2,993	6,795
Site III	-	2,500	2,500

Currently, the distribution warehouse at Site I has reached its maximum capacity of 4,302 pallet positions and does not have any extra space to extend its capacity. Meanwhile, the distribution warehouse at Site II has 2,993 pallet positions as its extra capacity. If later X-Firm needs more capacity larger than 3,000 pallet positions, it has to add another new distribution warehouse at Site II.

2.2.8 Inventory movement

After concerning several options of customer order delivery, X-Firm management finally decided to allocate each customer to one of both distribution warehouses regarding to its historical demand and the nearest distribution warehouse location (see Section 2.2.6). X-Firm allows every customer to order a combination of all SKUs from the distribution warehouse that it has been assigned to. Thus, each distribution warehouse serves different customer orders and must have all of X-Firm's SKUs. However, as we understand from its production location, not all SKUs are originally available at each distribution warehouse. Consequently, X-Firm has to maintain the SKUs availability in each distribution warehouse by doing replenishments between both distribution warehouses.

The logistics department carries out inventory movements between distribution warehouses daily. The target inventory level that X-Firm expects to maintain in both distribution warehouses is a DOI of 10 days. It is equal to the reorder point that the PPIC department sets. The process of inventory movement consists of 2 steps which are planning and physical execution.

In the planning process, a logistics administrator has to determine what SKU needs to be replenished, how much should be moved, and from which warehouse it needs to be moved by considering the last 12 days moving average demands (MAD12), DOI, and IP per SKU in both distribution warehouses. We introduce a distribution warehouse at Site *n* (i.e., with n = {I, II}) as replenishment destination warehouse and distribution warehouse at Site *m* (i.e., with m = {I, II}) as replenishment source warehouse.

First, the logistics administrator selects one distribution warehouse as a replenishment destination warehouse. Then he checks the DOI of all SKU in the destination warehouse. He filters SKUs with DOI less than 10 days and plans a replenishment order for these SKUs. To know how much inventory of an SKU (i.e., SKU_i with i = {1, 2, ... }) should be replenished from the source warehouse to the destination warehouse, he calculates the beginning replenishment quantity (BRQ) of SKU_i by considering the MAD12 and the IP of SKU_{in} as follows

Eq. 2.2-5

$$Beginning\ Replenishment\ Quantity\ (BRQ)\ of\ SKU_i = (10\ days\ \times Current\ MAD12\ \ SKU_{in}) - Current\ IP\ SKU_{in}$$

After knowing BRQ of SKU_i, he continues with checking the DOI, IP, and the MAD12 of SKU_i in the replenishment source warehouse, then calculates the excess inventory quantity (EIQ) of SKU_i as follows

Eq. 2.2-6

$$Excess\ Inventory\ Quantity\ (EIQ)\ of\ SKU_i = \ Current\ IP\ SKU_{im} - (10\ days\ \times Current\ MAD12\ SKU_{im}).$$

There are two possible decisions according to this check. First, do not replenish SKU_i if the DOI in replenishment source warehouse (i.e., SKU_{im}) is less than 10 days, since there is not enough inventory of SKU_{im}. Second, replenish SKU_i according to its BRQ, if DOI of SKU_{im} is more than 10 days and its EIQ is larger than its BRQ or replenish SKU_i as much as EIQ if DOI of SKU_{im} is more than 10 days, but its EIQ is less than its BRQ. The logistics administrator lists every SKU and its replenishment quantity of the second decision to a replenishment order draft.

Then to fix on a final replenishment quantity of each SKU, the logistics administrator adjusts the beginning replenishment quantity by considering the truck capacity, the quantity inventory on order from the production department, and the current DOI of the source and destination warehouse. The output of planning process is a final replenishment order sheet. Figure 2.2-6 shows the flowchart of X-Firm's inventory movement planning process.

If the storage warehouse at Site III runs in 2015, X-Firm has to do inventory movement for RTD products from Site III to Site I and II. The current approach for inventory movement planning is also relevant and applicable for this inventory movement. In this case, Site III will always be the source warehouse.

In the physical execution, logistics pickers prepare finished products according to the replenishment sheet order. When the truck is ready, they load the palletized finished products in the truck. X-firm has rented 2 built-up trucks (i.e., one truck for each distribution warehouse) to accommodate this physical movement. It can carry at most 16 palletized finished products per trip. Everyday X-Firm normally executes around 6 to 8 replenishment trips per day using 2 trucks (i.e., 3 to 4 full truckload trips per truck).

X-Firm realizes that the execution of this inventory movement is complicated and has become a bottleneck in the supply chain. Later with an additional plant for powder type II products at Site II and one plant for RTD products at Site III, X-Firm expects to have a less frequent inventory movement process. In this study furthermore, we look on the expected inventory movements around Sites I, II, and III on a monthly basis for capacity planning.

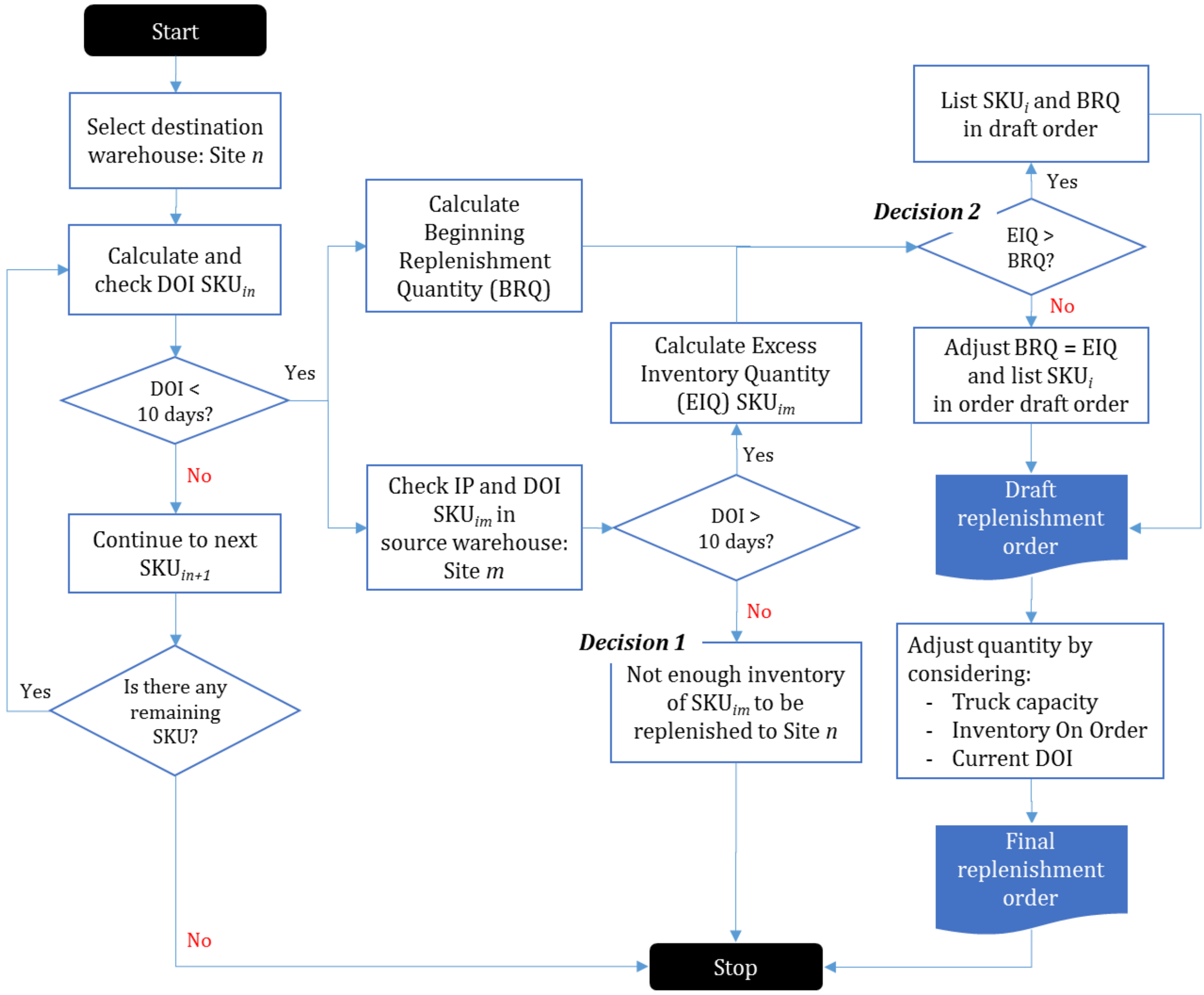

Figure 2.2-6. X-Firm's inventory movement planning process

2.3 Current Capacity Planning

After identifying information related to capacity planning, we now elaborate on the capacity planning process and present the current capacity plan of X-Firm's distribution warehouses for the second expansion. X-Firm made the current capacity plan in August 2013. At that time, X-Firm had not considered to add a manufacturing facility at Site III yet, since it was planned in the beginning of 2014. Accordingly, the goals of the expansion at Site II are to increase the production capacity by having one powder type II production plant and to balance the inventory level at both distribution warehouses. X-Firm's logistics manager coordinated the capacity planning process in collaboration with the brand operation department and the PPIC department.

When X-Firm's management decided to expand the manufacturing facility, there were two outputs that they wanted to acquire from the capacity plan. First, which customer should be served by which distribution warehouse regarding to the second expansion. Second, how much storage capacity was needed for each distribution warehouse to serve those customer demands for the next 4 years. Moreover, X-Firm's management wanted to have a capacity plan of the distribution warehouses that can be used to check the availability of the production capacity.

Based on these needs, the logistics manager developed the current approach of capacity planning that consisted of 4 main ideas. First, creating item groups that included (1) the product type that represents the production plant (i.e., ready to drink (RTD), powder type I, powder type II, powder type III, and other non-RTD) and (2) the production location (i.e., Site I, Site II, and outsource), so that the production manager can directly calculate the production capacity based on the capacity plan of the distribution warehouses. Second, doing customer allocation to Sites I and II, i.e., retailer allocation based on the fixed delivery route and distributor allocation based on the Demand Volume Proportion (DVP). Third, calculating the required storage capacity based on the output of the customer allocation and the expected demand growth per item group. Finally, the logistics manager adjusted the total required storage capacity of both distribution warehouses using "Lack DOI" of 1.5 that he got from comparing the required capacity with an empirical data (i.e., one random point of warehouse utilization in the low season).

From those ideas, X-Firm derived an approach for capacity planning that contains the following 8 steps

1. ***Create item groups***

   The logistics manager used this step to classify each SKU based on a combination of the product type and the production location. From the combination, he came up with 5 item groups: non-RTD outsource, powder type I, powder type II, powder type III, RTD internal, RTD outsource, and other non-RTD.

   After expansion, we know that manufacturing Site II will have 2 production plants (i.e., for powder type I and powder type III, and powder type II), while Site I remains with 4 production plants (i.e., for powder type II, powder type III, other non-RTD, and RTD). With these new settings, there are certain SKUs that can be produced and stored both at Sites I and II. The PPIC department provided the expected production location for every SKU (i.e., either at Site I, Site II, in both Sites I and II, or outsource);

2. ***Collect historical demand per item group per customer***

   The logistics manager collected historical demand in cartons of distributors and retailers to calculate the required storage capacity of each distribution warehouse. For distributor allocation, he also collected demand in volume (m^3) which is used to calculate a Demand Volume Proportion (DVP). Since a distributor's demand is usually large enough to occupy a full truckload, he thought using demand in volume is more appropriate than demand in cartons in order to standardize the demand by eliminating the variation of the packaging dimension;

3. ***Calculate Demand Volume Proportion (DVP) for distributor***

   The logistics manager wanted to assign the storage location of a distributor to a site where most of the ordered products are produced. For that purpose, he calculated the DVP per distributor per production location (i.e., DVP_{dp}) as follows

Eq. 2.3-1

$$Demand\ Volume\ Proportion\ (DVP_{d,p}) = \frac{\sum_g Demand\ Volume_{d,g,p}\ \ (in\ m^3)}{\sum_g \sum_{p'} Demand\ Volume_{d,g,p'}\ \ (in\ m^3)}$$

with

d = Distributor's name;
g = Item group: {RTD, powder type I, powder type II, powder type III, other non-RTD};
p = Production location: {outsource, Site I, Site I - Site II, Site II}.

Appendix A.1 provides the sample data of DVP per item group per location per distributor.

4. ***Assign the customer to the storage location***

The logistics manager directly assigned each retailer's storage location based on its fixed delivery route. For each distributor, he assigned its storage location to the site (i.e., either Site I or Site II) with the largest value of $DVP_{d,p}$. He omitted the DVP of Site I – Site II, because later both Sites I and II can fulfill the demand. For example, the DVP per location of Distributor 1 for Site I is 30.46% and for Site II is 42.99%. Because the DVP of Site II is larger than Site I, the logistics manager assigned Site II as storage location for Distributor 1. Appendix A.2 shows more examples of distributor's storage location assignment using DVP per location.

Table 2.3-1 shows the result of customer storage locations per distribution warehouse. The total number of customer for each customer category in this capacity planning is based on data in 2013.

Table 2.3-1. X-Firm's customer storage locations per distribution warehouse in 2013

Customer Category	Site I	Site II	Total Customers per Customer Category
Distributor	26	92	118
Retailer (modern outlet)	458	117	575
Total Customers per Site	484	209	693

5. ***Calculate demand in pallets per customer category***

After knowing the total demand in cartons per item group per customer category, the logistics manager converted the total demand into pallets using the average number of boxes per pallet. He wanted to calculate the warehouse capacity in pallets.

6. ***Calculate customer demand in pallets per storage location***

The logistics manager added the total demand per customer category in pallets for Site I and Site II. Since the total demand in pallets consists of demand in 15 months, he converted it to a daily demand in pallets per distribution warehouse using the following formula

Eq. 2.3-2

$$Daily\ demand_{gm}\ (in\ pallets) = \frac{Total\ demand_{gm}\ (in\ pallets)}{15\ months\ \times\ 26\ working\ days/month}$$

with

g = Item group: {RTD, powder type I, powder type II, powder type III, other non-RTD};
m = Manufacturing site: {Site I, Site II}.

7. ***Calculate the expected warehouse capacity for the next 4 years***

The logistics manager used the daily demand per item group per site and the target DOI per item group to calculate the initial storage capacity. He calculated initial storage capacity per item group per location as follows

Eq. 2.3-3

$$Initial\ storage\ capacity_{gm}\ (in\ pallets) = Target\ DOI\ _{g} \times Daily\ demand_{gm}$$

Finally, the logistics manager calculated the required capacity of each distribution warehouse by considering expected growth per item group, and the maximum capacity of each distribution warehouse. Using the expected growth per item group, he got the required storage capacity per item group for the first year using the following formula

Eq. 2.3-4

$$Expected\ storage\ capacity_{g,m,y}\ (in\ pallets) = Initial\ storage\ capacity_{g,m} \times Expected\ growth_{g,y}$$

with

g = Item group: {RTD, powder type I, powder type II, powder type III, other non-RTD};
m = Manufacturing site: {Site I, Site II};
y = Year: {1 = 2013, 2 = 2014, 3 = 2015, 4 = 2016}.

The total required storage capacity per item group is the total required storage capacity per distribution warehouse in each site. To extend the calculation until next 4 years, he iterated the same calculation by using required storage capacity of year *n* as beginning storage capacity of year *n+1*.

Figure 2.3-1 describes the detailed capacity planning process for X-Firm's distribution warehouse at Sites I and II.

The logistics manager used several assumptions to adjust the total required storage capacity of each distribution warehouse. First, he assumed that the storage capacity for export products at Site I is equal to 500 pallets and there is no storage for export products at Site II. Secondly, since there is a gap between the storage warehouse utilization at that time (i.e., randomly pick one day at low season) with the required total storage capacity in his capacity plan, he used a rationalization factor which he called a "lack DOI" to adjust the total required storage capacity of both distribution warehouses according to the real warehouse utilization (i.e., empirical data). He calculated the "lack DOI" as follows

Eq. 2.3-5

$$Lack\ DOI = \frac{Storage\ warehouse\ utilization\ of\ one\ day\ in\ 2013\ (in\ pallets)}{Total\ expected\ storage\ capacity\ from\ capacity\ plan\ in\ 2013\ (in\ pallets)}$$

After adjusting the required total storage capacity, the logistics manager obtained the final storage capacity. He compared the final storage capacity with the maximum capacity of each distribution warehouse to know whether the existing capacity of each distribution warehouse is sufficient or not. Table 2.3-2 and Table 2.2-3 present the current capacity plan of X-Firm's distribution warehouses.

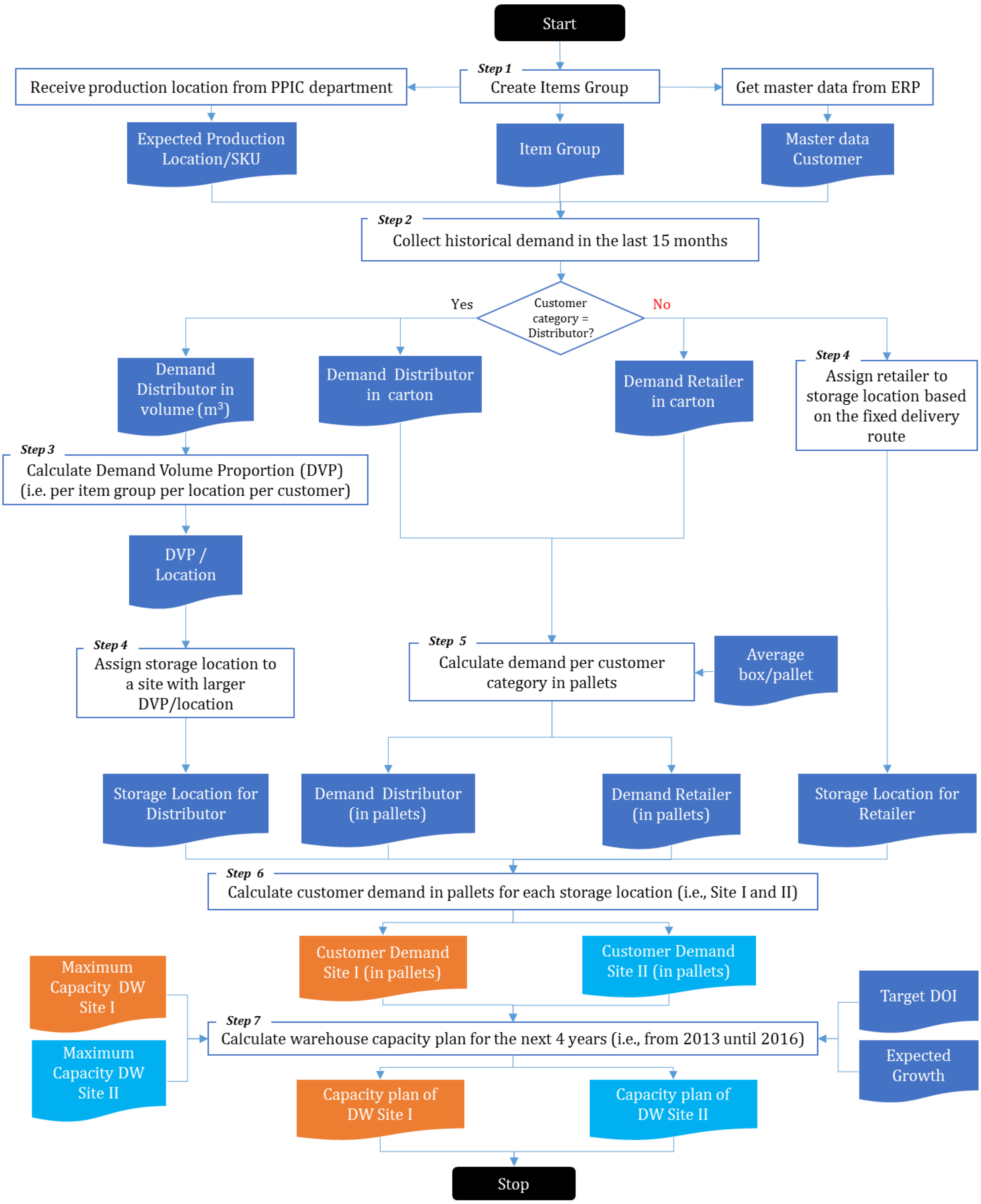

Figure 2.3-1. Flowchart of capacity planning process for X-Firm's distribution warehouses.

Table 2.3-2. Capacity plan of X-Firm's distribution warehouse at Site I

DW : Site I			Year	2013		2014		2015		2016	
Item Group	Target DOI	Daily Demand (pallet)	Beginning Expected Storage (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)
Non-RTD Outsource	12	0.78	9.41	5%	9.88	5%	10.37	5%	10.89	5%	11.43
Powder type II	6	40.00	240.00	40%	336.00	35%	453.60	20%	544.32	20%	653.18
RTD Internal	30	2.86	85.82	5%	90.11	5%	94.61	5%	99.34	5%	104.31
RTD Outsoruce	30	2.76	82.89	5%	87.04	5%	91.39	5%	95.96	5%	100.76
Powder type I	12	13.87	166.44	15%	191.41	15%	220.12	15%	253.13	15%	291.10
Powder type III	6	10.28	61.69	12%	69.10	12%	77.39	12%	86.68	12%	97.08
Other Non-RTD	12	2.52	30.26	5%	31.78	5%	33.37	5%	35.03	5%	36.79
Exp. Total Storage Capacity			676.51		815.30		980.84		1125.35		1294.65
Adjustment by lack DOI	1.5		1014.77		1222.95		1471.27		1688.03		1941.98
Export Products					500.00	25%	625.00	25%	781.25	25%	976.56
Final Storage Capacity			1014.77		1722.95		2096.27		2469.28		2918.54
Maximum Capacity of Site I					4,302		4,302		4,302		4,302
Remaining (Insufficient) Capacity	4,302				2579.05		2205.73		1832.72		1383.46

Table 2.3-3. Capacity plan of X-Firm's distribution warehouse at Site II

DW : Site II			Year	2013		2014		2015		2016	
Item Group	Target DOI	Daily Demand (pallet)	Beginning Expected Storage (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)	Exp. Growth (%)	Exp. Storage Cap. (pallet)
Non-RTD Outsource	12	1.39	16.64	5%	17.47	5%	18.34	5%	19.26	5%	20.22
Powder type II	6	100.00	600.00	40%	840.00	35%	1134.00	20%	1360.80	20%	1632.96
RTD Internal	30	5.22	156.65	5%	164.49	5%	172.71	5%	181.35	5%	190.41
RTD Outsoruce	30	5.43	162.94	5%	171.08	5%	179.64	5%	188.62	5%	198.05
Powder type I	12	48.07	576.90	15%	663.43	15%	762.95	15%	877.39	15%	1008.99
Powder type III	6	25.13	150.77	12%	168.86	12%	189.13	12%	211.82	12%	237.24
Other Non-RTD	12	8.83	105.95	5%	111.24	5%	116.81	5%	122.65	5%	128.78
Exp. Total Storage Capacity			1769.84		2136.58		2573.57		2961.88		3416.66
Adjustment by lack DOI	1.5		2654.76		3204.87		3860.35		4442.82		5124.99
Export Products					-		-		-		-
Final Storage Capacity			2654.76		3204.87		3860.35		4442.82		5124.99
Maximum Capacity of Site II					3,768		3,768		3,768		3,768
Remaining (Insufficient) Capacity					563.13		(92.35)		(674.82)		(1356.99)
Decision	Add capacity of DW Site II in 2014										
Excess (Under) Capacity after expansion	2,993						2900.65		2318.18		1636.01

According to the current capacity plan, X-Firm will have sufficient storage capacity at Site I for the next 4 years. Meanwhile, the storage capacity at Site II will be full in 2014. Since the insufficient capacity is only 92 pallets, X-Firm does not need to prepare the additional space in 2013. To anticipate insufficient capacity in 2015, the logistics manager suggested to increase capacity at Site II by adding 2,993 pallets of static rack in 2014.

2.4 Critical Remarks on X-Firm's Current Capacity Planning Method

In this section, we mention critical remarks on X-Firm current situation regarding the calculation of the service level, the calculation of the total distribution costs, the formula of the forecast error, the implementation of the item classification, the DOI, and the target service level in inventory control, and the approach for developing the current capacity plan.

The calculation of the service level

- X-Firm calculates the service level in money values.

  We note that the service level that is used for inventory control should be in unit cartons and not in money value. If we calculate the service level per SKU, the usage of unit cartons and money value will give the same results, since the price will be canceled out during the calculation. This is not the case if we calculate the aggregate service level, the usage of unit cartons and money value will give different results, since the price of each SKU may be different. The aggregate service level in money value tends to give higher results than the aggregate service level in unit cartons if you prioritize the demand fulfillment of the expensive SKUs (see Appendix B).

The calculation of total operational costs of distribution warehouses

- X-Firm only uses fixed holding costs and omits the product value in the total holding costs calculation.

  It means that the costs to store a high value SKU is relatively cheaper than to store a low value SKU and vice versa, since the carrying rate is the same. It is not common to calculate it that way. The calculation of the total inventory holding costs should also consider the product value.

- X-Firm uses the average number of pallets to calculate the total inventory holding costs.

  The use of the average number of pallets from the capacity plan is not equal to the required number of pallets to be stored in the warehouse, since it does not consider the demand fluctuation. We should use the expected or the maximum on-hand stock in pallets, since it takes into account the forecast errors.

The formula of the forecast error

- The denominator in the forecast error formula is the rolling forecast (see Equation 2.2-1).

  This practice underestimates the actual value of the forecast error, especially if the real sales is smaller than the sales forecast (i.e., the actual sales achievement is lower that the rolling forecast). Since the value of the rolling forecast, i.e., the denominator, is relatively larger than the value of the actual demand, X-Firm gets smaller forecast errors from that formula which is desirable by the sales department. Theoretically, the denominator should be the actual demand, since we want to measure an error of the forecast. Appendix C provides on example of different results if we calculate the forecast errors using X-Firm's approach and the theoretical approach. We use a different approach to calculate the forecast errors for our solution.

The implementation of item classification, DOI, and the target service level in inventory control

- X-Firm does not explicitly do an item classification for its inventory control.

  We note that X-Firm calculates its service level in money value on an aggregate level. It means that the fulfillment of fast moving and high price SKUs become a priority to get a higher service level (see Appendix B for a calculation example). By implementing this approach to calculate the service level, X-Firm has implicitly applied the ABC classification which is very useful for inventory control. Nevertheless, it is necessary to make a well-defined item classification to know how important an SKU is for X-Firm, so they can control the inventory according to the item class.

- X-Firm uses the same DOI as a reorder point for all SKUs.

  It is better to set a different DOI for a group of SKUs with a long production lead time (e.g., RTD products), because the longer the lead time, the higher inventory level or DOI it should hold.

- The DOI calculation is only based on the average demand.

  X-Firm has to consider the forecast errors to calculate the safety stock that influences the reorder point. X-Firm underestimates the reorder point by omitting the forecast errors.

- X-Firm also does not include the target service level to the safety stock calculation.

  The target service level determines the safety factor that is used to calculate the safety stock. By excluding the target service level, X-Firm also underestimates the buffer or safety stock that they should have to deal with demand uncertainty.

The approach of the current capacity plan

- The logistics manager did not consider the seasonal effect in capacity planning

  X-Firm has its seasonal period for brand category A1 from May until July 2012. The same seasonal period also holds for the year 2013. During the seasonal period, the demand (i.e., in money value) can increase between 35% - 260% depending on the SKU. In the current capacity plan, the logistics manager determined the required capacity for the distribution warehouse only based on the simple average of the 15 months historical demand without considering the seasonal period. Using this approach, we are certain that the needed capacity will be higher than the current capacity during the seasonal period even though it is only for 3 months. The capacity plan should consider the seasonal effect so the management of X-Firm can foresee and anticipate the risk of not having enough capacity during the seasonal period.

- The logistics manager used the historical demand of the last 15 months in capacity planning

  The logistics manager intended to use the historical demand from January 2012 until March 2013 because he wanted to include the demand of brand category A2 that were very high in the first quarter of 2013. It is not common to use the historical data of the last 15 months as an input for a capacity plan. Normally, people use the historical data of the last 12 months or one year period (i.e., from January until December). The assumption of "the more data is better" is not always correct, especially if the data contains seasonality. In the historical data of 15 months, X-Firm includes 12 months of regular demands and 3 months of seasonal demands. While using the 12 months historical data, X-Firm uses 9 months rather than 12 months of regular demands. Note that the regular demand has a lower value than the seasonal demand. As a result, the simple average demand of the historical demand of 15 months is lower than the simple average demand of the historical demand of 12 months. Another advantage of using the historical demand of 12 months is that it represents the natural demands of a complete period of sales in one year.

- The logistics manager used the DVP for distributor allocation.

  We argue the benefit of using the DVP, since the customer demands are considered in cartons or in money value. Since the volume and the quantity of customer demand is proportional, we can directly use the total demand of a distributor in cartons for distributor allocation.

- The logistics manager did not take into account the multi drop list in distributor allocation.

  As we understand from the customer allocation process, the multi drop list is very critical for the distributor's order delivery. By omitting the multi drop list in capacity planning, the probability that the logistics manager did not assign the distributor in the multi drop list to the correct site is very high. The results of incorrect distributor allocation results in a wrong capacity plan for each distribution warehouse.

- The logistics manager used "lack DOI" of 1.5 to adjust the total number of pallets in the current capacity plan.

  It means he upgraded the total number of pallets up to 50% of his original calculation which is very high for an adjustment. His approach to calculate the "lack DOI" based on one random point of warehouse utilization in the low season (i.e., as an empirical data) is also not correct, since the warehouse utilization might fluctuate daily.

2.5 Conclusions

Based on our observation on X-Firm's current situation, we conclude that there are several reasons to support X-Firm in improving their performance and capacity planning process. First, X-Firm is underperforming according to its service level. This is related with X-Firm's inventory control policy, especially the way they calculate reorder points and safety stocks. Second, there are no specific rules or procedures for the capacity planning process at X-Firm. The approach used for capacity planning is subjective to the manager who is responsible to make a capacity plan at that moment. The current total operational costs of X-Firm's distribution warehouse are € 677,745.61.

In Section 2.4, we discuss the weak points of X-Firm's current situation. We note that the service level for inventory control should be in unit cartons and not in money value. The calculation of total inventory holding costs should include the product value rather than using only the fixed carrying rate and use the expected or maximum on-hand stock in pallets, because it takes into account the demand fluctuation. The formula that X-Firm uses to calculate the forecast error underestimates the actual value of the forecast error, especially if the sales is under achievement (i.e., the actual sales achievement is lower than the rolling forecast), since the denominator is the rolling forecast while it should be the real demand. It is necessary to do an item classification to distinguish the inventory control of each item class. Regarding to the DOI, it is better to set a different DOI for a group of SKUs with a long production lead time, since the longer the lead time is, the higher inventory level or DOI that it should hold. Besides the average demand, X-Firm's calculation of DOI should also consider the standard deviation of the forecast error. X-Firm has to include the targeted service level when they determine the safety stock.

The critical remarks regarding the current capacity plan are as follows. The logistics manager did not consider the seasonal effect in the current capacity plan while it is important to foresee and anticipate the risk of not having enough capacity during the seasonal period. It is not common to use the historical data of the last 15 months as an input for a capacity plan. It is better to use the historical demand of 12 months, since it represents the natural demands of a complete period of sales in one year. We argue the benefit of using DVP, since we can directly use the total demand of a distributor in cartons for distributor allocation. The logistics manager did not consider the multi drop list in capacity planning that can lead to wrong capacity plan. The logistics manager's approach of using "lack DOI" of 1.5 to adjust the total number of pallets in the current capacity to represent the real warehouse utilization at one random point is not correct, since he upgraded the total number of pallets up to 50% of his original calculation which is very high for an adjustment. Moreover, taking one random point of warehouse utilization in the low season to calibrate the current capacity plan is also not correct, since the warehouse utilization might fluctuate daily. According to these critical remarks, we perform our literature review and develop a solution approach to create a capacity plan for X-Firm's distribution warehouses.

Chapter 3 Literature Review

In this chapter, we provide relevant literature to our research study. Section 3.1 presents the measures of inventory effectiveness. Section 3.2 discusses inventory management that covers item classification, review policy, and inventory policy and its related parameters (i.e., reorder point, safety stock, forecasts errors, and safety factor). Section 3.3 presents the modeling and solution methods of capacity planning. Finally, we draw our conclusions for this literature review in Section 3.4.

3.1 Measures of Inventory Effectiveness

There are two parameters typically used in the literature to indicate the degree of effectiveness of inventory management: inventory turnover ratio (ITR) and days of inventory (DOI). We use these inventory related performance indicators to compare the output of our solution with the output of the current solution.

3.1.1 Inventory turnover ratio

An inventory turnover ratio (ITR) determines how many times an average inventory level is sold in a certain period. For a future context, a projected inventory turnover ratio (PITR) is used. The PITR considers the expected inventory on-hand and the projected demand in unit quantity (Mercado, 2008). The formula to calculate ITR is as follows

Eq. 3.1-1

$$Inventory\ Turnover\ (ITR) = \frac{Demand\ (in\ pallets)}{Expected\ inventory\ on\ hand\ (in\ pallets)}$$

The higher the ITR means that the better a company manages its inventory (i.e., the inventory level reduces, the risk of obsolescence reduces, and it indicates a decreasing costs of financing the inventory). Meanwhile a low ITR shows an over investment in inventory, a high probability of stock accumulation at the end of the year, or it indicates an accumulation of slow moving inventories (Bose, 2006; Mercado, 2008; Weil, Schipper, & Francis, 2012). Ideally, the average inventory costs are between 12% - 20% of the sales revenue. Thus, the recommended ITR that a company should have is around 5.0 – 8.3 (Bose, 2006; Thukaram, 2007).

3.1.2 Days of Inventory

Days of inventory (DOI) determines how many days of customer demand is carried in the inventory on-hand (Ravindran & Warsing, 2012). The calculation of DOI can be done either for individual items by using its unit of measure (i.e., in carton, case, bottle, etc.) or for a particular category of items by using money value, since there are often different units of measure in one category (Mercado, 2008). In relation with ITR, the formula to calculate DOI is as follows

Eq. 3.1-2

$$Days\ of\ Inventory\ (DOI) = \frac{365}{ITR}$$

In general, a lower DOI indicates a better inventory management. However, increasing the DOI is an option to increase customer responsiveness at the expense of extra inventory costs (Ravindran & Warsing, 2012).

3.2 Inventory Management

In this section, we first address the importance of item classification in inventory control. We continue with discussing the review policy. Then, we elaborate on the inventory policy and how to determine a reorder point (s), safety stock (SS), forecast errors, and the safety factor (k).

3.2.1 Item classification

Axsäter (2007) and Silver et al. (1998) propose to do item classification to determine the appropriate inventory control decision and service requirement for different item classes. According to Kampen, Akkerman, & Donk (2012), ABC classification is extensively used for inventory control, because the approach is simply based on the customer demands analysis (see Axsäter (2007) and Silver & Peterson (1985) for the technique; Bacchetti & Saccani (2012), Duchessi, Tayi, & Levy (1986), and Gelders & Van Looy (1978) for application examples). Other methods for item classification are Analytic Hierarchy Process (AHP) for qualitative item classification (e.g., see Gajpal, Ganesh, & Rajendran (1994) and Subramanian & Ramanathan (2012)), VED analysis, TOPSIS, distance modelling, FSN analysis, bi-criteria ABC, graphical 2x2 matrix, decision tree, typical profiles, cluster analysis, optimization techniques, neural networks, and genetic algorithm (see Kampen et al. (2012) for a detailed explanation of each method).

We use the ABC classification in our solution approach in Chapter 4. The ABC classification plays an important role to determine which probability distribution should be used for the forecast errors. Table 3.2-1 summarizes the relation of ABC classification with the distribution of the forecast errors.

Table 3.2-1. The ABC classification in relation with the distribution of the forecast errors

Item Classification	Demand Type	Distribution of Forecast Errors
A item	Slow moving	Poisson distribution
	Fast moving	Normal distribution
B item	Slow & fast moving	Normal distribution
C item	Slow moving	Poisson distribution

3.2.2 Review policy

There are two review policies in inventory control: periodic review and continuous review. A review period (R) is a period of time between two consecutive events when a controller checks the inventory level (Silver et al., 1998). In a periodic review, a controller checks the inventory level only every R time units, the inventory level maybe uncertain between the review periods (Ravindran & Warsing, 2012; Silver et al., 1998). Meanwhile in a continuous review, R is 0, but in some cases R can be equal to 1 (i.e., if the controller checks the inventory level at the end of the day). Table 3.2-2 shows the advantages and disadvantages of periodic and continuous review policies.

Table 3.2-2. The advantages and disadvantages of a periodic and continuous review policies

Review Policy	Advantages	Disadvantages
Periodic review	• Enabling multi-item replenishment coordination from the same supplier or machines. • Predictable workload on the staff involved. • More effective in detecting spoilage on slow moving item.	• More safety stock needed due to a longer review period. Thus, the inventory carrying costs are also higher.
Continuous review	• Real time access to inventory status • Less safety stock (i.e., lower carrying costs) to provide the required service level.	• More expensive in terms of reviewing costs and reviewing errors • Unpredictable workload of staff involved

Source: Silver et al. (1998)

Based on Table 3.2-2, we deduce that X-Firm's decision to use periodic review policy is suitable to manage its 175 SKUs of local products. It allows X-Firm to have multi-item replenishment coordination, especially in purchasing raw materials from the same suppliers, and to have a stable workload for the production planner and inventory controller. Doing periodic review is also effective to evaluate the remaining shelf life of X-Firm's slow moving items periodically. As a trade-off, X-Firm has to keep more safety stocks and incur higher inventory carrying costs.

3.2.3 Inventory control policies

This subsection discusses inventory control policies and the related parameters (i.e., reorder point, safety stock, and safety factor). The common notations used in inventory control are as follows

R = Review period, in time units;

Q = Predetermined lot size, in units;

n = Integer number, a constant;

s = Reorder point, in units;

S = Order-up-to level, in units;

D = Demand, in units/time unit;

L = Replenishment lead time, in time units;

SS = Safety stock, in units;

k = Safety factor; a constant;

$\hat{x}_L$ = Expected demand during replenishment lead time, in units

σ_L = Standard deviation of forecast errors over a replenishment lead time, in units

The purpose of inventory control is to determine 3 decisions: (1) how often the inventory level should be reviewed; (2) when a replenishment order should be placed; and (3) how large the replenishment quantity should be. The combination of these three decisions creates inventory policies (Silver et al., 1998). Table 3.2-3 gives a summary of the inventory policies that are commonly used in practice.

Table 3.2-3. The summaries of inventory control policies (Adapted from Silver et al. (1998))

Review Policy	Lot Size	Inventory Control Policy	Replenishment Criteria
Periodic review	Fixed	(*R, s, Q*)	Review the *IP* every *R* periods; If *IP* < *s*, reorder a fixed quantity of *Q*
		(*R, s, nQ*)	Review the *IP* every *R* periods; If *IP* < *s*, reorder an integer multiple of *Q.*
	Variable	(*R, S*)	Review the *IP* every *R* periods; Reorder a variable lot size (*S* – *IP*) such that the *IP* is raised to the order-up-to level *S.*
		(*R, s, S*)	Every review period *R*; If *IP* < *s*, reorder a variable lot size (*S* – *IP*) such that the *IP* is raised to the order-up-to level *S*.
Continuous review	Fixed	(*s, Q*)	When *IP* < *s,* reorder fixed lot *Q* such that the IP is raised to a level above *s.*
		(*s, nQ*)	When *IP* < *s,* reorder an integer multiple of *Q* such that the IP is raised to a level above *s.*
	Variable	(*s, S*)	When *IP* < *s*, reorder a variable lot size (*S* – *IP*) such that the *IP* is raised to the order-up-to level *S.*

Silver et al. (1998) provide the detailed model and assumptions that are used for each inventory control policy. The (*s, Q*) system is the basic inventory policy that is extensively discussed in the literature. To adapt the parameters that are used in the (*s, Q*) policy to the periodic review policy with review period *R* and a variable lot size with order-up-to level *S*, Silver et al. (1998) show the relation between the parameters of (*s, Q*) and (*R, S*) systems. It means that the decision rule to determine the order up-to-level (*S*) value in an (*R, S*) system is obtained from the corresponding decision rule that is used to determine the reorder point (*s*) value in an (*s, Q*) system by simply making three substitutions given in Table 3.2-4. Thus, we use the (*s, Q*) system to explain the parameters that are commonly used for inventory control.

Table 3.2-4. The relation between the parameters of (*s, Q*) and (*R, S*) systems

In (*s, Q*) System	Substitute to	In (*R, S*) System
s	→	S
Q	→	DR
L	→	$R + L$

Inventory position plays an important role in deciding when to replenish. Axsäter (2007) defines the inventory position according to the following relation

Eq. 3.2-1

$$Inventory\ position = on - hand\ stock + outstanding\ orders - backorders.$$

Reorder point (s) is a level of inventory that is set as a signal to replenish. So, once the inventory level touches the reorder point or below, a controller places a replenishment order. The general formula to determine a reorder point in the (*s, Q*) policy is as follows

Eq. 3.2-2

$$Reorder\ point\ (s) = \hat{x}_L + Safety\ Stock\ (SS)$$

with

Eq. 3.2-3

$$Safety\ stock\ (SS) = k \cdot \sigma_L$$

Safety stock is the average inventory position just before the replenishment arrived, i.e., the average stock that a company keeps to deal with the demand uncertainty in the short run. It is also known as a buffer stock. Some important parameters that influence the amount of safety stock are the replenishment lead time (L), the forecast errors (σ), and the related shortage costs or the required service level.

To be able to calculate an appropriate safety stock to provide a required customer service, we need to know how uncertain the forecast is by calculating the forecast errors. Only knowing the mean of the future demand is not sufficient. We can measure the forecast error by comparing the real demand with the rolling forecast in every period (Axsäter, 2007; Silver et al., 1998).

There are two measurements of variability that are often used in connection with forecast errors: Mean Squared Error (MSE) and Mean Absolute Deviation (MAD). Silver et al. (1998) recommend to measure the forecast errors using the MSE, since it is easy to compute using spreadsheets. The formula of the MSE is as follows

Eq. 3.2-4

$$MSE = E(X - m)^2$$

And the relation of MSE and the standard deviation σ is

Eq. 3.2-5

$$\sigma = \sqrt{MSE}$$

Axsäter (2007) suggests to use the MAD to measure the variability, since it is more robust than the MSE. The formula of MAD is as follows

Eq. 3.2-6

$$MAD = E|X - m|$$

Note that a common assumption for the forecast errors is that the errors are normally distributed. Silver et al., (1998) provides 3 reasons to use a normal distribution for the forecast errors. First, the normal distribution empirically gives a better data fit than most other distributions. Second, if in particular the replenishment lead time and the review period are long, the forecast errors in many periods are added together, so we would assume a normal distribution based on the Central Limit Theorem (see Larsen & Marx (2012) for further details). Finally, a normal distribution directs to analytically tractable outcomes. Under this assumption, the relationship between MAD and σ is as follows

Eq. 3.2-7

$$\sigma = \sqrt{\pi/2} \cdot MAD \approx 1.25\, MAD$$

The estimation of the variability of the forecast during the lead time and the review period (σ_{L+R}) is an input for safety stock calculation. The formula to calculate σ_{L+R} under a normal distribution is as follows

Eq. 3.2-8

$$\sigma_{L+R} = \sqrt{L + R} \cdot \sigma$$

with

L = Replenishment lead time, in time unit;

R = Review period, in time unit.

Meanwhile for slow moving items, Silver et al. (1998) suggests to use the Poisson distribution to develop an estimation of σ_{L+R}. This approach gives a quick estimate of σ_{L+R} (i.e., it may not be an exact result) using the following formula

Eq. 3.2-9

$$\sigma_{L+R} = \sqrt{\hat{x}_{L+R}} = \sqrt{D \cdot (L + R)}$$

with

$\hat{x}_{L+R}$ = Mean demand during replenishment lead time and review period;

D = Demand, in unit;

R = Review period, in time unit.

Silver et al. (1998) discuss 4 different methods to determine an appropriate safety stock under probabilistic demand according to management perspective. We summarize these methods in Table 3.2-5.

The simple minded approach using equal time supplies is a straightforward and generally used method, but it is significantly leads to an error, since it does not consider the difference in forecast errors between items and it does not optimize inventory costs or the required service level. The customer service approach is mostly used in practice, because the costs of shortages are difficult to quantify in practice (Axsäter, 2007; Janssen, Heuts, & Kok, 1996; Silver et al., 1998).

Table 3.2-5. Summary of different methods of determining the safety stocks under probabilistic demand (Adapted from Silver et al. (1998))

Method	Approach	Criteria to derive k
Simple minded approach	Assigning a common time supply or safety factor as safety stock of each item.	• Equal time supplies (i.e., equal DOI) • Equal safety factor (k)
Costs minimization	Involving specific costs of shortage and then minimizing the total relevant costs.	• Costs per stock out occasion (i.e., B_1) • Fractional charge per unit short (i.e., B_2) • Fractional charge per unit short per unit time (i.e., B_3)
Customer service	Minimizing the inventory carrying costs subject to a required customer's service level.	• Specified probability of no stock out per replenishment cycle (i.e., P_1) • Specified fraction (P_2) of demand to be satisfied directly from stock (i.e., the fill rate P_2)) • Specified ready rate (i.e., P_3) • Specified average time between stock out occasions (i.e., *TBS*)
Aggregate considerations	Establishing the safety stocks of an individual item, using a given total budget, to provide the best possible aggregate service across a group of items.	• Minimize expected total stock out occasions per year (*ETSOPY*) subject to a specified total *SS* • Minimize expected total value short per year (*ETVSPY*) subject to a specified total *SS*

The key to determine a reorder point and a safety stock is the safety factor (k). The safety factor can be derived from each criterion in Table 3.2-5 (see Silver et al., (1998) for the detailed formulas, decision rules, and numerical illustration of each criterion). Figure 3.2-1 shows the general logic to determine the reorder point and the safety stock using the k value. Note that for the periodic review with review period R, we use the demand during replenishment lead time and review period or the ($L + R$) instead of the demand during replenishment lead time L only (Axsäter, 2007).

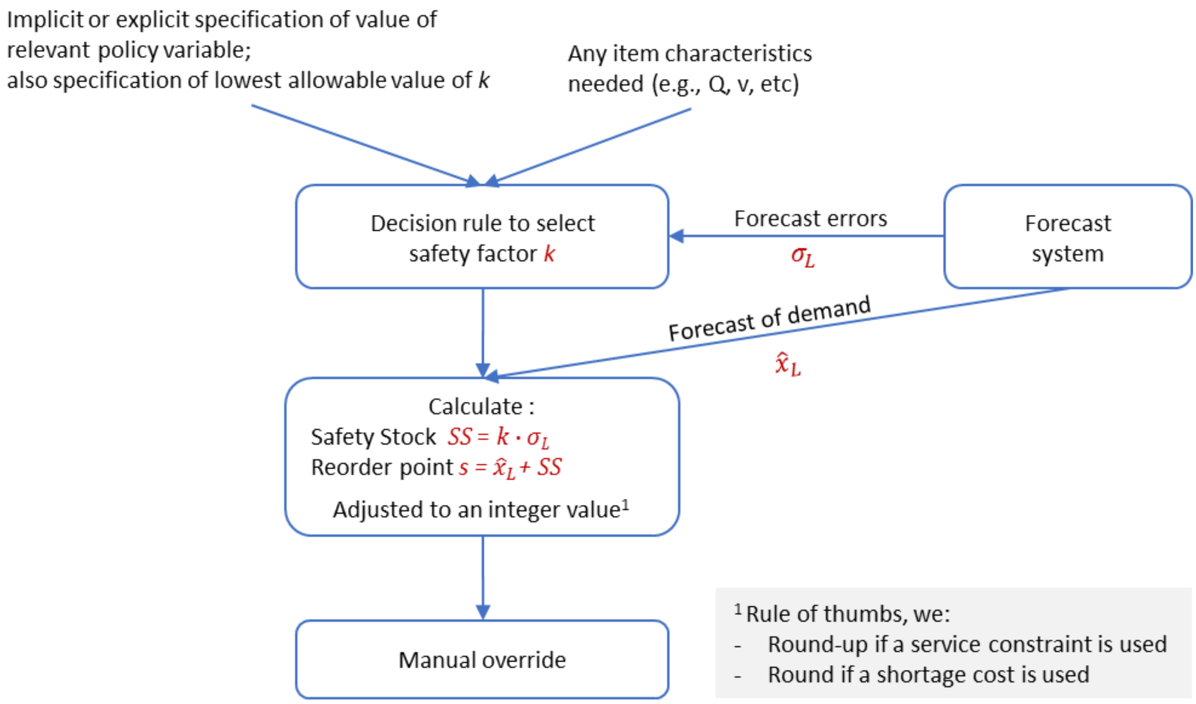

Figure 3.2-1. General decision logic to determine the value of *s* (Adapted from Silver et al., 1998)

In our solution approach in Chapter 4, we use the customer service methods, because X-Firm has a target service level of 97% and X-Firm currently does not quantify the shortage costs. We consider to use 2 service levels as our criteria to calculate the safety stocks: fill rate (P_2) and probability of no stock out per replenishment cycle (P_1).

The fill rate (P_2) is the fraction of demand that is fulfilled directly from the stock. It is the most used criterion to determine a safety stock based on customer service if the forecast errors have a Normal distribution (i.e., for A and B items). In the case of periodic review with complete lost sales as X-Firm does, Silver et al. (1998) and (Axsäter, 2007) appoint to the safety factor *k* that fulfills

Eq. 3.2-10

$$Normal\ loss\ function = G_u(k) = \frac{DR}{\sigma_{L+R}} \frac{(1 - P_2)}{P_2} = \emptyset(k) - k \cdot [1 - \Phi(k)]$$

with
- $G_u(k)$ = Normal loss function of an SKU, a constant;
- D = Demand, in unit;
- R = Review period, in time unit;
- P_2 = Fill rate, in fraction;
- σ_{L+R} = Standard deviation of forecast errors during $L+R$;
- $\phi(k)$ = Standard normal density function;
- $\Phi(k)$ = Standard normal distribution function.

The value of *k* is at least as large as the lowest allowable value of the safety factor, otherwise it might recommend to hold no inventory at all. After knowing *k*, we calculate the safety stock according to *Eq. 3.2-3*. Note that an increasing service level gives an exponential curve relationship in the additional safety stock required (Emmet, 2005; Silver & Peterson, 1985). The higher the service level means the higher the safety stocks that are needed.

The probability of no stock out per replenishment cycle (P_1) is a fraction of replenishment cycles in which a stock out does not occur. A stock out is a situation when the on-hand stock decreases to zero. Instead of P_2, we use this P_1 as service level for class C items to simplify the inventory control.

In the periodic review policy, Silver et al. (1998) use the following rule to determine the safety factor using P_1. First, select the desired value of P_1. Then, determine the k value based on P_1 with the following formula

Eq. 3.2-11

$$p_u(k) = 1 - P_1$$

$$k = \Phi^{-1}(P_1)$$

After determining the value of k, we calculate the safety stock according to *Eq. 3.2-3*.

3.3 Capacity Planning

Storage capacity planning is a critical process, because the storage area occupies a large space in a warehouse. Tompkins, White, Bozer, & Tanchoco (2010) consider the planned number of on-hand stocks that need to be stored based on the replenishment receiving schedule and the method of product allocation to a storage area. The common receiving schedules are either that all products are received together at the same time or that each product arrives over time. There are two methods for product allocation to a storage area: fixed or assigned location storage and random or floating location storage. To calculate the required storage space, Tompkins et al. (2010) suggest to use the maximum on-hand quantities if the replenishment orders of all products arrive at the same time and/or if the fixed location is used to assign the product to a storage area. Meanwhile, if the product arrives over time and the random location storage is used, they suggest to use the average on-hand quantities, because when the inventory level of one SKU is above average, another SKU will tend to be below average.

Several fields extensively discuss about capacity planning, such as in production, manufacturing, logistics, and healthcare. We select several relevant studies that give us insights on how to model the capacity planning problem and on how to solve the model. Mathematical modeling (i.e., integer linear programming or mixed integer linear programming) is commonly used for capacity planning.

Yao, Lee, Jaruphongsa, Tan, & Hui (2010) worked on an allocation and inventory problem in multi-source facility location that incorporates multiple resources of warehouses. In this problem, multiple products are produced in several production plants, the warehouses can receive products from several plants, each customer has stochastic demand, and a certain amount of safety stock must be maintained in the warehouses in order to achieve a certain customer service level. The objective function is to minimize the expected total costs to satisfy the target customer service level. The outcomes of the model are the number and location of warehouses, allocation of customers demand, and the inventory levels of the warehouses. The authors formulated the problem as a mixed integer nonlinear programming problem and solved the problem by an iterative heuristic method. Mirhassani, Lucas, Mitra, Messina, & Poojari (2000) developed a computational solution for a capacity planning model under uncertainty. The authors formulated the problem as an integer stochastic programming model that explicitly considers randomness and solved the problem using decomposition solution methods. The major drawback of using stochastic programming for capacity planning problems is that this is computationally demanding.

These studies from healthcare sector also gives us insights on how to model the capacity planning problem. Assume that the operating room is similar to a distribution warehouse and the hospital bed is similar to the required pallets needed. Cardoen, Demeulemeester, & Beliën (2010) reviewed recent operations research on operating room planning and scheduling by evaluating the literature on multiple areas that are related to the problem setting (i.e., performance measures or patient classes) or the technical aspects (i.e., solution methods). Bachouch, Guinet, & Hajri-Gabouj (2012) developed a decision support tool based on an integer linear programming model for hospital bed capacity planning. They took into account several constraints, such as incompatibility between pathologists, no mixed-sex rooms, continuity of care, etc. They used 3 solver software programs: GLPK, LINGO, and CPLEX. Previously, Harris (1986) also worked on hospital bed capacity planning but using a simulation model to help management decide on the bed allocation and operating schedules. Kuo, Schroeder, Mahaffey, & Bollinger (2003) used liner programming for optimizing the allocation of operating rooms (OR). The objective functions of the model are to maximize revenue and minimize operating costs. The inputs of the model are allocated OR time, case mix, total OR time used, and the normalized professional charges. The Solver linear programming was used to determine the optimal mix of surgical OR time allocation to maximize professional receipts.

These following studies show the possibility to include the production capacity in capacity planning of distribution warehouses that might be useful for the future research. Jolayemi & Olorunniwo (2004) worked on a deterministic model for planning production and transportation quantities in a multi-plants and multi-warehouses environment with extendible capacities using mixed integer programming. The model determines a production combination that maximizes the total profit over a finite planning horizon. If there is lack of production capacity, the model lets the subcontractor or the buffer inventory meets the demand shortage that cannot be produced internally. The outcomes of the model are the quantities of each product that need to be: (1) produced at each plant, (2) replenished from each plant, (3) subcontracted at each warehouse, and (4) kept as inventory at each warehouse. Catay, Erenguc, & Vakharia (2003) worked on tool capacity planning under time varying demand in semiconductor manufacturing. They developed a multi-period mixed integer linear programming model to minimize the machine operating costs, new tool acquisition, and inventory holding costs and solved the model using a Lagrangean-based solution method. Singh et al. (2012) described a mixed integer linear programming model for determining long term capacity requirements of the Hunter Valley Coal Chain by minimizing the total costs of infrastructure and demurrage. They tested different solution methods to solve the model (i.e., using CPLEX, generic algorithm heuristic, and large neighborhood search).

This kind of study is useful for X-Firm's management if they consider to open another manufacturing facility in the future capacity planning. Georgiadis, Tsiakis, Longinidis, & Sofioglou (2011) developed a mathematical formulation using mixed integer linear programming for the problem of designing supply chain networks that contain multi-products production facilities with shared production resources, warehouses, distribution centers and customer zones, and operating under time varying demand uncertainty. The model was solved to optimality using branch-and-bound. The proposed model aims to assist management to decide on the production allocation, production capacity per manufacturing site, purchase of raw materials, and network configuration that considers transient demand conditions. The model is attractive for the solution of large scale problems, because the computational costs of this model are relatively low.

3.4 Conclusions

A considerable amount of studies and literature are available on different topics of performance indicator for inventory effectiveness. There are 2 performance indicators (i.e., ITR and DOI) to measure the effectiveness of our solution approach and X-Firm's current approach.

Item classification should be carried out to consider how critical an SKU is to a firm and to determine which probability distribution of the forecast errors should be used. The ABC classification is commonly used in relation with inventory control. There are extensive literature discussions about inventory control. Based on the review policy (i.e., periodic or continuous review) and the lot size (i.e., fixed or variable), there are 7 inventory polices that are known in the literature (i.e., (*s, Q*), (*s, nQ*), (*s, S*), (*R, S*), (*R, s, Q*), (*R, s, nQ*), and (*R, s, S*)). There are 4 different methods to determine the safety stock that are a simple minded approach, a cost minimization approach, a customer service approach, and an aggregate consideration.

Literature extensively discusses the capacity planning problems in several fields, such as health care, production, manufacturing, and logistics. Mathematical programming models, such as linear programming, integer programing, mixed integer programming, and stochastic programming, are mostly used to formulate the problem that has a similar context as our study and different kind of solution methods are applied to solve the capacity planning problem. Besides mathematical programming, the literature also discusses about the application of simulation in capacity planning.

This literature study provides sufficient knowledge to address all critical remarks regarding to X-Firm's current condition (see Chapter 2). We apply it to develop a conceptual design in Chapter 4.

Chapter 4 Conceptual Design

This chapter discusses the requirements from X-Firm's management for a solution capacity plan and the conceptual framework of our solution approach. We first start with elaborating on several considerations and constraints from X-Firm's management in Section 4.1. Then, we discuss the motivation of every choice of our solution approach in Section 4.2. We present the conceptual framework of our solution approach to create a capacity plan in Section 4.3. We give our conclusions of this chapter in Section 4.4.

4.1 Requirements and Constraints from X-Firm's Management

There are 2 outputs that the management of X-Firm expects from the capacity plan. First, they want to know which customers should be served by which distribution warehouse (i.e., the customer allocation). Second, they want to know how much storage capacity is needed for each distribution warehouse to serve those customer demands over the next 3 years (i.e., instead of 4 years as the current solution has, because they want to have the same ending period in 2016).

In terms of the tool or application used for the capacity plan, the management of X-Firm expects to have it in Microsoft Excel, since it is handy and almost everyone in the company is familiar with it. The template of the capacity plan should be adaptable and extendable in terms of adding or deleting SKUs, parameters, or assumptions.

There are several constraints that the solution capacity plan should take into account:

1. **The expected demand growth in unit carton is 15% for brand category A2 and 8% for the other brand categories (i.e., the demand growths differ from the ones that are used now).**

   These expected demand growth are directly given by X-Firm's management based on the target sales that they want to achieve in 2014 – 2016;

2. **The rolling forecast and the sales achievement are on a monthly basis.**

   The brand operation department inputs and monitors the sales achievement and the rolling forecast on a monthly basis. It means that we can calculate the forecast error either monthly or yearly, but not in shorter time periods. Since X-Firm usually monitors the capacity plan annually, in this study we calculate the forecast errors on a yearly basis (i.e., on aggregate level);

3. **The probability of no stock out occasion (P_1) for C items is not specified by management. However, management expects us to come up with the P_1 that represents a fill rate of 97%**.

   We know that X-Firm applies the modification of the simple minded method to determine the safety stock of its products (see Table 3.2-5), so management is not familiar with P_1 for the customer service method. We come up with P_1 of 95% after observing the relation of P_1 and P_2 in terms of safety factor (k) and the normal loss function ($G_u k$). We want to know if an SKU has a certain k (i.e., k_{P1}) and normal loss function (i.e. $G_u K_{p1}$) according to P_1, what the fill rate P_2 is that has the normal loss function (i.e., $G_u k_{P2}$) equal to $G_u K_{p1}$? Here we assume that the item class C has a normal distribution. From the literature, we know that we can calculate k_{P1} using *Eq. 3.2-11*. We calculate the $G_u k_{P1}$ using the formula of normal loss function = $\emptyset(k) - k \cdot [1 - \Phi(k)]$. Then with Solver in Microsoft Excel, we can determine the P_2 using the other formula of $G_u k$ such that the value of $G_u k_{P2}$ = $G_u k_{P1}$ (see *Eq. 3.2-10*). Based on our calculation, we find that using P_1 of 95% for all item class C satisfies the average fill rate of 97%. Appendix D shows the fill rate P_2 of all item class C if P_1 is 95%;

4. **The retailer allocation should refer to the fixed delivery route that has been set by the transportation department.**

   X-Firm wants to use the fixed delivery route for retailer allocation, because this is their best practice for customer delivery management (i.e., transportation planning, on-time delivery monitoring, transportation costs controlling, etc.). The transportation department has worked on the fixed delivery route for years based on their experience in customer delivery. The transportation department assures to have an efficient transportation costs and schedule using the fixed delivery route for retailer allocation;

5. **The multi drop list given by the transportation department should remain the same.**

   The multi drop list is also the best practice of X-Firm's customer delivery management. The existing multi drop list is made by the transportation department in collaboration with the shipping department. These departments have different responsibilities in customer order delivery. The transportation department is in charge of delivering customer orders by land transportation (i.e., all retailers, all distributors that are located in Java island, and distributors that are located in Sumatra island, except for North Sumatra and Aceh), while the shipping department is in charge of delivering customer orders by sea transportation (i.e., distributors in South Sumatra and Aceh and all distributors outside Java island). The transportation and the shipping department also assure to have an efficient transportation costs and schedule by using the existing multi drop list for distributor allocation.

4.2 Solution Approach

In this section, we first present and compare the criteria and parameters that we consider in our solution approach to X-Firm's current approach in Table 4.2-1. Then, we explain the motivation of every choice in our solution approach.

Table 4.2-1. The approach used in this study in comparison with X-Firm's current approach

Parameter	Approach used in	
	X-Firm's current solution	This study
Historical demand	15 months (i.e., 01/2012 – 03/2013)	12 months (i.e. 01/2013 – 12/2013)
Item grouping	Combination of Product Type and Production location, e.g., powder type I – Site I/Site II/Outsource	ABC classification with 3 additional remarks: (*) for SKU in brand category A2, "S" for seasonal SKU in brand category A1, and "R" for RTD product that is internally produced.
Forecast errors	Not applied	For the class A and B items (assumption: fast moving): normal distribution using MAD; and Poisson distribution for class C items (assumption: slow moving).
Safety factor (*k*), Safety stock (*SS*),	Simple minded approach (i.e., using fixed DOI, not using *k*)	Customer service approach using service level P_2 for class A and B items and P_1 for class C items.
Reorder point (*s*)	DOI based on MAD12	$s = \hat{x}_{L+R} + Safety\ Stock\ (SS)$
Demand growth *(in unit cartons)*	• 15% for Powder type I • 40% for Powder type II • 12% for Powder type III • 5% for all RTD and Non-RTD	• 15% for brand category A2 (i.e., part of powder type II products); • 8% for other brand categories
Customer allocation (i.e., for capacity plan)	Retailers: Fixed route Distributors: DVP	Retailers: Fixed delivery route; Distributors: Total demands per site in unit pallets, multi drop list, customer's relative travel distance to Sites I and II, and direct assignment of M06.
Number of pallets in the capacity plan	The average historical demands	The expected on-hand stock *E(OH)* for regular products and the maximum on-hand stock *Max(OH)* for seasonal products.
Performance measurement	• Aggregate service level • Total operational costs	• Inventory turnover ratio (ITR) • Days of inventory (DOI) • Total operational costs • Total relevant costs, including unit value *v* in the total inventory holding costs.

We come up with our approach based on the information and critical remarks of X-Firm's current situation, the expectation of management, and the knowledge that we gathered from the literature study. Note that we use the (*R, s, nQ*) inventory policy in our solution approach, since we want to make a capacity plan that considers the current inventory policy. We underpin each criterion of our solution approach as follows:

Historical demand

Historical demand is the basic input both for the current and the solution capacity plans. In the solution capacity plan, we use the historical demands of 2013 (i.e., from January until December 2013) as the input to calculate the standard deviation of the forecast errors. Using the 12 months data, we can capture the regular and seasonal demands within a complete one year sales period.

Item grouping

Item grouping or SKU classification is an important step in inventory management. In the current capacity plan, the logistics manager did the item grouping based on the combination of the product type and production location. From those combinations, he came up with 5 item groups (see Section 2.3).

In our solution approach, we use the ABC classification as our main criterion to create the item group. We know from Section 2.1.1 that X-Firm measures their performance based on the aggregate service level in Euros. It means that the fulfillment of the fast moving and high price SKUs (i.e., the item classes A and B) becomes a priority. So, it is necessary to make an item classification based on how important an SKU is for X-Firm. From literature we learn that the ABC classification is suitable for grouping items based on demand in values and also there exists a specific probability distribution for each item class that will be needed for the forecast errors calculation. In the current practice, X-Firm has also implicitly implemented the ABC classification, since they calculate the service level in money value (see Section 2.4). Therefore, we use the ABC classification for item grouping in our solution approach.

To decide on the distribution for the forecast errors, we need to know whether an SKU is a fast moving or slow moving item. X-Firm has its own definition for the fast moving and slow moving items. An SKU is a fast moving item if the customer orders this SKU at least once a month, otherwise this SKU is a slow moving item. Based on the historical demand in 2013, we conclude in general that the item classes A and B consist of fast moving items and item class C consists of slow moving items. Therefore, we can assume that all the SKUs in the item classes A and B are all fast moving items and that all the SKUs in item class C are slow moving items. We merge the item classes A and B into 1 item class AB, since they have the same probability distribution of the forecast errors and we use the same service level policy, i.e., fill rate P_2 = 97% to determine the safety factor of each SKU in this item class.

To accommodate the calculation of our solution capacity plan, we want to distinguish the SKUs in each item class with 3 additional criteria: (1) demand growth, because there are 2 different demand growths given by the management of X-Firm (i.e., 15% and 8%); (2) seasonal or regular product, because we want to include the seasonal effect in our solution capacity plan; and (3) internal RTD or others, because we want to calculate the storage capacity needed for the internal RTD products at Site III. We formulate the item group based on the combination of the item class from the ABC classification and these additional criteria. The item group of SKU_i is the item class and a (*) sign if SKU_i is in the brand category A2 whose demand growth is 15%. The item group of SKU_i is the item class and an "S" remark if the SKU_i is in brand category A1 whose SKUs are seasonal products. The item group of SKU_i is the item class and an "R" remark if SKU_i is an RTD product that X-Firm produces internally and will be stored at Site III in 2015. If SKU_i has a demand growth of 8%, it is a regular product, and is not an internal RTD product, then the item group of SKU_i is only the item class. From these settings, we come up with 7 item groups: AB*, ABS, ABR, AB, CS, CR, and C. Table 4.2-2 shows the detailed criteria of each item group that we use in the solution approach.

Table 4.2-2. Detailed item grouping criteria in the solution approach

Item group	Grouping criteria			
	Item class	Demand growth	Seasonal product	Internal RTD SKU
AB*	AB	15%	No	No
ABS	AB	8%	Yes	No
ABR	AB	8%	No	Yes
AB	AB	8%	No	No
CS	C	8%	Yes	No
CR	C	8%	No	Yes
C	C	8%	No	No

Forecast errors

X-Firm does not take into account the forecast errors in its inventory management policy. We suspect this is one of the reasons why the logistics manager had to use "lack DOI" of 1.5 in the current capacity plan to adjust his calculation, since he only considered the average historical demand. As we learn from the literature, only knowing the mean of the demand is not sufficient. To be able to calculate an appropriate safety stock to provide a required customer service, we need to consider how uncertain the forecast is by calculating the forecast errors. Therefore, we include the forecast errors in our solution approach.

We use the MAD for the normal distribution to calculate the standard deviation of forecasts error for item classes A and B (i.e., we assume that those items are fast movers). We assume item class C are slow movers that has a Poisson distribution. Therefore, we calculate the forecast errors using a simplified method that is a square root of the expected demand during replenishment lead time and review period ($\sqrt{\hat{x}_{L+R}}$) (see *Eq. 3.2-9*).

Safety stock and safety factor

From the context analysis, we deduce that X-Firm implements a modification of a simple minded approach to determine the safety stock. Rather than using the same DOI to set a safety stock level, X-Firm uses equal DOI to determine its reorder point. Thus, the safety stock level (i.e., in terms of DOI) between items might be different, since the demand during replenishment lead time and review period between SKUs might be different. From the literature we learn that the simple minded approach is seriously in error, since it does not consider the difference of forecast error between items and it does not optimize required service level.

In our approach, we use the customer service methods to determine the safety stock and safety factor, because X-Firm has a target service level of 97% and X-Firm currently does not quantify the shortage costs. X-Firm only considers lost sales as loss of opportunity costs, but they cannot quantify how much the loss is, since they do not know how much real customer demand X-Firm misses when the products are not available at the retailer's shelf. We derive the safety factor (k) from the P_1 and P_2. We choose to use 2 service levels as our criteria to calculate the safety stocks. First, we use a target service level of 97% as a fill fate (P_2) to calculate the safety stock of item class A and B. Second, we use the probability of no stock out occasion (P_1) of 95% for item class C.

Reorder point

Currently X-Firm uses an equal DOI of 10 days as its reorder point. Since the DOI calculation is based on the MAD12 (see *Eq. 2.2-3*), the reorder point can be at a different level at every review period. In our solution, we determine the reorder point by taking into account the safety stock and demand during lead time and review period $\hat{x}_{L+R}$ using *Eq. 3.2-2* with review period R = 7 days for all SKUs and deterministic replenishment lead time L_i per SKU.

Demand growth

The demand growths given by X-Firm's management for the current capacity plan and the solution capacity plan are different (see Table 4.2-1). We directly use this new demand growth (i.e., 15% for brand category A2 and 8% for other brand categories) for our solution approach.

Customer allocation for the capacity plan

The logistics manager used the DVP for distributor allocation. In Section 2.4, we argued the benefits of using the DVP, since the customer demands are considered in cartons or in money value. As long as the variation of the packaging sizes are tolerable, we can directly use the total demand of a distributor in pallet for distributor allocation. Therefore, in our solution approach we use the total demand per site in unit pallets to assign a distributor's storage location rather than the total demand in volume. We consider the largest demand per site and multi drop list for distributor allocation. Later to improve our solution, we also consider the relative travel distance from the customer location to Sites I and II and swapping allocation of a multi drop list. For the retailer allocation, we assign the storage location according to the fixed delivery route.

After all the customers have been allocated to one of the distribution warehouses, we determine the fraction of customer demand per item group per site and use this fraction of customer demand to calculate the required number of pallets needed for the distribution warehouse at Sites I and II.

Number of pallets in the capacity plan

The logistics manager calculated the number of pallets in the capacity plan based on the average historical demand and the targeted DOI of each item group. In our solution approach, we use either the expected on-hand stock in pallets for the regular product or the maximum on-hand stock in pallets for the seasonal product to determine the initial on-hand stock per SKU. We use the expected on-hand pallets, because the replenishment order of each SKU arrives over time and X-firm adopts a random location storage method to store its products to storage area. We use the maximum on-hand stock for seasonal products based on their seasonality index to foresee and anticipate the risk of not enough capacity during the seasonal period, because based on X-Firm's experience, the customer demand (i.e., in money value) of seasonal products increases significantly between 35% - 260% depending on the SKU. The seasonality index is an integer number that shows how many times the demand in pallets of SKU_i maximally increases during seasonal period compare to the average demand. For the calculation of the initial on-hand stock, we consider the average inventory and the safety stock, while we consider the integer number of lot size (i.e., $nQ \approx DR$) and the safety stock for the calculation of the maximum on-hand stock.

Inventory movements

In developing the current capacity plan, the logistics manager did not calculate the estimated inventory movements between Sites I and II and between Site III to Site I or II after the second expansion. In our solution approach, we determine the estimated inventory movements between those sites according to the total demand per item group that is produced at the other sites and needs to be replenished to the customer allocation site. We use this estimated inventory movements to determine the expected replenishment costs in 2013 that is needed to calculate the total operational costs of our solution approach.

Performance measurement

We add 2 performance indicators, which are ITR and DOI, to measure the inventory effectiveness. To keep the comparison of the current and the solution capacity plans appropriate, we also calculate the ITR and DOI for the current capacity plan. Further, we calculate the total operational costs based on X-Firm's current operational costs and the total relevant costs based on what we learn from the literature. We also provide the sensitivity analysis to see the impact of the service level to the performance indicators.

4.3 Conceptual Framework

In this section, we summarize our solution approach in the form of a conceptual framework. The conceptual framework contains 6 steps which are divided into 2 major phases: (I) data grouping (i.e., Steps 1 – 4) and (II) the capacity planning process (Steps 5 – 6). Figure 4.3-1 describes what this conceptual framework looks like.

The step-by-step approach of each phase in the conceptual framework is as follows. The purpose of data preparation (phase I) is to segment the SKUs based on the ABC classification and determine the total initial on-hand stock per item group. This segmentation plays an important role in deciding which probability distribution of the forecast errors and which service level should be used to determine the safety factor (k) and the forecast errors for safety stock (SS) calculation according to the (R, s, nQ) inventory control policy. Thus, Step 1 of this phase is to do item grouping based on the Distribution by value ($\sum Dv$) analysis for the ABC classification of all SKUs.

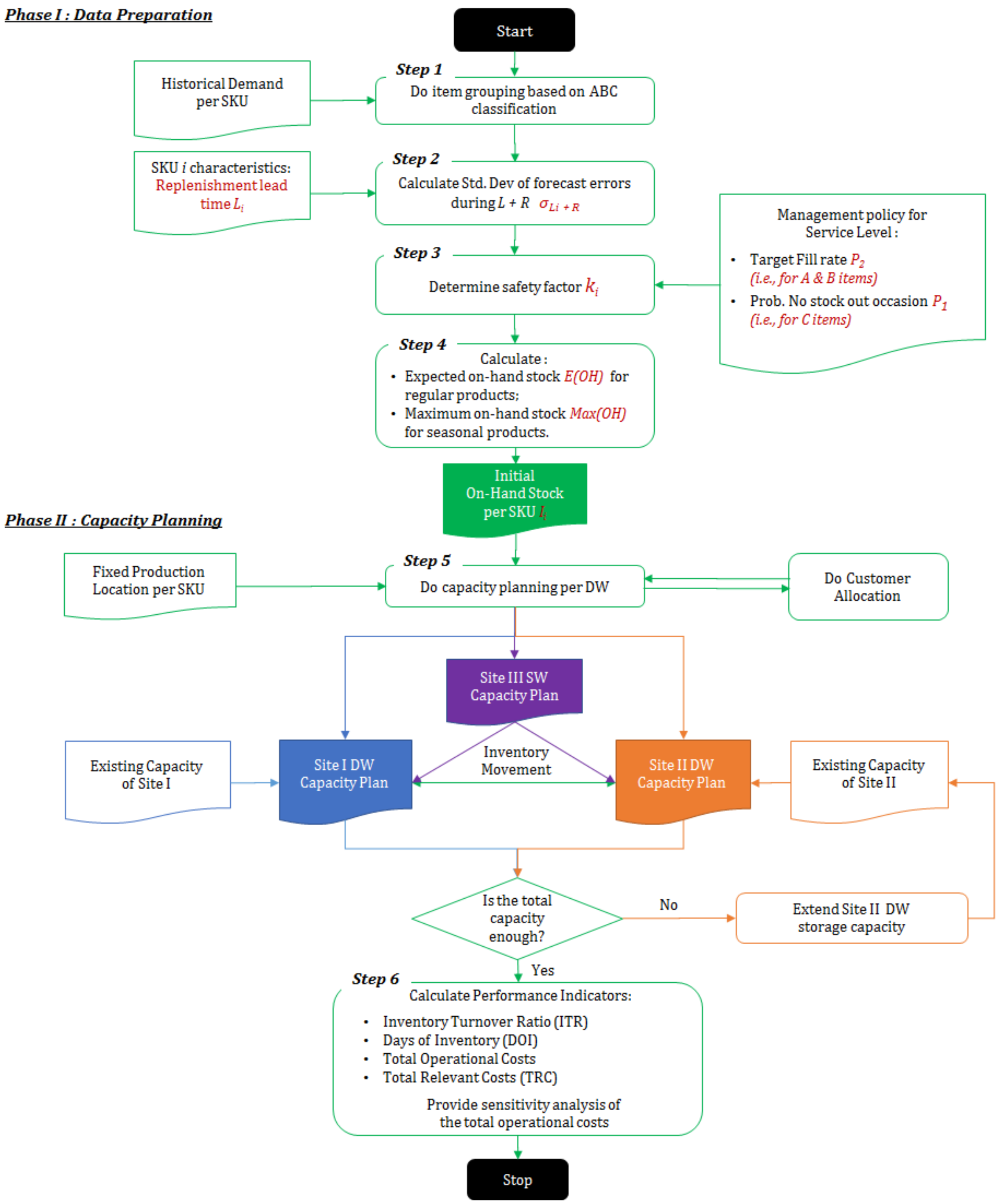

Figure 4.3-1. The conceptual framework for developing a capacity plan for X-Firm's distribution warehouses

Then, we continue with Step 2 to calculate the forecast errors during the replenishment lead time and review period ($L+R$) under the normal distribution for A and B items and under the Poisson distribution for C items. We first have to determine the MAD to calculate the forecast errors for A and B items. In Step 3, we determine the safety factor based on the management policy for the service level (i.e., fill rate (P_2) = 97% for A and B items and the probability of no stock out occasion (P_1) = 95% for C items). In Step 4, we calculate the safety stock, the reorder point, and the initial on-hand stock (i.e., the expected on-hand stock for the regular products or the maximum on-hand stock for the seasonal products). Then, we determine an initial on-hand stock in pallets per item group using the combination of the expected and maximum on-hand stock. The summation of this initial on-hand stocks per item group is equal to the total number of pallets that are needed by X-Firm in 2013.

In Phase II (capacity planning), we aim at creating a capacity plan for each distribution warehouse based on the fraction of customer demand per item group from the customer allocation. In Step 5, we perform the capacity planning based on customer allocation for distributors and retailers. From the customer allocation, we get the fraction of customer demand each distribution warehouse in 2013 and determine the initial on-hand stock for Sites I and II. We calculate the required capacity in pallets needed for each distribution warehouse in 2014 until 2016 and the storage warehouse at Site III in 2015 until 2016 by multiplying the initial capacity with the demand growth per item group. Then, we check whether the existing capacity is sufficient or not to hold the required capacity in pallets to be stored at Sites I and II. If it is not sufficient, we decide on when and by how many pallets the capacity of the distribution warehouse at Site II needs to be extended. We also give several short term recommendations to cope with the insufficient capacity for Sites I and II. In Step 6, we finalize our capacity plan by calculating the performance measurement in 2013 (i.e., the ITR, DOI, total operational costs, and TRC) in order to compare it with X-Firm's current performance.

4.4 Conclusions

The requirements from X-Firm's management regarding the outputs of the solution capacity plan are that they want to know the customer allocation and total number of pallet positions needed in 2014 until 2016 for each distribution warehouse. Management also requires an adaptable and extendable template of the capacity plan on Microsoft Excel file. There are 5 constraints that we have to consider in the solution design: the new expected demand growths, the rolling forecast and forecast errors on a monthly basis, the P_1 should represents a fill rate of 97%, the retailer allocation based on the fixed route delivery, and the multi drop list should remain the same.

We select our solution approach based on the information from X-Firm's current situation, the requirements of the management, and the knowledge that we gathered from the literature study. We use the (R, s, nQ) inventory policy that is the current inventory policy. We consider 9 parameters to develop our solution capacity plan: (1) the historical demand in 2013 (i.e., from January – December 2013); (2) the item grouping is based on the ABC classification with 3 additional remarks to distinguish the demand growth, seasonal products, and internal RTD products; (3) the forecast errors are based on the normal distribution for the A and B items and using the Poisson distribution for the C items; (4) the safety factor and safety stock are determined according to the customer service approach: P_2 for the A and B items and P_1 for the C Items; (5) the reorder point includes the safety stock that considers the forecast error; (6) the demand growths are 15% for brand category

A2 and 8% for other brand categories; (7) the customer allocation for retailers is based on the fixed delivery route and for distributors is based on the total demand per site in unit pallets, multi drop list, relative travel distance from customer to Sites I and II, and swapping allocation of a multi drop list; (8) the number of pallets in the capacity plan are the combination of the expected on-hand stock for regular products and the maximum on-hand stock for seasonal products; and (9) the performance measurement of ITR, DOI, total operational costs, and total relevant costs (see Table 4.2-1).

We summarize our solution approach in the form of a conceptual framework in Figure 4.3-1. We implement this conceptual framework in the solution test in Chapter 5.

Chapter 5 Solution Test

This chapter answer the fourth research question *What is the expected performance on the implementation of the solution approach?.* We determine the first solution capacity planning of Sites I and II from 2013 until 2016 in Section 5.1. Then, we discuss the improved solution capacity planning in Section 5.2. We determine the capacity plan for Site III in 2015 and 2016 in Section 5.3. In Section 5.4, we determine the estimated inventory movements between Sites I and II in 2013 and from Site III to Sites I and II in 2015. We carry out the performance measurement of our solution capacity plan in Section 5.5. We provide a sensitivity analysis of the total operational costs in Section 5.6. We conclude our solution test in Section 5.7.

5.1 The First Solution Capacity Planning of Sites I and II

This section discusses the capacity planning based on our conceptual framework in Chapter 4. We use 2 datasets to develop the solution capacity plan. The first dataset contains the SKU characteristics of the 175 SKUs, such as brand category, price per carton, number of cartons per pallet, number of cartons per lot size, replenishment lead time, historical demand in 2013, and the rolling forecasts in 2013. We use this dataset to work on the data preparation (Phase I). The second dataset contains the historical demand data per customer per SKU in 2013. We use the second dataset to work on the capacity planning (Phase II) that involves capacity planning for each distribution warehouse based on customer allocation and estimation of inventory movements.

Due to the large number of data and the confidentiality issue, we provide 15 SKUs out of 175 SKUs in the table that contains the result of the calculation on SKU level. For customer allocation, we provide the data of several customers in the main text to show how the customer allocation works.

We develop the solution capacity plan according to our conceptual framework (see Figure 4.3-1 on page 56). In this section, we discuss Step 1 until Step 5C (i.e., developing a solution capacity plan based on the fraction of customer demand per item group) and call the result as the first solution. Later in Section 5.2, we improve the first solution by relaxing the allocation criteria in Step 5B (i.e., distributor allocation) and recalculate the solution capacity plan in Step 5C. We call the result of this new solution the improved solution. Since we perform the conceptual framework step by step, you might want to skip some part of Sections 5.1 and 5.2. The important results of these sections are Table 5.1-17. Capacity plan per site from year 2014 until 2016 – based on the first solution and Table 5.2-4. Capacity plan per site for year 2014 until 2016 – based on the improved solution.

We discuss the last step of our conceptual framework: the performance measurement in Section 5.4 and the sensitivity analysis of the total operational costs in Section 5.5. We start our work on Phase I: data preparation as follows.

Phase I: Data Preparation

Recall from Section 4.3., the first phase consists of 4 Steps. In Step 1, we perform the item grouping based on the ABC classification. In Step 2, we calculate the standard deviation of forecast error during replenishment lead time and review period. Then in Step 3, we determine the safety factor (k_i), safety stock (SS_i), and reorder point (s_i) of SKU_i. Finally in Step 4, we determine the initial on-hand stock per item group (I_g).

Step 1. Item grouping based on the ABC Classification

We use the first dataset to do the ABC classification based on the demand value analysis. We first sort the SKUs from the highest to the lowest demand. Then using the sorted SKUs, we calculate fraction of demand of SKU_i to the total demand in 2013 and the accumulative fraction of demand. According to the accumulative fraction of demand, we decide on the item class of each SKU_i. We set the SKUs within the range of 0 – 80% as the class A items, the SKUs within the range of 80.01% – 95% as the class B items, and the rest SKUs within the range of 95.01% - 100% as the class C items. Table 5.1-1 shows the total number of SKU per item class.

Table 5.1-1. The total number of SKU per item class

Item Class	Number of SKUs
A	56
B	57
C	62
Grand Total	**175**

After knowing the item class, we check the 3 additional criteria on each SKU_i and remark the SKUs which are related with those criteria, i.e., give a (*) sign for the SKU with demand growth (G_i) = 15%; or give an "S" sign for the SKU which is a seasonal product; or give an "R" sign for the SKU which is an internal RTD. Then, we create the item group using the combination of the item class and the additional sign. Table 5.1-2 shows the results of demand value analysis, ABC classification, and item grouping per SKU and Table 5.1-3 shows the total number of SKUs of each item group. We use a blue font to show the item groups of the internal RTD products in Table 5.1-3.

Table 5.1-2. Demand per value analysis, ABC classification, and item grouping of 15 out of 175 SKUs

SKU_i	Brand Category	Demand SKU_i in 2013 D_i (in Euros)	% D_i to total demand in 2013	Acc. fraction demand	ABC Class	G_i = 15%	Seasonal Products?	RTD Internal?	Item Group (g)
1101909331	A2	€ 22,541,067.61	18.7%	18.7%	A	*			AB*
1101907331	A2	€ 8,627,251.63	7.1%	25.8%	A	*			AB*
2102900125	B2	€ 6,078,328.58	5.0%	30.9%	A				AB
2101651180	C4	€ 1,792,736.90	1.5%	52.3%	A				AB
2205061	E1	€ 1,089,540.07	0.9%	61.9%	A			R	ABR
2201057112	E1	€ 464,711.31	0.4%	83.2%	B				AB
1102101155	A1	€ 461,500.65	0.4%	83.6%	B		S		ABS
1101932331	A2	€ 355,019.40	0.3%	87.1%	B	*			AB*
2104402	B3	€ 350,672.84	0.3%	87.4%	B				AB
2101500190	C2	€ 175,584.45	0.1%	95.5%	C				C
2102040225	B2	€ 172,500.52	0.1%	95.7%	C				C
1101006155	A1	€ 164,641.97	0.1%	96.1%	C		S		CS
21014561	C5	€ 131,225.52	0.1%	97.5%	C			R	CR
2305000120	D1	€ 95,827.10	0.1%	98.7%	C				C
1103030	A3	€ 78,938.00	0.1%	99.1%	C				C

Table 5.1-3. The total number of SKUs per item group (g)

Items Group	Number of SKUs
AB*	17
ABS	12
ABR	3
AB	81
CS	13
CR	4
C	45
Grand Total	**175**

Step 2. Calculation of the standard deviation of the forecast error during replenishment lead time and review period (σ_{Li+R}) of SKU_i

We determine the standard deviation of the forecast error during replenishment lead time according to the item class. For item classes A and B, i.e., item group AB*, ABS, and ABR that has the forecast error under normal distribution, we first calculate the MAD_i as follows

Eq. 5.1-1

$$MAD_i = \frac{|\,Dm_i - RF_i|}{v_i \cdot b_i}$$

with MAD_i = Mean absolute deviation of SKU i, in pallets
Dm_i = Demand in 2013 of SKU i, in Euros;
RF_i = Rolling forecast in 2013 of SKU i, in Euros;
v_i = Price per box of SKU i, in Euros;
b_i = Number of boxes per pallet of SKU i, in carton/pallet.

Secondly, we calculate the standard deviation of forecast error as $\sigma_i \approx 1.25 * MAD_i$. Then, we determine the standard deviation during replenishment lead time and review period σ_{Li+R} as follows

Eq. 5.1-2

$$\sigma_{L_i+R} = \sqrt{(L_i + R)} \cdot \sigma_i \ , \qquad for\ i\ \in g = \{AB^*, ABS, and\ ABR\}$$

with σ_i = Standard deviation of demand SKU *i*, in pallets;
L_i = Replenishment lead time of *SKU i*, in years;
R = Review period of SKU *i*, in years.

For item class C, i.e., item group CS, CR, and C that has the forecast error under Poisson distribution, we do not need to calculate the MAD and the σ, since we can directly determine the σ_{Li+R} as follows

Eq. 5.1-3

$$\sigma_{L_i+R} = \sqrt{\hat{x}_{L_i+R}} = \sqrt{D_i\ (L_i + R)}\ , \qquad for\ i\ \in g = \{CS, CR, and\ C\}$$

with $\hat{x}_{L_i+R}$ = Mean demand during replenishment lead time and review period of SKU *i*, in pallets
D_i = Demand of SKU *i* in 2013, in pallets.

Table 5.1-4 shows the results of MAD_i, σ_i , and σ_{Li+R} .

Table 5.1-4. The MAD_i, σ_i , and σ_{Li+R} of 15 out of 175 SKUs

SKU	Item Group	Demand SKU$_i$ in 2013 D_i (in Euros)	Rolling Forecast 2013 (in Euros)	MAD_i 2013 (in pallets)	D_i of 2013 (in pallets)	σ_i (in pallets)	L_i (in year)	R (in year)	σ_{Li+R} (in pallets)
1101909331	AB*	€ 22,541,067.61	€ 25,496,774.19	2,651.23	20,219	3,314.04	0.010	0.023	603.05
1101907331	AB*	€ 8,627,251.63	€ 10,000,000.00	1,231.33	7,739	1,539.17	0.010	0.023	280.08
2102900125	AB	€ 6,078,328.58	€ 6,361,290.32	110.76	2,379	138.45	0.007	0.023	23.90
1101909019	ABS	€ 1,818,090.77	€ 1,812,903.23	3.19	1,112	3.98	0.010	0.023	0.73
2205061	ABR	€ 1,089,540.07	€ 1,251,612.90	81.01	545	101.27	0.050	0.023	27.33
2201057112	AB	€ 464,711.31	€ 429,032.26	10.47	136	13.09	0.017	0.023	2.61
1102101155	ABS	€ 461,500.65	€ 364,516.13	111.84	532	139.80	0.010	0.023	25.44
1101932331	AB*	€ 355,019.40	€ 464,516.13	98.23	318	122.79	0.010	0.023	22.34
2104402	AB	€ 350,672.84	€ 379,354.84	15.98	195	19.97	0.219	0.023	9.82
2101500190	C	€ 175,584.45	€ 174,193.55	-	94	-	0.017	0.023	1.93
2102040225	C	€ 172,500.52	€ 183,870.97	-	172	-	0.017	0.023	2.61
1101006155	CS	€ 164,641.97	€ 232,258.06	-	190	-	0.010	0.023	2.51
21014561	CR	€ 131,225.52	€ 232,258.06	-	96	-	0.050	0.023	2.64
2305000120	C	€ 95,827.10	€ 124,193.55	-	61	-	0.007	0.023	1.35
1103030	C	€ 78,938.00	€ 212,903.23	-	63	-	0.142	0.023	3.23

Step 3. Determination of the safety factor (k_i), safety stock (SS_i), and reorder point (s_i) of SKU_i

We also determine the safety factor according to the item class. For item class A and B, i.e., item group AB*, ABS, and ABR, we use the service level based on fill rate (P_2) = 97%, since X-Firm has a target service level 97% on aggregate level. To determine the safety factor k_i, we first calculate the normal loss function with respect to safety factor k_i using 2 different formulas that are correlated as follows

Eq. 5.1-4

$$\frac{D_i R}{\sigma_{Li+R}} \frac{(1 - P_2)}{P_2} = G_u(k_i) = \emptyset(k_i) - k_i \cdot [1 - \Phi(k_i)]$$

Left hand side *Right hand side*

with $G_u(k_i)$ = Normal loss function with respect to safety factor k_i, a constant;
P_2 = Fill rate, in fraction 0.97;
σ_{Li+R} = Standard deviation of forecast errors during $L_i + R$, in pallets;
$\phi(k_i)$ = Standard normal density function;
$\Phi(k_i)$ = Standard normal distribution function.

From the correlation of the $G_u(k_i)$, we determine the k_i using the Solver add-in in Excel by setting the value of k_i such that the $G_u(k_i)$ on the right hand side is equal to the $G_u(k_i)$ on the left hand side.

For item class C, we use service level based on probability of no stock out occasion (P_1) = 95%. We can directly determine k_i by using the following formula

Eq. 5.1-5

$$k_i = \Phi^{-1}(P_1)$$

with k_i = Safety factor of SKU i, a constant;
P_1 = Probability of no stock out occasion, in fraction of 0.95.

Then, we calculate the safety stock using *Eq. 3.2-3* and the reorder point using *Eq. 3.2-2*. We provide safety factor, safety stock, and reorder point per SKU in Table 5.1-5.

Table 5.1-5. The service level, $G_u(k_i)$, k_i, SS_i and s_i of 15 out of 175 SKUs.

SKU_i	Item Group	σ_{Li+R} (in pallets)	Service level	$Gu(k_i)$ left hand side	$Gu(k_i)$ right hand side	Safety factor k_i	Safety Stock SS_i	Reorder point s_i
1101909331	AB*	603.05	0.97	0.02404	0.02404	1.586	956.23	1,625.73
1101907331	AB*	280.08	0.97	0.01981	0.01981	1.667	466.90	723.16
2102900125	AB	23.90	0.97	0.07135	0.07135	1.080	25.82	96.72
2101651180	AB	21.54	0.97	0.02676	0.02676	1.540	33.16	65.11
2205061	ABR	27.33	0.97	0.01429	0.01429	1.800	49.19	88.89
2201057112	AB	2.61	0.97	0.03736	0.03736	1.392	3.63	9.04
1102101155	ABS	25.44	0.97	0.01499	0.01499	1.781	45.30	62.91
1101932331	AB*	22.34	0.97	0.01020	0.01020	1.931	43.14	53.67
2104402	AB	9.82	0.97	0.01424	0.01424	1.801	17.68	64.82
2101500190	C	1.93	0.95	-	-	1.645	3.18	6.91
2102040225	C	2.61	0.95	-	-	1.645	4.30	11.13
1101006155	CS	2.51	0.95	-	-	1.645	4.13	10.42
21014561	CR	2.64	0.95	-	-	1.645	4.35	11.34
2305000120	C	1.35	0.95	-	-	1.645	2.22	4.04
1103030	C	3.23	0.95	-	-	1.645	5.31	15.74

Step 4. Determination of the initial on-hand stock per item group (I_g)

We determine the initial on-hand stock per SKU, based on either the expected on-hand stock or the maximum on-hand stock. Since we use the (*R, s, nQ*) inventory control policy to develop our capacity plan, we assume that the cycle stock that will be considered in the initial on-hand stock should be equal to the integer multiple number of the lot size. Therefore, we calculate the cycle stock and the average cycle stock as follows

Eq. 5.1-6

$$Cycle\ stock\ = D_i R \approx n\, Q_i$$

and

Eq. 5.1-7

$$Average\ cycle\ stock\ = \frac{D_i R}{2} \approx \frac{n\,Q_i}{2}$$

with n = Integer number, a constant;
Q_i = Lot size of SKU *i*, in pallets.

We show the determination of nQ_i in Table 5.1-6.

Table 5.1-6. The nQ_i determination of 15 out of 175 SKUs.

SKU_i	Item Group	D_i of 2013 *(in pallets)*	*R (in year)*	D_i*R *(in pallets)*	Q_i *(in pallets)*	n = D*R/Q	nQ_i *(in pallets)*
1101909331	AB*	20,219	0.023	469	2	235	470
1101907331	AB*	7,739	0.023	179	2	90	180
2102900125	AB	2,379	0.023	55	4	14	56
1101909019	ABS	1,112	0.023	26	2	13	26
2205061	ABR	545	0.023	13	8	2	16
2201057112	AB	136	0.023	3	4	1	4
1102101155	ABS	532	0.023	12	3	5	15
1101932331	AB*	318	0.023	7	2	4	8
2104402	AB	195	0.023	5	25	1	25
2101500190	C	94	0.023	2	3	1	3
2102040225	C	172	0.023	4	2	2	4
1101006155	CS	190	0.023	4	3	2	6
21014561	CR	96	0.023	2	8	1	8
2305000120	C	61	0.023	1	4	1	4
1103030	C	63	0.023	1	11	1	11

We use the expected on-hand stock $E(OH)_i$ as the initial on-hand stock for the regular products, i.e., SKUs in the item groups AB*, ABR, AB, CR, and C. We calculate initial on-hand stock of SKU_i by using the following formula

Eq. 5.1-8

$$I_i = E(OH)_i \approx \frac{nQ_i}{2} + k_i \cdot \sigma_{Li+R}, \quad for\ i\ \in g = \{\text{AB}*, \text{ABR}, \text{AB}, \text{CR}, \text{C}\}$$

with I_i = Initial on-hand stock of SKU *i*, in pallets;
$E(OH)_I$ = Expected on-hand stock of SKU *i*, in pallets.

Meanwhile for the seasonal products, i.e., SKUs in the item groups ABS and CS, we use the maximum on-hand stock $Max(OH)_i$ as the initial on-hand stock. To get the $Max(OH)_i$, we multiply the $E(OH)_i$ with the seasonality index (*SI*) (i.e., an integer number that shows how many times the demand in pallets of SKU_i maximally increases during seasonal period compared to the average demand). We determine the seasonality index as follows

Eq. 5.1-9

$$SI_i = \left\lceil Max\left(\frac{D_{i,t}}{\frac{1}{m}\sum_{s=1}^{m} D_{i,s}}\right)\right\rceil$$

with SI_i = Seasonality index of SKU *i*, an integer number = {1, 2, .. n };
$D_{i,t}$ = Demand of SKU *i* in month *t* = {1, 2, ... m), in pallets.

We assume that the seasonality index of the seasonal products remains the same for 2014 – 2016. Appendix E provides the calculation of the seasonality index of the seasonal products (i.e., brand category A1).

Then, we calculate the initial on-hand stock of the seasonal SKU_i as follows

Eq. 5.1-10

$$I_i = Max(OH)_i \approx \frac{SI \cdot nQ_i}{2} + k_i \cdot \sigma_{Li+R}, \; for \; i \in g = \{ABS, CS\}$$

with I_i = Initial on-hand stock of SKU *i*, in pallets;
SI = Seasonality index, an integer number {1, 2, 3, 4};
$Max(OH)_I$ = Expected on-hand stock od SKU *i*, in pallets.

We show the seasonality index and provide the initial on-hand stock per SKU in Table 5.1-7.

Table 5.1-7. The initial on-hand stock per SKU (I_i) of 15 out of 175 SKUs

SKU_i	Item Group	σ_{Li+R} *(in pallets)*	Safety factor k_i	nQ_i *(in pallets)*	Seasonality Index *SI*	I_i *(in pallets)*
1101909331	AB*	603.05	1.586	470	1	1192
1101907331	AB*	280.08	1.667	180	1	557
2102900125	AB	23.90	1.080	56	1	54
2101651180	AB	21.54	1.540	21	1	44
1102101155	ABS	25.44	1.781	15	3	68
1101932331	AB*	22.34	1.931	8	1	48
2104402	AB	9.82	1.801	25	1	31
2101500190	C	1.93	1.645	3	1	5
2102040225	C	2.61	1.645	4	1	7
1101006155	CS	2.51	1.645	6	3	14
21014561	CR	2.64	1.645	8	1	9
2305000120	C	1.35	1.645	4	1	5
1103030	C	3.23	1.645	11	1	11

After knowing the initial on-hand stock per SKU, we calculate the initial on-hand stock per item group as follows

Eq. 5.1-11

$$I_g = \sum_{i \in g} I_i$$

with I_g = Initial on-hand stock of item group *g*, in pallets;
I_i = Initial on-hand stock of SKU *i*, in pallets.

Table 5.1-8 shows the initial on-hand stock per item group.

Table 5.1-8. The initial on-hand stock per item group (I_g) in 2013

Item Group	Ig
AB*	2,487
ABS	360
ABR	84
AB	2,216
CS	92
CR	25
C	255
Export	500
Total capacity	6,019

Phase II: Capacity Planning

Knowing the initial on-hand stock per item group in 2013, we can continue to Phase II. The second phase consists of 2 steps. In Step 5, we do capacity planning for each distribution warehouse based on customer allocation. Based on the customer allocation, we develop a solution capacity plan for each distribution warehouse from 2014 until 2016.

Step 5. Capacity planning for each distribution warehouse based on customer allocation

In general, Step 5 consists of 3 main steps that are (A) retailer allocation; (B) distributor allocation; and (C) developing a solution capacity plan for each distribution warehouse based on the fraction of customer demand per item group. We use the second dataset to work on the customer allocation (see Table 5.1-9).

In Step 5, we aim at acquiring a certain fraction of customer demand of each distribution warehouse such that the insufficient capacity that may occur is feasible for X-Firm. We have 2 preferences to get to the feasible solution. First, we expect to have a higher fraction of customer demand at Site II than at Site I, because Site II will produce more SKUs than Site I after the second expansion (see Table 5.1-10). Secondly, knowing that there is no possibility to extend the capacity of the distribution warehouse at Site I and there is a possibility to extend the capacity at Site II by 2,993 pallet positions, we prefer to let an insufficient capacity occur at Site II rather than at Site I.

Table 5.1-9. The dataset of historical demand per customer per SKU

Customer Code	Customer Type	Multidrop List	Item Code	Customer Demand/SKU Quantity (in cartons)	Quantity (in pallets)	Demand Produced by (in pallets) Current Situation	2nd Expansion	Item Group
D0001	Distributor	-	1101525326	5	0.13	Site I	Site I - Site II	AB*
D0001	Distributor	-	2101462302	6	0.06	Site II	Site II	AB
D0002	Distributor	-	1103111	40	0.25	Site I	Site III	CR
D0002	Distributor	-	1101005180	5	0.10	Site I	Site I - Site II	ABS
D0081	Distributor	-	2101584180	5	0.10	Site II	Site II	AB
D0087	Distributor	-	1101504333	218	2.27	Site I	Site I - Site II	AB*
D0092	Distributor	-	2102040225	2	0.06	Site I	Site I	C
D0092	Distributor	-	1103001	30	0.19	Outsource	Outsource	AB
D0092	Distributor	-	2202051	6	0.11	Site II	Site II	AB
D0094	Distributor	-	2101462302	40	0.37	Site II	Site II	AB
D0130	Distributor	M05	2101470	14	0.20	Outsource	Outsource	C
D0130	Distributor	M05	2205061	152	1.00	Site I	Site III	ABR
D0132	Distributor	M05	2101851302	1024	13.65	Site I	Site II	AB
D0133	Distributor	M05	1103100	141	2.01	Outsource	Outsource	C
D0134	Distributor	M05	2104390210	15	0.18	Site I	Site I	C
D0184	Distributor	M11	1101531016	12	0.38	Site I	Site I - Site II	CS
D0185	Distributor	M11	1101504333	625	6.51	Site I	Site I - Site II	AB*
D0185	Distributor	M11	1101531333	60	0.63	Site I	Site I - Site II	AB*
D0186	Distributor	M11	1101665317	93	0.85	Site I	Site I - Site II	AB*
D0186	Distributor	M11	1102011333	110	1.15	Site I	Site I - Site II	AB*
D0187	Distributor	M11	1101504333	1401	14.59	Site I	Site I - Site II	AB*
R0001	Retailer	-	2101461	1895	11.84	Site I	Site III	ABR
R0001	Retailer	-	2101461	200	1.25	Site I	Site III	ABR
R0003	Retailer	-	2102900130	71	1.29	Site I	Site I	AB
R0004	Retailer	-	2305000120	2	0.01	Site I	Site I - Site II	C
R0004	Retailer	-	2306536106	1	0.01	Outsource	Outsource	C

Table 5.1-10. Total number of SKUs produced by each production location after second expansion

Production Location after Second Expansion	Number of SKUs
Site I	26
Site I - Site II	49
Site II	73
Site III	7
Outsource	20

Step 5.A. Retailer allocation

Recall from Section 4.1, X-Firm wants to have the same retailer allocation with the fixed delivery route that has been set by the transportation department. Therefore, we directly assign the storage location of each retailer to the predetermined fixed delivery route. As the results, Table 5.1-11 shows the part of retailer allocation of each customer.

Table 5.1-11. The part of retailer allocation per customer based on the fixed delivery route

Customer Code	Fixed Customer Allocation	Customer Demand
R0001	Site II	373.93
R0002	Site I	236.35
R0003	Site I	45.47
R0065	Site II	67.77
R0066	Site I	35.68
R0127	Site I	3.55
R0152	Site I	4.18
R0153	Site II	4.42
R0154	Site II	6.20
R0155	Site I	4.13
R0156	Site I	3.80
R0157	Site II	3.32
R0158	Site I	5.94
R0169	Site I	37.86
R0171	Site I	30.36
R0230	Site II	31.51
R0277	Site I	40.66
R0278	Site I	41.52
R0279	Site II	17.53
R0280	Site I	29.07
R0372	Site I	150.41
R0396	Site II	854.75
R0524	Site I	0.73
R0525	Site I	1.17
R0530	Site II	13.27

From retailer allocation per customer, we calculate the total customer demand to get the fraction of customer demand per distribution site. A straightforward retailer allocation based on the fixed delivery route assigns more retailers and gives a higher fraction of customer demand to Site I than Site II (see Table 5.1-12). We keep and use this result of retailer allocation even though the results do not meet our first preference, because it is the constraint of our solution approach.

Table 5.1-12. Fraction of customer demand per site based on the retailer allocation

Retailer allocation to	Number of customers	Total customer demand (*in pallets*)	Fraction of customer demand
Site I	337	7,559.41	60.4%
Site II	91	4,949.22	39.6%
Total	**428**	**12,508.64**	**100.0%**

<u>Step 5.B. Distributor allocation</u>

Using the second dataset, we calculate the total demand in pallets per customer per production site after the second expansion (i.e., Site I, Site I – Site II, and Site II). We exclude the demand of Site I – Site II in this distributor allocation, because we assume that both manufacturing sites have enough production capacity to fulfill the demand. According to our solution approach, we first allocate a distributor to that site (i.e., either Site I or II) for which the total demand is larger. We call this first allocation as an initial customer allocation.

Note that each distributor in one multi drop list must be served by the same distribution warehouse. Therefore, if a distributor is in the multi drop list, we might need to adjust the initial allocation of the distributor to the site that has larger aggregate demand in a multi drop list, otherwise we keep the result of the initial customer allocation. We register the new allocation in the adjusted customer allocation. Table 5.1-13 shows the distributor allocation of each distributor. In this table, we can see that the distributor without a multi drop list has the same initial and adjusted allocation with the initial allocation. There are some distributors in the multi drop list whose first allocation is adjusted (e.g., D0138 in M05, D0197 in M15, etc.).

Then, we calculate the total customer demand to get the fraction of customer demand per distribution site from the distributor allocation per customer. Table 5.1-14 presents the fraction of distributor demand per site based on the first solution. It assigns more distributor and gives a higher fraction of customer demand to Site II (83.6%) rather than to Site I (16.4%) which meets our first preference.

Table 5.1-13. The adjusted distributor allocation per customer based on the total demand and multi drop list – based on the first solution

Multidrop List	Customer Code	2nd Expansion: Demand Produced by *(in pallets)*					Initial Customer Allocation	Adjusted Customer Allocation	Customer Demand *(in pallets)*
		Site I	Site I - Site II	Site II	Site III	Outsource			
⊟ -	⊟ D0001		1.40	0.06			Site II	Site II	1.46
	⊟ D0002	3.06	2.04	3.38	0.46	1.53	Site II	Site II	10.47
	⊟ D0003	236.18	243.80	303.64	39.09	64.16	Site II	Site II	886.88
	⊟ D0024	45.01	0.58	23.93		0.04	Site I	Site I	69.56
	⊟ D0025	7.79	0.05	5.78			Site I	Site I	13.62
	⊟ D0039	0.14	22.43	0.19			Site II	Site II	22.75
	⊟ D0042	203.98	1,753.33	300.09	44.80	105.34	Site II	Site II	2,407.55
	⊟ D0043	187.65	1,354.94	193.10	21.94	44.44	Site II	Site II	1,802.07
	⊟ D0052	26.41	15.74	22.66	1.68	4.19	Site I	Site I	70.68
	⊟ D0053		27.71	0.23			Site II	Site II	27.94
	⊟ D0054	0.50	0.28	0.46	0.08	0.83	Site I	Site I	2.15
⊟ M05	⊟ D0127	0.05	368.02	3.63	8.38	6.50	Site II	Site II	386.59
	⊟ D0128		826.56	9.92	12.42	7.25	Site II	Site II	856.15
	⊟ D0129		259.96	4.40	2.29	3.14	Site II	Site II	269.79
	⊟ D0130		400.83	3.71	9.20	7.92	Site II	Site II	421.66
	⊟ D0138	141.23	55.19	108.34		9.76	Site I	Site II	314.52
	⊟ D0139	2.12	3.61	4.31		0.36	Site II	Site II	10.39
	⊟ D0140	52.00	62.24	71.71		4.49	Site II	Site II	190.44
	⊟ D0141	87.03	90.97	102.86		5.39	Site II	Site II	286.24
	⊟ D0147	114.18	69.76	166.87		15.37	Site II	Site II	366.18
⊟ M06	⊟ D0148	0.53	294.76	8.73	1.51	7.79	Site II	Site II	313.32
	⊟ D0149	12.65	1,446.97	26.32	3.31	4.99	Site II	Site II	1,494.26
	⊟ D0150	0.82	1,112.65	16.25	1.23	4.46	Site II	Site II	1,135.41
	⊟ D0151		172.66	2.67	1.79	0.82	Site II	Site II	177.94
	⊟ D0152	12.38	1,138.89	19.01	8.05	10.39	Site II	Site II	1,188.73
	⊟ D0153	160.68	82.44	141.15	6.10	12.05	Site I	Site II	402.41
	⊟ D0156		2.08				Site I	Site II	2.08
	⊟ D0157	45.03	20.14	56.23	2.09	6.25	Site II	Site II	129.75
	⊟ D0158		0.91				Site I	Site II	0.91
	⊟ D0159	146.72	47.82	127.82	7.80	19.15	Site I	Site II	349.31
	⊟ D0160	81.94	48.96	86.78	3.94	11.92	Site II	Site II	233.53
	⊟ D0161		10.06				Site I	Site II	10.06
	⊟ D0162		51.88				Site I	Site II	51.88
⊟ M11	⊟ D0180	5.00	799.57	9.52	5.69	8.11	Site II	Site II	827.89
	⊟ D0181	61.07	2,101.94	98.01	15.12	12.44	Site II	Site II	2,288.58
	⊟ D0182		2,314.21	21.56	25.42	25.55	Site II	Site II	2,386.74
	⊟ D0183		2,308.24	19.96	16.20	18.98	Site II	Site II	2,363.37
	⊟ D0184	18.61	574.16	21.73	4.23	9.08	Site II	Site II	627.81
	⊟ D0185		9.49				Site I	Site II	9.49
	⊟ D0186		11.31				Site I	Site II	11.31
	⊟ D0187		23.13				Site I	Site II	23.13
⊟ M14	⊟ D0195	9.90	112.99	10.07	0.85	6.13	Site II	Site II	139.93
	⊟ D0196	15.83	75.61	18.89	1.27	5.62	Site II	Site II	117.22
⊟ M15	⊟ D0197	0.62	47.25	4.54	1.04	3.19	Site II	Site I	56.64
	⊟ D0198	41.65	26.07	34.33	3.21	11.99	Site I	Site I	117.24

Table 5.1-14. Fraction of distributor demand per site - based on the first solution

Distributor allocation to	Number of customers	Total customer demand (*in pallets*)	Fraction of customer demand
Site I	73	13,379.50	16.4%
Site II	114	68,334.64	83.6%

Step 5.C. Developing a solution capacity plan based on the fraction of customer demand per item group

After completing the retailer and distributor allocation, we continue with developing a solution capacity plan based on the customer allocations. Since we determine the initial on-hand stock based on the item group, therefore we need to define the fraction of customer demand per item group at Sites I and II. To be able to do so, we assign the allocation of each customer to the second dataset (see column "Customer Allocation" in Table 5.1-15). Then, we determine the total customer demand and fraction of customer demand per item group per distribution site (see Table 5.1-16).

Table 5.1-15. The dataset of historical demand per customer per SKU with the customer allocation – based on the first solution

Customer Code	Customer Type	Multidrop List	Item Code	Customer Demand/SKU		Demand Produced by (*in pallets*)		Item Group	Customer Allocation
				Quantity (*in cartons*)	Quantity (*in pallets*)	Current Situation	2nd Expansion		
D0001	Distributor	-	1101525326	5	0.13	Site I	Site I - Site II	AB*	Site II
D0001	Distributor	-	2101462302	6	0.06	Site II	Site II	AB	Site II
D0002	Distributor	-	1103111	40	0.25	Site I	Site III	CR	Site II
D0002	Distributor	-	1101005180	5	0.10	Site I	Site I - Site II	ABS	Site II
D0081	Distributor	-	2101584180	5	0.10	Site II	Site II	AB	Site I
D0087	Distributor	-	1101504333	218	2.27	Site I	Site I - Site II	AB*	Site I
D0092	Distributor	-	2102040225	2	0.06	Site I	Site I	C	Site I
D0092	Distributor	-	1103001	30	0.19	Outsource	Outsource	AB	Site I
D0092	Distributor	-	2202051	6	0.11	Site II	Site II	AB	Site I
D0094	Distributor	-	2101462302	40	0.37	Site II	Site II	AB	Site II
D0130	Distributor	M05	2101470	14	0.20	Outsource	Outsource	C	Site II
D0130	Distributor	M05	2205061	152	1.00	Site I	Site III	ABR	Site II
D0132	Distributor	M05	2101851302	1024	13.65	Site I	Site II	AB	Site II
D0133	Distributor	M05	1103100	141	2.01	Outsource	Outsource	C	Site II
D0134	Distributor	M05	2104390210	15	0.18	Site I	Site I	C	Site II
D0184	Distributor	M11	1101531016	12	0.38	Site I	Site I - Site II	CS	Site II
D0185	Distributor	M11	1101504333	625	6.51	Site I	Site I - Site II	AB*	Site II
D0185	Distributor	M11	1101531333	60	0.63	Site I	Site I - Site II	AB*	Site II
D0186	Distributor	M11	1101665317	93	0.85	Site I	Site I - Site II	AB*	Site II
D0186	Distributor	M11	1102011333	110	1.15	Site I	Site I - Site II	AB*	Site II
D0187	Distributor	M11	1101504333	1401	14.59	Site I	Site I - Site II	AB*	Site II
R0001	Retailer	-	2101461	1895	11.84	Site I	Site III	ABR	Site II
R0001	Retailer	-	2101461	200	1.25	Site I	Site III	ABR	Site II
R0003	Retailer	-	2102900130	71	1.29	Site I	Site I	AB	Site I
R0004	Retailer	-	2305000120	2	0.01	Site I	Site I - Site II	C	Site I
R0004	Retailer	-	2306536106	1	0.01	Outsource	Outsource	C	Site I

Table 5.1-16. Fraction of demand per item group per site – based on the first solution

Item Group	Allocated Demand/Item Group (in pallets)			Fraction of Demand	
(g)	Site I	Site II	Total	%Site I	%Site II
AB*	5,552.52	29,194.56	34,747.08	16%	84%
ABS	1,257.52	3,352.79	4,610.31	27%	73%
ABR	588.60	1,184.14	1,772.75	33%	67%
AB	9,732.11	23,016.98	32,749.10	30%	70%
CS	284.56	733.66	1,018.22	28%	72%
CR	62.75	183.77	246.52	25%	75%
C	784.62	1,949.40	2,734.02	29%	71%
Grand Total	18,262.70	59,615.30	77,878.00	23%	77%

Using the fraction of demand per item group per site in Table 5.1-16, we determine the solution capacity plan per distribution warehouse as follows

Eq. 5.1-12

$$I_{gm} = P_{gm} I_g$$

with I_{gm} = Initial capacity of item group g at site m, in pallets;
P_{gm} = Fraction of demand of item group g at site m, in percentage;
I_g = Total initial capacity of item group g, in pallets.

Then, we calculate required capacity per item group g per distribution warehouse at manufacturing site m in year y as follows

Eq. 5.1-13

$$C_{gmy} = G_{gy} I_{gm}$$

with C_{gmy} = Required capacity of item group g at site m in year y, in pallets;
G_{gy} = Demand growth of item group g in year y, in fraction of 0.15 or 0.08;

Finally, we get the required capacity per distribution warehouse at manufacturing site m in year y using the following formula

Eq. 5.1-14

$$C_{my} = \sum_{g} C_{gmy}$$

with C_{my} = Required capacity of at site m in year y, in pallets;

We assume that the storage capacity for the export products is equal to 500 pallet positions with a demand growth 25% per year and located only at Site I. This is the same assumption that X-Firm used in the current capacity plan.

In 2015, X-Firm will use the new warehouse at Site III to store the internal RTD products during incubation time and microbiological test (i.e., equal to the replenishment lead time L = 15 days). Afterward, X-Firm will replenish the RTD products from Site III to either Sites I or II. It means that the internal RTD products will be stored at Site III for L = 15 days and either at Sites I or II for R = 7 days. Thus, we assume that the required capacity for Site III and Sites I or II are equal to the storage lead time at each site, i.e., $C_{g,SiteIII,2015} = \frac{15}{22} \times G_g \times C_{g,2014}$ and $C_{g,2015} = \frac{7}{22} \times G_g \times C_{g,2014}$ with g = {ABR, CR}. Table 5.1-17 shows the solution capacity plan per site from 2014 until 2016 based on the first solution.

Table 5.1-17. Capacity plan per site from year 2014 until 2016 – based on the first solution

Item Group (g)	Total initial capacity I_g (in pallets)	Demand growth G_g	Site I					Site II				
			Fraction of demand $P_{g,SiteI}$	Initial capacity $I_{g,SiteI}$	Required capacity in			Fraction of demand $P_{g,SiteII}$	Initial capacity $I_{g,SiteII}$	Required capacity in		
					2014 $C_{g,SiteI,2014}$	2015 $C_{g,SiteI,2015}$	2016 $C_{g,SiteI,2016}$			2014 $C_{g,SiteII,2014}$	2015 $C_{g,SiteII,2015}$	2016 $C_{g,SiteII,2016}$
AB*	2,487	15%	16%	397.42	458	527	607	84%	2,089.58	2,404	2,765	3,180
ABS	360	8%	27%	98.19	107	116	126	73%	261.81	283	306	331
ABR	84	8%	33%	27.89	31	11	12	67%	56.11	61	21	23
AB	2,216	8%	30%	658.53	712	769	831	70%	1,557.47	1,683	1,818	1,964
CS	92	8%	28%	25.71	28	31	34	72%	66.29	72	78	85
CR	25	8%	25%	6.36	7	3	4	75%	18.64	21	8	9
C	255	8%	29%	73.18	80	87	94	71%	181.82	197	213	231
Export	500	25%	-	500.00	625	782	978	-	-	-	-	-
Total	**6,019**			**1,787.29**	**2,048**	**2,326**	**2,686**		**4,231.71**	**4,721**	**5,209**	**5,823**
Existing capacity per site					4,302	4,302	4,302			3,802	3,802	3,802
Excess / (under) capacity					2,254	1,976	1,616			(919)	(1,407)	(2,021)

The capacity plan of the first solution meets our second preference (i.e., to let an insufficient capacity occurs at Site II), but this capacity plan is not feasible, since the needed capacity between Sites I and II is imbalanced, i.e., 52% of remaining capacity at Site I (i.e., 2,254 pallet positions) and 24% of insufficient capacity at Site II (i.e., 919 pallet positions) in 2014. Since this solution is not working, we try to improve the first solution by relaxing the distributor allocation in Section 5.2.

5.2 The Improved Solution Capacity Planning of Sites I and II

We call the solution capacity plan from Section 5.1 as the first solution (see Table 5.1-17). In this section, we want to improve the distribution allocation such that the remaining capacity at Site I can be utilized to reduce the insufficient capacity at Site II by recalculating Step 5B and 5C. We keep the solution of Step 1 until Step 5A from Section 5.1, since those solutions remain the same. We call the new result after the improvement as the improved solution.

Step 5.B. Distributor allocation

The goal of distributor allocation in this section is to swap some customers of the first solution from Site II to Site I such that the new capacity plan is feasible for X-Firm (i.e., the insufficient capacity is minimal). We consider 2 improvement approaches for the improved solution. First, we swap the distributor allocation according to the relative travel distance from the distributor location to Sites I and II. Second, we swap a distributor allocation of multi drop list M06, i.e., the multi drop list which has the most distributors in the list.

The idea behind the relative travel distance approach is to allocate a distributor based on the shortest distance to the distribution warehouse thus the customer delivery costs can be minimized. To implement this approach, we ideally need to know the real travel distance from the customer location to each distribution warehouse and the delivery costs per kilometer. However since the transportation department does not have those data at the moment, we simply consider the relative travel distance rather than the real travel distance.

We obtain the relative travel distance by checking the distributor location on the predetermined delivery route from the transportation department. Note that X-Firm uses the fixed delivery route for the retailers who are located in the Jabodetabek region. Therefore, our target is to swap the allocation of the distributor in the Jabodetabek region, since the customers in this region are covered by the fixed delivery route. If the distributor location is in the fixed delivery route, we register the relative travel distance as either closer to Site I or closer to Site II according to the delivery route. If otherwise, we register the relative travel distance from the distributor location as not significantly different to Site I or II.

We provide the relative travel distance from distributor location to Sites I and II in Table 5.3-1. There are 17 distributors closer to Site I and 6 distributors closer to Site II. The travel distance of the remaining 164 distributors to both Sites I and II are not significantly different. For a distributor whose relative travel distance closer to site *m*, we assume that the customer delivery costs are also relatively less if we deliver the customer order from site *m*. For a distributor whose relative travel distance is not significantly different, we also assume that the customer delivery costs are also not significantly different between delivering the customer order from Site I and II. Since the Site II is over capacitated in the first solution, we add the constraint to not swap the distributor to Site II if the relative travel distance is closer to Site II. We only swap the allocation if the relative travel distance is closer Site I.

In the second improvement approach, we use a greedy approach to swap the distributor allocation of M06, i.e., the multi drop list with the most distributors in the list. Based on the first solution, the distributors in M06 are allocated to Site II. But if we look further, 10 out of 19 distributors (i.e., 53%) in M06 are initially allocated to Site I. Therefore, we directly adjust the distributor allocation of the distributors in M06 from Site II to Site I.

We proceed with these 2 improvement approaches and register the new result as the improved customer allocation. Table 5.2-1 shows the improved distributor allocation of each distributor. Based on the relative travel distance, we adjust the location of distribution warehouse of a distributor only if it is closer to Site I (e.g., D0111 and the distributors in M11 that we mark with *the blue box*), and do nothing if otherwise (e.g., see D0013, D0018, D0106, and D0107 that we mark with *the green box*). For the M06, we swap the allocation from Site II to Site I (see *the red box*).

Table 5.2-1. The improved distributor allocation based on the improvement approaches

Multidrop List	Customer Code	Relative Travel Distance from Sites I and II	2nd Expansion: Demand Produced by *(in pallets)*					Initial Customer Allocation	Adjusted Customer Allocation	Improved Customer Allocation	Customer Demand *(in pallets)*
			Site I	ite I - Site I	Site II	Site III	Outsource				
⊟ -	⊟ D0001	Not significantly different		1.40	0.06			Site II	Site II	Site II	1.46
	⊟ D0002	Not significantly different	3.06	2.04	3.38	0.46	1.53	Site II	Site II	Site II	10.47
	⊟ D0013	Closer to Site II	5.59	0.40	1.37		0.08	Site I	Site I	Site I	7.45
	⊟ D0014	Closer to Site I	4.04	0.11	0.46		0.04	Site I	Site I	Site I	4.65
	⊟ D0017	Closer to Site I	13.14	1.58	1.17		0.01	Site I	Site I	Site I	15.91
	⊟ D0018	Closer to Site II	21.09	3.47	2.88		0.15	Site I	Site I	Site I	27.59
	⊟ D0019	Closer to Site I	5.12	1.24	0.54		0.04	Site I	Site I	Site I	6.93
	⊟ D0035	Closer to Site I	3.46	0.25	0.70			Site I	Site I	Site I	4.41
	⊟ D0037	Closer to Site I	855.87	45.73	313.47		12.55	Site I	Site I	Site I	1,227.61
	⊟ D0038	Closer to Site I	431.77	45.25	24.56	4.82	3.23	Site I	Site I	Site I	509.63
	⊟ D0106	Closer to Site II	29.38	744.10	29.37		0.39	Site I	Site I	Site I	803.24
	⊟ D0107	Closer to Site II	77.48	857.79	68.78		2.48	Site I	Site I	Site I	1,006.53
	⊟ D0108	Closer to Site II	2.19	1.57	3.41		0.03	Site II	Site II	Site II	7.21
	⊟ D0109	Closer to Site I	41.71	796.26	34.62		1.61	Site I	Site I	Site I	874.20
	⊟ D0110	Closer to Site I	102.96	564.37	97.25		7.13	Site I	Site I	Site I	771.72
	⊟ D0111	Closer to Site I	85.20	297.99	160.27	12.44	23.23	Site II	Site II	Site I	579.13
	⊟ D0112	Closer to Site I	135.68	1,281.70	84.32		4.10	Site I	Site I	Site I	1,505.80
⊟ M06	⊟ D0148	Not significantly different	0.53	294.76	8.73	1.51	7.79	Site II	Site II	Site I	313.32
	⊟ D0149	Not significantly different	12.65	1,446.97	26.32	3.31	4.99	Site II	Site II	Site I	1,494.26
	⊟ D0153	Not significantly different	160.68	82.44	141.15	6.10	12.05	Site I	Site II	Site I	402.41
	⊟ D0156	Not significantly different		2.08				Site I	Site II	Site I	2.08
	⊟ D0157	Not significantly different	45.03	20.14	56.23	2.09	6.25	Site II	Site II	Site I	129.75
	⊟ D0158	Not significantly different		0.91				Site I	Site II	Site I	0.91
	⊟ D0159	Not significantly different	146.72	47.82	127.82	7.80	19.15	Site I	Site II	Site I	349.31
	⊟ D0160	Not significantly different	81.94	48.96	86.78	3.94	11.92	Site II	Site II	Site I	233.53
	⊟ D0161	Not significantly different		10.06				Site I	Site II	Site I	10.06
	⊟ D0162	Not significantly different		51.88				Site I	Site II	Site I	51.88
	⊟ D0163	Not significantly different	383.63	239.38	525.61	32.01	73.52	Site II	Site II	Site I	1,254.15
	⊟ D0164	Not significantly different		29.87				Site I	Site II	Site I	29.87
	⊟ D0165	Not significantly different	188.87	68.64	131.20	6.05	18.46	Site I	Site II	Site I	413.21
	⊟ D0168	Not significantly different		17.29				Site I	Site II	Site I	17.29
	⊟ D0169	Not significantly different	147.26	79.59	223.18	8.49	23.93	Site II	Site II	Site I	482.44
	⊟ D0170	Not significantly different	133.61	56.87	128.98	7.29	19.64	Site I	Site II	Site I	346.39
⊟ M11	⊟ D0180	Closer to Site I	5.00	799.57	9.52	5.69	8.11	Site II	Site II	Site I	827.89
	⊟ D0181	Closer to Site I	61.07	2,101.94	98.01	15.12	12.44	Site II	Site II	Site I	2,288.58
	⊟ D0182	Closer to Site I		2,314.21	21.56	25.42	25.55	Site II	Site II	Site I	2,386.74
	⊟ D0183	Closer to Site II		2,308.24	19.96	16.20	18.98	Site II	Site II	Site I	2,363.37
	⊟ D0184	Closer to Site I	18.61	574.16	21.73	4.23	9.08	Site II	Site II	Site I	627.81
	⊟ D0185	Closer to Site I		9.49				Site I	Site II	Site I	9.49
	⊟ D0186	Closer to Site I		11.31				Site I	Site II	Site I	11.31
	⊟ D0187	Closer to Site I		23.13				Site I	Site II	Site I	23.13

Then, we recalculate the total customer demand to get the fraction of customer demand per distribution site from the distributor allocation per customer (see Table 5.2-2). We call this new solution as the improved solution. According to the improved solution, the fraction of customer demand at Site II is 60.5% and at Site I is 39.5% which still meets our first preference.

Table 5.2-2. The distributor allocation per site - based on the improved solution

Distributor allocation to	Number of customers	Total customer demand *(in pallets)*	Fraction of customer demand
Site I	101	25,808.12	39.5%
Site II	86	39,561.24	60.5%
Total	187	**65,369.36**	**100.0%**

Step 5.C. Developing a solution capacity plan based on the fraction of customer demand per item group

Using the customer allocation from the retailer allocation from Section 5.1 and the improved distributor allocation, we reassign the improved allocation of each customer to the second dataset and recalculate the total customer demand and fraction of customer demand per item group per distribution site (see Table 5.2-3).

Table 5.2-3. The fraction of demand per item group per site – based on the improved solution

Item Group	Allocated Demand/Item Group (in pallets)			Fraction of Demand	
	Site I	Site II	Total	%Site I	%Site II
AB*	16,660.45	18,086.63	34,747.08	48%	52%
ABS	1,754.02	2,856.29	4,610.31	38%	62%
ABR	706.79	1,065.96	1,772.75	40%	60%
AB	12,711.13	20,037.97	32,749.10	39%	61%
CS	415.36	602.86	1,018.22	41%	59%
CR	93.20	153.33	246.52	38%	62%
C	1,026.59	1,707.43	2,734.02	38%	62%
Grand Total	**33,367.54**	**44,510.46**	**77,878.00**	**43%**	**57%**

Using the fraction of demand per item group per site from Table 5.2-3 and the initial on-hand stock per item group from Table 5.1-8, we recalculate the solution capacity plan per distribution warehouse. Table 5.2-4 shows the capacity plan per site based on the improved solution.

Table 5.2-4. Capacity plan per site for year 2014 until 2016 – based on the improved solution

Item Group *(g)*	Total initial capacity I_g *(in pallets)*	Demand growth G_g	Site I					Site II				
			Fraction of demand $P_{g,SiteI}$	Initial capacity $I_{g,SiteI}$	Required capacity in			Fraction of demand $P_{g,SiteII}$	Initial capacity $I_{g,SiteII}$	Required capacity in		
					2014 $C_{g,SiteI,2014}$	*2015* $C_{g,SiteI,2015}$	*2016* $C_{g,SiteI,2016}$			*2014* $C_{g,SiteII,2014}$	*2015* $C_{g,SiteII,2015}$	*2016* $C_{g,SiteII,2016}$
AB*	2,487	15%	48%	1,192.46	1,372	1,578	1,815	52%	1,294.54	1,489	1,713	1,970
ABS	360	8%	38%	136.96	148	160	173	62%	223.04	241	261	282
ABR	84	8%	40%	33.49	37	13	15	60%	50.51	55	19	21
AB	2,216	8%	39%	860.11	929	1,004	1,085	61%	1,355.89	1,465	1,583	1,710
CS	92	8%	41%	37.53	41	45	49	59%	54.47	59	64	70
CR	25	8%	38%	9.45	11	4	5	62%	15.55	17	6	7
C	255	8%	38%	95.75	104	113	123	62%	159.25	172	186	201
Export	500	25%	-	500.00	625	782	978	-	-	-	-	-
Total	**6,019**			**2,865.76**	**3,267**	**3,699**	**4,243**		**3,153.24**	**3,498**	**3,832**	**4,261**
Existing capacity per site					4,302	4,302	4,302			3,802	3,802	3,802
Remaining / (over) capacity					1,035	603	59			304	(30)	(459)

The capacity plan of the improved solution is feasible, since the capacity between Sites I and II are now relatively balanced. In 2015, there are 30 pallets insufficient capacity at Site II, but X-Firm has 603 pallets remaining capacity at Site I that can cover the insufficient capacity. In 2016, there are 459 pallets insufficient capacity at Site II and only 59 pallets remaining capacity at Site I. In Section 6.2, we give the recommendations regarding this insufficient capacity. We keep this capacity plan as our solution capacity plan and use it for the performance measurement in Section 5.5.

5.3 The Capacity Planning of Storage Warehouse at Site III

In 2015, X-Firm will use the new warehouse at Site III to store the internal RTD products during incubation time and microbiological test (i.e., equal to the replenishment lead time L = 15 days). When calculating the capacity plan of Sites I and II, we assume that that the required capacity for Site III is equal to the storage lead time at Site III, i.e., $C_{g,SiteIII,2015} = \frac{15}{22} \times G_g \times C_{g,2014}$ with $g = \{ABR, CR\}$. As a result, Table 5.3-1 shows the required number of pallets for the internal RTD at Site III in 2015 and 2016.

Table 5.3-1. The required number of pallets for internal RTD at Site III in 2015 and 2016

Item Group	G_g	$C_{g,SiteIII,y}$	
		2015	2016
ABR	8%	68	74
CR	8%	20	22
Total capacity		**88**	**96**

According to our solution capacity plan, X-Firm will need 88 pallet positions in 2015 and 96 pallets positions in 2016 if the number of SKUs of internal RTD and the customer demand remains the same. This required capacity at Site III is not a problem, since X-Firm plans to prepare a storage warehouse with capacity of 1,250 pallet positions at Site III in 2015 for a long term purpose.

5.4 The Estimated Inventory Movements

Based on the customer allocation, we can estimate the inventory movements to calculate the expected replenishment costs in 2013. In this section, we provide the expected inventory movements per item group according to our solution approach between Sites I and II and also the expected inventory movements of internal RTD from Site III to either Site I or II in 2015.

5.4.1 Inventory movements between Sites I and II in 2013

We calculate the expected inventory movements based on the current production location, because we want to compare the replenishment costs of our solution approach with the replenishment costs of current inventory movements in 2013 (i.e., 7 trips per day). We consider only the customer demand that is currently produced by Sites I and II and do not take into account the outsourced product, since it can be delivered directly to both Sites I and II. The inventory movements of each customer comes from the opposite site of the customer allocation. The quantity of inventory movements is directly related to the demand in pallet that is produced by the opposite site of the customer allocation. For example, customer D0001 is allocated to Site II. Therefore, X-Firm has to replenish 1.4 pallets from Site I (i.e., the opposite site of the customer allocation) to Site II. Table 5.4-1 shows the results of inventory movements per customer in 2013.

Table 5.4-1. Inventory movements per customer in 2013

Customer Code	Customer Allocation	Current Situation: Demand produced by *(in pallets)*			Inventory Movement/Customer	
		Outsource	Site I	Site II	Quantity *(in pallets)*	From
D0001	Site II		1.40	0.06	1.40	Site I
D0002	Site II	1.53	5.56	3.38	5.56	Site I
D0003	Site II	64.16	523.34	299.38	523.34	Site I
D0004	Site I	7.27	119.55	58.97	58.97	Site II
D0005	Site I	6.77	78.89	27.93	27.93	Site II
D0006	Site II	13.50	127.02	83.80	127.02	Site I
D0007	Site II	7.83	61.35	36.44	61.35	Site I
D0008	Site II	10.53	100.63	61.96	100.63	Site I
D0009	Site I	7.34	80.20	26.34	26.34	Site II
D0010	Site I		2.97	0.90	0.90	Site II
R0277	Site I	3.01	13.84	23.81	23.81	Site II
R0278	Site I	2.45	10.92	28.14	28.14	Site II
R0279	Site II	0.93	6.39	10.22	6.39	Site I
R0280	Site I	2.26	13.01	13.80	13.80	Site II
R0281	Site I	3.23	24.45	33.79	33.79	Site II
R0282	Site I	1.44	7.20	7.90	7.90	Site II
R0283	Site II	1.38	13.99	21.34	13.99	Site I
R0284	Site II	3.20	18.00	21.19	18.00	Site I
R0285	Site I	2.23	10.77	18.65	18.65	Site II

To know how many trips are needed for inventory movements per day, we calculate the estimated movements between Sites I and II. We assume that one year has 302 working days and one truck can carry at most 16 pallets per trip.

Table 5.4-2. The estimated inventory movements between Sites I and II in 2013

	Inventory Movement (IM) *(in pallets)*		IM/day *(in pallets)*		IM/day *(in number of trips)*	
From/To	Site I	Site II	Site I	Site II	Site I	Site II
Site I		34,922.42		115.64		8
Site II	6,926.35		22.93		2	

Based on the results in Table 5.4-2, we need 8 inventory movement trips per day from Site I to Site II and 2 inventory movement trips per day from Site II to Site I. It means that we need 10 inventory movement trips per day according to our solution approach.

5.4.2 Inventory movements from Site III to Sites I and II in 2015

To determine the expected inventory movements from Site III to Sites I and II, we first calculate the expected inventory movements of the internal RTD products per site in 2013. Then, we calculate the expected inventory movements in 2015 by multiplying the expected inventory movements in 2013 with the square of the demand growth. We assume that the customer allocation in 2015 is the same as the customer allocation in 2013 and the demand growth of 8% for the internal RTD products remains the same until 2015. From the result in Table 5.4-3, we need 1 inventory movement trip per day from Site III to both Sites I and II.

Table 5.4-3. The estimated inventory movements of internal RTD SKUs from Site III to Sites I and II in 2015

From/To	Inventory Movement (IM) in 2013 *(in pallets)*		IM in 2015 *(in pallets)*		IM/day *(in pallets)*		IM/day *(in number of trips)*	
	Site I	Site II	Site I	Site II	Site I	Site II	Site I	Site II
Site III	908.32	1,384.41	1,059.47	1,614.77	3.51	5.35	1	1

5.5 Performance Measurement

We finalize our solution approach by determining the performance measurement of our solution capacity plan to know the performance of our solution approach. We discuss the Inventory Turnover Ratio (ITR), Days of Inventory (DOI), total operational costs, and total relevant costs of our solution approach and compare the results with X-Firm's current capacity plan.

5.5.1 Inventory Turnover Ratio (ITR) and Days of Inventory (DOI)

The purpose of determining the ITR and DOI is to give X-Firm insight on how large the aggregate DOI that they should have based on our solution approach to achieve the targeted service level of 97%. Table 5.5-1 shows the aggregate ITR and DOI of the solution capacity plan and X-Firm's current capacity plan in 2013.

Table 5.5-1. The aggregate ITR and DOI of the solution and X-Firm's current approach

Approach	Demand in 2013 *(in pallets)*	Total initial capacity *(in pallets)*	ITR	DOI *(in days)*
Solution approach	5,519	77,878	14.11	22
X-Firm's current approach	3,670	77,878	21.22	15

To achieve the targeted service level of 97% and according to the solution capacity plan and the historical demand in 2013, X-Firm has to increase the DOI from 15 days to 22 days. From the ITR and DOI, we deduce that if X-Firm wants to have a higher service level, they have to hold more inventories to cope with the demand fluctuation. We also learn that the DOI of 10 days that X-Firm currently uses for production planning is too low to be used as a reorder point. Table 5.5-2 shows the ITR and DOI of each item group.

Table 5.5-2. The ITR and DOI per item group of the solution capacity plan

Item Group *g*	Demand in 2013 *(in pallets)*	Total initial capacity I_g *(in pallets)*	ITR	DOI *(in days)*
AB*	35,772	2,487	14.38	21
ABS	4,753	360	13.2	23
ABR	1,588	84	18.9	16
AB	31,947	2,216	14.4	21
CS	1,059	92	11.5	27
CR	236	25	9.4	32
C	2,523	255	9.9	31

5.5.2 Total operational costs of distribution warehouses

We calculate the total operational cost of the distribution warehouses in the same way as X-Firm calculate it (i.e., using a fixed holding costs and omitting the product value in the total inventory holding costs calculation). Table 5.5-3 shows the total operational costs of X-Firm's distribution warehouse in 2013 based on the solution capacity plan.

Table 5.5-3. Total operational of X-Firm's distribution warehouses in 2013 - based on the solution capacity plan

Costs component	Location	Total initial capacity I_m *(in pallets)*	Cost/day	Number of working day /year	Total costs/year
Inventory holding costs	Site I	2,865.76	€ 0.31	365	€ 324,260.36
	Site II	3,153.24	€ 0.31	365	€ 356,789.49
Replenishment costs	-	-	€ 436.00	302	€ 131,673.50
Total operational costs/year in 2013					**€ 812,723.35**

Recall from Table 2.1-1, total operational costs of X-Firm's distribution warehouse are € 677,745.61. Since in our approach, the expected on-hand stock and the expected inventory movements per day are higher than the results that X-Firm produced, it is obvious that the total operational costs of our solution approach are higher than what X-Firm has got. By implementing the solution approach, the operational costs increases 19.9% compared to X-Firm's current operational costs in order to improve the service level from 92.5% (i.e., the actual service level in 2013) to 97% (i.e., the targeted service level).

5.5.3 Total relevant costs

We adapt the formula of total ordering costs to total replenishment costs to align it with X-Firm inventory movement activity. We calculate the total relevant costs of the solution capacity plan as follow

Eq. 5.5-1

$$Total\ Relevant\ Costs\ (TRC) = Total\ Inventory\ Carrying\ Costs + Total\ Replenishment\ Costs$$

$$= r \cdot v_i \cdot \overline{I}_i + 302 \text{ working days/year} \cdot € 436{,}00\text{/day}$$

with r = Carrying rate per pallet, in Euros;
v_i = Unit value, in Euros;
$\overline{I}_i$ = The initial on-hand stock of SKUi, in pallets.

Since X-Firm cannot provide the cost of goods sold (COGS), we assume the unit value is equal to the unit price. Table 5.5-4 shows the result of total relevant costs of X-Firm's distribution warehouses in 2013.

Table 5.5-4. The total relevant costs of X-Firm's distribution warehouses in 2013

Costs component		Total costs/year
Total inventory holding costs/year	€	2,460,355.16
Total replenishment costs/year	€	131,673.50
Total relevant costs/year	**€**	**2,592,028.66**

The real total relevant costs should be smaller than this value, since the unit value does not take into account the profit margin. The total relevant costs of the distribution warehouse are relatively small, i.e., around 2% of X-Firm sales revenue in 2013.

5.6 Sensitivity Analysis

In this section, we perform one-way sensitivity analysis to see the impact of the increasing service level on the total operational costs, the required number of pallets needed, ITR, and DOI. We especially want to know by what percentage the total operational costs increase from the base line (i.e., X-Firm's current total operational costs) if we apply our solution approach under a certain target service level. We do this sensitivity analysis by changing the fill rate P_2 for item class A and B from 97% to 92% - 96% and 98%. For item class C, we keep using the probability of no stock out occasion P_1 of 95%, since this item class only occupies 372 pallet positions of the total required number of pallets needed (i.e., less than 10% of the total capacity needed). Table 5.6-1 shows the result of the sensitivity analysis.

Table 5.6-1. The results of the sensitivity analysis

Service Level	Fill rate (P_2)	Prob. no stockout occasion (P_1)	Expected number of pallets needed (*in pallets*)	Total Demand 2013 (*in pallets*)	ITR	DOI		Total Operational Costs	Compared to 92% SL of each appoach, Total Operational Costs Increases by			Total Relevant Costs
									X-Firm's Approach	Solution Approach		
98%	98%	95%	5,900	77,878	13.20	23	€	855,833.50	26.3%	23.3%	€	2,760,104.50
97%	97%	95%	5,519	77,878	14.11	22	€	812,723.35	19.9%	17.1%	€	2,592,028.66
96%	96%	95%	5,231	77,878	14.89	21	€	780,136.15	15.1%	12.4%	€	2,466,707.86
95%	95%	95%	5,000	77,878	15.58	20	€	753,998.50	11.3%	8.6%	€	2,362,429.74
94%	94%	95%	4,793	77,878	16.25	19	€	730,576.45	7.8%	5.3%	€	2,270,010.86
93%	93%	95%	4,625	77,878	16.84	18	€	711,567.25	5.0%	2.5%	€	2,196,671.82
92%	92%	95%	4,470	77,878	17.42	18	€	694,029.00	2.4%	-	€	2,128,575.26
92%	-	-	3,670	77,878	21.22	15	€	677,745.61	*X-Firm's current performance & capacity plan*			

From the results, first we observe that the required number of pallets needed under the service level of 92% in our solution approach is 800 pallet positions more than X-Firm's current approach. The total operational costs of our solution approach are 2.4% higher than for X-Firm's current approach. These differences occur, because we take into account more information regarding the SKU characteristics (i.e., forecast errors, integer batch size, production lead time, review period, and seasonal effect) in our solution approach, while X-Firm only considered the average demand and the target DOI. We also find that there is a trade-off between the service level and the total operational costs. It means that if X-Firm wants to have a higher service level, they have to hold more inventories. As a consequence, the DOI increases and the total operational costs also increase, because the inventory holding costs increase. In our research context, to improve the service level from 92.5% (i.e., the actual service level in 2013) to 97% (i.e., the targeted service level), the operational costs increase 19.9% compared to X-Firm's current operational costs.

To better describe the impact of service level on the required number of pallets needed and the total operational costs, we now use the service level of 92% from our solution approach as the base line. We show the impact of service level on the required number of pallets needed in Figure 5.6-1 and the impact of service level on the total operational costs in Figure 5.6-2.

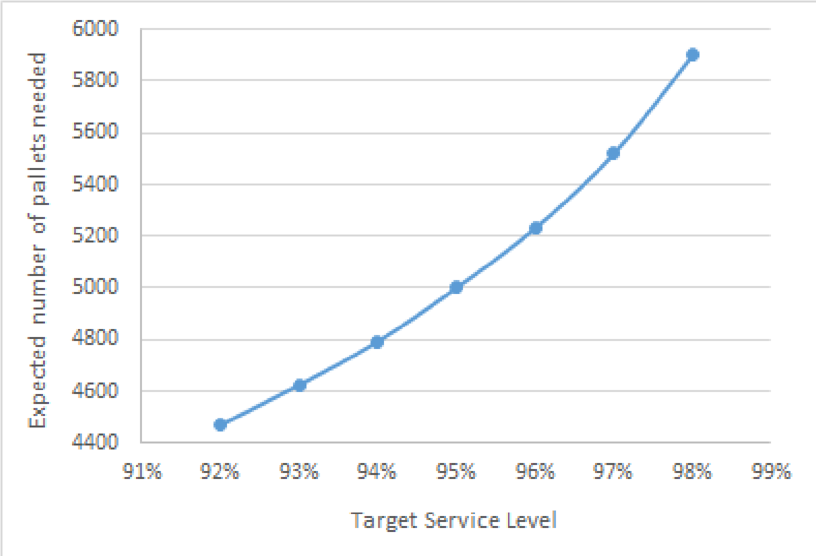

Figure 5.6-1. The impact of service level on the required number of pallets needed

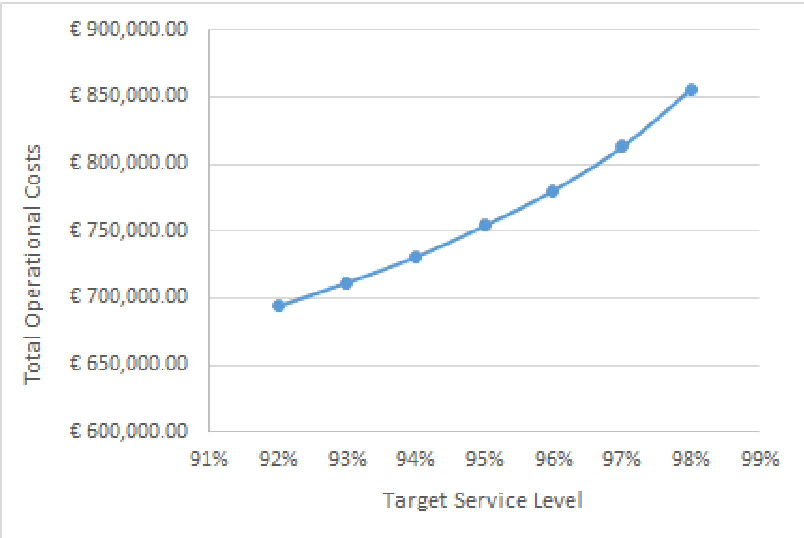

Figure 5.6-2. The impact of service level on the total operational costs of distribution warehouses

5.7 Conclusions

This chapter provides the result of our solution approach. First, we determine the capacity plan of Sites I and II. We implement the conceptual framework of our solution approach step by step. We have 2 preferences to get to the feasible solution that are to have a higher fraction of customer demand at Site II than at Site I and to let an insufficient capacity occur at Site II rather than at Site I. The solution capacity plan based on the first solution give an infeasible solution, since the needed capacities for Sites I and II are imbalanced, i.e., there is 52% of remaining capacity at Site I (2,254 pallet positions) and 24% of insufficient capacity at Site II (919 pallet positions) in 2014. Then, we improve the first solution by relaxing the distributor allocation by swapping the allocation for the distributors for which the relative travel distance is closer to Site I and by allocating the distributors in M06 to Site I. We get a feasible solution from the improved solution with an insufficient capacity of 30 pallet positions in 2015 and 459 pallet positions in 2016 occurring at Site II.

We provide the capacity plan of the storage warehouse at Site III in 2015 and 2016. Based on our solution approach, X-Firm still needs to move inventory between Sites I and II and from Site III to Site I and from Site III to Site II in 2015. In comparison with X-Firm's current performance, our solution underperforms in terms of aggregate ITR, aggregate DOI, and total operational costs, because the solution capacity plan yields on a larger numbers of pallets. By implementing our solution approach, the operational costs increase 19.9% compared to X-Firm's current operational costs in order to improve the service level from 92.5% (i.e., the actual service level in 2013) to 97% (i.e., the targeted service level). From the sensitivity analysis, we find that there is a trade-off between the service level and the total operational costs. Thus, to obtain a higher service level, X-Firm has to hold more inventories, increases the DOI, and spend more in the total operational costs, because the inventory holding costs increase.

Chapter 6 Conclusions and Recommendations

This chapter delivers the conclusions in Section 6.1 and recommendations for future research in Section 6.2.

6.1 Conclusions

The research objective of this study was

"To find an approach to come up with a capacity plan for X-Firm's distribution warehouses."

In order to achieve our research objective, we examined X-Firm's current performance and observed how X-Firm regularly organized its planning activities. We elaborated on the related information with the capacity planning process, i.e., historical demand, forecasting, production location, inventory control policy, customer allocation, inventory movements, and described how the current capacity planning was carried out.

From this study, we learned that a lot of data and parameters have to be considered to make a sound capacity plan. The right implementation of inventory control policy played an important role to help the achievement of the targeted service level. In practice, there were no specific rules or procedures for capacity planning process at X-Firm. The approach used for the current capacity planning was subjective to the manager who is responsible to make a capacity plan at that moment.

Our main findings on the current capacity planning are that the calculations are 'flawed' in the following ways:

- X-Firm determined the service level based on the money value while it supposed to be in unit quantity if it is used for inventory control;
- It is not common to determine the total inventory holding costs based on only the fixed holding costs and omit the unit value;
- The total inventory holding costs only considered the average number of pallets needed and did not take into account the maximum number of pallets needed during the seasonal period;
- Using the rolling forecasts rather than the actual demand as denominator in the forecast error formula underestimates the actual value of the forecasts error;
- It is necessary to make a well-defined item classification to know how important an SKU is for X-Firm, so they can control the inventory according to the item class;
- The same DOI was used as a reorder point for all SKUs while it should not be the case, since the SKU with longer lead time needs higher inventory level;
- The DOI calculation only considered the average demand and did not take into account the forecast error;

- The target service level was not included in the safety stock calculation. This practice underestimates the safety stock that they should have to deal with demand uncertainty;
- The seasonal effect was not included in the current capacity planning while it has to be considered to foresee and anticipate the risk of not enough capacity during the seasonal period;
- It is not common to use the historical data of 15 months in capacity planning, since it underestimates the average demand;
- The implementation of Demand per Volume (DVP) in capacity planning is not necessary, since we can directly use the demand in unit pallets to decide on the fraction of customer demands in distribution allocation;
- The logistics manager did not take into account the multi drop list in distributor allocation. This practice can give a wrong capacity plan of each distribution warehouse;
- The approach to adjust the current capacity plan with the empirical data (i.e., one random point of warehouse utilization in the low season) using "lack DOI" of 1.5 is not correct, because the warehouse utilization fluctuates daily and the adjustment is too high (i.e., to upgrade 50% of the original calculation).

Based on the critical remarks of X-Firm's current situation, the requirement of the management, and the knowledge that we gathered from the literature study, we set up a conceptual frame work for our solution approach in Chapter 4. The conceptual framework (i.e., Figure 4.3-1 on page 57) consists of 6 steps within 2 major phases: (I) data preparation; and (II) capacity planning. We used the (*R, s, nQ*) inventory policy in our solution approach that is similar to X-Firm's current inventory policy, applied the ABC classification, and determined the safety factor and safety stock based to the customer service approach: fill rate (P_2) of 97% for the A and B items and the probability of no stock out occasion (P_1) of 95% for the C Items. We determined the initial on-hand stock based on the expected on-hand stock for the regular products and the maximum on-hand stock that take into account the seasonality index for the seasonal products.

We allocated a retailer to a distribution warehouse according to the fixed delivery route and the distributor according to total demands per site and multi drop list. We determined the capacity plan for each distribution warehouse according the fraction of demand per site from the customer allocation. We used 2 preferences to decide on the feasible solution that are to have higher fraction of customer demand at Site II and to let an insufficient capacity occurs at Site II rather than at Site I. We determine the inventory turnover ratio (ITR), days of inventory (DOI), total operational costs, and total relevant costs) in order to measure the performance of our solution capacity plan and to compare it with X-Firm's current performance.

When testing our solution approach, we got the first solution that did not give a good solution. In the first solution, most customers were assigned to Site II and it caused the capacity of Site II was insufficient while the capacity at Site I was almost half-empty in 2014 - 2016. We learned that this first solution can be improved by relaxing the criteria of distributor allocation to get the feasible solution. We updated the first solution of distributor allocation according to customer's relative travel distance to Sites I and II and swapping distributor allocation of multi drop list M06.

According to the improved solution capacity plan, there was insufficient capacity of 30 pallet positions in 2015 and 459 pallet positions in 2016 at Site II. We learned that when the second expansion runs in 2015, the inventory movement will still occur between Sites I and II and from Site III to both Sites I and II. In comparison with X-Firm's current performance, our solution underperforms in terms of aggregate ITR, aggregate DOI, and total operational costs, because the solution capacity plan yields on a larger number of pallets. By implementing our solution approach, the total operational costs increased 19.9% compared to the X-Firm's current operational costs in order to improve the service level from 92.5% (i.e., the actual service level in 2013) to 97% (i.e., the targeted service level). We deduced that if X-Firm wants to have a higher service level, they have to hold more inventories to cope with the demand fluctuation. We provided the sensitivity analysis of the total operational cost for the fill rate of 92% until 98% in Table 5.6-1 on page 82.

Overall, we conclude that the conceptual framework of the step by step solution approach and the datasets of the solution capacity plan are potential to become a standard operating procedure to help the manager in creating a capacity plan. The datasets are adaptable and extendable in terms of adding or deleting SKUs and parameters, since we worked on it using Microsoft Excel.

6.2 Recommendations

In this section, we provide X-Firm with the recommendations that we notified while working on this research. The basic recommendation is to implement the step-by-step approach of the solution capacity planning in our conceptual framework using the historical demand of the last one year. The logistics manager can use the result of the implementation to check the capacity in 2015 and the following years. We recommend X-Firm to regularly update the SKU master data. In the data collection process, we found some missing or not updated data in the SKU master data that contains the SKU characteristics. It is very important, because the master data is one of the inputs of capacity planning. We recommend the management to use the solution capacity plan for strategic or tactical purpose only, because the solution approach does not accommodate the special cases or abnormalities that usually occur in operational level (i.e., quality problem, raw material availability problem, machine breakdown, lack of production capacity, etc.). Note that the solution capacity planning works under the assumptions that we mention in this study. If there are other assumptions that are not included in this study, we recommend the management to add the new assumptions or adapt the assumptions according to X-Firm's best practice.

In Section 5.1, we determine the k_i of class A and B items from the fill rate (P_2) using Solver add-in in Excel by setting the value of k_i such that the $G_u(k_i)$ of the right hand side is equal to the $G_u(k_i)$ of left hand side. This process is time-consuming and risky, because if the P_2 is changed then we have to recalculate the k_i all over again. We recommend to automate this process using Excel VBA.

In this study, we round the seasonality index to the nearest integer number. If later the number of seasonal product significantly increases, we recommend X-Firm to use the real seasonality index rather than the integer seasonality index to obtain more precise result of the maximum on-hand stock for the seasonal products.

To cope with the insufficient capacity in 2016, we recommend X-Firm to extend the capacity at Site II by at least 500 pallet positions. It is also possible to rent an external warehouse near Site II during the seasonal period or to occupy the excess capacity in the storage warehouse at Site III.

During this study, we observed several subjects that are interesting for future research at X-Firm. The determination of the operational costs of distribution warehouses in this study uses a simple approach and the value is relatively small. In the real practice, we recommend X-Firm to calculate the total operational costs using the total relevant costs approach. We also recommend X-Firm to consider the transportation costs of customer delivery, the opportunity costs of holding inventory, and also another related costs to know the real total operational costs.

If X-Firm can have the total transportation costs of customer delivery per customer, we recommend X-Firm to optimize the customer allocation by minimizing the total transportation costs of customer delivery. Note that to enable the optimization of customer allocation, X-Firm has to consider as well the travel distance from customer to each distribution site and the travel time, especially for the delivery using land transportation. As we learn from the literature, a mathematical programming model, such as integer linear programming (ILP) or Mixed ILP (MILP) can be developed to obtain an optimal solution.

We recommend X-Firm to review the current fixed delivery route and multi drop list according to the demand size and order behavior of each customer (i.e., day of order, order frequency per month, etc.). We also recommend to split the multi drop list with large number of distributors. Some multi drop list for distributors contains too many distributors, especially for M05 and M06. So, the updated fixed delivery route and multi drop list can be used for the next capacity planning.

Furthermore, we recommend X-Firm to take into account the production capacity in its future capacity planning. In this study, we assume that the production capacity at each manufacturing site is always sufficient to produce the customer demands of each manufacturing site. In the reality, the production capacity of the same production plant at Sites I and II might be different. By considering the real production capacity, the capacity plan of each distribution warehouse becomes more representative to X-Firm's real situation.

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Appendix A. Sample data of the current capacity planning

A.1. Sample data of DVP per item group per location

Volume (m^3) total	Non-RTD Outsource	Non-RTD Outsource Total	Powder Type II			Powder Type II Total	RTD Internal	RTD Internal Total	RTD Outsource	RTD Outsource Total	Powder Type I			Powder Type I Total	Powder Type III		Powder Type III Total	Other Non-RTD				Other Non-RTD Total
Row Labels	Outsource		Site I	Site I-Site II	Site II		Site I		Outsource		Site I	Site II	Outsource		Site I	Site II		Site I	Site I-Site II	Site II	Outsource	
Distributor 1	1.25%	1.25%	0.06%	17.97%	0.00%	18.03%	6.52%	6.52%	3.92%	3.92%	2.03%	37.96%	0.17%	40.74%	15.71%	7.63%	23.35%	3.26%	2.34%	0.16%	0.43%	6.19%
Distributor 2	0.20%	0.20%	0.02%	10.27%	0.00%	10.28%	5.66%	5.66%	3.03%	3.03%	2.12%	40.01%	0.24%	42.77%	22.90%	9.64%	32.54%	3.14%	2.10%	0.15%	0.13%	5.52%
Distributor 3	1.13%	1.13%	0.00%	15.10%	0.00%	15.10%	3.95%	3.95%	4.78%	4.78%	1.96%	35.01%	0.12%	37.92%	22.55%	8.60%	31.15%	2.47%	2.81%	0.03%	0.67%	5.97%
Distributor 4	0.62%	0.62%	0.05%	11.19%	0.00%	11.24%	5.82%	5.82%	3.91%	3.91%	2.51%	39.81%	0.14%	43.26%	19.49%	9.96%	29.45%	2.58%	1.81%	0.66%	0.66%	5.70%
Distributor 5	0.77%	0.77%	0.03%	18.58%	0.00%	18.62%	4.04%	4.04%	5.22%	5.22%	1.48%	39.32%	0.12%	41.73%	17.45%	6.95%	24.41%	2.89%	2.07%	0.00%	0.25%	5.22%
Distributor 6	0.95%	0.95%	0.07%	17.71%	0.00%	17.78%	3.75%	3.75%	3.10%	3.10%	1.61%	38.75%	0.12%	40.86%	18.43%	8.14%	26.57%	4.52%	1.90%	0.10%	0.49%	7.00%
Distributor 7	0.30%	0.30%	1.03%	22.53%	0.00%	23.56%	5.35%	5.35%	3.60%	3.60%	2.51%	31.66%	0.27%	35.72%	16.85%	10.09%	26.94%	2.43%	0.90%	0.09%	1.11%	4.53%
Distributor 8	0.04%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	17.71%	0.00%	17.71%	55.65%	23.22%	78.87%	2.57%	0.62%	0.15%	0.03%	3.37%
Distributor 9	0.00%	0.00%	0.00%	60.75%	0.00%	60.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	8.45%	16.23%	24.68%	14.57%	0.00%	0.00%	0.00%	14.57%
Distributor 10	0.00%	0.00%	0.00%	98.12%	0.00%	98.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.94%	0.00%	1.88%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

A.2. Sample data of DVP per location to assign storage location for distributor

Distributor	Demand Volume Peroportion (DVP) per location			Storage Location
	Site I	Site I - Site II	Site II	
Distributor 1	30.46%	17.65%	42.99%	Site II
Distributor 2	29.93%	12.83%	49.77%	Site II
Distributor 3	25.28%	20.21%	45.28%	Site II
Distributor 4	27.66%	19.16%	45.92%	Site II
Distributor 5	27.83%	23.22%	41.47%	Site II
Distributor 6	25.67%	33.12%	37.79%	Site II
Distributor 7	21.21%	26.28%	39.96%	Site II
Distributor 8	25.04%	25.78%	38.64%	Site II
Distributor 9	58.22%	0.62%	41.08%	Site I
Distributor 10	48.25%	4.67%	45.45%	Site I

A.3. Sample data of customer demand in carton per item group per location

Carton total/ Item Group	Non-RTD Outsource	Non-RTD Outsource Total	Powder Type II			Powder Type II Total	RTD Internal	RTD Internal Total	RTD Outsource	RTD Outsource Total	Powder Type I			Powder Type I Total	Powder Type III		Powder Type III Total	Other Non-RTD				Other Non-RTD Total	Grand Total
Location	Outsource		Site I	Site I-Site II	Site II		Site I		Outsource		Site I	Site II	Outsource		Site I	Site II		Site I	Site I-Site II	Site II	Outsource		
Distributor 1	504	504	41	7,216		7,257	9,186	9,186	4,728	4,728	2,548	21,911	117	473	9,301	3,533	12,834	1,773	980	124	240	3,117	38,099
Distributor 2	14	14	2	1,000		1,002	1,544	1,544	763	763	541	4,712	30	94	2,463	836	3,299	294	161	22	13	490	7,205
Distributor 3	42	42		671		671	591	591	576	576	233	2,077	8	44	1,305	405	1,710	132	114	2	36	284	3,918
Distributor 4	62	62	8	1,380		1,388	1,993	1,993	1,038	1,038	710	5,314	22	119	2,784	1,091	3,875	337	186	117	88	728	9,202
Distributor 5	26	26	2	814		816	519	519	596	596	145	1,971	7	42	922	272	1,194	142	77		12	231	3,424
Distributor 6	57	57	8	1,228		1,236	858	858	594	594	267	3,417	13	75	1,761	605	2,366	354	125	12	43	534	5,720
Distributor 7	12	12	61	911		972	657	657	346	346	241	1,516	16	36	852	399	1,251	120	32	6	52	210	3,484
Distributor 8	41	41				-	-	-	1	1	9	30,060		532	92,791	29,287	122,078	4,258	586	288	48	5,180	127,832
Distributor 9				97		97	-	-	-	-					10	21	31	15				15	143
Distributor 10				418		418	-	-	-	-		10		0			-					-	418

A.4. Sample data of adjusted distributor demand in carton per item group per location

Adjusted Carton total/ Item Group	Non-RTD Outsource	Non-RTD Outsource Total	Powder Type II			Powder Type II Total	RTD Internal	RTD Internal Total	RTD Outsource	RTD Maklon Total	Powder Type I			Powder Type I Total	Powder Type III		Powder Type III Total	Other Non-RTD				Other Non-RTD Total	Grand Total
Location	Outsource		Site I	Site I-Site II	Site II		Site I		Outsource		Site I	Site II	Outsource		Site I	Site II		Site I	Site I-Site II	Site II	Outsource		
Distributor 1	476	476	23	6,847	-	6,870	2,484	2,484	1,493	1,493	772	14,463	66	15,523	5,987	2,908	8,895	1,241	892	63	162	2,358	38,099
Distributor 2	14	14	1	740	-	741	408	408	218	218	153	2,883	17	3,081	1,650	694	2,345	227	151	11	9	398	7,205
Distributor 3	44	44	-	592	-	592	155	155	187	187	77	1,372	5	1,486	883	337	1,220	97	110	1	26	234	3,918
Distributor 4	57	57	5	1,029	-	1,034	535	535	360	360	231	3,664	13	3,981	1,794	916	2,710	237	166	60	61	525	9,202
Distributor 5	26	26	1	636	-	637	138	138	179	179	51	1,346	4	1,429	598	238	836	99	71	-	9	179	3,424
Distributor 6	54	54	4	1,013	-	1,017	215	215	177	177	92	2,217	7	2,337	1,054	465	1,520	258	108	6	28	400	5,720
Distributor 7	11	11	36	785	-	821	186	186	126	126	87	1,103	10	1,244	587	351	938	85	31	3	39	158	3,484
Distributor 8	55	55	-	-	-	-	-	-	0	0	7	22,639	-	22,645	71,141	29,686	100,827	3,285	792	188	39	4,304	127,832
Distributor 9	-	-	-	87	-	87	-	-	-	-	-	-	-	-	12	23	35	21	-	-	-	21	143
Distributor 10	-	-	-	410	-	410	-	-	-	-	-	4	-	8	-	-	-	-	-	-	-	-	418

Appendix B. Example of service level calculation

B.1. The different result of service level in carton and in money value

SKU	Unit Price	Demand						Service Level	
		in carton			*in money value*			in carton	in money value
		Total	Delivered	Undelivered	Total	Delivered	Undelivered		
1	€ 120.00	100	97	3	€ 12,000.00	€ 11,640.00	€ 360.00	97%	97%
2	€ 95.00	90	88	2	€ 8,550.00	€ 8,360.00	€ 190.00	98%	98%
3	€ 50.00	80	76	4	€ 4,000.00	€ 3,800.00	€ 200.00	95%	95%
4	€ 30.00	78	60	18	€ 2,340.00	€ 1,800.00	€ 540.00	77%	77%
5	€ 20.00	45	38	7	€ 900.00	€ 760.00	€ 140.00	84%	84%
Aggregate		**393**	**359**	**34**	**€ 27,790.00**	**€ 26,360.00**	**€ 1,430.00**	**91%**	**95%**

↑

The service level based on money value tend to give higher results

Appendix C. Example of forecast errors calculation

From Eq. 2.2-1, X-Firm's approach to calculate forecast error is as follows

$$Forecast\ error\ (\%) = \frac{\sum_{i=1}^{n}(Rolling\ forecast\ - Actual\ demand\ )}{\sum_{i=1}^{n} Rolling\ forecast}$$

While the theoretical approach to calculate forecast error is as follows

$$Forecast\ error\ (\%) = \frac{\sum_{i=1}^{n}(Rolling\ forecast\ - Actual\ demand\ )}{\sum_{i=1}^{n} Actual\ demand}$$

C.1. The forecast errors based on X-Firm's and theoretical approaches.

SKU $_i$	*Rolling forecast*	*Actual demand*	*Forecast error*	
			X-Firm's	*Theoretical*
1	1,000,000	903,627	9.6%	10.7%
2	200,000	236,443	-18.2%	-15.4%
3	4,500,000	3,418,905	24.0%	31.6%
4	500,000	347,349	30.5%	43.9%
5	340,000	360,902	-6.1%	-5.8%
Forecast error on aggegate			19.5%	24%

↑

X-Firm's approach gives smaller forecast errors compare to the theoretical approach

Appendix D. Comparisson of service level P_1 and P_2

D1. Service level P_1 and P_2 based on the normal loss function

SKU_i	Item Group	P_1	Safety factor k_i	*Normal loss function $Gu(k_i)$*	P_2
2105500225	C	0.95	1.645	0.02089	0.9858
2101449148	C	0.95	1.645	0.02089	0.9816
1101531016	CS	0.95	1.645	0.02089	0.9845
2101500190	C	0.95	1.645	0.02089	0.9818
2102040225	C	0.95	1.645	0.02089	0.9865
2151051180	C	0.95	1.645	0.02089	0.9752
1101541016	CS	0.95	1.645	0.02089	0.9847
1101006155	CS	0.95	1.645	0.02089	0.9882
1101003180	CS	0.95	1.645	0.02089	0.9870
2204584106	C	0.95	1.645	0.02089	0.9739
2104390210	C	0.95	1.645	0.02089	0.9780
2102511120	C	0.95	1.645	0.02089	0.9837
1103100	C	0.95	1.645	0.02089	0.9680
2101151151	C	0.95	1.645	0.02089	0.9766
2101470	C	0.95	1.645	0.02089	0.9685
2152051	C	0.95	1.645	0.02089	0.9764
1102102030	CS	0.95	1.645	0.02089	0.9815
21014561	CR	0.95	1.645	0.02089	0.9758
2101471	CR	0.95	1.645	0.02089	0.9768
2151084145	C	0.95	1.645	0.02089	0.9768
2101200151	C	0.95	1.645	0.02089	0.9742
1103021	C	0.95	1.645	0.02089	0.9639
2102100225	C	0.95	1.645	0.02089	0.9840
2106017	C	0.95	1.645	0.02089	0.9727
2151051145	C	0.95	1.645	0.02089	0.9771
2306055148	C	0.95	1.645	0.02089	0.9750
2102800129	C	0.95	1.645	0.02089	0.9798
2101462301	C	0.95	1.645	0.02089	0.9793
2101461148	C	0.95	1.645	0.02089	0.9759
1102262114	CS	0.95	1.645	0.02089	0.9750
2305000120	C	0.95	1.645	0.02089	0.9805
1101558017	CS	0.95	1.645	0.02089	0.9784
2101751105	C	0.95	1.645	0.02089	0.9729
1101031155	CS	0.95	1.645	0.02089	0.9841
1103030	C	0.95	1.645	0.02089	0.9558
2103600128	C	0.95	1.645	0.02089	0.9732
2103100125	C	0.95	1.645	0.02089	0.9709
1103031	C	0.95	1.645	0.02089	0.9544
2101369108	C	0.95	1.645	0.02089	0.9768
1101932105	CS	0.95	1.645	0.02089	0.9812
2101045151	C	0.95	1.645	0.02089	0.9677
1101665104	CS	0.95	1.645	0.02089	0.9821
1103050	C	0.95	1.645	0.02089	0.9533
1103000	C	0.95	1.645	0.02089	0.9492
1103111	CR	0.95	1.645	0.02089	0.9605
2102800119	C	0.95	1.645	0.02089	0.9744
2306536106	C	0.95	1.645	0.02089	0.9536
2305551294	C	0.95	1.645	0.02089	0.9486
2104392210	C	0.95	1.645	0.02089	0.9623
2304056291	C	0.95	1.645	0.02089	0.9462
1101557016	CS	0.95	1.645	0.02089	0.9416
2204552293	C	0.95	1.645	0.02089	0.9317
2102500318	C	0.95	1.645	0.02089	0.9507
2306536306	C	0.95	1.645	0.02089	0.9208
2151575143	C	0.95	1.645	0.02089	0.9507
2101800108	C	0.95	1.645	0.02089	0.9060
1101547105	CS	0.95	1.645	0.02089	0.9529
1101553104	CS	0.95	1.645	0.02089	0.9372

Appendix E. Seasonality Index

E.1. The determination of seasonality index of brand category A1 (i.e. seasonal products)

SKU	Total demand 2013 *(in pallets)*	Ave. Demand - 2013	Seasonality Index 2013	Round Seasonality Index	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
1102102030	76.27	6.36	1.86	2	1.148	0.770	0.899	1.060	1.233	1.172	1.862	0.700	0.819	0.766	0.872	0.698
1102101155	532.24	44.35	3.39	3	0.190	0.131	0.113	1.164	3.120	3.390	2.778	0.432	0.255	0.114	0.111	0.200
1102101180	621.52	51.79	3.53	4	0.469	0.281	0.306	1.428	1.777	3.532	2.653	0.277	0.315	0.292	0.175	0.496
1102101190	302.49	25.21	2.15	2	0.932	0.772	0.686	0.952	1.422	1.860	2.148	0.631	0.636	0.572	0.673	0.717
1102102225	153.90	12.82	3.56	4	0.285	0.192	0.143	1.297	3.563	2.648	2.686	0.377	0.177	0.163	0.154	0.314
1101003180	154.01	12.83	2.66	3	0.905	0.757	0.659	0.733	1.100	2.656	2.263	0.555	0.587	0.492	0.641	0.651
1101006155	189.88	15.82	2.90	3	0.603	0.326	0.298	1.056	1.778	2.900	2.784	0.621	0.524	0.338	0.250	0.522
1101005180	213.93	17.83	3.23	3	0.677	0.386	0.332	1.181	1.342	2.681	3.234	0.653	0.425	0.339	0.289	0.459
1101025155	243.12	20.26	3.06	3	0.482	0.337	0.355	1.362	2.809	3.060	2.173	0.354	0.304	0.245	0.197	0.321
1101031155	102.83	8.57	3.40	3	0.738	0.529	0.485	0.526	1.231	2.002	3.402	0.628	0.568	0.785	0.535	0.572
1101907019	839.33	69.94	1.59	2	0.833	0.671	0.801	1.013	1.337	1.461	1.587	0.640	0.802	1.021	1.022	0.812
1101909019	1,111.92	92.66	2.10	2	0.732	0.596	0.752	1.043	2.103	1.625	1.357	0.468	0.642	0.905	1.032	0.744
1101515016	211.61	17.63	1.57	2	0.973	0.636	0.887	1.076	1.327	1.340	1.570	0.628	0.712	1.064	1.085	0.702
1101558017	54.78	4.98	1.49	1	-	-	-	1.208	1.449	1.386	1.492	0.996	0.928	1.054	1.478	1.009
1101525016	211.38	17.61	2.14	2	0.880	0.616	0.744	1.271	1.672	2.137	1.402	0.509	0.603	0.748	0.799	0.619
1101531016	108.18	9.01	1.32	1	0.818	0.731	0.900	1.028	1.315	1.109	1.310	0.934	0.772	0.972	1.290	0.820
1101532019	117.14	9.76	1.67	2	0.999	0.741	0.911	1.061	1.240	1.107	1.674	0.725	0.802	0.944	1.160	0.636
1101932105	72.95	6.08	1.50	2	0.621	0.690	0.917	0.953	1.389	0.958	1.281	0.380	1.235	1.503	1.187	0.888
1101534016	194.94	16.24	2.29	2	0.849	0.575	0.606	1.085	2.294	1.543	1.615	0.491	0.625	0.743	0.945	0.629
1101541016	111.24	9.27	1.73	2	0.790	0.705	0.710	1.078	1.175	1.230	1.728	0.756	0.651	1.043	1.336	0.798
1101557016	7.01	0.58	1.88	2	1.651	0.326	1.017	1.149	0.901	1.161	1.033	0.470	0.290	0.850	1.878	1.273
1102262114	41.31	3.44	1.44	1	0.856	0.738	0.909	0.939	1.174	0.845	1.436	1.085	1.166	1.139	1.096	0.617