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Optimizing Storage Capacity in the Public Distribution Centre

By

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Abstract

Globalization has been accelerating since the 1990s. Increased globalization has forced many companies in the supply chain industry to start to conduct business with distribution centres that are located near their business area in order to shorten the distance between manufacturers and customers, as well as to shorten lead-times and maintain tighter delivery windows. Thus, many companies have outsourced their logistics functions over the past 10 years, especially logistics function through a public distribution centre. Conducting business with a public distribution centre begins with signing a contract with the third party logistics providers. Thus, well defined processes and tools to determine optimal storage space have become indispensable techniques for their successful business.

This thesis looks closely at how to decide the optimal contract storage space (ft^2) for a firm in a public distribution centre while minimizing the total cost. The objective of this research is to provide the practitioners in the supply chain industry with a decision tool for determining optimal contract storage space.

In this research, we develop a formula and two mathematical models. The formula is used to compute the required storage space as basic demand information. The mathematical models are used to determine the optimal contract storage space with and without based on some of the candidate scenarios provided. In order to solve the mathematical models, solution methodologies are suggested. One suggestion is to simplify the model with new constant and the second suggestion is to linearize the model. Thus the model can be solved easily by Excel Solver.

Finally, we have derived a number of conclusions from the numerical examples; the first, solution time by the Excel Solver program is quite fast by virtue of the linear programming model. In 1 second, the optimal solution is found. The second, optimal solution is determined when total cost is minimized. Total cost is the sum of the cost using the public distribution centres and overflow warehouse. The third, suggested optimal solution is not to use the overflow warehouse unless demand severely fluctuates. The fourth, shorter contract period is better than a longer one as far as the contract logistics market allows. It suggests that the model in the monthly contract period is a more optimal solution, than a solution on a yearly contract basis.

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List of abbreviation

DC	*Distribution Centre*
EDC	*European Distribution Centre*
RDC	*Regional Distribution Centre*
NDC	*National Distribution Centre*
TPL	*Third Party Logistics Provider*
SCM	*Supply Chain Management*
WMS	*Warehouse Management System*
SKU	*Stock Keep Units*
VAL	*Value Added Logistics Service*
W/H	*Warehouse*
EU	*European Union*
EMEA	*European, Middle-East and Africa*
APICS	*American Production & Inventory Control Society*
ERSS	*Estimated required storage space*
CSS	*Contract Storage Space (at the Distribution Centre)*
ESS	*Excess Storage Space (at the Distribution Centre)*
ROSS	*Required Overflow Storage Space*
ARSS	*Actual Required Storage Space*
RCSP	*Required Contract Storage Pallets*
NDL HIDC	*Nederland Distributieland Holland International Distribution Council*

Chapter 1 Introduction

Chapter 1 will address the motivations for embarking on this research, research objectives, research questions and the methodology with the aim of introducing this research to the readers. The entire research is also structured at the end of this chapter to help with understanding how we ought to approach this study in order to solve the problems which are generated by the research questions it raises.

1.1 Introduction

Globalization has been accelerating since the 1990s and it has continually required efficiency and responsiveness through well designed supply chains and new information technology in order to meet a variety of customers needs in the supply chain industry. Furthermore, globalization has forced many companies in the supply chain industry to do their business with distribution centres located near their business area in order to overcome long distances between manufacturers and customers, as well as in order to meet shorten lead-times and tighter delivery windows.

The Distribution Centre (DC) is a kind of warehouse for the storage of goods that is generated by the difference between demand and supply or by a strategic goal of future sales. Moreover, these stored goods are finally redistributed either to the wholesalers, retailers or to the customers directly. In Europe, many companies use the European Distribution Centre (EDC) in order to minimize the whole inventory in their business area. The EDC has developed with macro economics and globalization over the past decades, and is defined as the place for the central storage of goods for the European, Middle-East and Africa (EMEA) regions and for the replenishment of the different Regional Distribution Centre (RDC) (Transport Intelligence, 2005). Thus, the EDC has not only been an indispensable connecting node between manufacturers in Asia and customers in Europe, but also been one of the strategic tools for improving supply chain management.

Therefore, the optimal use of the distribution centre in the supply chain industry can be among the competitive factors that contributed to the success of their business. Figure 1.1 shows the function of the European Distribution Centre as an indispensable connecting node.

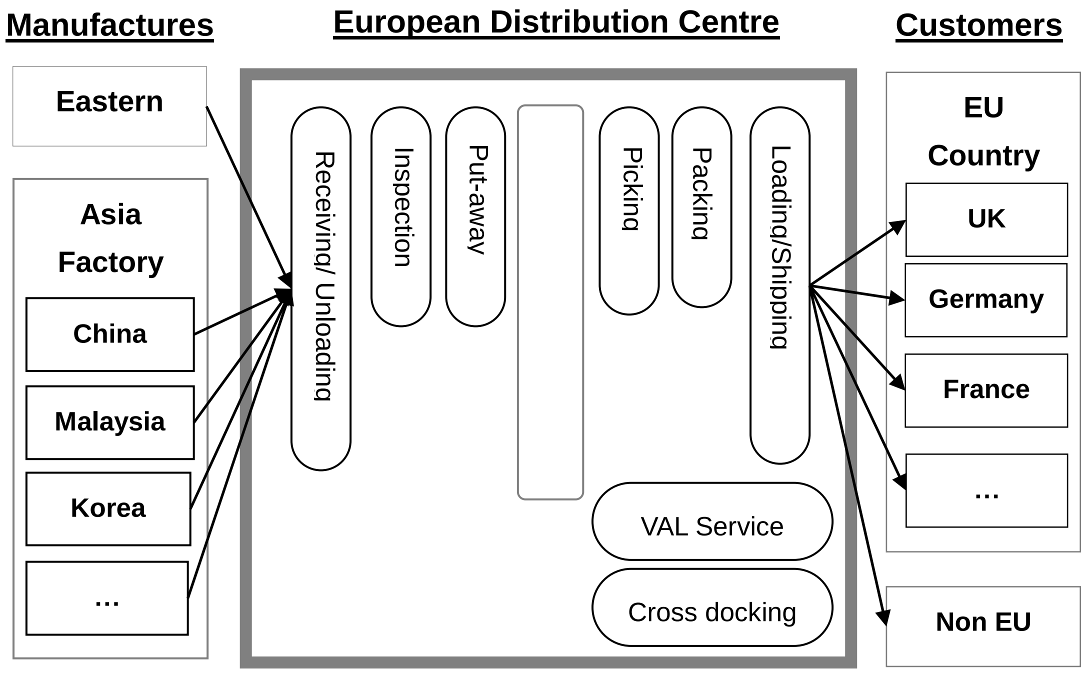


Figure 1.1 The function of the European distribution centre

1.2 Motivation

Uncertainties in the supply chain industry, that may include changes in the economic situation, seasonality, a competitor's promotion and the bullwhip effect, can create many difficulties for using the distribution centre in supply chain management.

There are three phases in supply chain management. The first is the supply chain strategy; the company decides how to structure the supply chain over the next several years. The second phase is the supply chain planning; the company has to maximize the net value over a quarter to a year based on the accepted supply chain strategy. The third phase is the supply chain operation; the company has to make decisions based on customer orders on a weekly or daily basis (Chopra, 2007). Thus, wrong planning in the 2nd phase supply chain management is likely to cause failure in the daily and weekly operations in the 3rd phase of the supply chain management. Thus, for business through the distribution centre, optimal capacity planning of storage space at the distribution centre should be taken into consideration as an important procedure for maximizing net value in the 2nd phase of supply chain management.

For instance, poor capacity planning and wrong decisions can have an impact on efficiency, as well as on the responsiveness of the supply chain. The first, from the perspective of efficiency, is that an excess or lack of capacity (storage space, ft^2) at a distribution centre can lead to an increase in the total cost; in the case of excess capacity, the storage cost caused by empty space should be added on to the goods which are stored at the distribution centre. Namely, a cost ratio of goods compared to sales amount increases. And also, there are high potential risks that can increase the total cost such as during periods of economics crisis like the current crisis. Lack of capacity can also lead to an increase in the total cost due to the possibility of using the *overflow warehouse*[1] for the storage of goods in another area. The second, from the point of view of responsiveness is that a lack of capacity (space, ft^2) at the distribution centre can lead to an increase of operational lead time in the supply chain and this can in the end reduce the revenue of the company as a result of customer dissatisfaction sequentially; e.g. delay in the timely receiving of goods at the distribution centre, less product availability, delay in the timely shipment of goods from the distribution centre to customers, delay of the delivery of goods to the customers, less order fill rate, an increase in customer dissatisfaction, a decrease in the amount of sales for the company and a decrease in company revenue.

Therefore, well defined processes for optimizing storage capacity in the public distribution centre of the supply chain is an indispensable technique and one of the critical steps for the supply chain management.

1.3 Research question and objective

As mentioned in the introduction, many companies in Europe are conducting their business through the European Distribution Centre in the supply chain industry. As a result, many companies have outsourced their logistics functions to third party logistics providers (TPL) over the past 10 years. Recently, this has been one of the

[1] A temporary public warehouse for the storage of overflow goods from the DC

strongest trends in the supply chain industry.

In a survey of manufactures and retailers that are related to the financing of European warehouse properties, 20.6% leased their warehouses, 23.5% rented their warehouses, 14.7% directly owned their warehouses and 41.2% of companies managed a mix of the three approaches across their distribution facilities (Transport Intelligence, 2005). This means that at least more than 50% of the manufacturers and retailers prefer to rent or lease for their European warehousing. According to Koster and Balk (2008), public EDCs are more efficient than own-account EDCs. Therefore, capacity planning of storage space at the EDC is a necessary step before signing a contract with third party logistics providers for the business through the distribution centre.

When circumstances require following forecasts (sales plans) provided by the sales and marketing department, practitioners who are in charge of Supply Chain Management (SCM) and Logistics must optimize storage space at the public distribution centre for the success of their business in the future. Under these circumstances, optimal solutions for determining the contract storage space (ft^2) should be taken into account trying to minimize total cost. Moreover, required storage space from the estimated demand for future sales should be secured optimally in the distribution centre or overflow warehouse. Therefore, the main research question is:

"How to decide the optimal contract storage space (ft^2) of the distribution centre by minimizing the total cost"?

In order to solve the problem which is generated by the main research questions, first of all, we need to answer some of the more basic sub-research questions. These sub-research questions include:

- **How to calculate the required storage space (ft^2) based on the given information such as demand forecast (Sales plan)?**
  In order to solve the problem which is generated by the main research question, one starting point is to determine the required storage space for future business as demand information. In other words, calculating the required storage space should be taken into consideration first as a necessary phase for determining the optimal contract storage space.

- **How to build mathematical models for determining the optimal contract storage space and for determining what are the components of the total cost?**

  Mathematical models are required as computing tools for determining the optimal contract storage space by minimizing the total cost for using the distribution centre.

- **How to apply weekly demand forecast for static and dynamic distribution centre (warehouse) sizing problems?**

  In real contract logistics and supply chain industry, although contract storage space at the public distribution centre could be determined on a minimum monthly basis, it would be better to require demand forecasts as frequently as possible such as on a weekly basis in order to ensure more forecast accuracy.

- **What is the solution methodology to solve the real case problems?**

  Mathematical models which are developed in this research should be able to apply to the real contract logistics and supply chain industry with fast solution time.

- **What is a software program to solve the formulated mathematical models?**

  Formulated mathematical models with decision variables should not be solved by on-hand processing but by implementing a functional programming system in order to cut the time and costs involved in the capacity planning of storage space for the distribution centre.

Meanwhile, the objective of this research study is not only to make a scientific contribution, but also to make a practical contribution for managerial practitioners, who are in charge of logistics in a firm of the supply chain industry, to be able to utilize by providing them with a decision tool for determining optimal contract storage space using a suggested methodology to solve the problems which are generated by the research questions.

1.4 Methodology

This research study introduces three conceptual models in order to define the research questions and the logical relations between each variable.

The first conceptual model is related to calculating the required storage space. Therefore, one starting point is to obtain the demand forecast (sales plan) as basic information. This requires, first of all, that the quantity based demand forecast should be converted to the pallet based demand forecast by SKU (Stock Keep Units) material master table which includes the number of piece of SKU per pallet, size of SKU, net and gross weigh of SKU, and etc. The number of the pallet places to be stored at the distribution centre is the easiest way for calculating the required storage space because most of goods are stored with palletizing in the distribution centre. After that, ordering cycle, peak index, rack/bulk ratio in the storage zone of distribution centre and floor area occupation (ft^2 per pallet) are among other factors that will be considered in determining the required storage space (ft^2).

The second conceptual model is related to choosing the best scenario out of the four scenarios provided. Scenario 1: max-one step planning is to apply maximum required storage space (ft^2) in a year on the basis of the calculated required storage space (ft^2); scenario 2: max-dynamic planning is to apply maximum required storage space (ft^2) in each quarter on the basis of the calculated required storage space (ft^2); scenario 3: min-dynamic planning is to apply minimum required storage space (ft^2) in each quarter on the basis of the calculated required storage space (ft^2); scenario 4: average-dynamic planning is to apply average required storage space (ft^2) in each quarter on the basis of the calculated required storage space (ft^2). There are three Input parameters that are applied for this; required storage space, contract storage space based on four scenarios, and cost tariffs.

In the contract logistics industry, however, it is possible to come up with many other scenarios, which can be taken into account as optimal solutions. Thus, the third conceptual model is related to giving the solutions to determine the optimal contract storage space without any given scenarios. In this case, the contract storage space is considered not as an input parameter but as a decision variable. To solve this model, however, a new variable is introduced to determine whether storage space in the overflow warehouse is required or not.

In sum, two mathematical models are suggested for optimal solutions; one is related to choosing the best scenario out of the four given scenarios and the other is related to determining the optimal contract storage space (ft^2) without any given scenarios. Both models are concerned with minimizing the total cost which can be incurred by conducting business through the distribution centre. In order to solve these problems with numerical examples, a solver function that is developed by Micro Excel software is applied for the universal use in the supply chain industry.

1.5 Research structure

The entire research is structured to help understand how we ought to approach this study in order to solve the problems which are generated by the research questions it raises. This research study consists of seven chapters as follows:

Chapter 1: This study begins with an introduction that discusses my motivations for embarking on this research, the research objectives, the research questions examined and the methodology used with the aim of introducing this subject to the readers.

Chapter 2: The available literature on this subject can substantially contribute not only to the knowledge of practitioners in the real contract and supply chain industry but also to scientific researchers. Three fields of literature are reviewed for the good research design. These include supply management, the European Distribution Centre, and Distribution Centre (warehouse) operations and sizing problems.

Chapter 3: Chapter 3 introduces the conceptual models used which are the bridge linking the research questions in the introduction and the mathematical models. The use of a conceptual model suggests a clear direction of how to develop mathematical models from the problems which are generated by the research questions.

Chapter 4: Chapter 4 introduces two mathematical models with assumptions in order to solve the problems which are generated by the research questions. For calculating the required storage space as one of input parameters in two mathematical models, functional formulas are placed at the beginning of this chapter. And two mathematical models are developed here: the first mathematical model is choosing the best scenario out of four given scenarios and the second one is determining the optimal contract storage space without any given scenarios. Both models are focused on minimizing the total cost.

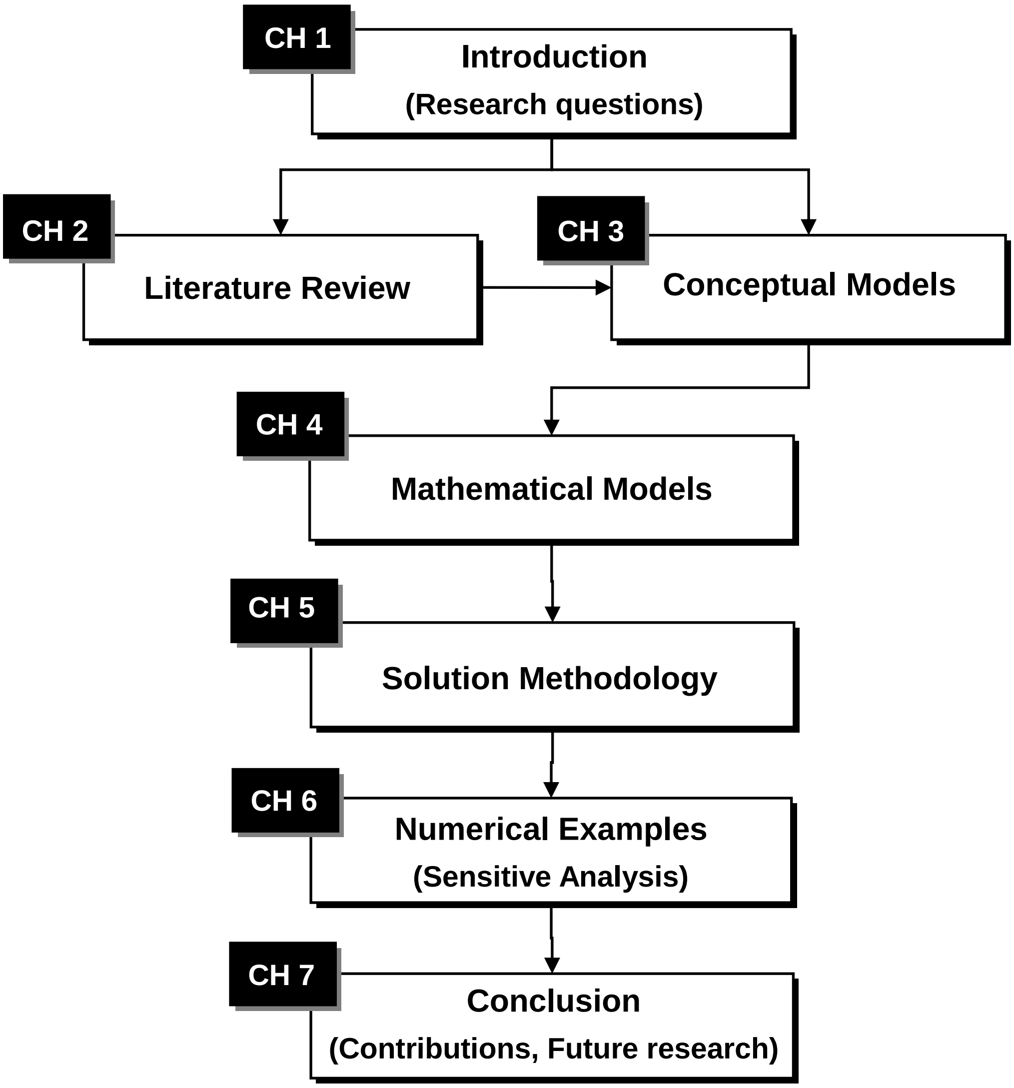


Figure 1.2 Research structure

Chapter 5: Chapter 5 introduces solution methodology to solve a real problem on the basis of a functional formula and mathematical models. Thus, two solution methodologies are introduced: one is to reformulate the model for simplifying the date entry and the other is to change the non linear programming model into a linear programming model for fast solution time and wider use in the contract logistics and supply chain industry.

Chapter 6: Chapter 6 shows the analysis results of the numerical examples examined for this research. Real data in the contract logistics industry are applied for a functional formula and two mathematical models that were developed in Chapters 4 and 5. Thus, this chapter would be very useful for further research whether or not there are any additional factors to consider for the real contract logistics industry. This chapter is structured according to Numerical examples. These include Numerical example 1: calculating required storage space; Numerical example 2: choosing the best scenario; Numerical example 3: determining optimal contract storage; and Numerical example 4: sensitive analysis. Most of these analyses are conducted by using “Excel Solver”.

Chapter 7: Chapter 7 summarizes this research study, and discusses the managerial and scientific contributions it offers, as well as addressing some of the study’s limitations before providing final suggestions for further research.

A mock table relationship between thesis objective and structure is summarized as follows:

Table 1.1 A mock table relationship between thesis objectives and structure

Thesis Objectives	CH 1	CH 2	CH 3	CH 4	CH 5	CH 6	CH 7
Research questions	●	○	●	○	○	○	○
Methodology	○	○	●	●	●	○	○
Optimal Solutions	○	○	○	○	●	●	●
Contributions	●	○	○	●	●	●	●

Note: ● = Strong relationship; ○ = weaker relationship

Chapter 2 Literature Review

2.1 Introduction

A literature review can help provide insights for good research design and what this research can contribute to the scientific research community that is different when compared to other research studies. In this chapter, three fields of literature are reviewed such as the Supply Chain Management (SCM), the European Distribution Centre, and Distribution Centre (warehouse) operations and sizing problems.

2.2 Supply chain management

The importance of Supply Chain Management has increasingly grown over the past years and SCM is now considered a management philosophy (Mentzer, 2001). Many authors have sought to define SCM. According to Chopra, a supply chain is structured by all parties directly or indirectly involved in order to fulfill customer's requests (Chopra, 2007). Tan believes that SCM includes purchasing and supply activities, transportation and logistics functions, and all the value added activities from suppliers to the end users (Tan, 2001). For Stevens, SCM is used to control the flow of material from suppliers to customers though the value added processes and distributions channels (Stevens, 1990). SCM has also been defined by the American Production & Inventory Control Society, as the design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value …, synchronizing supply with demand (APICS, 2007). The definition of the net value is the difference between the value of the final goods and the cost incurs in order to fulfil customer's requests in the supply chain for the final goods (Chopra, 2007).

Meanwhile, there are many entities in the supply chain and these entities should be optimized as part of the supply chain. Thus, network optimization can be considered one of the important strategies for maximizing net value in the supply chain. Tsiakis, Shah and Pantelides (2001) suggested that supply chain networks should take into consideration the number, size and physical location of factories and warehouses (Distribution Centre). Perl and Daskin (1985) discussed warehouse locations and routing problems. Baker (2007) presented the role of inventory and warehousing within international supply chains. While Kalfakakoua, Katsavounisb and Tsourosa (2003) suggested adopting a method to search for the smallest number of warehouses that can store products. However, the companies should first define the characteristics of their products in order to design the optimal supply chain. Namely, the companies have to know whether their products are functional or innovative products (Fisher, 1997). In sum, the key objective of supply chain management is to maximize net value in the supply chain, satisfying various customer needs, and reconciling supply and demand. Thus, business through the distribution centre can be considered one of the solutions for reconciling supply and demand in supply chain management.

2.3 European distribution centre

As mentioned in the introduction, many companies in Europe are using the European Distribution Centre (EDC) for their businesses in order to meet various customers' needs and in order to obtain better efficiency. The European warehousing and distribution market has been affected by macro economics and political consideration such as the support of a single European market within the EU over the past decades (Transport Intelligence, 2005). EDC is defined as the place of central storage of goods for the European, Middle East and Africa (EMEA) regions and replenishment of the different regional distribution centre (Transport Intelligence, 2005). EDC is also defined as a pioneer in order to implement advanced logistics systems because the role of EDC is to distribute manufacturer's goods to customers in Europe, the Middle East and Africa (Koster, 2005).

On the one hand, because the contract logistics industry is under extreme cost pressure, its need for low cost facilities has led to a high demand for centralized warehouses, even in some cases, in locations away from hubs with well-connected sites (LaSalle, 2006). On the other hands, according to Maister, if inventories of a product are consolidated into one centralized location from "n" decentralized location, the safety stock will be reduced by square root of "n" number of location (Maister, 1976). This means that moving from a national warehouse in each of the fifteen EU countries to a single Pan European warehouse could reduce the safety stock by roughly three quarters (ECMT, 2002). Thus, the location of the EDC can be considered one of the crucial factors for the success of a company's business. Meanwhile, according to the survey by Capgemini consultants, many companies prefer the Netherlands, France, UK and Germany for the location of their distribution centres. More than half of total surface areas of distribution centres are located in the Netherlands, France, UK, and Germany (see Figure 2.1). Among these countries, the Netherlands offers a highly qualitative location along with competitive total supply chain costs (NLD/HIDC, 2007). In addition to its central location, the Netherlands possesses several other advantages including excellent logistics infrastructure and facilities, Tax and customs advantages, an internationally oriented business community, and a flexible, productive, and highly educated labor force (HIDC, 2007).

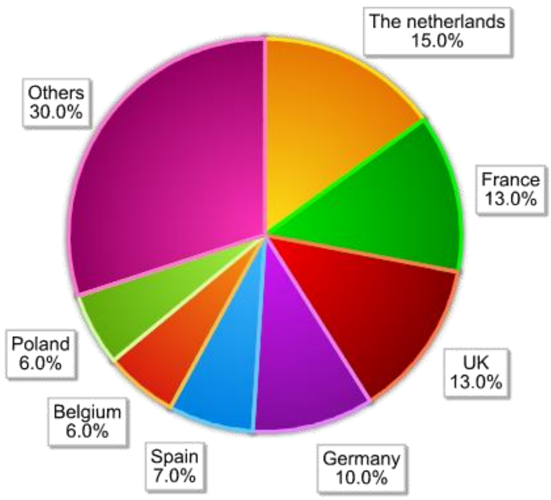


Figure 2.1 Share of total distribution centres in Europe per country
Source: Capgemini consultants, Europe's Most Wanted Distribution Centre Locations, 2006

Meanwhile, the function of the distribution centre has been increasingly diversified with the value added logistics (VAL) service for the product customizing with postponement strategy in order to satisfy various customer needs in the supply chain industry. But the major function of the distribution centre is still the storage of goods that is effected by the difference between demand and supply or by the companies' strategy for future sales.

According to a survey conducted by Capgemini and Prologis (2006), 30%~32% of respondents said that the key bottleneck in the distribution facilities was caused by not enough space in the operating area. This was the second key bottleneck after the security issue. This means that optimizing storage capacity in the distribution centre is one of the most important techniques to help solve some of the difficult issues confronting the supply chain industry. In order to accomplish this aim, a review of the available literature concerning distribution centre (warehouse) operations and sizing problems has been collected for the past several decades.

2.4 Distribution centre (warehouse) operations and sizing problems

In their work, Gu, Goetschalckx, McGinnis (2006) focused on decision support models and solutions for warehouse operations for a short duration. Aghezzaf (2004) proposed a deterministic model for the strategic capacity planning and warehouse location problems in supply chain operating when faced with uncertain demand variability. Aghezzaf (2007) also offers a capacity and warehouse management plan in the supply network, satisfying the expected demands with the lowest possible cost. In their text, Cormier and Gunn (1992) defined throughput capacity models, storage capacity models, and warehouse design models. The storage capacity model is designed to find warehouse size which minimizes either total costs or allows a required service level. Mark, Ou, Teo (2001) introduced a warehouse sizing problem in their research in order to minimize the total cost of ordering, holding, and warehousing. Cormier and Gunn (1996) have proposed the model that can allows the optimal warehouse size as well as the ratio of investment cost which is related to inventory cost. Rosenblatt and Roll (1998) discussed the major elements that can have an influence on the required capacity of a warehouse. While Rao and Rao (1998) proposed models that minimize the total warehousing cost over a finite planning horizon with dynamic warehouse sizing problems. Ballau (1974) suggested a model to determine warehouse sizing and the allocation of storage space when the total cost is minimized in the static problem. Hung and Fisk (1984) examine further developed models that are concerned with the static problem and the dynamic problem on the basis of the first model introduced by Ballau. The model introduced by Hung and Fisk provides a good method for determining the most economical solutions for the static and dynamic warehouse sizing problems.

However, the models that will be introduced in this research study have different characteristics as follows:

- First, for the dynamic distribution centre (or warehouse) sizing problems in the real contract logistics and supply chain industry, it would be better to require demand forecasts (required storage space) as frequently as possible such as on a weekly basis in order to ensure more forecast accuracy even if the period of the contract is only allowed based on the monthly minimum. Thus, the model in this research is developed so that demand forecast can be applied on a weekly basis and to enable the optimal contact storage space to be shown on a monthly, quarterly, a half yearly and yearly basis.

- Second, distribution centre (or warehouse) demand, such as the amount of storage space required, is basic information for the capacity planning of storage space at the distribution centre. Thus, in this research, a mathematical formula is first introduced to calculate required storage space based on the quantity demand forecast from the sales and marketing department.

- The third concerns the dynamic distribution centre (or warehouse) sizing problems for private warehouses. It is difficult to apply different optimal solutions to the real contract logistics and supply chain industry because even if the model suggests different optimal solutions (contract storage space) for the future period, storage space in private distribution centres (warehouses) can not be expanded or reduced. This means storage cost in private warehouses should be paid regardless of expansion or reduction of the required storage space based on the different optimal solutions for the future period. Thus, for the model in this research, this is taken into consideration. Namely, the model is based on the public distribution centre instead of the private distribution centre, in order to get flexible storage space at the early contract stage.

2.5 Summary

This chapter introduced the necessary literature used for this research dealing with issues of Supply chain management, the European Distribution Centre as well as Distribution Centre operations and sizing problems. The supply chain is a global network linking all related entities. The objective of supply chain management is to maximize net value in the supply chain, satisfying various customer needs, and reconciling supply and demand. Supply change management considers conducting business through the distribution centre as one of the solutions to reconcile supply and demand. As a result, many companies in Europe are conducting their business through the EDC in order to meet various customer needs and to obtain greater efficiency. The EDC has been developed with macro economics and political considerations over the past several decades. According to a survey conducted, 30%~32% of respondents believed that the key bottleneck for distribution facilities in the supply chain was insufficient space in the operating area. This means capacity planning of storage space at the distribution centre is one of the important techniques to solve some of the issues faced by changes in the supply chain. There is a lot of valuable literature available for determining economic solutions to the static and dynamic distribution sizing problems. However, the models which will be introduced in this research have three different characteristics; applying demand forecast (required storage space) as frequently as possible such as on a weekly basis, introducing a mathematical formula to calculate required storage space as demand information, as well as looking at public distribution centre instead of private ones in order to obtain more flexibility in storage space.

Chapter 3 Conceptual Models

3.1 Introduction

This chapter introduces three conceptual models in order to better define the research questions with logical relations in each variable. These conceptual models will help the readers to better understand how we ought to approach this research study to solve the problems which were generated by the research questions in Chapter 1.

3.2 Conceptual model for required storage space

Figure 3.1 shows various independent variables that may have an affect on such a dependent variable as required storage space (ft^2). Namely, it shows how required storage space is developed based on various independent variables.

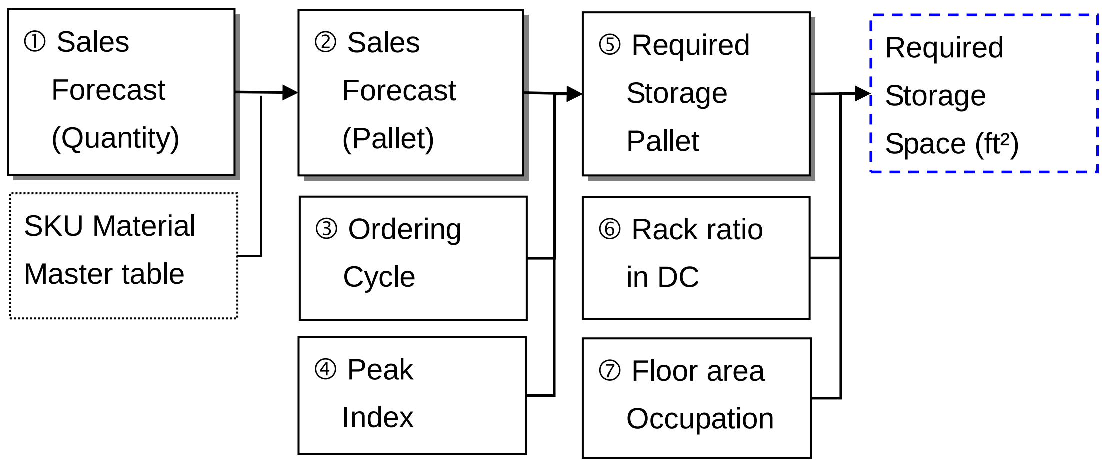


Figure 3.1 The conceptual model for required storage space

3.2.1 Terminology

- **Sales Forecast**
  - A weekly sales plan based on sales unit

- **SKU Material Master Table**
  - Units of SKU per pallet, weight, size of SKU and etc.
- **Sales Forecast (A number of pallets)**
  - A weekly sales plan based on palletized products.
- **Ordering Cycle (Lot size divided by demand)**
  - Required days that can satisfy incoming demand on the basis of current stocks without making new purchasing order (lot size).
- **Peak Index (An annual base)**
  - The index calculated based on the peak sales unit of a day of the week in a year.
- **Required storage pallet**
  - Estimated a number of pallets to be stored at the distribution centre.
- **Rack ratio in Distribution Centre**
  - The ratio of rack area in total storage zone of the distribution centre.
- **Floor area occupation (ft^2 per pallet)**
  - The ratio of floor area (ft^2) compared to pallet.
- **Required storage space (ft^2)**
  - Required space (ft^2) for the storage of goods at the distribution centre.

3.2.2 Relations in variables

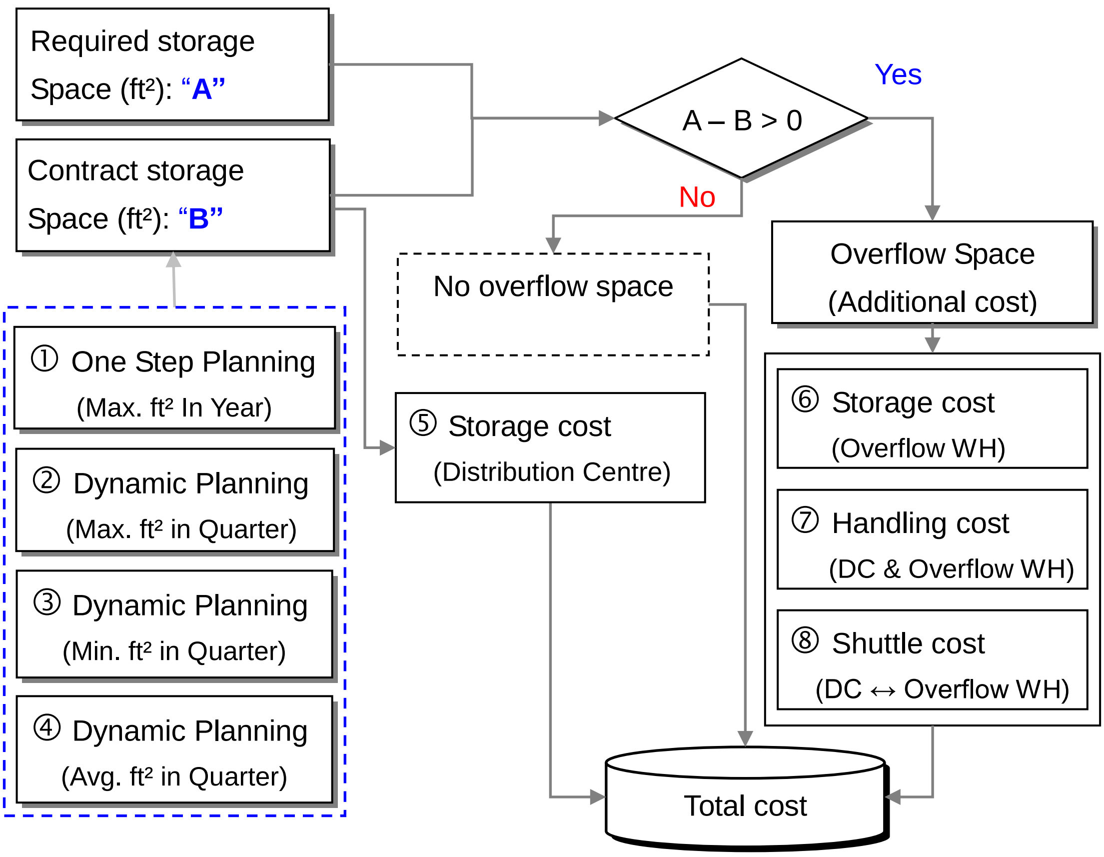
Sales Forecast (Pallet): This is calculated from sales forecast on the basis of product quantity. Once quantity based sales forecast gathers from the sales and marketing department, they combine with the SKU material master table in order to be converted into pallet unit sales forecasts. Namely, quantity unit sales forecasts and SKU material master table are requisites for calculating pallet unit sales forecasts.

Required storage pallet: The next step is to calculate the required number of storage pallets. This step makes it possible for the sale unit to be converted into a storage unit. In order to do this, ordering cycle (days) and peak index should be taken into account. Namely, this calculation is related to that how many pallets are required to be stored in order to meet incoming demand without making a new purchasing order. The Peak index is considered from a risk management point of view because required storage pallets should be considered on the basis of maximum quantity for a certain day in the week. However, sales forecast are usually given by week average.

Required storage space (ft²): A final step is to calculate the required storage space (ft²) on the basis of the required number of storage pallets. This step is to convert pallet unit of the storage goods into square meter unit of storage goods. Rack ratio in storage zone of the DC and occupation of floor area (ft² per pallet) are requisites in order to calculate the required storage space (ft²). This will be discussed in further detail in Chapter 4

3.3 Conceptual model for choosing the best scenario

Figure 3.2 shows how total cost is calculated for the contract storage space on the basis of required storage space (ft²). Namely, one of the suggested scenarios is chosen as an optimal solution when the total cost is minimized.



Note) ① ~ ④: Scenarios for determining contract storage space (ft²)

⑤ ~ ⑧: Components of total costs

Figure 3.2 The conceptual model for choosing the best scenario

3.3.1 Terminology

- **Four scenarios**
  - Suggested scenarios which can be considered as optimal solutions.
- **Contract storage space** (ft^2 In the distribution centre)
  - The contract storage space (ft^2) for the storage of goods at the distribution centre. This was given separately by the four suggested scenarios
- **Storage cost** (€ / ft^2 in the distribution centre)
  - The cost for the storage of goods at the distribution centre.
- **Storage cost** (€ / ft^2)
  - The cost for the storage of goods at the overflow warehouse.
- **Handling cost** (€ / pallet)
  - The cost for the loading (unloading) on (from) the truck at the distribution centre and overflow warehouse.
- **Shuttle cost** (€ / pallet)
  - The cost for the transportation between distribution centre and overflow warehouse.

3.3.2 Relations in variables

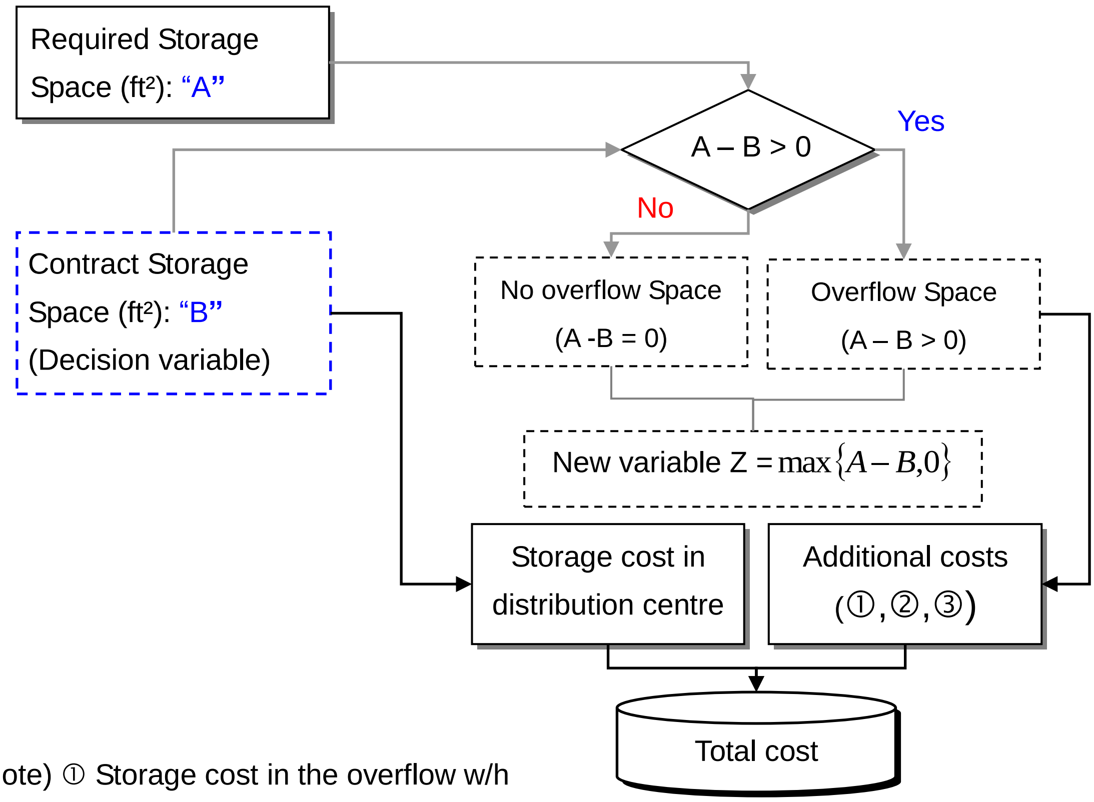
Required storage space (ft^2): Required storage space as demand information is addressed in the first conceptual model.

Contract storage space (ft^2): Contract storage space generated by four scenarios provided is chosen when the total cost is minimized on the basis of required storage space. The scenario consists of two planning methods. One is one-step planning and the other is dynamic planning. The one-step planning is to apply maximum storage space for a year on the basis of required storage space. In the dynamic planning, the first dynamic planning is to apply maximum storage space in each quarter on the basis of the required storage space, the second dynamic planning is to apply minimum storage space in each quarter on the basis of required storage space, the third dynamic planning is to apply average storage space in each quarter on the basis of the required storage space.

Overflow space (ft²) (A - B > 0): A diagram starts with the given scenario on the basis of the required storage space that we have addressed. If required storage space is larger than the suggested storage space of each scenario, additional cost is applied (storage cost in overflow warehouse, unloading or loading handling cost in the distribution centre and the overflow warehouse, and the shuttle costs between the distribution centre and the overflow warehouse). There are no additional costs otherwise. However, the storage costs at the distribution centre are required regardless of the use of the overflow storage space. All related costs are treated as coefficients in the model.

The total cost: The total cost is a dependent variable in this conceptual model. The total cost in each scenario is calculated by contract storage space of each scenario on the basis of required storage space.

3.4 Conceptual model used to determine the contract storage space



Note) ① Storage cost in the overflow w/h
② Handling cost in the DC & overflow w/h
③ Shuttle cost between the DC & overflow w/h

Figure 3.3 The conceptual model for determining contract storage space

Figure 3.3 represents a conceptual mode that helps to calculate optimal contract storage space on the basis of the required storage space (ft^2). The difference compared to Figure 3.2 is that the contract storage space is not treated as given information, but instead as a decision variable. In this case, there are no given scenarios so that contract storage space as a decision variable is determined when total cost is minimized

3.4.1 Terminology

Terminology in this conceptual model was already addressed in the first and second conceptual model

3.4.2 Relations in variables

Required storage space (ft^2): Required storage space as demand information is addressed in the first conceptual model.

Contract storage space (ft^2): Contract storage space is a decision variable when total cost is minimized.

Overflow space (ft^2) ($A - B > 0$): The general procedure is the same as the procedure introduced in the previous conceptual model. If required storage space (A) is larger than contract storage space (B), additional cost is applied (storage cost in overflow w/h, handling cost in distribution centre & overflow w/h and shuttle costs between distribution centre & overflow w/h). And otherwise, it is counted as “zero”. Moreover, storage cost on the basis of contract storage space is considered at minimum cost for the storage of goods at the distribution centre regardless of the use of overflow space. All related costs are also acted as coefficients in this model.

A new variable Z: A new variable Z is an additional variable for the linear programming model. This can be “zero” or the difference between required storage space (A) and contract storage space (B). Namely, the necessary condition is that if A – B is a positive value, a new variable Z is A – B. However, if A – B is 0 (zero) or a negative value, a new variable Z is 0 (zero). And therefore, it can be explained such as $A - B \leq Z$ ($A - B > 0$, $A - B = Z$ and so $A - B \leq 0$, $A - B \leq Z$)

3.5 Trade-off to determine contract storage space (ft²)

There are trade-off relations between the storage space at the distribution centre and the storage space at the overflow warehouse for determining optimal contract storage space. For instance, if storage space at the distribution centre compared to required storage space (ft²) is insufficient, a manager who works in the supply chain or logistics industry will try to find additional overflow storage space located nearby the distribution centre. However, if the storage space at the distribution centre is enough to cover the required amount of storage space needed, then the storage space at an overflow warehouse will not be required. The storage space at DCs and overflow warehouses vary indirect proportion on the basis of three estimated future economic statuses.

Table 3.1 shows the excess storage space in DC and required overflow storage space when the economic status outlook would be more pessimistic which would mean that an actual storage space of 20,000 ft² is required. In this case, overflow storage space is not required. However, there is excess storage space if contract storage space is determined on the basis of an economic equilibrium and an optimistic projection.

- **ERSS**: Required storage space
- **CSS**: Contract storage space at the Distribution centre
- **ESS**: Excess storage space at the Distribution centre
- **ROSS**: Required overflow storage space
- **ARSS**: Actual required storage space

Table 3.1 Contract storage space on the basis of pessimistic projection

(Unit: ft²)

	ERSS	CSS	ARSS	ESS	ROSS
Pessimistic	20,000	20,000	20,000	0	0
Equilibrium	25,000	25,000	20,000	5,000	0
Optimistic	30,000	30,000	20,000	10,000	0

Meanwhile, Table 3.2 shows the excess storage space in DC and required overflow storage space when the economic status outlook would be placed in

Equilibrium which means that an actual storage space of 25,000 ft² is required. In this case, there is excess storage space in DC if contract storage space is determined on the basis of an optimistic projection. On the other hand, overflow storage space is required if contract storage space is determined on the basis of a pessimistic projection.

Table 3.2 Contract storage space on the basis of economic equilibrium (Unit: ft²)

	ERSS	CSS	ARSS	ESS	ROSS
Pessimistic	20,000	20,000	25,000	0	5,000
Equilibrium	25,000	25,000	25,000	0	0
Optimistic	30,000	30,000	25,000	5,000	0

Table 3.3 shows the excess storage space in DC and required overflow storage space when the economic status outlook would be more optimistic which means actual storage space of 30,000 ft² is required. In this case, there is no excess storage space in DC. However, overflow storage space is required if contract storage space is determined on the basis of a pessimistic or an equilibrium projection.

Table 3.3 Contract storage space on the basis of optimistic projection (Unit: ft²)

	ERSS	CSS	ARSS	ESS	ROSS
Pessimistic	20,000	20,000	30,000	0	10,000
Equilibrium	25,000	25,000	30,000	0	5,000
Optimistic	30,000	30,000	30,000	0	0

Therefore, storage spaces at the distribution Centre and at the overflow warehouses have trade-off relations on the basis of the given economic situation. Namely, in Table 3.1 ~ 3.3, excess storage space in the distribution centre or required storage spaces at the overflow warehouses are placed depending on the economic situation. Theoretically, if the cost of using the distribution Centre is much lower than the cost of using the overflow warehouse, an optimal solution to determine contract storage space (ft²) is to make capacity planning when the excess storage spaces at the distribution Centre and additional storage spaces at the overflow warehouse are "zero". For instance, the pessimistic situation in Table 3.1, the equilibrium situation in Table 3.2, the optimistic situation in Table 3.3.

3.6 Summary

This chapter dealt with three conceptual models that are used to help define the research questions with logical relations between each variable. These conceptual models show how to approach to solve the problems which are generated by the research questions. The first conceptual model is to calculate the required storage space (ft^2) as basic information. The second conceptual model is to choose an optimal scenario out of four scenarios provided by minimizing total costs. The last model is used to determine contract storage space without any given scenarios by minimizing total costs as well. Meanwhile, there are trade-off relations between space at the distribution centre and space at the overflow warehouse in order to determine contract storage space. Theoretically, if the cost between using the distribution centre is lower relatively than the cost of using the overflow warehouse, then an optimal solution to determine contract storage space (ft^2) is determined when excess storage spaces at the distribution centre and additional storage spaces at the overflow warehouse are “zero”.

Chapter 4 Mathematical Models

4.1 Introduction

This chapter proposes a functional formula and two mathematical models in order to help solve the problems generated by the research questions. A functional formula is used to calculate the required storage space which is basic demand information and one of the input parameters for both mathematical models. The 1st mathematical model is intended to choose the best scenario out of four given scenarios, and the 2nd mathematical model is to help determine contract storage space. The objective function for both mathematical models is to minimize the total cost.

4.2 Assumptions

4.2.1 Initial contract storage space (ft^2)

As introduced in Chapter 1, many companies have outsourced their logistics functions to third party logistics providers (TPL) over the past 10 years. Thus, this research study is focused on logistics operations at the public distribution centres. This means that in order to use the public distribution centre, a contract with a third party logistics provider must be signed. Therefore, it is assumed that there is enough storage space (ft^2) at the public distribution centre to cover the entire amount of estimated required storage space (ft^2) on the basis of the sales forecast. However, it is not allowed within the initial contract periods for the contract storage space (ft^2) at the distribution centre to be changed.

4.2.2 Length of contract period

The contract period can have an impact on the optimal solution, because contract storage space is not allowed to be changed within the initial contract period. This means that if contract storage space at the public distribution centre could not cover entire amount of required storage space, storage space with additional cost at the overflow warehouse is required. Therefore, the contract period, whether yearly, half-yearly, quarterly or monthly, should first be determined in order to formulate a mathematical model that can obtain the optimal contract storage space. In this chapter, the period of contract is placed by quarterly basis.

4.2.3 Space (ft^2) in overflow warehouse

If additional storage space (ft^2) is required after signing an initial contract with a third party logistics provider, then storage space can be rented from an overflow warehouse that is located nearby the distribution centre. The storage space in the overflow warehouse is assumed as bulk zone with single high stack. Thus, whenever a distribution centre is not able to provide adequate storage space, then the goods can stored at an overflow warehouse.

4.2.4 Inbound and outbound flows of goods

The logistics operation considers that the receiving and the shipping of goods is only possible at the distribution centre, since using an overflow warehouse is understood as a temporary solution in order to secure storage space for overflow goods so it is not necessary to set up a warehouse management system (WMS). This is considered a reasonable solution for reducing total cost in the supply chain.

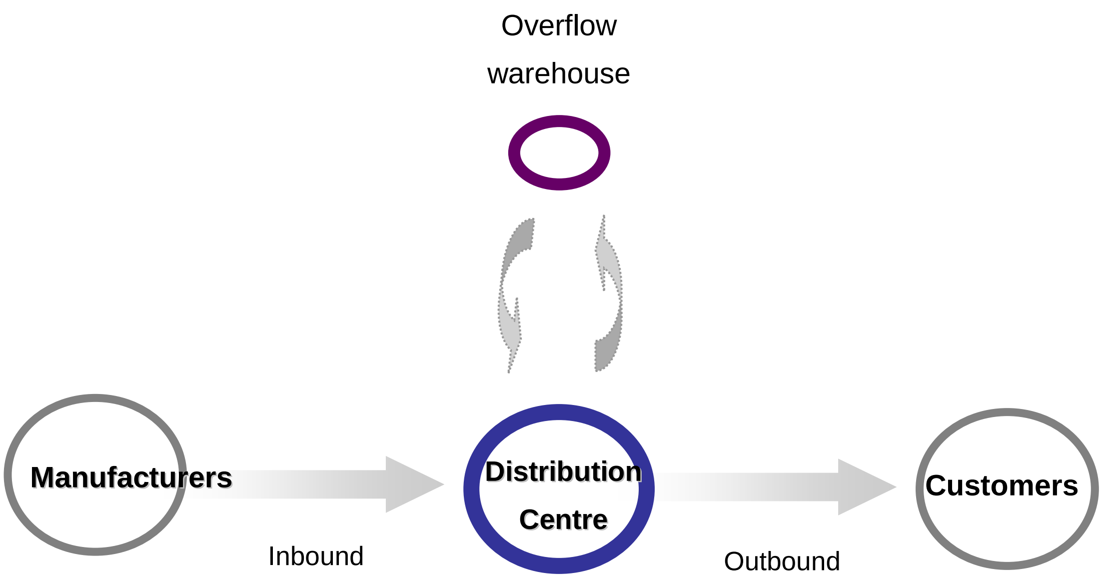


Figure 4.1 Material flows

4.3 Definition of notation

The notation is grouped into three categories as follows:

4.3.1 Decision variable

- Y_m — A binary variable which is 1 if scenario m is selected and Zero otherwise.
- CS_t — Contract storage space (ft²) in week t
- X_t — A binary variable which is 1 if required storage space is greater than contract storage space in week t and zero otherwise. (In general model)

4.3.2 Indices

- i — The number of product groups
- t — Weeks in the contract period
- m — The number of scenarios
- k — SKU (stock keep unit) in product group i
- d — Date index (Monday ~ Friday; d = 1, 2, 3, 4, 5)
- q — Quarter in a year (q = 1, 2, 3, 4)
- M — A very large positive number in the period of contact

4.3.3 Input Parameters

- R_i — Weighted average quantity per pallet of product group i
- D_i — Actual demand of product group i
- D_{ki} — Actual demand of SKU k within product group i
- r_k — Quantity per pallet of SKU k
- v_{it} — Average daily pallets of product group i to be sold in week t
- v_{iT} — Average daily pallets of product group i to be sold in week T (week t + 1)
- F_{it} — Weekly sales forecast (quantity units) of product group i in week t
- W — Total working days per week (Normally, 5 working days)
- P_A — An annual average peak index
- P_t — Peak index in week t

- AD_t Average demand (pallet units) in week t
- AD_{dt} Actual demand (pallet units) on day in week t (d = 1,2,3,4,5)
- w_i Weekly ordering cycle of product group i
- RP_{it} Required storage pallets of product group i to be stored on the basis of sales forecast in week t
- RS_{it} Required storage space(ft²) of product group i to be stored on the basis of sales forecast in week t
- k_r A constant of "square metre per pallet" in rack area of DC
- k_b A constant of "square metre per pallet" in bulk area of DC
- r The ratio of rack area within the storage zone in a distribution centre, e.g. rack area vs. bulk area: 80% vs. 20%
- RS_t Required storage space (ft²) on the basis of sales forecast in week t
- RP_t Required storage pallets on the basis of sales forecast in week t
- CS_{mt} Contract storage space (ft²) of scenario m to be stored in dstribution centre in week t
- CP_{mt} Contract storage pallets of scenario m to be stored in distribution centre in week t
- SC_{dt} Storage cost per square metre in the distribution centre in week t
- SC_{ot} Storage cost per square metre in the overflow warehouse in week t
- C_{st} Shuttle cost per pallet between the distribution centre and the overflow warehouse in week t
- C_{ht} Handling (loading, unloading) cost per pallet in a distribution centre and an overflow warehouse in week t
- CP_t Contract storage pallet in week t
- X_t A variable which is 1 if required storage space is greater than contract storage space in week t and zero otherwise. (In the 1st mathematical model)

4.4 Functional formulas for required storage space (ft²)

The required amount of storage space is basic information that is necessary for capacity planning of storage space at a distribution centre. The required storage space is demand information for this and it can be calculated in stages.

4.4.1 Weighted average quantity per pallet of product group i

The first thing to do in planning capacity for a distribution centre is to determine the number of pallets that can be stored in a distribution centre and to convert the sales forecast of quantity unit into a sales forecast of pallet unit. Thus, the first formula is to calculate the average quantity per pallet of product group i on the basis of actual sales results. However, the quantity per pallet of product group i is different on the basis of stock keep unit (SKU) in product group i so that SKU material master table and historical sales results are needed to calculate for this. Thus, the weighted average quantity per pallet of product group i can be formulated as follows:

$$R_i = \sum_{k=1}^{n} \frac{D_{ki}}{D_i} \times r_k \qquad (4.1)$$

4.4.2 Average daily pallets of product group i to be sold in week t

Average daily pallets of product group i to be sold in week t can be simply calculated: weekly sales forecast (quantity units) of product group i divided by weighted average quantity per pallet of product group i divided by working days.
The equation is as follows:

$$v_{it} = \sum_{i=1}^{n} (F_{it} \div R_i) \div W \qquad (4.2)$$

4.4.3 Required storage pallet of product group i in week t

The next step is to calculate the required number of storage pallets. This step makes it possible for the sales units to be converted into storage units. This calculation is related to how many pallets are required to be stored at the distribution centre. Thus, the first factor to be considered is to define the ordering cycle. The ordering cycle is the number of days required to satisfy incoming demand on the basis of current stocks at the distribution centre without issuing a new purchasing order (lot size). For instance, suppose that if demand of product A is stable at 100 pieces per day, lot size of order is 1,400 pieces, and then it takes 14 days until the product A is completely sold out, which means that 14 days stock should be stored at the distribution centre to help satisfy the expected incoming demand. Here the ordering cycle is 14 days when demand is 100 pieces per day and the lot size is

1,400 pieces. Table 4.1 shows how the number of required storage pallets are calculated on the basis of the ordering cycle and placed repeatedly.

Table 4.1 Required storage pallets based on ordering cycle and sales forecast

	Product Group	Week 1	Week 2	Week 3	Week 4
Sales Forecast (Pallets)	A	100	**(1) 100**	**(2) 100**	**(3) 100**
	B	50	**(4) 50**	**(5) 50**	**(6) 50**
	C	75	**(7) 75**	**(8) 75**	**(9) 75**
	Total	225	225	225	225
Ordering Cycle	A	14 days	14 days	14 days	14 days
	B	21 days	21 days	21 days	21 days
	C	14 days	14 days	14 days	14 days
Required storage Pallets	A	***200 (1+2)***	…	…	…
	B	***150 (4+5+6)***	…	…	…
	C	***150 (7+8)***	…	…	…
	Total	***500***	…	…	…

The second factor to be considered is the annual average peak index. Figure 4.2 shows a basic concept to calculate peak index of the week. Peak index of the week in Figure 4.2 is 1.5 on Friday.

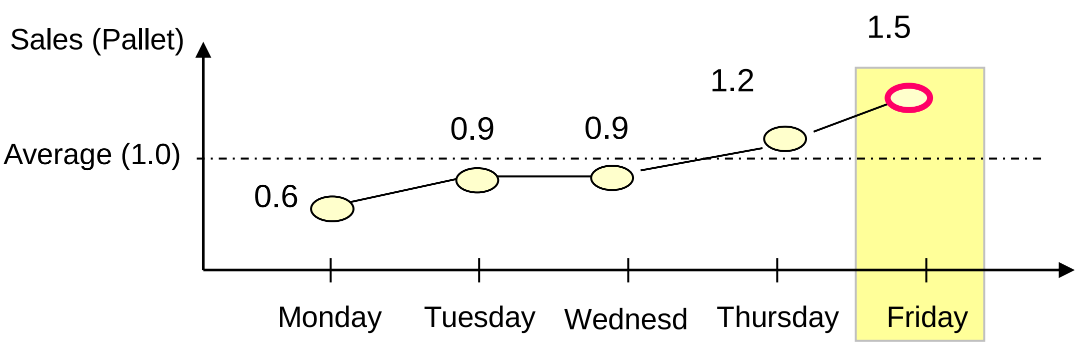


Figure 4.2 Basic concepts about daily peak index

Thus, the required number of storage pallets which are calculated by weekly sales forecast and the ordering cycle must also take into account the annual average peak index since the required number of storage pallets based on the sales forecast is not calculated on the maximum demand of the week but on the average demand of the week. In other words, if we would base the calculation on the average demand, then there would be a lack of available storage space on Thursday and Friday. Thus, the equation used to calculate an annual average peak index is as follows:

$$P_A = Max\left\{\sum_{t=1}^{52}((\frac{1}{AD_t}\times AD_{1t}),(\frac{1}{AD_t}\times AD_{2t}),(\frac{1}{AD_t}\times AD_{3t}),(\frac{1}{AD_t}\times AD_{4t}),(\frac{1}{AD_t}\times AD_{5t}))\right\}$$

(4.3)

P_A, an annual average peak index is calculated in stages: total yearly demand on the day divided by total yearly demand. After that, the maximum peak index out of 5 indexes is chosen. The application of the annual average peak index is better than the application of weekly based peak index in order to reduce uncertainty in the supply chain. And then, we can finally formulate required storage pallets of product group i to be stored in week t at the distribution centre. The formula is:

$$RP_{it} = \sum_{T=t+1}^{t+w_i} v_{iT} \times W \times P_A \qquad (t = 1\ldots 52) \qquad (4.4)$$

The above formula is derived from Table 4.1 and Figure 4.2 in the previous pages. Again, this is to make it possible for the sale unit to be converted into the storage unit. This convertible formula is related to how many pallets are required to be stored at the Distribution Centre to satisfy incoming demand without issuing a new purchasing order (lot size).

4.4.4 Required storage space of product group i in week t

And finally, the last step is to calculate RS_{it} required storage space (ft²) of product group i to be stored in week t at the distribution centre. The formula is as follows:

$$RS_{it} = \sum_{i=1}^{n} [(RP_{it}\times k_r \times r) + (RP_{it}\times k_b \times (1-r))] \qquad (t = 1\ldots 52) \qquad (4.5)$$

In order to solve the formulated equation (4.5), we define that k_r is a constant of "square meter per pallet" with 4.5 high stacks in rack area, k_b is a constant of "square meter per pallet" with single stack in bulk area, and r is a constant that the ratios of rack area within the storage zone in a distribution centre. Thus, constants are given in this research as Table 4.2.

Table 4.2 Constants to convert pallet unit into square meter unit

Area	*Kr*	*Kb*	***r***
Constants	0.797	2.512	0.8

Source: Company in contract logistics industry (Confidential)

Table 4.3 Square feet (ft²) per pallet

Area	**Max capacity** (Pallets)	**Allocated space** (ft²)	ft² / **pallet**	**Assumption** (Stack height)
Rack zone	18,825	15,000	0.797	4.5 stack
Bulk zone	3,304	8,300	2.512	Single stack

Source: Company in contract logistics industry (Confidential)

And therefore, the equation (4.5) becomes again for the simplifying of data entry:

$$RS_{it} = \sum_{i=1}^{n} ((RP_{it} \times 0.797 \times 0.8) + (RP_{it} \times 2.512 \times 0.2)) \qquad (t = 1 \ldots 52) \qquad (4.6)$$

$$= \sum_{i=1}^{n} ((0.638 \times RP_{it}) + (0.502 \times RP_{it})) \qquad (t = 1 \ldots 52)$$

$$= \sum_{i=1}^{n} (1.14 \times RP_{it}) \qquad (t = 1 \ldots 52)$$

4.5 Model for choosing the best scenario

This model is to choose the best scenario out of the four given scenarios by minimizing the total cost. The required storage space introduced in the equation (4.6) is needed as one of the input parameters in this model.

4.5.1 Creating four scenarios

In order to formulate a mathematical model for choosing the best scenario out of the four scenarios provided, the first step is to create four scenarios that can be considered as optimal solutions by minimizing the total cost. The stage growth in capacity is as follows (APICS Building Competitive Operations Planning and Logistics, 2007).

- (a) By expanding all at once ahead of required space (ft^2).
- (b) By expanding in steps ahead of required space (ft^2).
- (c) By expanding in steps behind required space (ft^2).
- (d) By expanding in steps that are sometimes ahead of and sometimes behind required space (ft^2).

In this research, therefore, four scenarios as optimal solutions are suggested such as "One-step planning" and "Dynamic planning." The definition and formulas of these scenarios are as follows:

Scenario 1: **max-one step planning** is to apply maximum required storage space (ft^2) for a year on the basis of the calculated required storage space (ft^2) such as (a) in Figure 4.3. Thus, contract storage space in week t is:

$$CS_t = \text{Max} \ \{S_1 .... S_{52}\} \qquad (t = 1 \ldots 52) \qquad (4.7)$$

Scenario 2: **max- dynamic planning** is to apply the maximum required storage space (ft^2) in each quarter on the basis of the calculated required storage space (ft^2) such as (b) in Figure 4.3. Thus, contract storage space in week t is:

$$\begin{aligned} CS_t &= \text{Max} \ \{S_1 ... S_{13}\} && (t = 1...13) \qquad (4.8) \\ CS_t &= \text{Max} \ \{S_{14} ... S_{26}\} && (t = 14..\ 26) \\ CS_t &= \text{Max} \ \{S_{27} ... S_{39}\} && (t = 27...39) \\ CS_t &= \text{Max} \ \{S_{40} ... S_{52}\} && (t = 40...52) \end{aligned}$$

Scenario 3: **min- dynamic planning** is to apply the maximum required storage space (ft^2) in each quarter on the basis of the calculated required storage space (ft^2) such as (b) in Figure 4.3. Thus, contract storage space in week t is:

$$\begin{aligned} CS_t &= \text{Min} \ \{S_1 ... S_{13}\} && (t = 1...13) \qquad (4.9) \\ CS_t &= \text{Min} \ \{S_{14} ... S_{26}\} && (t = 14...\ 26) \\ CS_t &= \text{Min} \ \{S_{27} ... S_{39}\} && (t = 27...39) \\ CS_t &= \text{Min} \ \{S_{40} ... S_{52}\} && (t = 40...52) \end{aligned}$$

Scenario 4: **average-dynamic planning** is to apply the average required storage space (ft^2) in each quarter on the basis of the calculated required storage space (ft^2)

such as (d) in Figure 4.3. Thus, contract storage space in week t is:

$$CS_t = \frac{1}{13} \{S_1 \ldots S_{13}\} \qquad (t = 1 \ldots 13) \qquad (4.10)$$

$$CS_t = \frac{1}{13} \{S_{14} \ldots S_{26}\} \qquad (t = 14 \ldots 26)$$

$$CS_t = \frac{1}{13} \{S_{27} \ldots S_{39}\} \qquad (t = 27 \ldots 39)$$

$$CS_t = \frac{1}{13} \{S_{40} \ldots S_{52}\} \qquad (t = 40 \ldots 52)$$

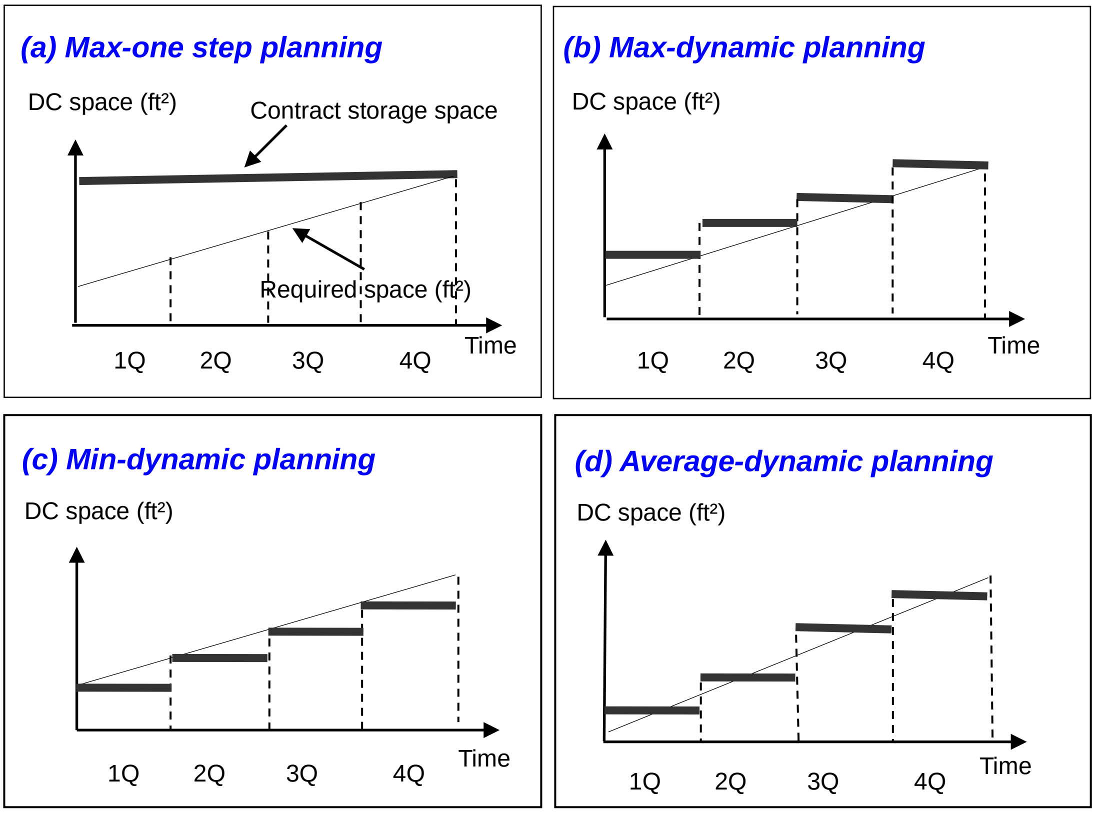


Figure 4.3 Four ways to stage capacity growth

Source: APICS Building competitive operations planning and logistics, 2007

4.5.2 Objective function

The objective function is to minimize the total cost by the chosen optimal scenario out of the four given scenarios. The mathematical model is as equation (4.11).

$$Min\ TC = \sum_{m=1}^{n} Y_m \times \sum_{t=1}^{52}((CS_{mt} \times SC_{dt}) + X_t(((RS_t - CS_{mt}) \times SC_{ot}) + ((RP_t - CP_{mt}) \times C_{st}) + ((RP_t - CP_{mt}) \times C_{ht})))) \quad (4.11)$$

Subject to

$$\sum_{m=1}^{n} Y_m = 1 \quad (4.12)$$

$$Y_m \in \{0,1\} \qquad m = 1 \ldots n \quad (4.13)$$

4.5.3 Interpretation of the model

The objective function in equation (4.11) is to minimize the total cost. The formulated model can be applied on the basis of weekly demand forecast such as weekly required storage space and pallets. The model consists of two parts: one is a decision variable and the other is related to the total costs such as storage costs at a distribution centre, storage costs at an overflow warehouse, shuttle costs between a distribution centre and an overflow warehouse and loading and unloading handling costs at the distribution centre and overflow warehouse.

Again, as a decision variable, Y_m is a binary variable that is 1, if scenario m is selected and zero otherwise, which means a chosen scenario gives the lowest costs out of the four given scenarios.

$\sum_{t=1}^{52} CS_{mt} \times SC_{dt}$; Total storage cost of scenario m at the distribution centre in week t

$\sum_{t=1}^{52} X_t((RS_t - CS_{mt}) \times SC_{ot})$: Total storage cost of scenario m in the overflow w/h in week t. $X_t = 1$, if $RS_t > CS_{mt}$ and zero otherwise.

$\sum_{t=1}^{52} X_t((RP_t - CP_{mt}) \times C_{st})$: Total shuttle cost of scenario m between the distribution centre and the overflow warehouse in week t. $X_t = 1$, if $RP_t > CP_{mt}$ and zero otherwise.

$\sum_{t=1}^{52} X_t((RP_t - CP_{mt}) \times C_{ht})$: Total loading and unloading handling cost of scenario m at the distribution centre and the overflow warehouse in week t. X_t = *1,* if $RP_t > CP_{mt}$ and zero otherwise.

4.6 General model for determining the optimal contract storage space

The model introduced hereunder is used to determine the optimal contract storage space while minimizing the total cost without any given scenarios. The required storage space introduced in equation (4.6) is also required in this model as one of input parameters that is demand information. Moreover, this model can be applied on the basis of weekly demand information.

4.6.1 Objective function

The objective function is to minimize the total cost by the optimal contract storage space which is not given by scenarios but a decision variable. Thus, two decision variables are required: CS_t contract storage space and X_t a binary variable. And Y_m a binary decision variable introduced in the 1st mathematical model is not necessary for this model. Thus, the model is formulated as follows:

$$Min\ TC = \sum_{t=1}^{52}(CS_t \times SC_{dt}) + X_t \times (((RS_t - CS_t) \times SC_{ot})$$
$$+ ((RS_t - CS_t) \times C_{st}) + ((RS_t - CS_t) \times C_{ht}))) \quad (4.14)$$

Subject to

$$(RS_t - CS_t) \le (X_t \times M) \quad (t = 1 \ldots 52) \quad (4.15)$$

$$(CS_t - RS_t) \le ((1 - X_t) \times M) \quad (t = 1 \ldots 52) \quad (4.16)$$

$$X_t \in \{0,1\} \quad (t = 1 \ldots 52) \quad (4.17)$$

4.6.2 Interpretation of the model

The objective function with equation (4.14) is to minimize the total cost on the basis of optimal contract space (ft²) at the distribution centre within the period of contract. Two decision variables are introduced in this model: one is CS_t contract storage space (ft²) in week t and the other is X_t a 0, 1 binary variable to determine whether storage space at the overflow warehouse is required or not.

The model consists of two parts: the first part of equation (4.14) is the total storage costs at the distribution centre. The second one is the total storage costs at the overflow warehouse, the total shuttle costs between the distribution centre and the overflow warehouse, and total for loading and unloading handling costs at the distribution centre and the overflow warehouse. Moreover, in the second part, if the required storage space is greater than the contract storage space, then X_t=1 and zero otherwise. In order to understand this better, suppose that M is a very large number of constraints.

The first case is that the left side of constraint (4.15) is a positive number if required storage space (ft²) is larger than contract space (ft²) in week t. In this case, storage space at the overflow warehouse is needed so that X_t should be 1 (one). While, the left side of constraint (4.16) is a negative number, if required storage space (ft²) is larger than contract space (ft²) in week t. With this case, storage space at the overflow warehouse is also required so that X_t could be 0 (zero) or 1 (one). Therefore, X_t that can satisfy both constraint (4.15) and (4.16) must be 1 (one).

In constraint (4.15), if $RS_t > CS_t$ $X_t = 1$ and in constraint (4.16), if $CS_t < RS_t$ $X_t = 0$ or 1. Thus, $X_t = 1$ to satisfy both constraints (4.15) and (4.16)

The second case is that the left side of constraint (4.15) is a negative number if contract storage space (ft²) is larger than the required storage space (ft²) in week t. In this case, storage space at the overflow warehouse is not required so that X_t could be 0 (zero) or 1 (one). While, the left side of constraint (4.16) is a positive number, if contract storage space (ft²) is larger than the required storage space (ft²) in week t. With this case, storage space at the overflow warehouse is not required so that X_t should be 0 (zero). Therefore, X_t that can satisfy both constraint (4.15) and (4.16) must be 0 (zero).

In constraint (4.15), if $RS_t < CS_t$, $X_t = 0$ or 1 and in constraint (4.16), if $CS_t > RS_t$ $X_t = 0$. Thus, $X_t = 0$ to satisfy both constraints (4.15) and (4.16)

And therefore, X_t can be considered as a 0.1 binary variable.

4.7 Summary

This chapter discussed functional formulas that are used in order to calculate required storage space as demand information, a mathematical model to choose the best scenario out of the suggested four scenarios, and a mathematical model to determine optimal contract storage space. Four assumptions are made concerning the initial contract storage space, length of contract period, space at the overflow warehouse and in-outbound flow of goods at the distribution centre. Equations to calculate the required storage space are formulated in stages on the basis of the conceptual model introduced in Chapter 3 and this is required for one of the input parameters for two mathematical models. In the 1st mathematical model that is used to choose the best scenario, four scenarios are created, which could be considered optimal solutions. And objective function is to minimize the total cost by the selected scenario. The 2nd mathematical model as general model is formulated in order to determine the optimal contract storage space. The objective function here is also formulated to minimize the total cost with optimal contract storage space.

Chapter 5 Solution Methodology

5.1 Introduction

This chapter introduces solution methodology to solve the mathematical models developed in Chapter 4 for real cases that can be found within the contract logistics and supply chain industry.

5.2 Choosing the best scenario

The objective function introduced in Chapter 4 (equation 4.11) is a linear programming model which is used to choose the best scenario out of the four given scenarios. And decision variable Y_m is a 0, 1 binary variable, which means that sum of suggested scenario *m* should be 1 (one). Namely, only one of the scenario m must be chosen. Meanwhile, Excel Solver is introduced in order to solve the problem because this is the easiest, most effective and widely used among practitioners working in the contract logistics and supply chain industry. Thus, the initial steps required to compute the numerical examples with Excel Solver are as follows:

- **Put the input parameters in Excel Spread Sheet**
  - Required storage space
  - Contract storage space on the basis of four given scenarios
  - Cost tariffs: Storage costs at distribution centre and overflow w/h.
    Shuttle costs between the distribution centre and overflow w/h
    Handling costs at the distribution centre and overflow w/h.
- **Put the formula in Excel Spread Sheet based on objective function**
- **Click the Solver under “TOOL menu” in Excel.**
- **Set target cell, changing cell and constraints in solver parameter box.**
- **Set “assume linear model and non negative” in option.**
- **Click the solver button.**

The computing time will be quick by virtue of the linear programming model. Figure 5.1 shows how Excel Solver can be set up to solve the problems with the formulated model.

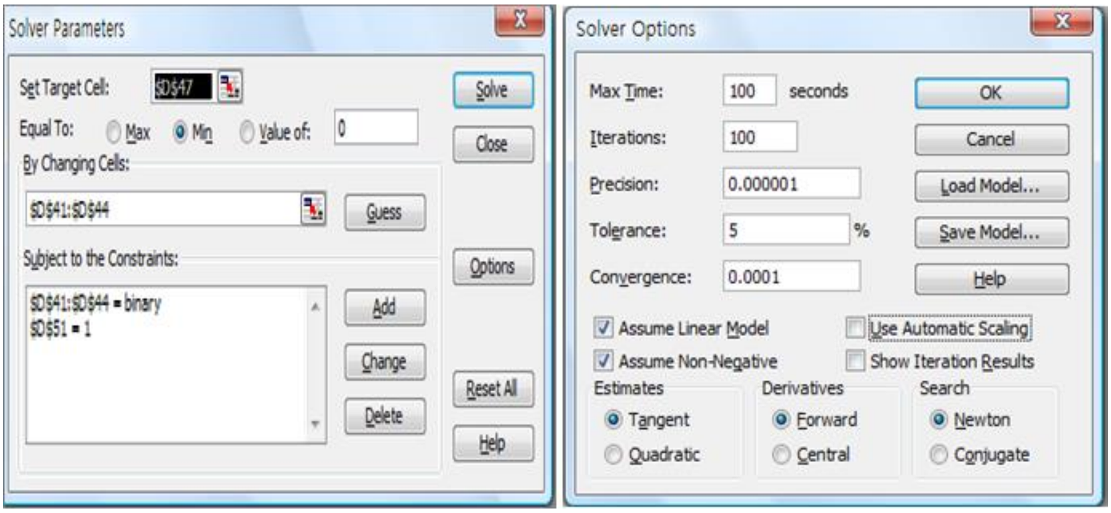


Figure 5.1 Solving the model by Excel Solver

5.3 Determining the optimal contract storage space

5.3.1 Model simplification

The objective function introduced in equation (4.14) is quite complicated due to the non linear programming. Therefore, first the equation can be formulated again simplifying data entry with the new constant. The objective functions become again:

$$\textit{Min TC} = \sum_{t=1}^{13}(S_1 \times 1.14SC_{dt}) + Max(RP_t - S_1, 0) \times (1.14C_{ot} + C_{st} + C_{ht}) \quad (5.1)$$

$$+ \sum_{t=14}^{26}(S_2 \times 1.14SC_{dt}) + Max(RP_t - S_2, 0) \times (1.14C_{ot} + C_{st} + C_{ht})$$

$$+ \sum_{t=27}^{39}(S_3 \times 1.14SC_{dt}) + Max(RP_t - S_3, 0) \times (1.14C_{ot} + C_{st} + C_{ht})$$

$$+ \sum_{t=40}^{52}(S_4 \times 1.14SC_{dt}) + Max(RP_t - S_4, 0) \times (1.14C_{ot} + C_{st} + C_{ht})$$

Subject to

$$S_1 \geq 0 \quad (5.2)$$

$$S_2 \geq 0 \quad (5.3)$$

$$S_3 \geq 0 \quad (5.4)$$

$$S_4 \geq 0 \quad (5.5)$$

The period of contract for this model is assumed by quarterly basis. Therefore, decision variables are defined on the basis of the contract periods as follows:

- S_1 Contract storage pallets in quarter 1 (week 1 … 13)
- S_2 Contract storage pallets in quarter 2 (week 14 … 26)
- S_3 Contract storage pallets in quarter 3 (week 27 … 39)
- S_4 Contract storage pallets in quarter 4 (week 40 … 52)

5.3.2. Interpretation of the model

In the contract logistics and supply chain industry, storage costs are determined on the basis of square feet (ft^2). While shuttle and handling costs are determined on the basis of pallets. Thus, a cost unit is required for this model to be identified as a pallet base in order to simplify data entry; it is reasonable to calculate handling costs and shuttle costs on the basis of pallets instead of square feet (ft^2) in the contract logistics industry. Therefore, some additional data is included for this model. First, the unit of storage cost at the distribution centre and overflow warehouse can be converted from “cost per ft^2” to “cost per pallet.” A convertible constant is “1.14” (one point one four). It is calculated from Table 4.2: (0.797 $\times$ 80%) + (2.512 $\times$ 20%) = 1.14.

The objective function is separated on the basis of each quarter and consists of two parts: the first part is the total storage cost at the distribution centre on the basis of each quarter and the second part is the cost for using the overflow warehouse. However, the second part is determined when required storage space is greater than contract storage space, zero otherwise.

The notable thing with this model is that the weekly based forecast can be applied. This means that it would be better to apply demand forecast as frequently as possible in order to improve the accuracy of capacity planning even though it is not actually possible in today’s contract logistics industry to obtain weekly contract storage space at public distribution centres.

5.3.3 Linear programming model

The modified objective function in equation 5.1 is still not a linear programming model due to the formulas as follows:

$Max(RP_t - S_1, 0)$, $Max(RP_t - S_2, 0)$, $Max(RP_t - S_3, 0)$ and $Max(RP_t - S_4, 0)$

Thus, if we would use this objective function, Excel Solver might require a long solution time to solve the problem. Therefore, a new variable Z_t is required in order to create a linear programming model. So the new objective function is as follows:

$$\begin{aligned} Min\ TC = & \sum_{t=1}^{13}(S_1 \times 1.14SC_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht}) \\ & + \sum_{t=14}^{26}(S_2 \times 1.14SC_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht}) \\ & + \sum_{t=27}^{39}(S_3 \times 1.14SC_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht}) \\ & + \sum_{t=40}^{52}(S_4 \times 1.14SC_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht}) \end{aligned} \tag{5.6}$$

Subject to

$RP_t - S_1 \le Z_t$ *(t = 1… 13)* (5.7)

$RP_t - S_2 \le Z_t$ *(t = 14… 26)* (5.8)

$RP_t - S_3 \le Z_t$ *(t = 27… 39)* (5.9)

$RP_t - S_4 \le Z_t$ *(t = 40… 52)* (5.10)

$Z_t \ge 0$ *(Z_t is not an integral number)* (5.11)

where to Z_t *The difference between required storage pallets in week t and contract storage pallets in each quarter*

Note that if $RP_t - S_j \le 0$, $Z_t = 0$ *and* $RP_t - S_j > 0$, $Z_t = RP_t - S_j$ *(j=1, 2, 3, 4)*

5.3.4 How to solve in Excel Solver

The objective function introduced with equation (5.6) becomes a linear programming model so that Excel Solver program will quickly determine the optimal contract storage space. In order to solve the problem, the Excel Solver is used again. The initial steps to compute numerical example by Excel Solver are the same as the steps introduced for choosing the best scenario. However, contract storage space is not an input parameter, but a decision variable in this model. Thus, set target cell, changing cell and constraints in solver parameter box should be reconsidered on the basis of this model.

5.4 Summary

This chapter dealt with the solution methodology for choosing the best scenario and for determining optimal contract storage space. In order to do that, first of all, we have modified the model for simplifying the data entry with an additional convertible constant. And second, in order to reduce the solution time by Excel Solver, the model was changed again to a linear programming model with new variable.

Chapter 6 Numerical Examples

6.1. Introduction

This chapter presents numerical examples in order to help solve the problems that have been generated by the research questions. Real data from the contract logistics industry are applied to the functional formulas and the two mathematical models that were developed in Chapter 4 and 5. Thus, this chapter can be useful in determining whether the models developed can be applied to the real contract logistics and supply chain industry or not, as well as establishing if in the continue development of future models, whether there are any other factors from the real contract logistics that should be taken into account. This chapter is structured according to the following data collection: Numerical example 1: calculating required storage space; Numerical example 2: choosing the best scenario; Numerical example 3: finding out the optimal contract storage space; and Numerical example 4: a sensitive analysis.

6.2. Data collection

6.2.1. What to collect

The required data for numerical examples can be segmented into 2 phases. The first sector is to calculate the required storage space (ft^2). The second is to choose an optimal scenario and to determine the optimal contract storage space while minimizing the total cost. The first phase is to calculate the required storage space (ft^2). Four data sets are required. The primary data required as basic information for the capacity planning is sales forecast information. Three additional data sets are applied with the sales forecast information, these include the SKU material master table which can convert quantity unit into pallet unit, the daily sales results for one year to calculate the peak index, and establishing the floor area occupation (ft^2 / pallet) which can convert pallet unit into square meter (ft^2) unit. The SKU material master table is the data set which is actually measured for the specification of goods that arrive and depart from the distribution centre. While the case of the ordering cycle and rack ratio at the storage area of the distribution centre is not required here, it is assumed because it may be different from the company's own sales strategy. The second phase is to choose an optimal scenario and to determine optimal contract storage space while minimizing the total cost. Thus, the required data sets are related to cost tariffs: storage costs at the distribution centre and overflow warehouse, shuttle costs between the distribution centre and overflow warehouse, loading/ unloading handling costs at the distribution centre and overflow warehouse. With this information, the total cost can be calculated in order to choose an optimal scenario and in order to determine the optimal required contract storage space.

Table 6.1 Required data for numerical examples

	Required Data	Period	Note
1st Phase	Sales forecast (Quantity unit)	2007	-
	SKU material master table	2007	-
	Sales results (ITEM level)	2007	-
	Ordering cycle	N/A	Assumption
	Floor area occupation (ft^2 per pallet)	2007	-
	Rack ratio (%) in storage zone	N/A	Assumption
2nd Phase	Storage tariff at Distribution Centre (€/ft^2)	2005	-
	Storage tariff at overflow warehouse (€/ft^2)	2006	-
	Shuttle tariff between DC and Overflow warehouse (€/pallet)	2006	-
	Handling tariff at DC and Overflow warehouse (€/pallet)	2006	-

6.2.2. How to collect

The required data used in Table 6.1 for the numerical examples was obtained in an interview with the management of an actual company[2] from the contract logistics and supply chain industry.

6.2.3. Common input parameters

In order to solve the models for choosing an optimal scenario and for determining the optimal contract storage space while minimizing the total cost, some parameters are required as follows:

[2] The name of the company is withheld for reasons of confidentiality

- The required cost tariffs for using the DC and the overflow w/h: Table 6.2
- The required storage space (ft^2): Table 6.8

Table 6.2 Storage, shuttle and handling tariffs

Item	Tariff	Unit	Remarks
a) Storage cost at the distribution centre	€ 1.66	(m2)	€ 1.89 per pallet
b) Storage cost at the overflow warehouse	€ 1.65	(m2)	€ 1.89 per pallet
c) Shuttle cost between DC and overflow w/h	€ 6.25	(Pallet)	
d) Handling cost (Loading/Unloading)	€ 24.00	(Pallet)	

Source**:** Company in the contract logistics industry (Confidential)

6.3. Numerical example 1: Calculating required storage space (ft^2)

6.3.1. Sales forecast (Quantity)

Sales forecast information based on sales unit is basic demand information required for the capacity planning of storage space at distribution centres. Five product groups were applied for this numerical example: air conditioner, optical disk drive, printer/fax hardware, printer consumable and display monitor. See Figure 6.1 for a weekly trend of sales forecasts. Peak weeks in sales forecasts are found in week 39, 48 and its peak index is 1.85 and 1.93 when the average sales forecast in the whole year is placed by “1”.

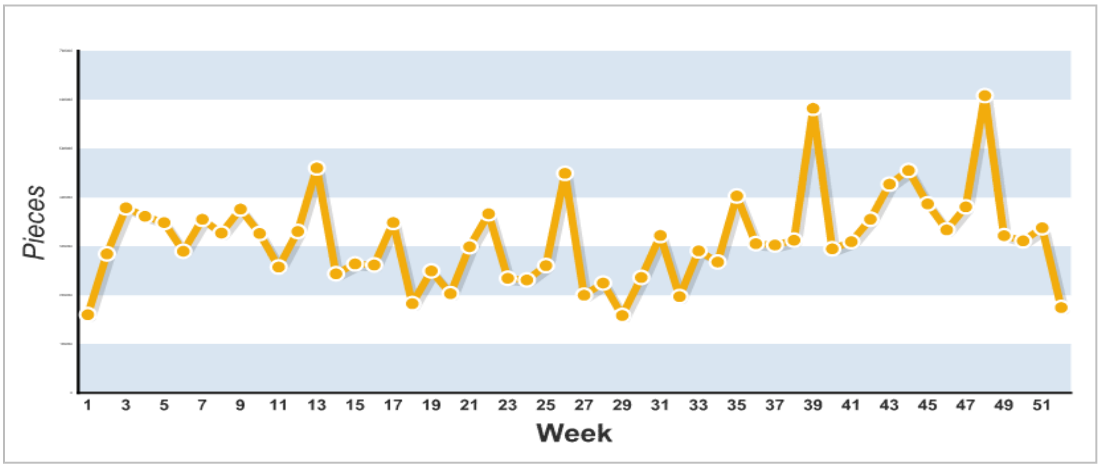


Figure 6.1 A weekly trend of the sales forecasts (Sales unit basis)

Source: Company in the contract logistics industry (Confidential)

6.3.2. Average quantities per pallet of product group *i*

The first thing to do when capacity planning in order to establish the number of pallets to be stored in a distribution centre, is to convert the sales forecast based on quantity unit into the sales forecast based on pallet unit. Thus, from the corresponding equation (4.1) in Chapter 4, the weighted average quantity per pallet of product group i is calculated and summarised in Table 6.3.

Table 6.3 Weighted average quantities per pallet

Product Group	Applied SKUs	Weighted average quantities per pallet
1) Air conditioner	238	**5**
2) Optical Disk Drive	192	**482**
3) Printer/Fax Hardware	214	**30**
4) Printer Consumable	121	**1,273**
5) Display Monitor	229	**68**

Source: Company in the contract logistics industry (Confidential)

6.3.3. Sales forecast (Pallet)

Average pallets of product group i to be sold a day in week t can be simply calculated from the weekly sales forecast (quantity units) of the product group i divided by the weighted average quantity per pallet of product group i in Table 6.3 divided by working days. Figure 6.2 shows its week average trend.

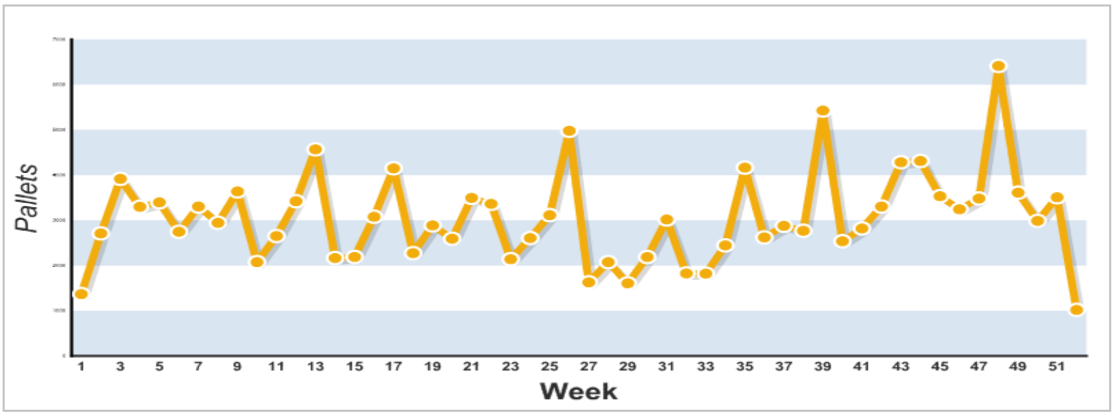


Figure 6.2 A weekly trends of the sales forecast (Pallet unit basis)

Thus, a weekly trend of sales forecast based on the pallet unit is similar to the weekly trend of sales forecast based on the quantity unit. However, its peak index for the whole year has slightly changed to 1.78 in week 39 and 2.10 in week 48. (These were 1.85 and 1.93, respectively, in quantity based sales forecast).

6.3.4. Required storage pallets: converting sales unit into storage unit

Capacity planning begins with obtaining the sales forecast. However, this information presents a sales plan and not a storage plan. Thus, in order to convert sales unit into storage unit, the ordering cycle of product groups should first be defined. As mentioned in Table 6.1, the ordering cycle of each product is assumed as follows:

Table 6.4 Ordering cycle of each product group.

Product Group	Ordering cycle (weeks)	Ordering cycle (days)
1) Air conditioner	12 week	**84 days**
2) Optical Disk Drive	4 week	**28 days**
3) Printer/Fax Hardware	3 week	**21 days**
4) Printer Consumable	3 week	**21 days**
5) Display Monitor	2 week	**14 days**

In order to better understand this factor, Figure 6.3 shows the required storage inventory level on the basis of the ordering cycle.

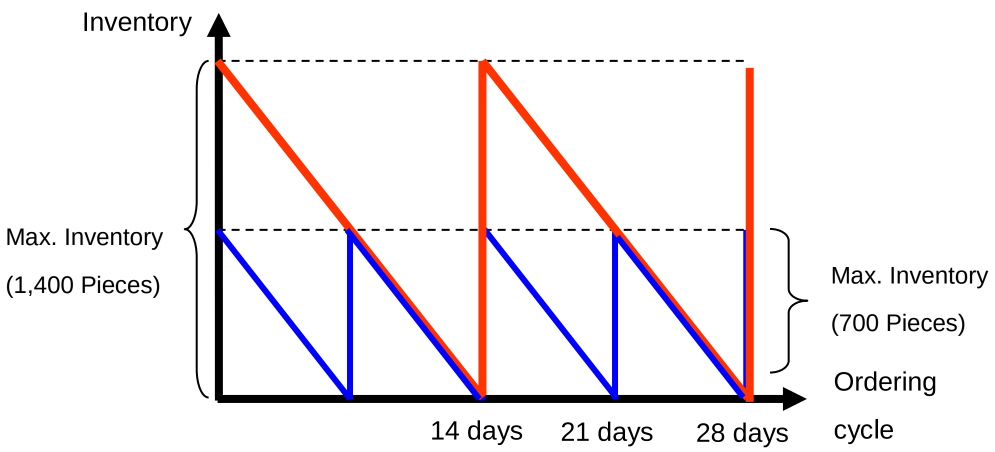


Figure 6.3 Required inventory level based on the ordering cycle

Suppose that the demand for the display monitor is 100 pieces per day. If the ordering cycle is 14 days, then 1,400 pieces of display monitor should be stored for sales. However, if the ordering cycle is changed to 7 days, then this is decreased by up to 50% and just 700 pieces of display monitor are required to be stored for incoming sales. Thus, there are positive relations between the ordering cycle and the required level of storage. In this way the shorter ordering cycle would led to the reduction of the amount of inventory required to be stored at the distribution centre.

The next step is to calculate an annual average peak index. As discussed in Chapter 4, an annual average application of the peak index is one way that can reduce uncertainty in the supply chain instead of the weekly application of the peak index. On the basis of the equation (4.3) in Chapter 4, an annual peak index in a year is calculated by "1.31." Inter alias, the peak day of the week in the whole year is Friday as shown in Table 6.5.

Table 6.5 An annual average peak index in a day of the week.

	Mon	Tue	Wed	Thu	Fri	Peak Index
Average in a year	0.61	0.96	1.04	1.07	**1.31**	**1.31**

Finally, we can now calculate the required storage pallets on the basis of the sales forecast (pallet basis) after considering the ordering cycle and the peak index. The equation to calculate the required storage pallets of product group i in week t at a distribution centre is formulated in Chapter 4 (equation 4.4). The equation is used to make it possible for sale units to be converted into storage units and the result is as follows:

Table 6.6 Required storage pallets of each product group (Unit: pallet)

Product Group	Week 1	Week 2	…	Week 51	Week 52
1) Air conditioner	3,890	4,454	…	3,408	3,692
2) Optical Disk Drive	925	923	…	793	831
3) Printer/Fax Hardware	3,973	4,634	…	2,015	3,015
4) Printer Consumable	343	369	…	212	277
5) Display Monitor	4,124	4,591		1,627	2,646
Total	13,254	19,287		8,055	10,462

6.3.5. Required storage space (ft²)

Until now, we have calculated the required storage pallets for each week in order to satisfy incoming sales demand. It is now time to convert the number of required storage pallets into required storage space (ft²). The equation is formulated in Chapter 4 (4.5). And in order to solve the problem, we have defined constants in Chapter 5: k_r =0.79, k_b =2.51, r =0.8. Again, where to k_r is a constant of "square meter per pallet" with 4.5 high stacks in rack area, k_b is a constant of "square meter per pallet" with single stack in bulk area and *r* is a constant that the ratios of rack area in the storage zone of the distribution centre. And finally, the required storage space for each product group is summarised in Table 6.7.

Table 6.7 Required storage space (ft²) of each product group (Unit: ft²)

Product Group	Week 1	Week 2	…	Week 51	Week 52
1) Air conditioner	4,434	5,077	…	3,885	4,209
2) Optical Disk Drive	1,054	1,052	…	904	948
3) Printer/Fax Hardware	4,529	5,283	…	2,297	3,437
4) Printer Consumable	391	420	…	241	316
5) Display Monitor	4,701	5,234	…	1,855	3,016
Total	**15,109**	**17,066**	**…**	**9,182**	**11,926**

Figure 6.4 shows the weekly trend for this and Table 6.8 shows the required storage space for the whole year.

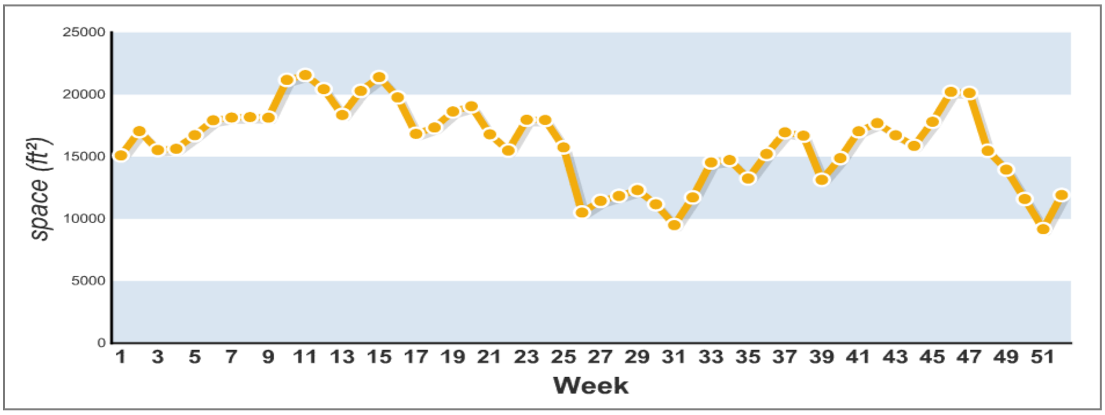


Figure 6.4 A weekly trend of the required storage space (ft²)

Table 6.8 The required storage space (ft^2) in a year

Week	Space	Unit	Week	Space	Unit
Week 1	15,109	ft^2	Week 27	11,455	ft^2
Week 2	17,066	ft^2	Week 28	11,855	ft^2
Week 3	15,546	ft^2	Week 29	12,326	ft^2
Week 4	15,651	ft^2	Week 30	11,186	ft^2
Week 5	16,739	ft^2	Week 31	9,504	ft^2
Week 6	17,942	ft^2	Week 32	11,731	ft^2
Week 7	18,164	ft^2	Week 33	14,547	ft^2
Week 8	18,196	ft^2	Week 34	14,743	ft^2
Week 9	18,151	ft^2	Week 35	13,257	ft^2
Week 10	21,186	ft^2	Week 36	15,233	ft^2
Week 11	21,575	ft^2	Week 37	16,975	ft^2
Week 12	20,439	ft^2	Week 38	16,700	ft^2
Week 13	18,364	ft^2	Week 39	13,149	ft^2
Week 14	20,304	ft^2	Week 40	14,897	ft^2
Week 15	21,414	ft^2	Week 41	17,057	ft^2
Week 16	19,777	ft^2	Week 42	17,714	ft^2
Week 17	16,847	ft^2	Week 43	16,736	ft^2
Week 18	17,362	ft^2	Week 44	15,882	ft^2
Week 19	18,647	ft^2	Week 45	17,822	ft^2
Week 20	19,070	ft^2	Week 46	20,226	ft^2
Week 21	16,811	ft^2	Week 47	20,138	ft^2
Week 22	15,501	ft^2	Week 48	15,486	ft^2
Week 23	17,985	ft^2	Week 49	13,968	ft^2
Week 24	17,968	ft^2	Week 50	11,608	ft^2
Week 25	15,761	ft^2	Week 51	9,182	ft^2
Week 26	10,514	ft^2	Week 52	11,926	ft^2

Note**:** This table was calculated on the basis of sales forecast

6.3.6. Findings from Numerical example 1

The Peak index for storage space is one or two weeks before the month end. We have calculated the required storage space (ft²) on the basis of sales forecast (quantity) after considering the weighted average quantity per pallets, ordering cycle, peak index, floor area occupation (ft² per pallet) and rack ratio in the storage zone of the distribution centre. From Figure 6.5, we found basically that the sales trends show the peak weeks are at the months end. However, required storage space (ft²) is vice versa, which means peak storage space (ft2) at the distribution centre is required one or two weeks before the month ends in accordance with the ordering cycle.

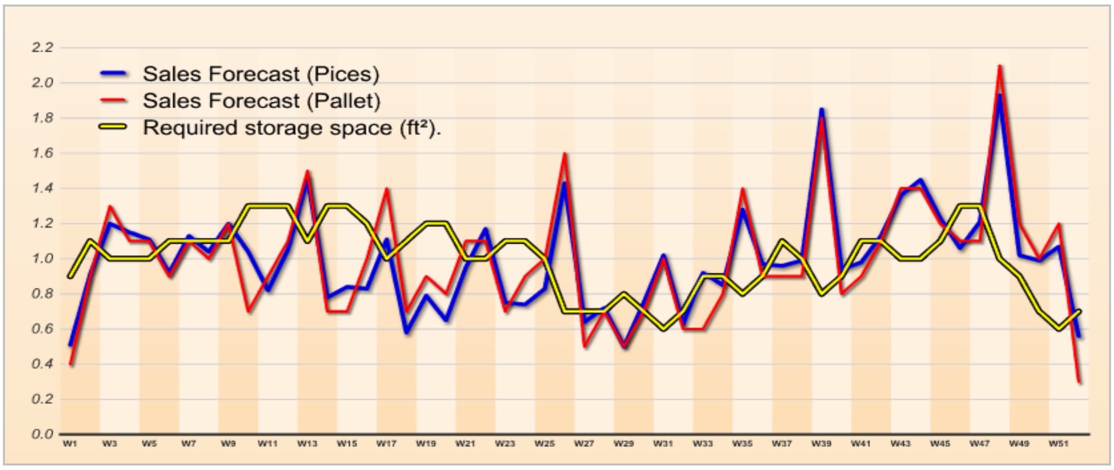


Figure 6.5 Weekly trends of peak index when annual average is “1”

There are no peak index correlations between storage and sales plan. The correlation for three peak index trends was computed and summarized in Table 6.9. The correlation is 92.8% between quantity unit and pallet unit of sales forecasts. However, the correlation between sales forecasts and required storage space (ft²) is 1.2 and 1.3%.

Table 6.9 Correlations in three trends

	Sales Forecast (Pieces)	Sales Forecast (Pallet)	required Space (ft²)
Sales Forecast (Pieces)	100.0%	-	-
Sales Forecast (Pallet)	92.8%	100.0%	-
Required Space (ft²)	1.2%	1.3%	100.0%

6.4. Numerical example 2: Choosing the best scenario

6.4.1. Input parameters

In order to solve the model of choosing the most optimal scenario out of the four given scenarios by minimizing total cost, other input parameters are needed in addition to the common input parameters for capacity planning. These are as follows:

- The convertible constant from "cost per ft²" to "cost per pallet" : Table 6.10
- The contract storage space (ft²) by scenario one: Appendix 1
- The contract storage space (ft²) by scenario two: Appendix 2
- The contract storage space (ft²) by scenario three: Appendix 3
- The contract storage space (ft²) by scenario four: Appendix 4

Table 6.10 The convertible constant for "cost per pallet"

Area	Max capacity (Pallets)	Allocated space (ft²)	Rack ratio	ft² / pallet
Rack zone	18,825	15,000	80%	0.797
Bulk zone	3,304	8,300	20%	2.512
Convertible constants	(0.797 × 80%) + (2.512 × 20%) =		**1.14**	

Source: Company in the contract logistics industry (Confidential)

Figure 6.6 shows the contract storage space (ft²) given by four scenarios (Appendix 1 ~ 4).

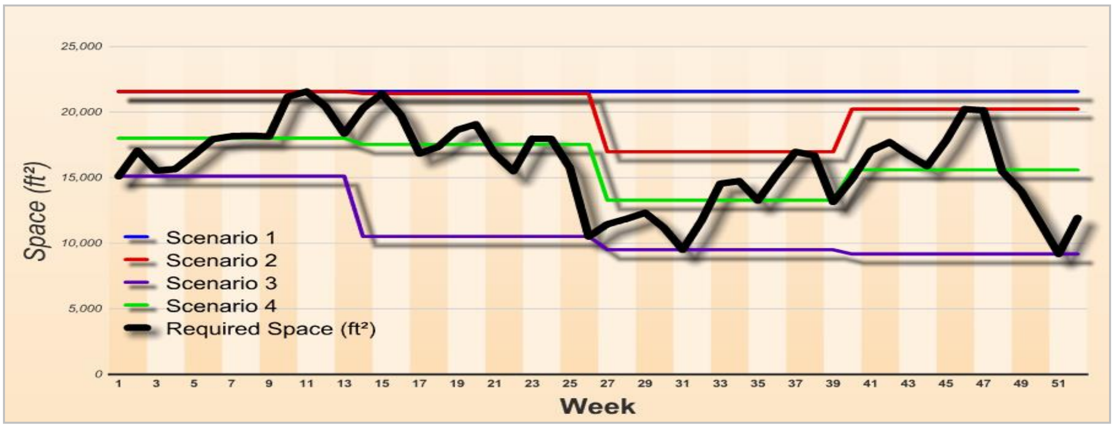


Figure 6.6 Four contract storage spaces (ft²) by given scenarios

6.4.2. Solving the model in Excel Solver

In order to solve the model developed in Chapter 4 (equation 4.11), the solver function in Micro Excel software was used. The solution time was quite fast. It did not take more than one second by virtue of a linear programming model as follows:

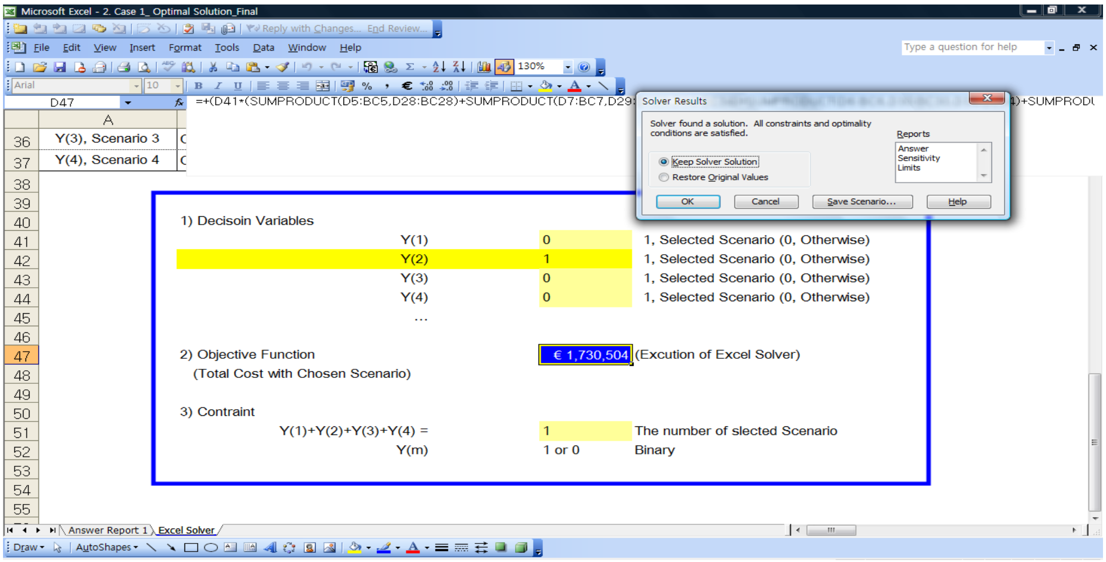


Figure 6.7 The results by the Excel Solver.

The program suggests that the most optimal solution is the second scenario, the max- dynamic planning which applies maximum required storage space (ft^2) within each quarter in order to meet the required storage space (ft^2) at the distribution centre.

- An optimal scenario: Scenario 2.
- The expected total cost in a year: € 1,730,504.

Table 6.11 Optimal scenarios while minimizing the total cost.

Scenarios	Contract storage space (ft^2)	Total Cost (€)	Remarks
Scenario 1	21,575	1,862,374	Max in a year
Scenario 2	21,575, 21,414, 16,975, 20,226	**1,730,504**	**Max in each quarter**
Scenario 3	15,109; 10,514; 9,504; 9,182	8,323,009	Min in each quarter
Scenario 4	18,010, 17,536, 13,282, 15,558	2,818,288	Avg. in each quarter

6.4.3. Findings from Numerical example 2

The optimal solution is not to use the overflow warehouse unless the required storage space (demand) is highly fluctuating and the cost of using the overflow warehouse is relatively lower than the cost of using the distribution centre. Numerical example 2 is intended to choose the most optimal scenario out of the four given scenarios while minimizing the total cost. The program suggests that the most optimal scenario is the second one which is to choose maximum required storage space (ft^2) in each quarter. This is the best solution to minimize the total cost, satisfying required storage space on the basis of sales forecasts. The solution suggested by the program was generated by the fact that the most optimal solution is not to use the overflow warehouse because the cost per square meter at the distribution centre is lower than the cost of using the overflow warehouse with normal seasonal demand. However, from numerical example 2, we see that even though the program suggested "scenario 2", this can not always be considered as an optimal solution because an optimal solution is affected by input parameters such as cost tariffs and required storage space. Of course, even though we applied real data from an actual company within the contract logistics and supply chain industry to this mathematical model but input parameters, especially cost tariffs can be changed in accordance with circumstances within the contract logistics and supply chain industry and depending on the given economic situation.

6.5. Numerical example 3: Determining optimal contract storage space

Numerical example 3 is used to determine the optimal contract storage space (ft^2) while minimizing the total cost without any given scenarios. First of all, as mentioned previously, all business begins by signing a contract to use the public distribution centre. Thus, contract periods should be defined in order to determine the optimal contract storage space because the optimal contract storage space depends on the length of the contract period. Moreover, storage space at the distribution centre can not be changed within the period of the contract. Four types of contract periods, including yearly, half yearly, quarterly, and monthly contracts are considered for Numerical example 3 in this chapter, even though the developed mathematical model in Chapter 5 was only formulated on the basis of quarterly contracts.

6.5.1. Input parameters

In order to solve the model to determine optimal contract storage space while minimizing total cost, in addition to the common input parameters for capacity planning, the convertible constant for cost per pallet is still required as shown in Table 6.10.

6.5.2. Optimal solution in annual contract period

6.5.2.1. Objective function

The basic objective function was introduced on the basis of the quarterly contract period in Chapter 5. Thus, the objective function for an annual contract can be simply modified on the basis of the mathematical model developed for the quarterly contact. The objective function is:

Min TC = $\sum_{t=1}^{52}(S_y \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$ (6.1)

where to S_y A decision variable to determine contract storage pallets in a year

Z_t A decision variable to calculate the difference of storage pallets between required storage pallets and contract storage pallets in week t

Subject to

$RP_t - S_y \le Z_t$ (t = 1… 52) (6.2)

$Z_t \ge 0$ (Z_t Not an integral number) (6.3)

Note that if $RP_t - S_y \le 0$, $Z_t = 0$ and $RP_t - S_y > 0$, $Z_t = RP_t - S_y$

6.5.2.2. Solving the model in Excel Solver

Excel solver was used again in order to solve this problem. The solution time was still quite fast and the program suggested an optimal solution as Table 6.12.

Table 6.12 An optimal contract storage space and total cost in annual contract period

	The results	Remarks
Contract storage pallets	17,929	Given by week 12
Contract storage space (ft²)	20,439	Given by week 12
Total Cost (€)	1,844,848	In a year

Note that the storage space from week 1 to week 52 for the entire year is continually required for 20,439 (ft²) and its storage cost in a year is € 1,844,848.

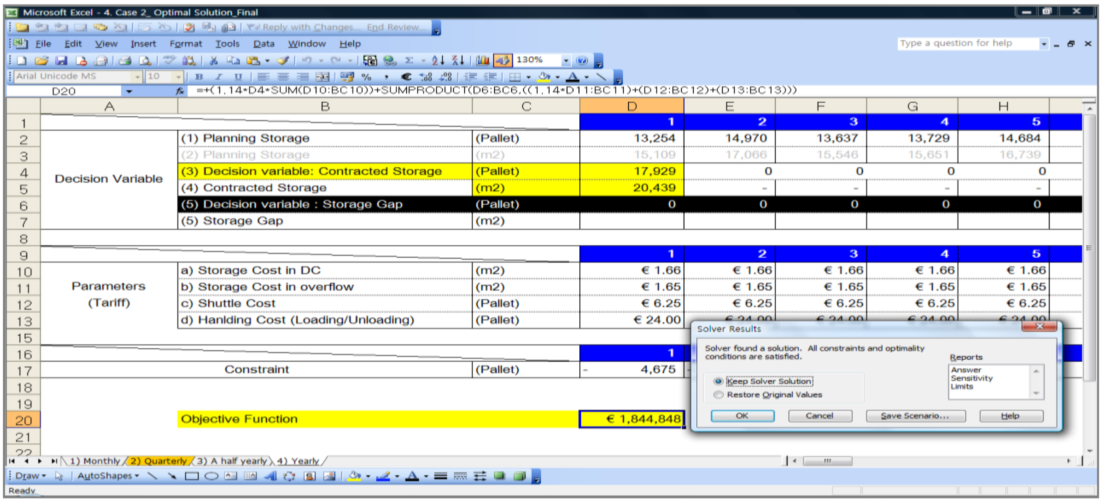


Figure 6.8 The results by the Excel Solver in annual contract period

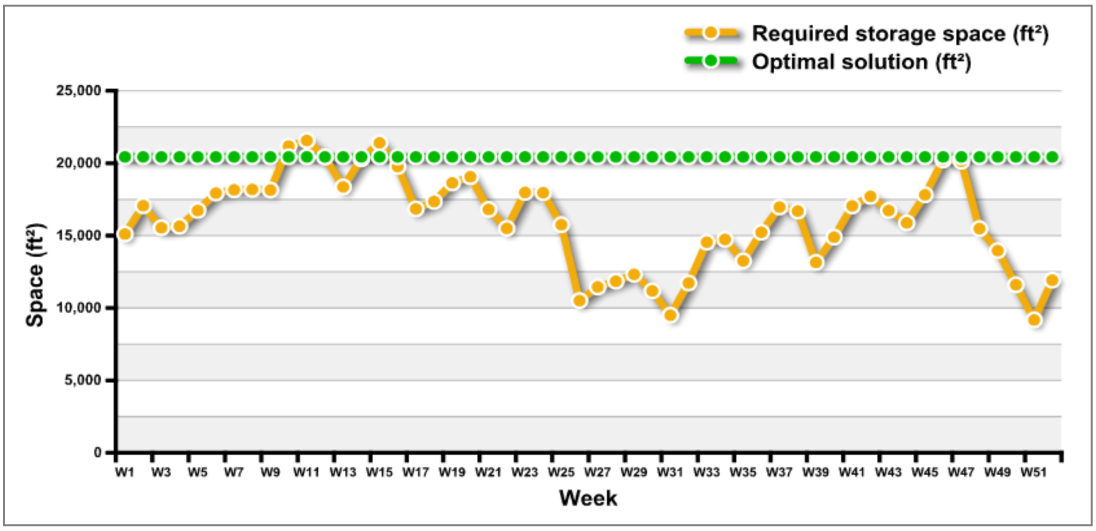


Figure 6.9 Optimal contract storage spaces (ft²) in annual contract period

6.5.2.3. Conclusion

The program suggested 20,439 (ft²) for the contract storage space as an optimal solution for the annual contract period. This was given by the required storage space in week 12. Figure 6.9 shows the contract storage space that can minimize the total cost, satisfying the required storage space on the basis of capacity planning is calculated in Table 6.8.

Even though the same assumptions and cost tariffs as an input parameter were applied, the total cost suggested by the model (6.1) has slightly decreased when compared to the total cost suggested by the first scenario in Numerical example 1 (Table 6.11). This means that from a cost saving point of view, the mathematical model suggests the better optimal solution than the first model introduced in Chapter 4 (4.11). The result generated by the two different models is as follows:

Table 6.13 The different optimal solution in Numerical example 2 and 3

	The first scenario in Numerical example 2	Annual contract period in Numerical example 3	Reduction
Assumptions	Yearly contract base	Yearly contract base	-
Contract storage space (ft²)	21,575	20,439	1,136 ↓
Total cost (€)	1,862,374	1,844,848	17,526 ↓

6.5.3. Optimal solution in a half-yearly contract period

6.5.3.1. Objective function

The objective function in a half-yearly contract can be also modified from the mathematical model developed for the quarterly contact. The objective function is:

$$Min\ TC = \sum_{t=1}^{26}(S_{1hy} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht}) + \sum_{t=27}^{52}(S_{2hy} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht}) \quad (6.4)$$

Where to S_{1hy} A decision variable to determine optimal contract storage pallets in the first half of the year

S_{2hy} A decision variable to determine optimal contract storage pallets in the second half of the year

Z_t A decision variable to calculate the difference of the storage pallets between the required storage pallets and the required contract storage pallet in week t

Subject to

$$RP_t - S_{1hy} \leq Z_t \qquad (t = 1\ldots 26) \qquad (6.5)$$

$$RP_t - S_{2hy} \leq Z_t \qquad (t = 27\ldots 52) \qquad (6.6)$$

$$Z_t \geq 0 \qquad (Z_t \text{ Not an integral number}) \qquad (6.7)$$

Note that if $RP_t - S_{jhy} \leq 0, Z_t = 0$ *and* $RP_t - S_{jhy} > 0, Z_t = RP_t - S_{jhy}$ (j = 1, 2)

6.5.3.2. Solving the model in Excel Solver

Excel solver was used again in order to solve this problem. The solution time was still quite fast and the program suggested the following:

Table 6.14 An optimal solution and total cost in a half-yearly contract period

		The results	Remarks
Contract storage pallets	First half	18,784	Given by week 15
	Second half	17,665	Given by week 47
Contract storage space (ft²)	First half	21,414	Given by week 15
	Second half	20,138	Given by week 47
Total cost (€)		1,800,399	-

Note that storage space from week 1 till week 26 in the 1st half of year is continually required for 21,414 (ft²), the 2nd half of year is 20,138 (ft²). And its total cost in a year is € 1,800,399.

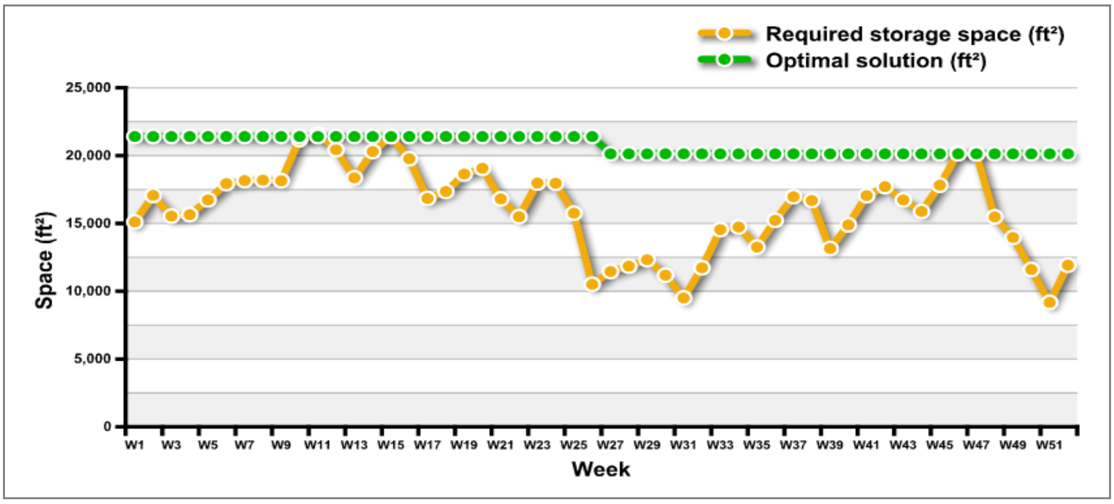


Figure 6.10 Optimal contract storage spaces (ft²) in a half-yearly contract period

6.5.3.3. Conclusion

The program suggested 21,414 (ft²) in the 1st half of the year and 20,138 (ft²) in the 2nd half of year for the contract storage space in a half-yearly contract period. This was given by the required storage space in week 15 and week 47. Figure 6.10 shows the contract storage space that can minimize the total cost, satisfying the required storage space on the basis of capacity planning that was calculated in Table 6.8.

Meanwhile, the total cost decreased slightly when compared to the total cost suggested by the annual contract period base. Therefore, this means from the cost savings point of view, we can conclude that the model suggests that a half-yearly contact is the optimal solution rather than the annual contract. The results generated by the two different contract periods are as Table 6.15.

Table 6.15 Reduced total cost in a half-yearly contract period.

	Total cost	Reduction
1) Annual contract	€ 1,844,848	-
2) A half-yearly contract	€ 1,800,399	(1) 2.4% ↓

6.5.4. Optimal solution in quarterly contract period

6.5.4.1 Solving the model in Excel software

The objective function was already introduced in Chapter 5 (5.6). Excel solver was used again in order to solve this problem. The solution time was still quite fast and the program suggested the following:

Table 6.16 An optimal solution and total cost in quarterly contract period

		The results	Remarks
Contract storage pallets	First quarter	18,926	Given by week 11
	Second quarter	18,784	Given by week 15
	Third quarter	14,891	Given by week 37
	Fourth quarter	17,742	Given by week 46
Contract storage Space (ft^2)	First quarter	21,575	Given by week 11
	Second quarter	21,414	Given by week 15
	Third quarter	16,975	Given by week 37
	Fourth quarter	20,226	Given by week 46
Total cost (€)		1,730,504	

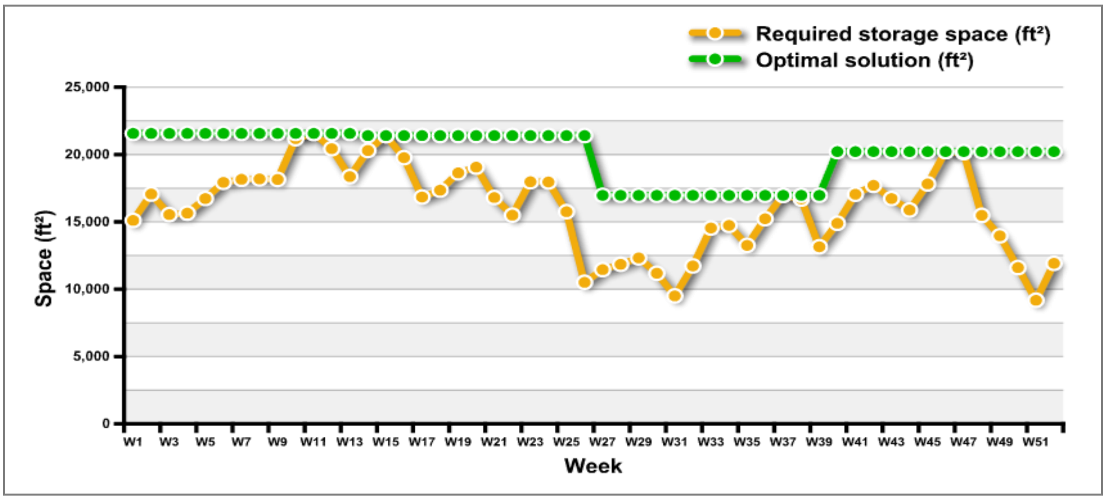


Figure 6.11 Optimal contract storage spaces (ft^2) in quarterly contract period

6.5.4.2 Conclusion

The program suggested 21,575 (ft^2) in the 1st quarter, 21,414 (ft^2) in the 2nd quarter, 16,975 (ft^2) in the 3rd quarter and 20,226(ft^2) in the 4th quarter for the contract storage space in the quarterly contract period. This was given by the required storage space in week 11, week 15, week 37 and week 46. Figure 6.11 shows the contract storage space that can minimize the total cost, satisfying the required storage space on the basis of capacity planning that was calculated in Table 6.8. The solution suggested by the program was to choose the maximum required storage space within each quarter. In this way, the result was exactly the same as scenario 2 in Numerical example 2 as follows:

Table 6.17 Optimal solution comparison between Numerical example 2 and 3

		The second scenario in Numerical example 2	Quarterly contract period in Numerical example 3
Assumptions		Max. space in each quarter	Quarterly contract
Suggested Optimal Space (ft^2)	1st Quarter	21,575	21,575
	2nd Quarter	21,414	21,414
	3rd Quarter	16,975	16,975
	4th Quarter	20,226	20,226
Total Cost (€)		1,730,504	1,730,504

Meanwhile, the total cost decreased continually when compared to the total cost suggested for the annual and a half-yearly contract period basis. Therefore, this means that optimal solution still suggested a shorter period of contract base. The comparative results generated by the three different contract periods are as follows.

Table 6.18 Cost comparison on the basis of contract period

	Annual contract	Reduction
1) Annual contract	€ 1,844,848	-
2) A half-yearly contract	€ 1,800,399	(1) 2.4% ↓
3) Quarterly contract	€ 1,730,504	(1) 6.2%↓, (2) 3.9%↓

6.5.5. Optimal solution in monthly contract period

6.5.5.1 Objective function

The objective function for the monthly contract period can be also modified from the mathematical model developed for the quarterly contact. The objective function is:

Min TC = $\sum_{t=1}^{5}(S_{1m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$ (6.8)

$$+\sum_{t=6}^{9}(S_{2m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=10}^{13}(S_{3m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=14}^{18}(S_{4m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=19}^{22}(S_{5m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=23}^{26}(S_{6m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=27}^{31}(S_{7m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=32}^{35}(S_{8m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=36}^{40}(S_{9m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=41}^{44}(S_{10m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=45}^{48}(S_{11m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$
$$+\sum_{t=49}^{52}(S_{12m} \times 1.14C_{dt}) + Z_t(1.14C_{ot} + C_{st} + C_{ht})$$

Where to S_{1m} ~ S_{12m} *Decision variables;*

S_{1m} *Contract storage pallets in January*

S_{2m} *Contract storage pallets in February*

S_{3m} *Contract storage pallets in March*

S_{4m}	*Contract storage pallets in April*
S_{5m}	*Contract storage pallets in May*
S_{6m}	*Contract storage pallets in June*
S_{7m}	*Contract storage pallets in July*
S_{8m}	*Contract storage pallets in August*
S_{9m}	*Contract storage pallets in September*
S_{10m}	*Contract storage pallets in October*
S_{11m}	*Contract storage pallets in November*
S_{12m}	*Contract storage pallets in December*

Subject to

$$RP_t - S_{1m} \le Z_t \quad (t = 1 \ldots 5) \quad (6.9)$$

$$RP_t - S_{2m} \le Z_t \quad (t = 6 \ldots 9) \quad (6.10)$$

$$RP_t - S_{3m} \le Z_t \quad (t = 10 \ldots 13) \quad (6.11)$$

$$RP_t - S_{4m} \le Z_t \quad (t = 14 \ldots 18) \quad (6.12)$$

$$RP_t - S_{5m} \le Z_t \quad (t = 19 \ldots 22) \quad (6.13)$$

$$RP_t - S_{6m} \le Z_t \quad (t = 23 \ldots 26) \quad (6.14)$$

$$RP_t - S_{7m} \le Z_t \quad (t = 27 \ldots 31) \quad (6.15)$$

$$RP_t - S_{8m} \le Z_t \quad (t = 32 \ldots 35) \quad (6.16)$$

$$RP_t - S_{9m} \le Z_t \quad (t = 36 \ldots 40) \quad (6.17)$$

$$RP_t - S_{10m} \le Z_t \quad (t = 41 \ldots 44) \quad (6.18)$$

$$RP_t - S_{11m} \le Z_t \quad (t = 45 \ldots 48) \quad (6.19)$$

$$RP_t - S_{12m} \le Z_t \quad (t = 49 \ldots 52) \quad (6.20)$$

$$Z_t \ge 0 \quad (Z_t = \text{not an integral number}) \quad (6.21)$$

Note that if $RP_t - S_{jm} \leq 0$, $Z_t = 0$ *and* $RP_t - S_{jm} > 0$, $Z_t = RP_t - S_{jm}$ *(j=1…12)*

6.5.5.2 Solving the model in Excel Solver

The Excel Solver was used again in order to solve this problem. The solution time was still quite fast and the program suggested that the optimal contract storage space (ft²) in a monthly contract period is as Table 6.19. And its expected total cost of € 1,515,281 a year.

Table 6.19 Optimal contract storage space (ft²) in monthly contract (Unit: K ft²)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
17	18	22	21	19	18	12	15	17	19	20	14
(W2)	(W7)	(W11)	(W15)	(W20)	(W23)	(W29)	(W34)	(W37)	(W42)	(W46)	(W49)

Note: (W2)… (W49) is given weeks for maximum required storage space in each month

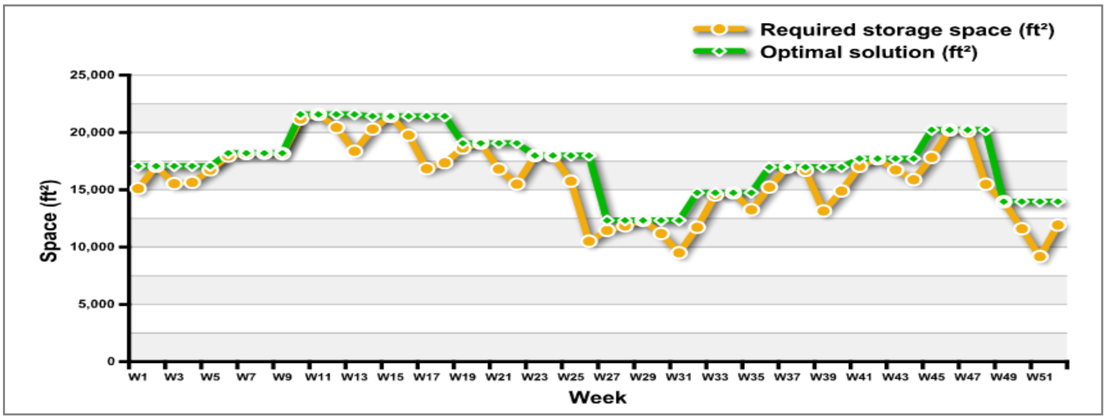


Figure 6.12 Optimal contract storage spaces (ft²) in monthly contract

6.5.5.3 Conclusion

The program suggested the optimal contract storage space presented in Table 6.19 on the basis of the monthly contract period. And Figure 6.12 shows graphically that the optimal solution in the monthly contract is the same as the maximum required storage space in each month. Moreover, the total cost has also increasingly decreased to 12.4% when compared to a quarterly contract, 15.8% when compared to a half yearly contract and 17.9% when compared to a yearly contract. Thus, we have concluded based on the program results that the more optimal solution is a shorter contract period. The comparison of the results generated by the four different contract periods is as follows:

Table 6.20 The total cost comparison on the basis of contract period.

	Total cost	Reduction
1) Annual contract	€ 1,844,848	-
2) A half-yearly contract	€ 1,800,399	(1) 2.4% ↓
3) Quarterly contract	€ 1,730,504	(1) 6.2%↓, (2) 3.9%↓
4) Monthly contract	€ 1,515,281	(1) 17.9%↓, (2) 15.8%↓, (3) 12.4%↓

6.5.6. Findings from Numerical example 3

Contract period is a necessary condition: The numerical example 3 is used to determine the optimal contract storage space while minimizing total cost. In order to find out the most optimal solution, we found that the contract period should first be defined because the optimal contract storage space can be changed on the basis of length of contract period. This means that the contract storage space of DC and overflow warehouse should be kept within the contract periods even if the required storage space is expected to expansion and reduction in the future period. Thus, the period of contract is a necessary condition for determining the optimal contract storage space in Numerical example 3. Figure 6.13 shows four different optimal solutions graphically on the basis of the period of the contract.

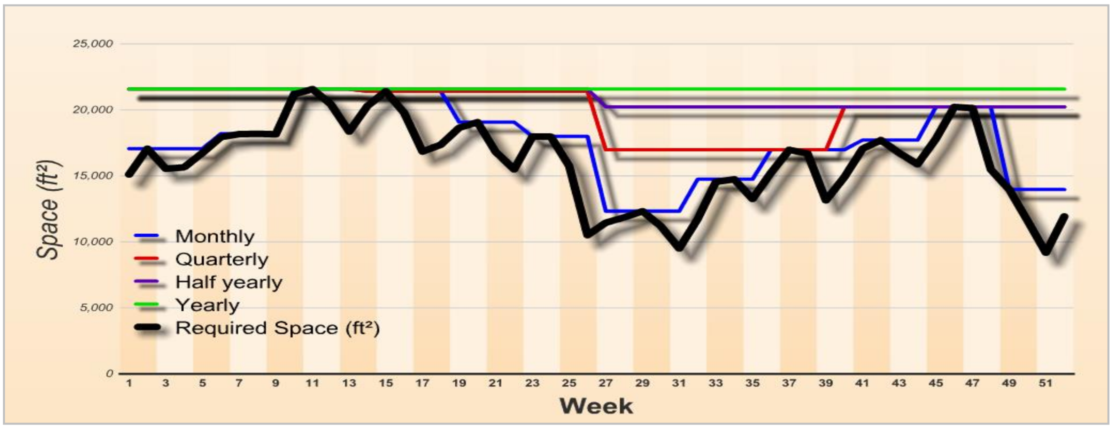


Figure 6.13 Four optimal solutions based on the contract periods

Optimal contract storage space is determined when total cost is minimized: Figure 6.14 shows the change of costs when the contract storage space at the distribution centre increases, including storage costs at the distribution centre, other costs using the overflow warehouse and then the total cost.

The first, the storage costs (yellow dotted line) at the distribution centre increase gradually with increases in contract storage space, because storage costs at the distribution centre are paid on the basis of contract storage space. For instance, suppose that if the required storage space is 10,000 (ft^2) and contract storage space is 11,000 (ft^2) or 12,000 (ft^2) or 13,000 (ft^2) or 14,000 (ft^2)…, then the storage cost at the distribution centre is paid not on basis of the required storage space, but on the basis of the contract storage space. Thus, the storage cost increases gradually when contract storage space at the distribution centre increases. The second, the other costs (green dotted line) for using the overflow warehouse decreases until the other costs equal zero and after that, this cost are maintained horizontally. This means that there are no other costs associated for using the overflow warehouse when the required storage space is totally satisfied by the contract storage space at the distribution centre. Thus, the other costs line decreases and keep horizontally. Finally, the total cost (red dotted line) is drawn like a “U shape hockey stick curve” after considering both cost lines. In other words, the optimal contract storage space (ft^2) is determined when the total cost is minimized.

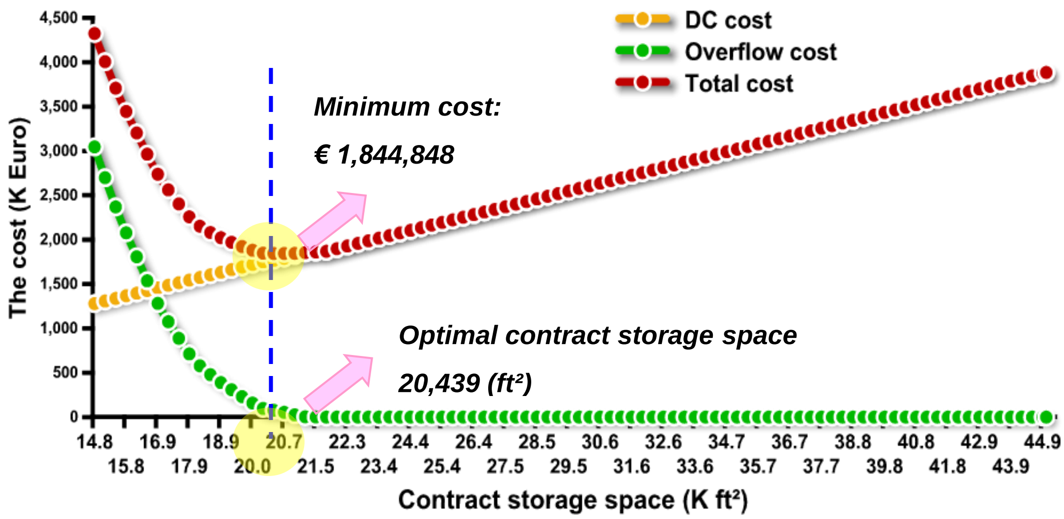


Figure 6.14 Optimal contract storage space (Yearly contract base)

The shape of the cost line can be differentiated by input parameters such as the cost tariffs at the distribution centre and the overflow warehouse. In this case, the cost for using the overflow warehouse is relatively higher than the cost for using the distribution centre. However, the total cost line would be symmetric if there was no difference between the cost of using the distribution centre and overflow warehouse. Figure 6.14 shows the optimal contract storage space on the basis of an annual contract period so that its optimal solution is suggested by 20,439 (ft^2) when the total cost is dropped up to € 1,844,848. This is the same as the Table 6.12.

Optimal solution is placed in the short contract period compared to long one: As shown in Table 6.20, the total cost for the optimal contract storage space can be effected by different contract periods. In sum, a shorter contract period will be better than a longer contract period from a cost savings perspective.

The second mathematical model provides better optimal solutions than the first mathematical model. We found that the second mathematical model (5.6) in Chapter 5 offered more advantages for saving on the total cost when compared to the first mathematical model (4.11) in Chapter 4 under the same assumptions as presented in Table 6.21 and 6.22. For instance, even if the period of contract is the same between Scenario 1 in the 2nd Numerical example and annual contact period in the 3rd Numerical example, the total cost in annual contract of the 3rd Numerical example is slightly cheaper than the cost in scenario 1 of the 2nd Numerical example. However, even though the models were formulated differently, they suggested that the total cost of the two models could be the same between the cost in the second scenario of the 2nd Numerical example and the cost in the quarterly contract of the 3rd Numerical example since the cost of using the overflow warehouse is relatively higher than the cost of only using the distribution centre. Thus, both programs suggested not using the overflow warehouse.

Table 6.21 Total cost comparison between Numerical example 2 and 3

2nd Numerical example (Model 1)		3rd Numerical example (Model 2)	
Given Scenarios	Total Cost	Contract Periods	Total cost
a) Scenario 1	€ 1,862,374	1) Annual contract	€ 1,844,848
b) Scenario 2	*€ 1,730,504*	2) A half-yearly contract	€ 1,800,399
c) Scenario 3	€ 8,323,009	3) Quarterly contract	€ 1,730,504
d) Scenario 4	€ 2,818,288	4) Monthly contract	€ 1,515,281

Table 6.22 Cost reduction by general model based on the same contract period

2nd Numerical example (Model 1)		3rd Numerical example (Model 2)		Cost Reduction
Given Scenarios	Total Cost	Contract Periods	Total cost	
Scenario 1	€ 1,862,374	Annual contract	€ 1,844,848	0.9% ↓
Scenario 2	*€ 1,730,504*	Quarterly contract	€ 1,730,504	0% ↓
Scenario 3	€ 8,323,009			79% ↓
Scenario 4	€ 2,818,288			39% ↓

6.6 Numerical example 4: Sensitive analysis

6.6.1 Allowable change of storage tariffs at the Distribution Centre

The sensitive analysis can be executed with the 2nd linear programming model (5.6) in Chapter 5 which does not have 0, 1 binary decision variable. We simulated to find out an optimal contract storage space from the developed mathematical model with the application of the real tariffs found in the contract logistics industry. However, we found that the optimal solution could be changed with the change of input parameters such as cost tariffs. Therefore, the purpose of this analysis is to find out by how much the storage tariffs at the distribution centre could allow for increases or decreases to maintain the current optimal solutions. Assume that the period of contract is on a quarterly basis. The objective function (5.6) of Chapter 5 could be simplified with given tariffs (Table 6.2). Thus, it was formulated again as follows.

$$Min\ TC = \sum_{t=1}^{13}(24.6S_1 + 417.8Z_t) + \sum_{t=14}^{26}(24.6S_2 + 417.8Z_t) + \sum_{t=27}^{39}(24.6S_3 + 417.8Z_t) + \sum_{t=40}^{52}(24.6S_4 + 417.8Z_t) \qquad (6.22)$$

Note that 24.6 is the sum of the storage tariff at the distribution centre (1.89 € per pallet) and 417.8 is the sum of the other tariffs using the overflow warehouse (32.1 per pallet) in each quarter. (13 weeks)

- 24.6 € = 1.89 € x 13 weeks
- 417.8 € = 32.1[3] € x 13 weeks

---

[3] 32.1 € = 1.89 € + 6.25 € + 24 € (Table 6.2)

Excel solver suggested the sensitive analysis report as Table 6.23.

Table 6.23 Sensitive analysis report: Based on quarterly contract

Quarter	Optimal CSP	Optimal CSS (ft²)	Total Cost (€)	Objective Coefficient	Allowable Increase	Allowable Decrease
1	18,926	21,575	465,594	24.60	7.53	24.60
2	18,784	21,414	462,116	24.60	7.53	24.60
3	14,891	16,975	366,325	24.60	7.53	24.60
4	17,742	20,226	436,470	24.60	7.53	24.60

Note that for easier formulation, all cost parameters were identified "euro per pallet" in Chapter 4. Thus, optimal contract storage space was converted again from the optimal contract storage pallets with constants "1.14". The total cost represented by the sensitive analysis report is the same as the total cost in Numerical example 2 (Table 6.16): 1,730,504 € = ((18,926 pallets x 24.60 €) + (18,784 pallets x 24.60 €) + (14,981 pallets x 24.60 €) + (17,742 pallets x 24.60 €)). Note that the optimal solution is not using overflow warehouse so that the $Z_t = 0$ in equation (6.22)

Therefore, from the sensitive analysis report, we found the objective coefficients, the range of the storage tariff 1.89 € per pallet per week at the Distribution Centre is between 2.472[4] € and 0. . In addition, we can also say that the range of the storage tariff 1.66 € per ft² per week is also between 2.168[5] € and 0. Thus, there would be no impact on the optimal solution if the storage tariff 1.66 € per ft² per week at the distribution Centre does not increase more than 2.168 €.

Figure 6.15 shows the optimal solutions for contract storage pallets at the distribution center does not change until the cost of the storage tariffs (€ per ft²) reach 2.168 €. . In other words, if the storage tariff at the distribution center would increase to over 2.168 €, then the contract storage pallets at the distribution center would decrease and the contract storage pallets at the overflow warehouse would increase from that point.

[4] 2.472 € = (24.60 € + 7.53 €) / 13 weeks
[5] 2.168 € = (24.60 € + 7.53 €) / 13 weeks / 1.14 convertible constant

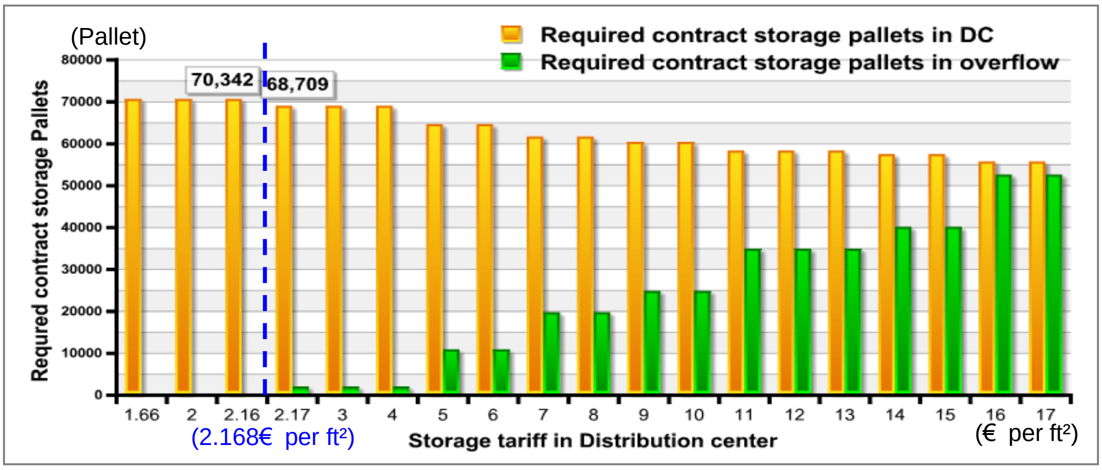


Figure 6.15 Change of the optimal solution when storage tariff at DC increases

Note that 70,342 pallets is the sum of the optimal contract storage pallets in each quarter as presented in Table 6.23.

6.6.2 Relations between storage tariffs in DC and the total cost

The linear model by two variables (storage tariff at the distribution centre and the total cost) was formulated on the basis of the regression analysis in Figure 6.16 of the next pages. Thus, from this model, we can estimate how much the total cost would increase if the storage tariff at the distribution centre would increase by 1 €.

$$Y = 815190X + 1171318 \qquad (6.23)$$

This means that with an additional 1 € increase of the storage tariff (€ per ft²) at the distribution centre, then the total cost increase on average would be 815,190 €. R square for this model is 99.65%, which means 99.65% of the variation in the total cost is explained by the variation in the storage tariff. The rest 0.35% remains unexplained by this model. Note that R square takes any value between zero and one; if R square equals to 1, it means a perfect match between the line and the data points. If R square equals to zero, it means that there are no linear relations between the storage tariffs at the DC and the total cost. And also, P-value: 0.000…, which means that the model has explanatory power so that storage tariffs at the distribution centre are significantly related to the total cost (Michel, 2008).

SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.9964678				
R Square	0.99294808				
Adjusted R Square	0.99271302				
Standard Error	635021.283				
Observations	32				
ANOVA					
	df	SS	MS	F	Significance F
Regression	1	1.7034E+15	1.7034E+15	4224.162626	7.68792E-34
Residual	30	1.20976E+13	4.03252E+11		
Total	31	1.7155E+15			
	Coefficients	Standard Error	t Stat	P-value	
Intercept	1,171,318	215,725	5.429686802	6.92403E-06	
Storage cost in DC	815,190	12,543	64.99355834	7.68792E-34	

Figure 6.16 Simple regression analysis: storage tariffs vs. the total cost

6.6.3 Optimal solution by changed input parameters

6.6.3.1 Problem generating

Numerical example 2 is to choose an optimal scenario out of the four given scenarios and numerical example 3 is to determine an optimal contract storage space without any given scenarios. The necessary conditions of both mathematical models are to minimize the total cost. However, the problem is that the program in Numerical example 2 and 3 suggested the most optimal solution is the use of the maximum or almost maximum required storage space at the distribution centre within the period of the contract because the costs associated with using the overflow warehouse are much higher than the costs of only using the distribution centre..

Table 6.24 Optimal solutions

Numerical example	Contract Period	Optimal solutions
a) Numerical example 2	Among four scenarios	Max. Required Storage Space (RSS)
b) Numerical example 3	Monthly and quarterly	Max. RSS
	A half yearly	99.3%, 99.6% of max. RSS
	Yearly	94.7% of max. RSS

Thus, in this sensitive analysis, we will see how an optimal solution would change when the cost tariffs would change.

6.6.3.2. Assumption with input parameters

In Chapter 4, one of assumptions discussed was that the receiving and shipping of goods is only possible from and to the distribution centre because using the overflow warehouse is temporary solutions in order to secure storage space for overflow goods so that there is no reason to set up a warehouse management system. That was the reason why the cost of using the overflow warehouse is relatively higher than the cost of using only the distribution centre so that program suggested not using the overflow warehouse. Thus, we assumed this again when conducting this sensitive analysis as found in Table 6.25; storage cost at the distribution centre is slightly lower than the sum of the other costs for using the overflow warehouse, which means that we reduced the cost difference between storage cost at the distribution centre and the sum of the other costs for using the overflow warehouse for this sensitive analysis.

Table 6.25 Adjusted cost tariffs in DC and overflow warehouse.

Item	Tariff	Unit	Remarks
a) Storage Cost in distribution centre	€ 5.00	(m2)	€ 5.7[6] per pallet
b) Storage cost in overflow warehouse	€ 1.50	(m2)	€ 1.7 per pallet
c) Shuttle Cost between DC and overflow w/h	€ 2.00	(Pallet)	-
d) Handling Cost (Loading/Unloading) for the replenishments	€ 4.00	(Pallet)	-

6.6.3.3 Choosing the best scenario out of four given scenarios

Solving the model by Excel Solver

In order to solve the problem, Excel solver was used again. The Excel solver suggested a different optimal solution this time, so that the most optimal scenario is

[6] € 5.7 was calculated by convertible "1.14" in Table 6.10

not the second scenario, but the fourth scenario, the average-dynamic planning which is to apply average required storage space (ft²) in each quarter in accordance with the required storage space (ft²) in Table 6.8. The suggested the total costs are as follows.

Table 6.26 The total cost of each scenario

Scenarios	Description of the scenario	Total Cost[7]
a) Scenario 1	the max-one step planning	€ 5,609,561
a) Scenario 2	the max- dynamic planning	€ 5,212,362
a) Scenario 3	the Min- dynamic planning	€ 4,647,806
a) Scenario 4	**Average- dynamic planning**	**€ 4,529,672**

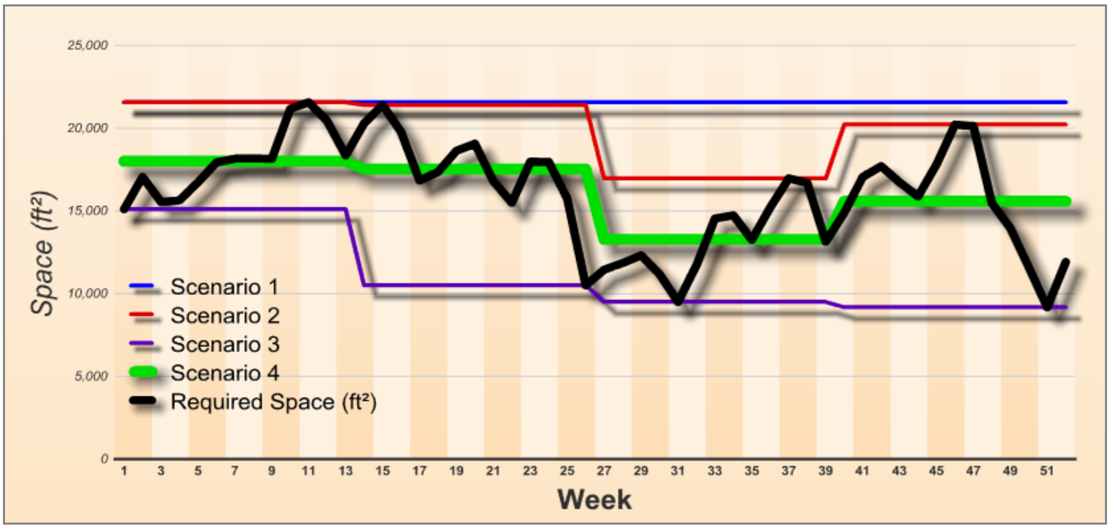


Figure 6.17 An optimal scenario by new input parameters (Cost tariffs)

6.6.3.4 Determining an optimal contract storage space

Solving the model by Excel Solver

For this analysis, the formulated model was applied based on the quarterly contract period (equation 5.6) out of four types of contract period. Excel solver was used again to settle this problem and suggested the optimal contract storage space

[7] Note that the total cost is changed due to the change of cost tariffs

as presented in Table 6.27 and i**ts total cost**[8] **is € 4,473,128 a year.** This is the cheapest solution compared to the total cost suggested by the 1st model in Table 6.26.

Table 6.27 The optimal required contract storage space with new input parameters

Quarter	Optimal required contract storage space	Given By
1	16,739(ft²)	Week 5
2	16,811(ft²)	Week 21
3	11,731(ft²)	Week 32
4	11,731(ft²)	Week 49

In this sensitive analysis, the optimal solution is not the maximum required storage space but points which were given by a certain week in the period of the contract.

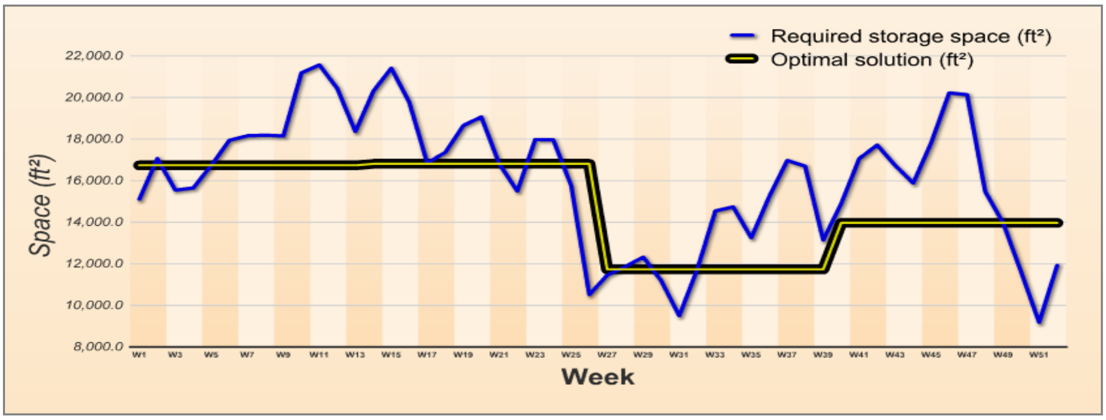


Figure 6.18 Optimal required contract storage space by new input parameters

6.6.3.5 Conclusion

The purpose of this section was to know how an optimal solution would change when input parameters (cost tariffs) would change. And finally, the generated problem was solved by additional computing with new input parameters. The program suggested different optimal solutions to minimize the total cost as shown in Table 6.28

[8] The total cost: **€**4,360,129 for monthly contract, **€**4,479,871 for a half-yearly contract, **€**4,582,971 for yearly contract period

Table 6.28 The results of models verification

		1st Input parameters	2nd input parameters (Sensitive Analysis)
Model 1 (4.11)	Optimal solutions	The scenario 2	The scenario 4
Model 2 (5.6)	Optimal solutions	Max required storage space within contract periods	Storage space given by a certain week within contract periods

6.6.4. Findings from Numerical example 4

There are tradeoffs between contracting storage space at the Distribution Centre and at the overflow w/h. The more storage space at the distribution centre that would be contracted, the less storage space at an overflow warehouse would be required and vice versa. For instance, contract storage space at the distribution centre would not change at the point when the storage tariff at the distribution centre would not increase to more than 2.168 € and vice versa.

The storage tariff at the distribution centre is significantly related to the total cost. According to the regression analysis by the linear model of two variables, the two variables have significantly correlated and 99.65% of the variation in the total cost is explained by the variation in the storage tariff at the distribution centre.

Optimal solutions do not always suggest not using the overflow warehouse. An optimal solution highly depends on the input parameters. Thus, the optimal solutions may change if demand is highly fluctuating or the cost of using the overflow warehouse is relatively lower than the cost of using the distribution centre.

6.7 Summary

This chapter dealt with four numerical examples that applied real data from a company working in the contract logistics and supply chain industry. The formulated models were operated correctly and the solution time by Excel Solver worked quite fast by virtue of the linear programming model. Before the execution of the numerical examples with real data, we first introduced what data is required and how it should be collected for the numerical examples.

The first, Numerical example 1 is to calculate the required storage space, which is basic demand information for capacity planning of storage space at the public distribution centre, on the basis of quantity based sales forecast after considering peak index, ordering cycle, floor area occupation and rack ratio in the storage zone. Based on the result, we found that there is little correlation in the peak index between sales and storage trends.

The second, Numerical example 2 is to choose an optimal scenario out of the four given scenarios. The results for this example suggested scenario 2, the max-dynamic planning, as the most optimal scenario which is to apply the maximum required storage space (ft^2) in each quarter based on the required storage space (ft^2). We also found that the optimal solution is normally not to use the overflow warehouse if the required storage space (Demand) is not highly fluctuating because the cost using of the overflow warehouse is higher than cost using of the distribution centre. Thus, optimal solution can be influenced by the change in input parameters.

The third, Numerical example 3 is to determine the optimal contract storage space without any given scenarios. The program suggested different optimal contract storage space in accordance with contract period as shown in Table 6.24. Therefore, we found that the period of contract is a necessary condition to determine the optimal contract space; the optimal contract storage space (ft^2) is determined when the total cost is minimized; a shorter contract period is better than a longer contract period from a cost savings perspective; and the mathematical model in this numerical example gives more optimal solutions than the model in the 2nd numerical example.

Moreover, we have found that the optimal solutions can easily be influenced on the basis of the input parameters such as cost tariffs. Thus, three sensitive analyses are executed; allowable change of storage tariffs at the Distribution Centre, relations between the storage tariffs at the distribution centre and the total cost, and optimal solution by changed input parameters. From these sensitive analyses, we found that with the mathematical model in the quarterly contract period, there would be no impact on the optimal solution if the storage tariff of 1.66 € per ft^2 per week at the distribution centre would not increase to more than 2.168 €; in the mathematical model for the quarterly contract period, an additional 1 € increase of storage tariff (€ per ft^2) at the distribution centre would the total cost increase average would be 815,190 €. The program suggests a different optimal solution on the basis of the input parameters, which means it does not always give the maximum or almost maximum required storage space within the period of the contracts.

Chapter 7 Conclusion

Well defined processes and tools for capacity planning of storage space at public distribution centres are indispensable in supply chain management. Therefore, one of the most critical steps for managers working in the supply chain and logistics industries is to determine the most optimal and cost effective plan in using distribution centre. This research has begun with the following main research question: “How can we determine the optimal contract storage space (ft^2) for a public distribution centre while minimizing total cost”? Thus, in order to answer this research question, we proposed a set of functional formulas for computing the required storage space as basic demand information and two mathematical models for determining the optimal contract storage space at the public distribution centre of the supply chain. We proposed a solution methodology to solve the functional formulas and mathematical models: one is to reformulate the models for simplifying data entry and the other is to change the non linear model into a linear programming model. Finally, we dealt with numerical examples that applied real data taken from the contract logistics and supply chain industry. The formulated models provided the optimal solution correctly and solution time by Excel Solver worked quickly by virtue of the linear programming model.

7.1 Contributions

7.1.1 Managerial contribution

The results of this research study can make a significant contribution for managers working in the supply chain and logistics industries. This research can provide the following practical benefits

7.1.1.1 Optimal solutions

The optimal contract storage space is determined when the total cost is minimized. The total cost includes the cost of using the distribution centre plus the cost of using the overflow warehouse and these costs are tradeoff relations. In other words, the more contract storage space we have at a public distribution centre, the less we would require for temporary storage space at an overflow warehouse. Thus, Figure 7.1 shows the optimal solutions, optimal contract storage space when the total cost is minimized. Namely, the total cost curve has drawn like U shape curve due to the tradeoffs between two variables which are the cost of using the public distribution centre and the cost of using overflow warehouse.

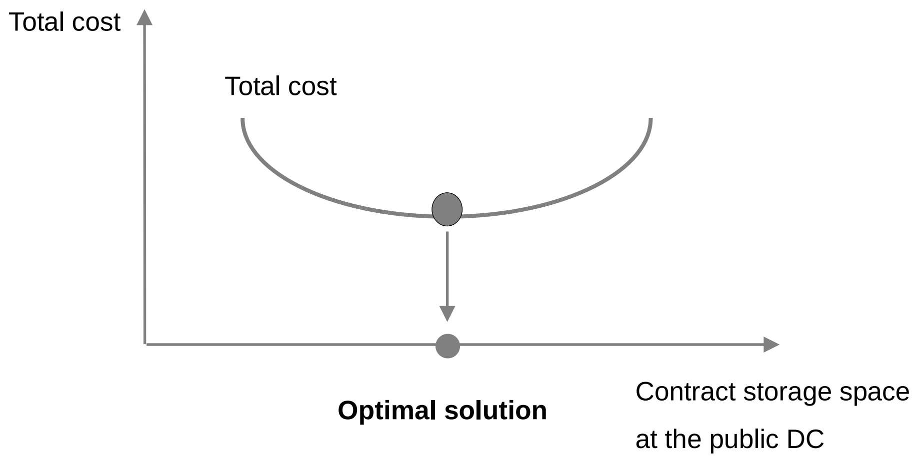


Figure 7.1 Optimal contract storage spaces

7.1.1.2 Not recommended using overflow w/h

Normally, the optimal solution suggested not to use the overflow warehouse, because the cost of using the overflow warehouse was relatively higher than the cost using only the distribution centre in the real contract logistics and supply chain industry. This means that optimal solution is to take the maximum required storage space within the contract period. However, we must know that this is recommended on the basis of the following conditions when demand is not highly fluctuating or when the cost of using the overflow warehouse is relatively high. However, the optimal solution can change if demand is highly fluctuating or if the cost of using the overflow warehouse is relatively cheaper than or similar to the cost of using the distribution centre such as in Figure 6.17 and 6.18.

7.1.1.3 Length of contract period

If the market would allow, from a cost savings point of view, a shorter contract period would be better than a longer contract period. The shorter the period of contract can have an influence on the contract storage space at public distribution centre(Table 6.20). This is one way to help reduce uncertainties in the supply chain industry.

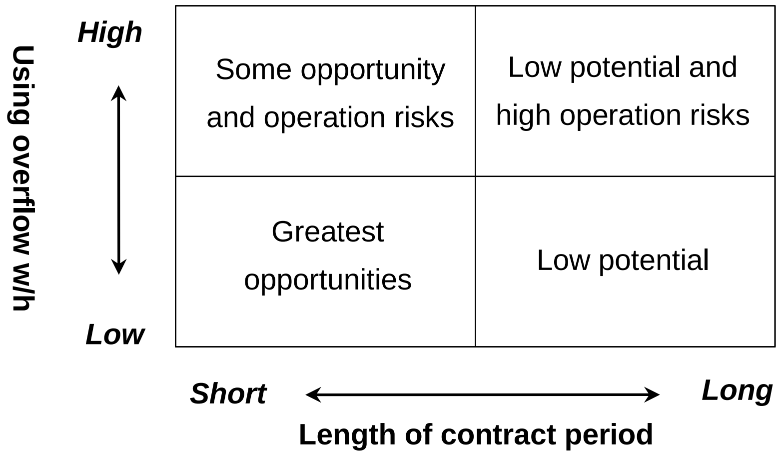


Figure 7.2 Optimal solutions in the contract logistics and supply chain industry

7.1.1.4 Decision tools

The models in this research can be used by practitioners as decisions tools in their own supply chain management. By using this optimal solution, the total cost generated in the contract logistics and supply chain industry can be reduced. For instance, the 1st linear programming model (4.11) in Chapter 4 for choosing the best scenario suggested that the second scenario offers benefits of cost savings up to 7% compared to scenario 1, 79% when compared to scenario 3 and 39% when compared to scenario 4 (Table 6.11). And the 2nd linear programming model (5.6) in Chapter 5 for determining optimal contract storage space on the basis of a monthly contract period offers more benefits to save the cost of up to 18% compared to the yearly based contract (Table 6.20). And the 2nd linear programming model as general model which was used in the 3rd numerical examples provides more opportunity to save costs compared to the 1st linear programming model used in the 2nd numerical example. Moreover, the formulated models can be used easily and widely by Excel Solver.

7.1.2 Scientific contribution

This study can also be seen as making a scientific contribution to the available research on storage space planning at the distribution centres. The conceptual and numerical models introduced in this research study can provide useful insights for academic researchers in their future research to better reconcile scientific theory with the actual practice in the real contract logistics and supply chain industry.

7.1.2.1 Mathematical models

This research presents two mathematical models that can be applied to different circumstances. One is to choose the best scenario out of four given scenarios. The other is to determine the optimal contract storage space without any given scenarios because there are lots of scenarios which can be considered as optimal solutions in the real supply chain industry.

7.1.2.2 Solution methodology

This research suggests optimal solution to determine contract storage space efficiently and effectively. Optimal solutions are suggested by liberalized programming model with minimal total cost and quite fast solution time.

7.1.2.3 Mathematical formulations for required storage space (ft^2)

This research provides the method to calculate required storage space on the basis of sales unit forecasts. Thus, this research provides not only supply information as optimal contract storage space but also demand information as required storage space.

7.2 Future Research

This research can provide several advantages to academic researchers and practitioners in the contract logistics and supply chain industry. However, the mathematical model for optimizing storage capacity at the distribution centre in this research does not take into account the service factors, such as lead time and on time delivery. The focus of this research is primarily on efficiency points for supply chain management. Namely, the optimal solution is determined when the total cost is minimized. However, practitioners in actual supply chain industry must consider not only cost factors, but also service factors which can have an impact on customer satisfaction. Moreover, the solution methodology for choosing an optimal scenario and for determining the optimal contract storage space is started with the use of sales forecasts. However, what if the sales forecasts are wrong? A forecast does not represent reality but it at most estimation for the future. Thus, no matter how well we skillfully plan, it can differ from the actual demand because of several reasons that will affect the supply chain.

For future research, therefore, I would like to study further models to find out the best solution after considering both cost factors and service factors by adopting a quantitative approach, as well as looking at various risk management solutions by adopting a qualitative approach for improving supply chain management. This future research will help contribute further to the practical and theoretical tools necessary for practitioners in the real contact logistics and supply chain industry and for academic researchers in supply chain management.

Reference

Aghezzaf, E. (2004), *'Capacity planning and warehouse location in supply chains with uncertain demands'*, Journal of the Operational Research Society, Vol. 56, No. 4, pp. 453-462.

Aghezzaf, E.H. (2007), *'Production planning and warehouse management in supply networks with inter-facility mold transfers'*, European Journal of Operational Research, Vol. 182, No. 3, pp. 1122-1139.

American Production & Inventory Control Society (2007), *Supply Chain Management fundamentals*, Alexandria, Virginia: APICS.

Angel, B.W.F., Damme, D.A., Ivanovskaia, A., Lenders, R.J.M. and Veldhuijzen, R.S. (2006), *'Warehousing space in Europe: meeting tomorrow's demand',* The Netherlands, Capgemini consultants, ProLogis.

Chopra, S. and Meindl, P. (2007), *Supply Chain Management*, New Jersey, Pearson Prentice Hall.

Cormier, G. and Gunn, E. A. (1992), *'A review of warehouse models'*, European Journal of Operational Research, Vol. 58, No. 1, pp. 3-13.

Cormier, G. and Gunn, E.A. (1996), *'Simple Models and Insights for Warehouse Sizing'*, The Journal of the Operational Research Society, Vol. 47, No. 5, pp. 690-696.

ECMT (2002), *'Managing the fundamental drivers of transport demand'*, 16 December 2002. Belgium: ECMT

Fisher, M.L. (1997), *'What is the right supply chain for your product?'* Harvard Business Review, March-April, pp. 105-116.

Gu, J., Goetschalckx, M. and McGinnis, L.F. (2006), *'Research on warehouse operation: A comprehensive review'*, European Journal of Operational Research, Vol.

177, No. 1, pp. 1-21.

Holland International Distribution Council (2007), *'High quality, competitive costs: Benchmarking the Netherlands as Gateway to Europe'*, Zoetermeer, NDL/HIDC.

Holland International Distribution Council (2007), *'Advantages of centralized European Distribution through the Netherlands'*, Zoetermeer, NDL/HIDC.

Hung, M.S. and Fisk, J.C. (1984), *'Economic Sizing of Warehouses'*, Computers & Operations Research, Vol. 11, No, 1, pp. 13-18.

Gray. A. (2006), *'European warehousing report'*, UK, Jones Lang LaSalle.

Brissy. L. and Mitsostergiou. E. (2009), *'European Warehousing Markets'*, UK, Savills.

Keller, G. (2005), *'Statistics for management and economics'*, Mason, Thomson.

Lenders, R., Loon, E., Rustenburg, M. and Speksnijder, M. (2006), *'Europe's Most Wanted Distribution Center Locations: Result of a survey'*, The Netherlands, Capgemini consultants.

Kalfakakoua, R., Katsavounisb, S. and Tsourosa, K. (2003), *'Minimum number of warehouses for storing simultaneously compatible products'*, International Journal of Production Economics, Vol. 81-82, No. 11, pp. 559-564.

Koster, M.B.M. and Warffemius, P.M.J. (2005), *'American, Asian and third party international warehouse operations in Europe: A comparison'*, International Journal of Operation and Production Management, Vol. 25, No 8, pp. 762-780.

Koster, M.B.M. and Balk, B.M. (2008), *'Benchmarking and Monitoring International Warehouse Operations in Europe'*, Production and Operations Management, Vol. 17, No. 2, pp. 1-9.

Maister, D.H. (1976), *'Centralization of Inventories and the Square Root Law'*, International Journal of Physical Distribution, Vol. 6, No. 3, pp. 124-134.

Mark, G., Ou, J. and. Teo, C.P. (2001), *'Warehouse Sizing to Minimize Inventory and Storage Costs'*, Naval Research Logistics, Vol. 48, No. 4, pp. 299-312.

Mentzer, J.T., DeWitt, W. and Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. and Zacharia, Z.G. (2001), *'Defining supply chain management'*, Journal of Business Logistics, Vol. 22, No. 2, pp. 1-25.

Perl, J. and Daskin, M.S. (1985), *'A warehouse location-routing problem'*, Transportation Research Part B: Methodological, Vol. 19, No. 5, pp. 381-396.

Rao, A.K. and Rao, M.R. (1998), *'Solution procedures for sizing of warehouses'*, European Journal of Operational Research, Vol. 108, No. 1, pp. 16-25.

Rosenblatt, M.J. and Roll, Y. (1998), *'Warehouse capacity in a stochastic environment'*, International Journal of Production Research, Vol. 26, No. 12, pp. 1847-1851.

Stevens, G.C. (1990), *'Successful Supply-chain management'*, Management decision, Vol.28, No. 8, pp. 25-30.

Tan, K.C. (2001), *'A framework of supply chain management literature'*, European Journal of Purchasing & Supply Management, Vol. 7, No.1, pp. 39-48,

Transport Intelligence (2006), *'Global Logistics Strategy 2006'*, UK, Transport Intelligence.

Transport Intelligence (2006), *'Global Contract Logistics 2006: Outsourcing and Collaboration'*, UK, Transport Intelligence.

Transport Intelligence (2006*), 'Central and Eastern Europe Logistics Report 2007'*, UK, Transport Intelligence.

Transport Intelligence (2005), *'European Distribution Warehousing 2006'*, UK, Transport Intelligence.

Transport Intelligence (2007), *'European Transport & Logistics Markets 2007'*, UK, Transport Intelligence.

Tsiakis, P. Shah, N. and Pantelides, C.C. (2001), *'Design of Multi-echelon Supply Chain Networks under Demand Uncertainty'*, Industrial and Engineering Chemistry Research, Vol. 40, No. 16, pp. 3585-3604.

Velden, M. (2008), *'Simple Linear Regression', Statistics and Economics 6*. Handout, Erasmus University Rotterdam, Rotterdam, The Netherlands.

Appendix

Appendix 1. The contract storage space (ft²) in scenario one

Week	Space	Unit	Week	Space	Unit
Week 1	21,575	ft²	Week 27	21,575	ft²
Week 2	21,575	ft²	Week 28	21,575	ft²
Week 3	21,575	ft²	Week 29	21,575	ft²
Week 4	21,575	ft²	Week 30	21,575	ft²
Week 5	21,575	ft²	Week 31	21,575	ft²
Week 6	21,575	ft²	Week 32	21,575	ft²
Week 7	21,575	ft²	Week 33	21,575	ft²
Week 8	21,575	ft²	Week 34	21,575	ft²
Week 9	21,575	ft²	Week 35	21,575	ft²
Week 10	21,575	ft²	Week 36	21,575	ft²
Week 11	21,575	ft²	Week 37	21,575	ft²
Week 12	21,575	ft²	Week 38	21,575	ft²
Week 13	21,575	ft²	Week 39	21,575	ft²
Week 14	21,575	ft²	Week 40	21,575	ft²
Week 15	21,575	ft²	Week 41	21,575	ft²
Week 16	21,575	ft²	Week 42	21,575	ft²
Week 17	21,575	ft²	Week 43	21,575	ft²
Week 18	21,575	ft²	Week 44	21,575	ft²
Week 19	21,575	ft²	Week 45	21,575	ft²
Week 20	21,575	ft²	Week 46	21,575	ft²
Week 21	21,575	ft²	Week 47	21,575	ft²
Week 22	21,575	ft²	Week 48	21,575	ft²
Week 23	21,575	ft²	Week 49	21,575	ft²
Week 24	21,575	ft²	Week 50	21,575	ft²
Week 25	21,575	ft²	Week 51	21,575	ft²
Week 26	21,575	ft²	Week 52	21,575	ft²

Appendix 2. The contract storage space (ft²) in scenario two

Week	Space	Unit	Week	Space	Unit
Week 1	21,575	ft^2	Week 27	16,975	ft^2
Week 2	21,575	ft^2	Week 28	16,975	ft^2
Week 3	21,575	ft^2	Week 29	16,975	ft^2
Week 4	21,575	ft^2	Week 30	16,975	ft^2
Week 5	21,575	ft^2	Week 31	16,975	ft^2
Week 6	21,575	ft^2	Week 32	16,975	ft^2
Week 7	21,575	ft^2	Week 33	16,975	ft^2
Week 8	21,575	ft^2	Week 34	16,975	ft^2
Week 9	21,575	ft^2	Week 35	16,975	ft^2
Week 10	21,575	ft^2	Week 36	16,975	ft^2
Week 11	21,575	ft^2	Week 37	16,975	ft^2
Week 12	21,575	ft^2	Week 38	16,975	ft^2
Week 13	21,575	ft^2	Week 39	16,975	ft^2
Week 14	21,414	ft^2	Week 40	20,226	ft^2
Week 15	21,414	ft^2	Week 41	20,226	ft^2
Week 16	21,414	ft^2	Week 42	20,226	ft^2
Week 17	21,414	ft^2	Week 43	20,226	ft^2
Week 18	21,414	ft^2	Week 44	20,226	ft^2
Week 19	21,414	ft^2	Week 45	20,226	ft^2
Week 20	21,414	ft^2	Week 46	20,226	ft^2
Week 21	21,414	ft^2	Week 47	20,226	ft^2
Week 22	21,414	ft^2	Week 48	20,226	ft^2
Week 23	21,414	ft^2	Week 49	20,226	ft^2
Week 24	21,414	ft^2	Week 50	20,226	ft^2
Week 25	21,414	ft^2	Week 51	20,226	ft^2
Week 26	21,414	ft^2	Week 52	20,226	ft^2

Appendix 3. The contract storage space (ft^2) in scenario three

Week	Space	Unit	Week	Space	Unit
Week 1	15,109	ft^2	Week 27	9,504	ft^2
Week 2	15,109	ft^2	Week 28	9,504	ft^2
Week 3	15,109	ft^2	Week 29	9,504	ft^2
Week 4	15,109	ft^2	Week 30	9,504	ft^2
Week 5	15,109	ft^2	Week 31	9,504	ft^2
Week 6	15,109	ft^2	Week 32	9,504	ft^2
Week 7	15,109	ft^2	Week 33	9,504	ft^2
Week 8	15,109	ft^2	Week 34	9,504	ft^2
Week 9	15,109	ft^2	Week 35	9,504	ft^2
Week 10	15,109	ft^2	Week 36	9,504	ft^2
Week 11	15,109	ft^2	Week 37	9,504	ft^2
Week 12	15,109	ft^2	Week 38	9,504	ft^2
Week 13	15,109	ft^2	Week 39	9,504	ft^2
Week 14	10,514	ft^2	Week 40	9,182	ft^2
Week 15	10,514	ft^2	Week 41	9,182	ft^2
Week 16	10,514	ft^2	Week 42	9,182	ft^2
Week 17	10,514	ft^2	Week 43	9,182	ft^2
Week 18	10,514	ft^2	Week 44	9,182	ft^2
Week 19	10,514	ft^2	Week 45	9,182	ft^2
Week 20	10,514	ft^2	Week 46	9,182	ft^2
Week 21	10,514	ft^2	Week 47	9,182	ft^2
Week 22	10,514	ft^2	Week 48	9,182	ft^2
Week 23	10,514	ft^2	Week 49	9,182	ft^2
Week 24	10,514	ft^2	Week 50	9,182	ft^2
Week 25	10,514	ft^2	Week 51	9,182	ft^2
Week 26	10,514	ft^2	Week 52	9,182	ft^2

Appendix 4. The contract storage space (ft^2) in scenario four

Week	Space	Unit	Week	Space	Unit
Week 1	18,010	ft^2	Week 27	13,282	ft^2
Week 2	18,010	ft^2	Week 28	13,282	ft^2
Week 3	18,010	ft^2	Week 29	13,282	ft^2
Week 4	18,010	ft^2	Week 30	13,282	ft^2
Week 5	18,010	ft^2	Week 31	13,282	ft^2
Week 6	18,010	ft^2	Week 32	13,282	ft^2
Week 7	18,010	ft^2	Week 33	13,282	ft^2
Week 8	18,010	ft^2	Week 34	13,282	ft^2
Week 9	18,010	ft^2	Week 35	13,282	ft^2
Week 10	18,010	ft^2	Week 36	13,282	ft^2
Week 11	18,010	ft^2	Week 37	13,282	ft^2
Week 12	18,010	ft^2	Week 38	13,282	ft^2
Week 13	18,010	ft^2	Week 39	13,282	ft^2
Week 14	17,536	ft^2	Week 40	15,558	ft^2
Week 15	17,536	ft^2	Week 41	15,558	ft^2
Week 16	17,536	ft^2	Week 42	15,558	ft^2
Week 17	17,536	ft^2	Week 43	15,558	ft^2
Week 18	17,536	ft^2	Week 44	15,558	ft^2
Week 19	17,536	ft^2	Week 45	15,558	ft^2
Week 20	17,536	ft^2	Week 46	15,558	ft^2
Week 21	17,536	ft^2	Week 47	15,558	ft^2
Week 22	17,536	ft^2	Week 48	15,558	ft^2
Week 23	17,536	ft^2	Week 49	15,558	ft^2
Week 24	17,536	ft^2	Week 50	15,558	ft^2
Week 25	17,536	ft^2	Week 51	15,558	ft^2
Week 26	17,536	ft^2	Week 52	15,558	ft^2

Appendix 5. Optimal contract storage space (ft²) in yearly contract

Week	Space	Unit	Week	Space	Unit
Week 1	20,439	ft²	Week 27	20,439	ft²
Week 2	20,439	ft²	Week 28	20,439	ft²
Week 3	20,439	ft²	Week 29	20,439	ft²
Week 4	20,439	ft²	Week 30	20,439	ft²
Week 5	20,439	ft²	Week 31	20,439	ft²
Week 6	20,439	ft²	Week 32	20,439	ft²
Week 7	20,439	ft²	Week 33	20,439	ft²
Week 8	20,439	ft²	Week 34	20,439	ft²
Week 9	20,439	ft²	Week 35	20,439	ft²
Week 10	20,439	ft²	Week 36	20,439	ft²
Week 11	20,439	ft²	Week 37	20,439	ft²
Week 12	20,439	ft²	Week 38	20,439	ft²
Week 13	20,439	ft²	Week 39	20,439	ft²
Week 14	20,439	ft²	Week 40	20,439	ft²
Week 15	20,439	ft²	Week 41	20,439	ft²
Week 16	20,439	ft²	Week 42	20,439	ft²
Week 17	20,439	ft²	Week 43	20,439	ft²
Week 18	20,439	ft²	Week 44	20,439	ft²
Week 19	20,439	ft²	Week 45	20,439	ft²
Week 20	20,439	ft²	Week 46	20,439	ft²
Week 21	20,439	ft²	Week 47	20,439	ft²
Week 22	20,439	ft²	Week 48	20,439	ft²
Week 23	20,439	ft²	Week 49	20,439	ft²
Week 24	20,439	ft²	Week 50	20,439	ft²
Week 25	20,439	ft²	Week 51	20,439	ft²
Week 26	20,439	ft²	Week 52	20,439	ft²

Appendix 6. Optimal contract storage space (ft^2) in half-yearly contract

Week	Space	Unit	Week	Space	Unit
Week 1	21,414	ft^2	Week 27	20,138	ft^2
Week 2	21,414	ft^2	Week 28	20,138	ft^2
Week 3	21,414	ft^2	Week 29	20,138	ft^2
Week 4	21,414	ft^2	Week 30	20,138	ft^2
Week 5	21,414	ft^2	Week 31	20,138	ft^2
Week 6	21,414	ft^2	Week 32	20,138	ft^2
Week 7	21,414	ft^2	Week 33	20,138	ft^2
Week 8	21,414	ft^2	Week 34	20,138	ft^2
Week 9	21,414	ft^2	Week 35	20,138	ft^2
Week 10	21,414	ft^2	Week 36	20,138	ft^2
Week 11	21,414	ft^2	Week 37	20,138	ft^2
Week 12	21,414	ft^2	Week 38	20,138	ft^2
Week 13	21,414	ft^2	Week 39	20,138	ft^2
Week 14	21,414	ft^2	Week 40	20,138	ft^2
Week 15	21,414	ft^2	Week 41	20,138	ft^2
Week 16	21,414	ft^2	Week 42	20,138	ft^2
Week 17	21,414	ft^2	Week 43	20,138	ft^2
Week 18	21,414	ft^2	Week 44	20,138	ft^2
Week 19	21,414	ft^2	Week 45	20,138	ft^2
Week 20	21,414	ft^2	Week 46	20,138	ft^2
Week 21	21,414	ft^2	Week 47	20,138	ft^2
Week 22	21,414	ft^2	Week 48	20,138	ft^2
Week 23	21,414	ft^2	Week 49	20,138	ft^2
Week 24	21,414	ft^2	Week 50	20,138	ft^2
Week 25	21,414	ft^2	Week 51	20,138	ft^2
Week 26	21,414	ft^2	Week 52	20,138	ft^2

Appendix 7. Optimal contract storage space (ft²) in quarterly contract

Week	Space	Unit	Week	Space	Unit
Week 1	21,575	ft²	Week 27	16,975	ft²
Week 2	21,575	ft²	Week 28	16,975	ft²
Week 3	21,575	ft²	Week 29	16,975	ft²
Week 4	21,575	ft²	Week 30	16,975	ft²
Week 5	21,575	ft²	Week 31	16,975	ft²
Week 6	21,575	ft²	Week 32	16,975	ft²
Week 7	21,575	ft²	Week 33	16,975	ft²
Week 8	21,575	ft²	Week 34	16,975	ft²
Week 9	21,575	ft²	Week 35	16,975	ft²
Week 10	21,575	ft²	Week 36	16,975	ft²
Week 11	21,575	ft²	Week 37	16,975	ft²
Week 12	21,575	ft²	Week 38	16,975	ft²
Week 13	21,575	ft²	Week 39	16,975	ft²
Week 14	21,414	ft²	Week 40	20,226	ft²
Week 15	21,414	ft²	Week 41	20,226	ft²
Week 16	21,414	ft²	Week 42	20,226	ft²
Week 17	21,414	ft²	Week 43	20,226	ft²
Week 18	21,414	ft²	Week 44	20,226	ft²
Week 19	21,414	ft²	Week 45	20,226	ft²
Week 20	21,414	ft²	Week 46	20,226	ft²
Week 21	21,414	ft²	Week 47	20,226	ft²
Week 22	21,414	ft²	Week 48	20,226	ft²
Week 23	21,414	ft²	Week 49	20,226	ft²
Week 24	21,414	ft²	Week 50	20,226	ft²
Week 25	21,414	ft²	Week 51	20,226	ft²
Week 26	21,414	ft²	Week 52	20,226	ft²

Appendix 8. Optimal contract storage space (ft²) in monthly contract

Week	Space	Unit	Week	Space	Unit
Week 1	17,006	ft²	Week 27	12,326	ft²
Week 2	17,006	ft²	Week 28	12,326	ft²
Week 3	17,006	ft²	Week 29	12,326	ft²
Week 4	17,006	ft²	Week 30	12,326	ft²
Week 5	17,006	ft²	Week 31	12,326	ft²
Week 6	18,196	ft²	Week 32	14,743	ft²
Week 7	18,196	ft²	Week 33	14,743	ft²
Week 8	18,196	ft²	Week 34	14,743	ft²
Week 9	18,196	ft²	Week 35	14,743	ft²
Week 10	21,575	ft²	Week 36	16,975	ft²
Week 11	21,575	ft²	Week 37	16,975	ft²
Week 12	21,575	ft²	Week 38	16,975	ft²
Week 13	21,575	ft²	Week 39	16,975	ft²
Week 14	21,414	ft²	Week 40	16,975	ft²
Week 15	21,414	ft²	Week 41	17,714	ft²
Week 16	21,414	ft²	Week 42	17,714	ft²
Week 17	21,414	ft²	Week 43	17,714	ft²
Week 18	21,414	ft²	Week 44	17,714	ft²
Week 19	19,070	ft²	Week 45	20,226	ft²
Week 20	19,070	ft²	Week 46	20,226	ft²
Week 21	19,070	ft²	Week 47	20,226	ft²
Week 22	19,070	ft²	Week 48	20,226	ft²
Week 23	17,985	ft²	Week 49	13,968	ft²
Week 24	17,985	ft²	Week 50	13,968	ft²
Week 25	17,985	ft²	Week 51	13,968	ft²
Week 26	17,985	ft²	Week 52	13,968	ft²