A framework to select and assign a CODP and corresponding inventory control policy to the different end products in food processing industry

The framework consists of two models: a multi-criteria inventory classification and a 0-1 integer linear programming (ILP) model. Both models assign a CODP and corresponding inventory control policy to the different end products by considering perishability, service levels, and inventory capacity. A (r, Q) inventory control model is used to consider inventory capacity. The results of both models are compared. Moreover, a tool is made from the framework, so the company can reuse the framework easily.

Lieke Ebrecht

Master Thesis

MSc Industrial Engineering & Management
Production & Logistics Management

University of Twente

Holten, 23-07-2019

A framework to select and assign a CODP and corresponding inventory control policy to the different end products in food processing industry

Master Thesis

Industrial Engineering & Management
Production & Logistics Management

Name: Lieke Ebrecht
Student Number: S1490796
Phone number: +316-10324669

July 23, 2019

Supervisors of University of Twente:

Dr. E. Topan
Faculty of Behavioral Management and Social Science
Phone number: +31 53 489 3143

Dr. I. Seyran Topan
Faculty of Behavioral Management and Social Science

Information of food processing company:

CONFIDENTIAL

UNIVERSITY
OF TWENTE.

Management summary

This research is conducted at the supply chain department of a food processing company. The company, located in the Netherlands, is a production company that produces food. The companies producing food have to consider the enormous growth and changes in the market. The food processing company has to meet a service level of 99% to satisfy her customers, while cost have to be reduced. Therefore, to be able to be competitive, striving for an optimal supply chain is required for the food processing company. However, the supply chain of the food processing company is not optimal; the service levels are below target and the costs can be reduced by one third by balancing the inventory. To fulfill this aim, the food processing industry started with the implementation of the forecasting and inventory management system called Slimstock. The basis for a well-functioning system is having the correct values of all inputs, which is missing at the moment. Since the inventory management part of the system is new, the inputs related to the inventory management, which includes the CODP determination and the inventory control policy for each item, are the important ones. We focus on the end products, since starting from the customer viewpoint, the demand of end products is most important, and therefore the start point. Moreover, in food processing industry, perishability of items is most challenging. Therefore, this research focuses on the fresh end products from the food processing industry. Therefore, this research answers the following main research question:

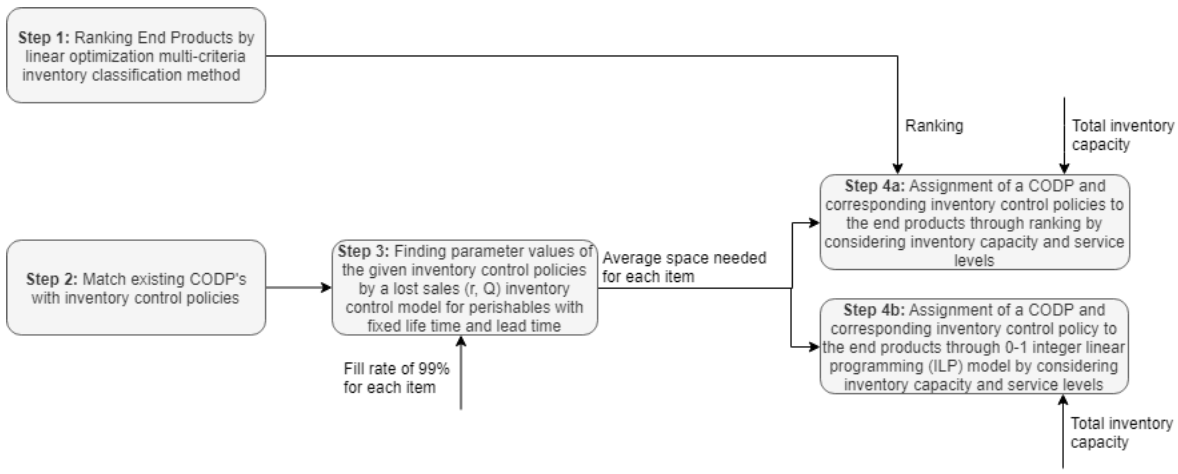
How can a framework that selects and assigns a CODP and corresponding inventory control policy to different end products in food processing industry be created and implemented?

Currently, from the 224 end products, 201 end products are assigned as make-to-stock item (MTS) items, while the remaining 23 end products are assigned as make-to-order (MTO) items. This CODP partition is based on common sense. In addition, at first sight, it seems that many items are make-to-stock items, which the food processing company prefers in order to meet a service level of 99%. However, due to the shelf-life of items the planners seem to be very careful with setting items in inventory, which means that items are treated as make-to-stock and make-to-order depending on the customer orders for the next few days. This results in a hybrid MTO/MTS system per item. By making a production and packaging planning on common sense rather than using policies, there is a risk that the items are not in stock or exceeding the best before date when too much

stock is built. This results in suboptimal service and inventory levels. Moreover, the make-to-order/make-to-stock decision is only based on demand and best before date, while in a food processing company other criteria can also be important as well, like the limited inventory capacity. The CODP partition is crucial as input for Slimstock, since Slimstock does calculations based on these inputs to decide how much and when production will take place to fulfill the customer demand in time. Moreover, an optimal partition of the make-to-order/make-to-stock items provides cost reduction in inventory while the delivery reliability will be met (van Donk, 2001). Concluding, an optimal determination of the CODP and corresponding inventory control policy adds value in implementing Slimstock to improve the service levels and reduce the cost.

To be able to answer the research question, we review literature on CODP decision in food processing industries, multi-criteria inventory classification, and inventory control models that consider perishability. Reviewing inventory control models is needed to be able to consider the limited inventory capacity. By using an inventory control model, the inventory space needed for all items can be calculated by finding the optimal parameter values. Note that the sum of the inventory space needed for all make-to-stock items has to be lower than the maximum inventory capacity. The inventory control model has to match the inventory control model that uses Slimstock to get equivalent policies.

In order to select and assign a CODP and corresponding inventory control policy to different end products, a framework is designed. The flow diagram of the framework is represented below. Arrows define an input for the next step. As can be seen, the framework consists of four steps: ranking the end products, match CODP's with inventory control policies, finding parameter values of the given inventory control policies, and assigning of a CODP and corresponding inventory control policy to the end products. Assigning of a CODP and corresponding inventory control policy to the end products can be done by both using the ranking model (step 4a) and the 0-1 integer linear programming (ILP) model (step 4b). As can be seen, step 1 is only needed for step 4a.



The framework contributes to the literature, since the literature lacks a user-friendly quantitative model to decide the CODP of item in the food processing industry. The framework contains a ranking method and an inventory model that come from the literature. To take into account meeting a service level, we add a service level constraint to the inventory model. The 0-1 ILP model is made by ourselves.

Due to the constantly changing environment the framework is implemented in Excel by using Visual Basic for Applications (VBA) to be able to reuse the framework easily. The results from both models can be produced by using this tool. Employees only have to insert the needed data and press the button to get the solution. Therefore, the tool is user-friendly.

To check whether the framework meets the requirements and specifications, we verify the proposed tool by running analyses on the limited inventory capacity, ranking method, and the normal distribution approximation used in the inventory model. In all cases, the proposed tool meets the requirements and specifications. Moreover, to check whether the model fulfills its intended purpose, we validate on the policy parameters and classifications. We validate by asking expert opinion and putting the current situation in the 0-1 ILP model. Finally, although we use indications for all cost parameters, since details are too confidential, the average space needed per item seem not far from reality and the classifications make sense. Unfortunately, another validation method is not possible, since the project about implementing new supply chain systems is behind schedule, which means that Slimstock is not implemented yet. Moreover, unfortunately, Slimstock does not have a test environment, and the current planning system does not have the required data.

When comparing the ranking model to the 0-1 ILP model, we can conclude that, even though the 0-1 ILP model is not entirely exact, the 0-1 ILP model is still better than the heuristic approach, which refers to the ranking model. In case of the 0-1 ILP model, the total cost per year and overall service level is equal to €17,785,066 and 94%, respectively. In case of the ranking model, the total cost per year and the overall service level are, respectively, €4,132,879 higher and 8% lower. Note that the cost and service levels are based on the framework and not based on the real world. In addition, based on the classification, the 0-1 ILP model classifies better. Moreover, the total computation time from the 0-1 ILP model is equal to 5 minutes and is, thereby, twice as fast as the ranking model.

To find out how and to what extent the solution depends on the input parameters, we did sensitivity analysis. Using the maximum inventory space needed per item rather than the average inventory space needed does not influence the results. On the other hand, the criteria selection, lost sales cost and standard deviation of the lead time of the make-to-order items do influence the results. By removing food processing industry related criteria, the service levels become lower. The higher the lost sales cost and standard deviation, the higher the cost and the lower the overall average service level. Moreover, the classification will be different in all cases. Therefore, it is crucial to consider the criteria selection and make good assumptions.

We compare the results of the proposed tool to the current situation by putting the current situation in the 0-1 ILP model. Note that, unfortunately, putting our suggestions in Slimstock is not possible. The results of both models are better than the current situation. The total costs per year in case of the ranking model and the 0-1 ILP model are, respectively, 24% and 29% lower than in the current situation. The overall average service level in case of the ranking model and the 0-1 ILP model are, respectively, 2.4% and 13.3% higher than in case of the current situation.

Concluding, the results of the proposed tool have a positive impact on the service level and total cost per year. By feeding Slimstock with the suggested CODP and corresponding inventory control policy for each end product, the service level will be improved and the cost will be reduced by balancing the inventory. By using the 0-1 ILP model, the target values of the supply chain key performance indicators will be reached; the make-to-stock items will have a service level of 99% and the cost will reduced by 29%, which is equal to one third. In addition, the overall average service level is equal to 94%. Note that the overall average service level can never reach the 99% in the proposed framework and may be higher in real case, since we use a standard deviation of the lead time of the make-to-order items of one day to cover some uncertainties, which means that the service levels of the make-to-order items may be higher in real case. Note also that the accuracy of the values of the input is a strict requirement of the 0-1 ILP model. In case of doubt about the accuracy of the values of the input, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results.

For implementation, standardizing logistics tasks, standardizing data implementation, and running the tool with the correct values of the cost parameters is required. In addition, to be able to run the tool, the OpenSolver for Excel has to be downloaded. Moreover, we have to explain the proposed tool to the employees and convince them of the results. Although the proposed model is user-friendly and knowledge about the subjects is not a necessity, it is good to have some background about the models to understand them, in order to potentially spot flaws and incorrect outcomes of calculations. This will prevent people from uninformed copying of the outcomes and instead support informed decisions are taken. Moreover, employees have to support the results in order for them to implement the results.

UNIVERSITY
OF TWENTE.

Acknowledgements

This thesis is the final result for completion of the *Production & Logistics Management* specialization of the Industrial Engineering and Management Master's degree at University of Twente. I am glad to get the opportunity to conduct my research at the food processing company. Therefore, I would like to thank the food processing company for this opportunity. Especially, I would like to thank my supervisor for his guidance and the great collaboration. In addition, I would like to thank all my colleagues for the great time and their helpfulness.

Moreover, I would like to thank my first supervisor from University of Twente Engin Topan for the helpful meetings, valuable feedback, and support. I would also like to thank my second supervisor Ipek Topan for her feedback and support in the last stages of the project.

I wish you a lot of pleasure in reading my Master Thesis.

Lieke Ebrecht

Holten, 23-07-2019

Contents

List of Figures

List of Tables

List of abbreviations

Integer linear programming	ILP
Analytic Hierarchy Process	AHP
Lot for Lot	L4L
Make-to-order	MTO
Make-to-stock	MTS
Stock Keeping Unit	SKU
Customer order decoupling point	CODP

Chapter 1

Introduction

The market in which the food processing company acts, is growing rapidly. In the Netherlands, over the last five years the market has grown by 12% and the expected growth is 6% and 8% in 2018 and 2019, respectively. Besides, due to a change in customer demands over the last decade, food processing industries have to deliver a greater variety of products and have to meet higher logistical demands, while keeping costs as low as possible (van Donk, 2001). Therefore, the companies producing food have to consider the enormous growth and changes in the market to be able to be competitive.

To be able to be competitive, striving for an optimal supply chain is required for the food processing company. However, the food processing company observes inefficiencies in the supply chain. Therefore, this research is about improving the supply chain. In more detail, the research is about setting the right values for the input parameters needed for the inventory management planning systems. According to Nagib (2016), inventory management is vital in the food and beverage processing industry as it involves the perishability of the items despite the costs.

This chapter introduces the research subject and elaborates the research plan. Section 1.1 introduces the food processing company. Section 1.2 and section 1.3 describe the research motivation and the problem description, respectively. In section 1.4 the scope and limitations of this research will be described, followed by the objective of this research in section 1.5. Finally, section 1.6 and 1.7 represent the research questions and the research plan, and the deliverables of this research.

1.1 The food processing company

CONFIDENTIAL

1.2 Research motivation

Starting from 2017, the supply chain manager observed an inefficient supply chain. The service levels are lower than the target service levels due mainly to missing end products. According to him, the performance of the supply chain can be improved. Therefore, in 2017, the food processing company started with the optimization of the supply chain. Especially, the food processing company focused on the development of the supply chain planning tool. In the end of 2018, some new supply chain systems, i.e. the forecasting and inventory management system (Slim4) and the planning system, were introduced to improve the supply chain performance. Working with these systems provides for further automation of the supply chain. Determining, filling and maintaining the input of these supply chain systems are essential for functioning properly. At the moment, the food processing industry is in the middle of the transition. The next step is to give the systems the right input.

To date, the database used for the systems contains several inputs per semi-finished products and end products. The database is not up to date and unclear with regards to the necessary inputs. Besides, the supply chain manager knows for sure that many inputs are based on common sense rather than data. What the supply chain manager actually wonders is: which semi-finished products and end products need which inputs and how can these inputs be determined to get well-functioning systems?

Because of the supply chain performance improvement project with regards to the supply chain systems, determining, filling and maintaining the input is essential for a well-functioning system. Well-functioning systems will lead to a stronger supply chain and a stronger supply chain influences the companies success indirectly. Therefore, determining the needed inputs is essential to let the project succeed.

1.3 Problem statement

The food processing company started with implementing the new supply chain systems Slim4 and scheduling system to improve the supply chain performance. The supply chain performance is defined as service level and the total on hand in inventory (cost). The goal of implementing the new systems is meeting a service level of 99% per item and reducing the inventory (cost) by one third by balancing the inventory level. We define the service level of a make-to-stock item as the number of quantities delivered from stock in time divided by the total quantity of the demand (Nahmias & Olsen, 2015), which is equal to the fill rate. The service level of a make-to-order item is defined as the probability that an item is too late. The current supply chain performance of the food processing company is described below.

Table 1.1 represents the average service level in 2018 and 2019, respectively. Due to the market requirements, the food processing company has to meet a service level of 99% per item to be able to be competitive. In all situations, the average service level is below the 99%. Note that these service levels are based on all kind of sales items, i.e. bulk, frozen, and fresh items.

Table 1.1: Average service level

	2018	**2019**
Service level	93%	95%

The food processing company measures the inventory on hand by using the balance of coverage. Figure 1.1 represents the ideal balance of coverage, with the number of items on the y-axis and the number of weeks in inventory on the x-axis. The number of weeks in inventory represents the on hand inventory expressed in weeks. There exists an ideal number of weeks in inventory for each item. For the food processing company, the ideal number of weeks in inventory of the semi-finished and the end-products is equal to three weeks and two days, respectively. When the number of weeks in inventory is lower or higher than the ideal, the food processing company will face backorders or the shelf-life of the items will be exceeded. Naturally, there are always several items that deviate from the ideal number of weeks in inventory for several reasons. Keep in mind that this is an average measure rather than an exact measure. When the balance of coverage follows a normal distribution with a mean equal to the ideal number of weeks in inventory, the total inventory of the food processing company is balanced.

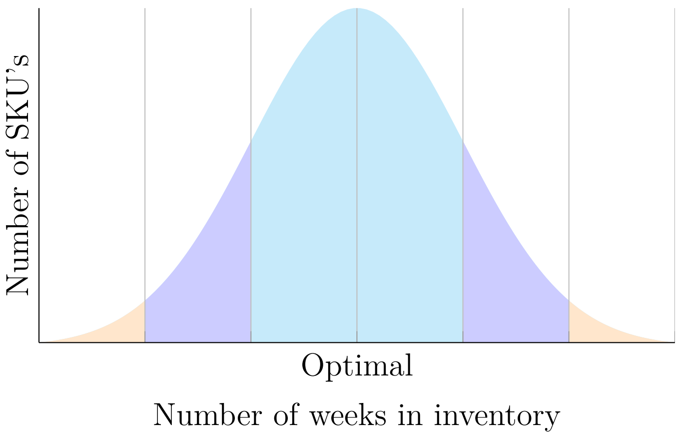
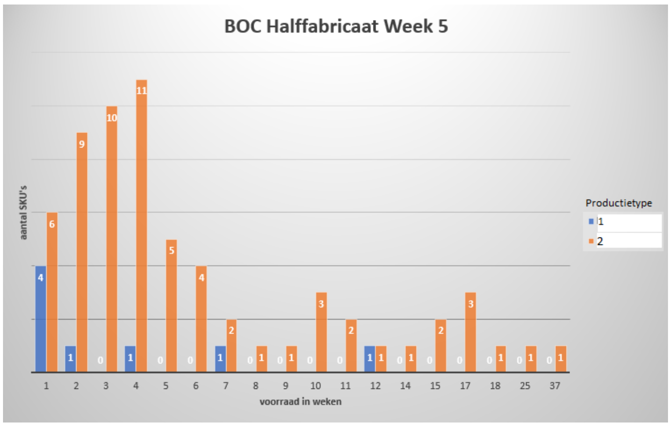
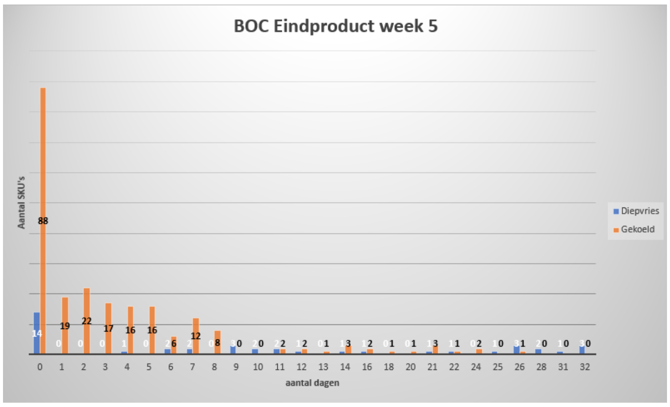


Figure 1.1: The ideal balance of coverage

The food processing company updates the balance of coverage every week. Figure 1.2 represents, respectively, the balance of coverage of the semi-finished products and the end products of the food processing company from week 5 in 2019. At the moment, the inventory is not balanced. In many cases, the right raw materials and semi-finished products are not in stock to produce and package the needed products. However, other raw materials and semi-finished products are in large quantities on stock. Most notably, the balance of coverage of the semi-finished products shows a peak at four weeks and a reasonable number of SKU's are in stock for longer than ten weeks, and the balance of coverage of the end-products shows a peak at zero days. The reason for the last observation have many reason, e.g. the optimal quantity for certain items are not in stock. In summary, the number of semi-finished products and end-products in stock can be balanced and reduced.



(a) Balance of coverage of semi-finished products



(b) Balance of coverage of end products

Figure 1.2: The balance of coverage of the food processing company

Concluding, both performances can be improved. The current average service level is below 99% and the total cost can be reduced by balancing the inventory. Implementing the new planning systems have to improve this performance. However, the new planning systems have to function properly to support increased service level and reduce the costs.

The basis for a well-functioning supply chain planning system is determining, filling and maintaining the inputs. At the moment, this basis of the new supply chain planning system from the food processing company is missing. To be able to find the main problem, we visualize the problem by a problem cluster, which is represented in figure 1.3. Each box refers to a problem, which is stated by a number. Firstly, many inputs needed for the supply chain planning systems, in this case the forecasting and inventory control system (Slim4) and the planning system, are based on common sense [1]. The make-to-order/make-to-stock decision is an example of a common sense-based input. Determining the inputs based on calculations gives much more certainty and will improve the performance of the supply chain, since the right ones will be on stock with the optimal quantity, which ensures that the service levels will be met and the cost will be reduced. In addition, at the moment, the food processing company does not maintain the inputs [2], while elements in the supply chain are constantly changing due to the growth impact. Therefore, once the inputs are determined, maintaining the inputs is essential to keep the correct values of the inputs. Moreover, there is no clear overview of the needed inputs [3]. These three problems result in wrong/misleading or missing inputs [4]. The basis for a well-functioning supply chain planning system is missing, which leads to a system that is functioning improperly [5]. And therefore, the supply chain planning systems may not provide the right optimal decisions but rather suboptimal decisions, which create inefficiency in the planning [6]. Because of inefficiency in the planning, the supply chain performance goal, which is explained above, can not be achieved [7]. Moreover, the implementation of the new systems risk to be wasted time and money [8].

In summary, the main problem is that many inputs needed for the supply chain planning systems are based on common sense rather than calculations. By implementing the new systems, setting the correct values of the inputs is crucial to be able to let them function properly, since this leads to the achievement of the performance goal. Maintaining the inputs and creating a clear overview are only important after solving the problem of reliable values of the inputs.

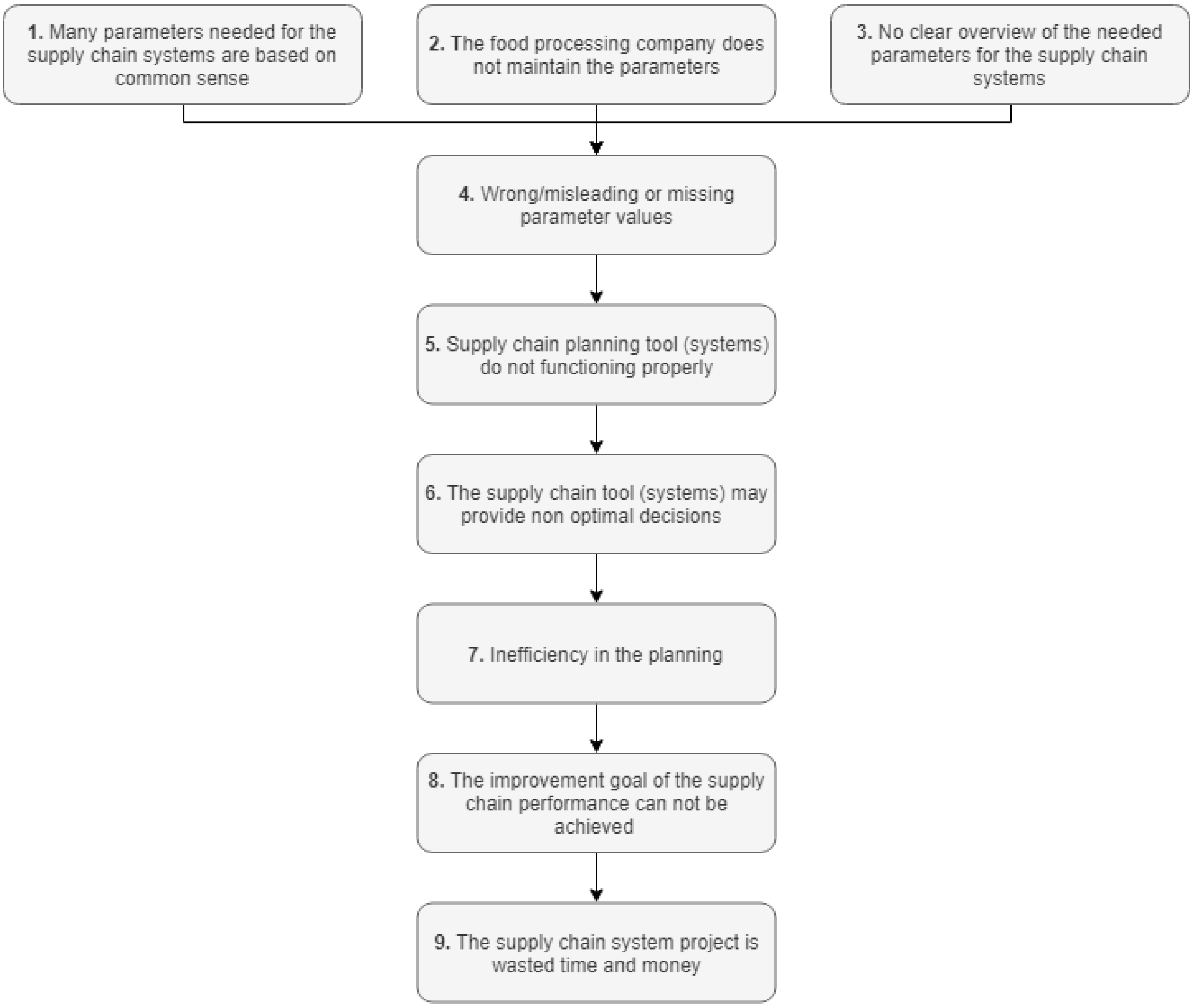


Figure 1.3: Problem cluster

1.4 Scope and limitations

The food processing company has to deal with many inputs needed for the supply chain systems. Although there are many inputs which are fixed or the food processing company has no influence on these inputs, there are also inputs that the food processing company does influence. The updated Slim4 will provide, in addition to forecasting, also inventory management and therefore the Slim4 needs many new inputs to function properly. Moreover, the results of Slim4 are input for the planning system. Therefore, the inputs related to inventory control are crucial to improve the service levels, and reduce the cost. The inputs related to the inventory control are the CODP and corresponding inventory control policy for each item. An optimal partition of the make-to-order/make-to-stock items provides cost reduction in inventory while the delivery reliability will be met (van

Donk, 2001), which results in an improvement of the supply chain.

To be able to conduct this research within the restricted time, this research is only limited to the inputs mentioned above.

In addition, the food processing company has multiple levels on which inventory can be held. These are the raw material level, intermediate level, and the finished product level. Starting from the customer viewpoint, the demand of end products is most important and therefore the start point. The decisions on the finished product level will then influence the other levels. Therefore, this research is limited to the products on the finished product level, from now called the end products. Note that there are also products at the intermediate level that are directly sold to the customer. These products are the purchase products and products that are sold in bulk. These products are out of this scope of this research.

Furthermore, an important aspect of this research is the perishability of products in food processing industries, which makes this research unique and challenging. We define a perishable item as one that has constant utility up until an expiration date (which may be known or uncertain), at which point the utility drops to zero (Nahmias, 2011). The end products of the food processing company can be divided in fresh and frozen products. This research is limited to the fresh products, since frozen products have nothing to do with perishability of products, and therefore frozen products have to be treated differently. So from now on, when we talk about end products or items, we mean the fresh end products at the finished product level.

1.5 Research objective

Concluding from the above sections, the main objective of this research is to improve the supply chain by implementing a new framework to select and assign a CODP and corresponding inventory control policy to the different end products in food processing industry. These will be inputs for the forecasting and inventory control system Slimstock. The supply chain system will then have the correct inventory management inputs, which will lead to an improvement in the production and packaging planning. Because of the fact that the planning is responsible for the balanced inventory level and the customer service level, an improvement in the planning provides an improvement in the supply chain performance. By selecting and assigning CODP's and corresponding inventory control policies, we have to consider the perishability of items and the limited inventory capacity in food processing industries, which are the challenging aspects of this research.

We define the research objective as:

Create and implement a framework to select and assign a CODP and corresponding inventory control policy to the different end products

in food processing industry to improve the supply chain performance by increasing the customer service level, and reducing the cost by balancing the inventory indirectly.

Note that the framework will not increase the service level and reduce cost directly, since the result of the framework is input for the inventory control and planning system Slimstock, and Slimstock will improve the supply chain performance. Many other aspects than just the result of our framework will ensure for a well-functioning system, and the well-functioning system ensures for an improvement in the supply chain.

1.6 Research questions

To reach our research objective, we will define the main research questions followed by sub research questions.

We define the main research question as:

How can a framework that selects and assigns a CODP and corresponding inventory control policy to different end products in food processing company be created and implemented?

To answer the main research questions, the following sub research questions are defined.

1. *What is the current forecasting and planning system at the food processing company?*

    a. *How is the supply chain organized and how does the supply chain perform?*

    b. *What end products are produced according to a make-to-order, make-to-assembly or make-to-stock strategy, and how is this determined?*

    c. *Which inventory control policy is used?*

    Chapter 2 elaborates the current situation at the food processing company. In order to gain insight in the current situation, the supply chain and the forecasting and planning systems used will be explained first. Thereafter, we discuss the current selection of make-to-order, make-to-assembly, and make-to-stock products at the food processing company. Finally, the inventory control policy used is discussed.

2. *Which methods are available in the literature to select and assign a CODP and corresponding inventory control policy to different end products in the food processing industry?*

a. *Which methods are available in the literature for CODP determination in the food processing industry?*

b. *Which methods are available in the literature for multi-criteria inventory classification in the food processing industry?*

c. *Which methods are available in the literature for parameter setting of the inventory control policies considering perishability?*

Chapter 3 represents several literature reviews. Firstly, a literature review on the CODP decision in food processing industry is performed to be able to select and assign inventory control policies. This literature review provides a useful framework to select and assign both the CODP and inventory control policy to the products. To use this framework in the food processing industry, some adjustments have to be done. Therefore, a literature review on multi-criteria inventory classification is performed to consider perishability of products, followed by a literature review on parameter setting of the inventory control policies considering perishability of products to be able to deal with limited inventory capacity in food processing industries.

3. *How can a framework be built to select and assign a CODP and corresponding inventory control policy to different end products in food processing industry?*

   a. *How can the multi-criteria inventory classification to rank the products be applied in food processing industry?*

   b. *How can inventory control policies be matched with the existing CODP's in food processing industry?*

   c. *How can the parameter values of the given inventory control policies be determined considering the perishability of products?*

   d. *How can the CODP's and the corresponding replenishment policies assigned to the end products considering limited inventory capacity in food processing industry?*

   Chapter 4 describes the proposed framework to assign a CODP and corresponding inventory policy to different end products in food processing industry. The framework consists of two different approaches: one approach by using multi-criteria inventory classification and the other by using an 0-1 ILP model. The framework will be implemented with both approaches and then the models will be compared.

4. *How can the proposed framework be applied to the food processing company?*

5. *What is the effect of implementing the proposed framework on the performance of the supply chain of the food processing company?*

   Chapter 5 provides the proposed framework applied to the food processing company. First, the model is tested, which implies the results of both models, a comparison of the both models, a verification and validation of the model, sensitivity analysis, and model comparison to the current situation. Moreover, we evaluate the model. In the end, a conclusion is drawn.

Finally, chapter 6 provides conclusions and recommendations for the food processing company.

1.7 Deliverables

This research provides an user-friendly tool to assign CODP and the corresponding inventory policy to the end products of the food processing company. This tool can be used periodically in an easy way. In this way, the food processing company can respond to the constantly changing environment. Moreover, we run the tool in order to produce and analyze the results. The results of the tool can be implemented in the forecasting and inventory control system Slimstock, which will lead to an improvement of the supply chain; increasing service levels and reducing cost.

Chapter 2

Context analysis

This chapter elaborates the current situation at the food processing company, and answers therefore the first sub question: *"What is the current forecasting and planning system at the food processing company?"*. Section 2.1 represents the supply chain of the food processing company. Section 2.2 describes the systems used by the food processing company to make their production and packaging planning. Finally, section 2.3 elaborates which product is either produced according to a make-to-order or make-to-stock strategy.

2.1 Supply chain of food processing company

Section 1.3 already described the performance of the supply chain. In this section the supply chain of the food processing company will be explained. Since the detailed supply chain of the food processing company is confidential, a comprehensive supply chain is represented. Figure 2.1 represents the supply chain of the food processing company.

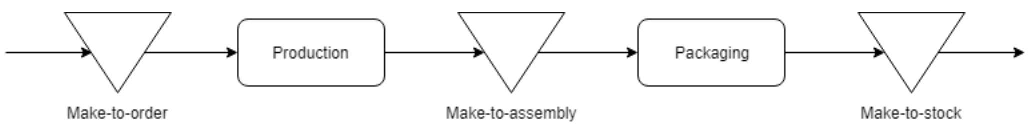


Figure 2.1: Schematic supply chain of the food processing company

First, the raw materials go into production. The produced products will be stocked at the intermediate stock point. These products will be packaged and stocked at the finished stock point. As can be seen, food processing companies have three decoupling points, namely make-to-order, make-to-assembly, and make-to-stock. Note that a description of the detailed supply chain is left out, since this information is too confidential.

The food processing company has a low inventory capacity of the end products compared to the production capacity of packaging. Therefore, the inventory capacity of the end product is a bottleneck.

In summary, making decisions in end products inventory influences the decision making in all other inventory points. In addition, in contrast to the other outgoing products, the flow of the end products is complex, i.e. the perishability of products play a role. Moreover, end products provide by far the largest part of the total sales. Concluding, end products inventory is the most critical one, and therefore this research is limited to the end products.

2.2 The supply chain planning tool (systems)

The supply chain planning tool allows the food processing company to make an effective and efficient production and packaging planning. The food processing company uses three different systems to make their production and packaging planning. These systems are the ERP system, Slim4, and a custom made planning tool. The ERP system is the database of the food processing company. This system contains all information about the several products, suppliers, customers, etcetera. Slim4 software is a system designed by the company Slimstock. Slim4 provides input, like forecasting of the demand, for the custom made planning tool. The custom made planning tool is the planning system designed by the food processing company herself. At the moment, based on the forecast from Slimstock and inventory position from the ERP system, the planners decide how much and when products have to be produced and packaged with help of the custom made planning tool. The decisions are based on common sense, which leads to ineffectiveness and inefficiency. Therefore, the food processing company has decided to choose for an updated Slimstock system and switch to another planning system to prevent (human) error. Slim4 will be updated to be able to calculate how much and when should be produced and packaged, and the planning system will be a more user-friendly, effective, and efficient planning system. At the moment, the food processing company is in the middle of the transition.

The updated Slim4 will be able to determine, based on forecast, inventory control policy, and inventory position, how much and when a certain product has to be produced and packaged. To date, Slim4 provides only the forecasting for the planning system. Besides, the planning system will be able to make a planning, such that the planner has only to check and adjust the planning. Furthermore, both systems consider constraints, like capacity and the best-before date. Therefore, the production and packaging planning will be highly accurate. However, the right inputs are required for a well-functioning system. In contrast to the past, Slim4 will provide inventory management decisions and therefore, Slim4 needs inputs related to the inventory control, which are the make-to-order/make-to-stock (CODP) decision and the inventory control policy assignment. Therefore, these inputs are the subjects of this research.

2.3 Make-to-stock and make-to-order items

The custom made planning tool represents whether an item is produced according to a make-to-order or make-to-stock strategy. The make-to-order/make-to-stock decision is based on the demand and the best before date of an item. Figure 2.1 represents the matrix of the make-to-order/make-to-stock decision at the food processing company. Finally, this decision is based on common sense, since an item with a high demand and short best before date (and vice versa) the food processing company has to made the CODP decision on common sense.

Table 2.1: Make-to-order/make-to-stock matrix

		Best before date	
		Short	Long
Demand	Low	MTO	MTO/MTS
	High	MTO/MTS	MTS

Table 2.2 represents the number of make-to-order and make-to-stock end items at the food processing company. 201 and 23 end products are make-to-stock and make-to-order items, respectively.

Table 2.2: The number of make-to-order and make-to-stock end items at the food processing company

Item	**Make-to-stock**	**Make-to-order**	**Total**
End products	201	23	224

However, some data does not match with the strategy of the item. Having make-to-stock items not in inventory is an example of a mismatch. The food processing company has many make-to-stock items not in inventory, while a few make-to-order items are in inventory. The reason for this is that due to creating a planning on common sense, the planners use a hybrid make-to-order/make-to-stock system per item. Based on forecast, inventory position, and real order of the upcoming weeks, planners decide how much and when will be produced or packaged. In this way, an item is never entirely a make-to-order or a make-to-stock item.

Concluding, at first sight, it seems that many items are make-to-stock items, which the food processing company prefers due to meet a service level of 99%. However, due to the shelf-life of items the planners seem to be very careful with setting items in inventory. This results in a hybrid make-to-order/make-to-stock decision per item. By making a production and packaging planning on common sense, there is a decent chance that the items are not in stock or the items exceeding the best-before date. Moreover, the make-to-order/make-to-stock decision is only based on demand and best-before date, while in a food processing company other criteria can also be important as well. Therefore, the make-to-order/make-to-stock partition can be improved. An optimal partition of the make-to-order/make-to-stock items provides cost reduction in inventory while the delivery reliability will be met (van Donk, 2001), which is exactly the purpose of this research.

2.4 Inventory control policy used

The current systems do not use a inventory control policy, since the planning is based on common sense. In contrast to the current systems, the updated Slim4 uses a (r, s, Q) inventory control policy assignment with r is equal to one. This actually implies a (s, Q) inventory control policy. Because the food processing company has to deal with perishability, Slim4 does also consider this. After calculating the inventory replenishment order of an item, Slim4 will check if the product is exceeding the best-before date before expected selling. If this is the case, the inventory replenishment order will decrease to an appropriate inventory replenishment order that meets the best-before date. Slimstock actually uses a (s, Q) inventory replenishment policy. Therefore, by considering the limited inventory capacity, we have also to use a (r, Q) policy to determine the average inventory space needed per make-to-stock item.

Chapter 3

Literature review

This chapter represents several literature reviews, and answers therefore the second sub question: *"Which methods are available in the literature to select and assign a CODP and corresponding inventory control policy to different end products in the food processing industry?"*. Section 3.1 provides a literature review on the CODP determination in food processing industry in order to select and assign inventory control policies to the different end products. This literature review provides a useful framework to select and assign both CODP's and replenishment policies. To use this framework in food processing industries, the framework needs some adjustments. Therefore, section 3.2 represents a literature review on multi-criteria inventory classification, followed by a literature review on parameter setting of the inventory control policies considering perishability of products to be able to deal with limited inventory capacity in food processing industries.

3.1 Determination of CODP in food processing industry

Food processing industries are part of very competitive supply chains and have to cater to an increasing number of products and SKUs of varying logistical demands like specific features, special packaging and short due dates (Soman, van Donk, & Gaalman, 2002). Before, most food processing companies produced in large batches to keep production cost low and limit the number of set-ups, but due to changes in customer demands only producing make-to-stock is not possible anymore. A combination between make-to-order and make-to-stock is required. For a make-to-stock system, finished or semi-finished products are produced to stock according to the forecasts of the demands, while in a make-to-order system, work releases are authorized only according to the external demand arrivals (Zaerpour et al., 2008). In order to take advantages of two make-to-order and make-to-stock production systems, hybrid MTO/MTS production systems have recently attracted academicians and practitioners (Elbaz & Abdelsalam, 2017).

Before getting into the CODP determination, the main characteristics of a food processing industry have to be considered (Soman et al., 2002). The characteristics are described below.

1. *Plant characteristics*
    - *Extensive capacity of the shop floor with oriented flow design*
    - *Extensive cleaning times and sequence dependent setup times differ among products*
2. *Product characteristics*
    - *Variety of quality as well as supply for raw materials*
    - *Limited shelf life for its raw material, semi-finished product, and finished product*
    - *Using either volume or weight as the unit of measure*
3. *Production process characteristics*
    - *A variable yield and processing time for its processes*
    - *A divergent flow structure*
    - *Multiple recipes for a single product*
    - *Labour intensive at the packaging stage and not at the processing stage*
    - *The capacity determines the production rate*

The frame of van Donk (2001) helps to detect the relevant factors for locating the decoupling point and to decide which products should be make-to-order and which make-to-stock. Changing the decoupling point for a number of products affects performance measures. The customer service level improves, the number of obsolete products will be reduced, and the inventory will be reduced. However, to be able to make decisions about CODP, better knowledge of the market and the production capabilities and their interrelationship is required. Elbaz and Abdelsalam (2008) investigate the decision about which items have to be produced according to a make-to-stock strategy and which ones according to a make-to-order strategy based on a mathematical model, which minimize the difference between the costs of the two approaches. However, the model does not consider the delivery reliability and the obsolescence. Zaerpour et al. (2008) provide a fuzzy AHP-SWOT methodology to decide whether an item should be produced as either make-to-order or make-to-stock. This methodology is both qualitative and quantitative. The SWOT-analysis is a qualitative method and the pairwise comparison on the SWOT-analysis is a quantitative method. The disadvantage of this model is the unreliability of the qualitative method. Ohta et al. (2006) propose not only the optimal condition for make-to-order and make-to-stock policies but also the optimal base-stock level for make-to-stock policy using the M/Er/1 queuing model instead of the M/G/1 queuing model. Using numerical experiments, a cost analysis is performed. Soman et al. (2002) review the state-of-the-art in the area of combined make-to-order/make-to-stock production and introduce a general framework to decide on the main problems in managing a combined make-to-order/make-to-stock system in food processing. Sun (2008) provides a mathematical model which decides whether a product has to be make-to-order or make-to-stock. The objective function is the minimization of the supply chain network cost subject to the required customer delivery time. However, this model does not consider the perishability and demand volumes. Perona et al. (2009) presented a new, easy-to-use and sufficiently straightforward decisional framework to propose a rational and quantitative inventory planning approach which retains its usability in practical environments. Although the framework does not optimize any explicit objective function, the framework supports a large amount of decision-making with quantitative and rational methods and bridges the theory-practice gap. However, the framework does not consider the perishability and available capacity.

Next to all models discussed in the papers, all papers mention characteristics which influence the CODP determination. A summary is represented in table 3.1. Based on these criteria a CODP determination can be made.

Table 3.1: Important criteria affecting make-to-stock/make-to-order decision

Product-related criteria	**Firm and process-related criteria**
Cost of each item	Demand variability
Risk of obsolescence and perishability	Volume of demand
Holding and backordering cost	Predictability of demand
Controllability	Delivery lead time (and variance)
Specificity (Customized)	Customer commitment
BOM	Supplier commitment
Unit price	Set-up times
	Order size requirements
	Production capacity
	Human resource flexibility
	Equipment flexibility
	Integration the function of production and marketing
	Shop floor
	Information flow
	Strict regulations
	Rewards, recognition and pay system
	Customer feedback
	Return of investment

We can conclude that the literature contains many discussions about the CODP determination in the food processing industry. Mainly, the literature discuss the characteristics affecting the CODP determination. Many papers propose a mathematical model with minimization of costs as objective function and the service level is considered either in the objective function or as an external constraint. However, these mathematical models are not easily applicable in practice due to the complexity of companies. Besides, these mathematical models are often too difficult to understand, which makes the model not user-friendly for the managers and users. Also, these models do not consider the perishability of products, which is crucial in food processing companies. On the other hand, some papers propose a framework, which is easy to understand by managers, but these frameworks provide suggestions and qualitative decisions rather than detailed procedures and quantitative decision goals, except from one paper. Perona et al. (2009) provide a framework that bridges the theoretical-practice gap.

Concluding, the literature lacks a user-friendly quantitative model to decide the CODP of products in the food processing industry. However, although the model described by Perona et al. (2009) do not consider perishability of products and limited inventory capacity, the model can be used as a basis framework to select and assign a CODP and corresponding inventory control policy to different end products in food processing industries. The framework of Perona consist of four steps; segmentation into homogeneous product groups, CODP determination per product group, inventory control policy assignment per product group, and parameter setting for each item based on its inventory control policy.

This research will provide a new framework to select and assign a CODP and corresponding inventory control policy to different end products in food processing industry by adjusting Perona's framework. We will adjust the sequence of steps and the content of some steps of the framework to include the perishability of the products, the limited inventory capacity and the service level. To be able to consider these factors we have to do further research. Below, we briefly describe our proposed framework to explain the subjects of further research. To fully understand the proposed framework, a detailed description of the proposed framework is described in chapter 4.

Due to many criteria affecting the CODP determination in food processing industry, especially the perishability of products, the segmentation into homogeneous product groups, step 1 of Perona's framework, will be performed by a multi-criteria inventory classification to rank the end products rather than the traditional ABC classification. Therefore, a literature review on multi-criteria classification is described in the next section. To be able to consider the limited inventory capacity, step 2 will be matching inventory control policy with existing CODP's, followed by finding parameter values of the given inventory control policies in step 3. Although Slimstock calculates and updates the inventory control policy constantly, we have to calculate the policy parameters by ourselves, since Slimstock has no try environment, which means that the policy parameters of the current make-to-stock items are only available. Therefore, a literature review on parameter setting considering perishability of products is described below. Note that finding the parameter values is only needed to consider the inventory capacity rather than finding the optimals.

In addition to the ranking method, we will also perform a mathematical model, since these models are accurate. In contrast to the multi-criteria classification, a literature review on the 0-1 ILP model is no longer necessary, since such types of models have already been discussed above. The 0-1 ILP model is not as complex as the mathematical models explained above, i.e. the model will be easily applicable and user-friendly. Note that a less complex model can lead to a less precise model. The 0-1 ILP model does consider limited inventory capacity and required service levels. We will set up this model by ourselves.

Finally, step 4 assigns a CODP and corresponding inventory control policy to different end products by using either the ranking method or the 0-1 ILP model.

In the next sections, a literature review on both multi-criteria classification and parameter setting of inventory control policy in food processing industry is performed.

3.2 Multi-criteria inventory classification

ABC inventory classifications are widely used in practice, where the items are classified based on one criteria, the annual use value, which is the product of annual demand and average unit price (Teunter et al., 2009) (Ramanathan, 2006). The framework of Perona et al. (2009), which is used as basis framework in this research, uses this traditional ABC inventory classification. However, for many items there may be other criteria that represent important considerations for management (Flores & Whybark, 1987). The rate of obsolescence in food processing industry is an example of such considerations. Therefore, a literature review is conducted to find an ABC inventory classification model where the items are classified based on multi-criteria. Note that we use an ABC inventory classification to be able to only rank the end products rather than classify them, since the limited inventory capacity will probably determine the classification.

In general, the ABC inventory classification method classifies items in a class (A, B or C) based on a criterion or criteria. Class A indicates to the most important items and need the most attention, where on the other hand class C indicates to the less important items (Teunter et al., 2009). The most common rule is that class A, class B, and class C consists of 20%, 30%, and 50% of the total items, respectively (Silver et al., 2017). Class A consists of 20%, since in many cases 20% of all items ensures for 80% of the total revenue. This is also called the 80/20 rule. The most important reason to classify items is that many companies have to deal with thousands of items, and therefore implementing a item-specific inventory control method is infeasible.

The literature consists of many papers about multi-criteria inventory classification. Many papers propose ABC inventory classification with multiple criteria methods where managers' knowledge determines the ranking of the criteria. A disadvantage of these methods is the subjectivity involved when making pair-wise comparisons. VED, AHP and distance modeling are examples of such methods (van Kampen et al., 2012). In contrast to many papers, Ramanathan (2006) provides an advanced statistical approach. Ramanathan (2006) proposes a simple classification scheme using weighted linear optimization, from now called R-model. The model is closely similar to the concept of data envelopment analysis. This model can automatically generate a set of criterion weights for each item and assign a normalized score to this item for further ABC analysis (Zhou & Fan, 2007). The model is simple and easy to understand for managers. Also, the model can easily integrate additional information. By solving the R-model repeatedly for each item, we obtain a set of aggregated performance scores, which can be used to classify the M inventory items. However, if an item has a value dominating other items in terms of a certain criterion, this item would always obtain an aggregated performance score of 1 even if it has added values with respect to other criteria (Zhou & Fan, 2007). Therefore, Zhou and Fan (2007) have made an extension to the model from now called ZF-model. Zhou and Fan (2007) propose an extended version of the model by incorporating some balancing features for multi-criteria ABC inventory classification. The extended version could be viewed as providing a more reasonable and encompassing index since it uses two sets of weights that are most favorable and less favorable for each item, while keeping the simplicity of the R-model (Zhou & Fan, 2007). The total aggregated performance score of an item is the combination of the normalized aggregated performance score of an item of the R-model and the ZF-model, which is expressed in equation 1.

$$nI_i(\lambda) = \lambda \times \frac{gI_i - gI^-}{gI^* - gI^-} + (1 - \lambda) \times \frac{bI_i - bI^-}{bI^* - bI^-}, \quad (1)$$

where $nI_i(\lambda)$ denotes the total aggregated performance score of an item, $gI^* = \max(gI_i, i = 1, 2, ..., M)$, $gI^- = \min(gI_i, i = 1, 2, ..., M)$, $bI^* = \max(bI_i, i = 1, 2, ..., M)$, $bI^- = \min(bI_i, i = 1, 2, ..., M)$ and $0 \leq \lambda \leq 1$ is a control parameter which may reflect the preference of decision maker on the good and bad indexes.

Despite the advantages of the R-model and the ZF-model, it should be noted that under these models each item uses a set of weights either most or least favorable to itself for performance self-estimation. In other words, the weights for self-estimation may differ from one item to another. This actually implies that the resulting performance scores of all items obtained from either model are less comparable (Chen, 2011). Therefore, Chen (2011) proposes an improved approach to the ZF-model by which all items are peer-estimated. Chen (2011) extended the ZF-model by peer estimation and replaces the employed λ in equation (1) by a maximizing deviation method due to the subjectivity of the λ. Hereby, the performance index provided by the proposed approach could be viewed as more reasonable and comprehensive for multi-criteria inventory classification, which result in a more appropriate ranking (Chen, 2011).

Although the models are simple and easy to use, the processing time can be very long when the number of inventory items is large in scale of thousands of items in inventory (Ng, 2007). Therefore, Ng (2007) proposes an alternative weight linear optimization model (model (2)). Ng (2007) makes some adjustments to the R-model. Namely, Ng (2007) transforms all measures to comparable base and the decision maker has to rank the importance of the criteria. Although this involves certain degree of subjectivity, this is a far weaker requirement than that in AHP (Ng, 2007), where only ranking is required.

$$\begin{aligned} maxS_i = \quad & \sum_{n=1}^{N} \mathrm{w}_{in} y_{in} \\ \text{s.t.} \quad & \sum_{n=1}^{N} \mathrm{w}_{in} = 1, \\ & \mathrm{w}_{in} - \mathrm{w}_{i(n+1)} \geq 0, n = 1, 2, ..., (N-1), \\ & \mathrm{w}_{in} \geq 0, n = 1, 2, ..., N, \end{aligned} \tag{2}$$

where $maxS_i$, y_{in} and w_{in} denote the aggregated performance score of an item, the performance score of the ith item in terms of the nth criterion, and the weight of the ith item terms of the nth criterion, respectively. The model automatically calculates the weights of each criterion with such each item can achieve the maximal score (Ng, 2007). However, the processing time can be very long as well. Therefore, Ng (2007) adopts a transformation to simplify the model (model (3)). This model can be easily solved without a linear optimizer.

$$\begin{aligned} maxS_i = \quad & \sum_{n=1}^{N} \mathrm{u}_{in} x_{in} \\ \text{s.t.} \quad & \sum_{n=1}^{N} j\mathrm{u}_{in} = 1, \\ & \mathrm{u}_{in} \geq 0, n = 1, 2, ..., N, \end{aligned} \tag{3}$$

where $\mathrm{u}_{in} = \mathrm{w}_{in} - \mathrm{w}_{i(n+1)}$,
and $\mathrm{u}_{iN} = \mathrm{w}_{iJ}$,
and $\mathrm{x}_{in} = \mathrm{w}_{in}$

Although this model can be easily solved without a linear optimizer, the model has some limitations. One of the limitations is the number of criteria. When the number of criteria is large, it is not an easy task for decision makers to rank all criteria (Ng, 2007). Moreover, the model can handle only continuous measures and the normalization scaling requires the extreme values of measures. And thus, all normalized measures will be affected if the extreme changes. Hadi presented an extended version of the Ng-model. Hadi (2010) provides a model for ABC classification that not only incorporates multiple criteria, but also maintains the effects of weights in the final solution (Hadi-Vencheh, 2010).

Finally, Douissa and Jabeur (2016) tackle the ABC inventory classification problem as an assignment problem and not as a ranking problem, which is the case of the most existing ABC classification models. The PROAFTN method is used to classify inventory items into ABC categories and the Chebyshevs theorem is used to estimate the PROAFTN parameters (Douissa & Jabeur, 2016). A comparative study is conducted to test the performance of PROAFTIN with respect to some other existing classification. The performance is defined as the inventory costs and the service level. This comparative study is represented in table 3.2. The NG model provides the highest fill rate, while the PROAFTN model provides the lowest inventory cost.

Classification model	Total inventory cost	Fill rate
NG model	1011.007	0.991
Hadi model	999.892	0.990
Peer model	958.14	0.988
ZF model	945.357	0.984
R model	927.517	0.986
PROAFTN	897.31	0.983

Table 3.2: Comparative study from Douissa and Jabeur (2016)

There are many SKU classification models available in the literature, which have their own advantages and disadvantages. In food processing industry, multi-criteria ABC inventory classification is useful, since food processing companies have to deal with perishability of products while in need to meet a relative high service level. However, in many multi-criteria ABC classification methods is either subjectivity involved or the method can not be easily implemented due to the complexity of the company. In contrast to these models, the six models described above can be easily implemented and subjectivity is limited. Since we prefer a model with limited subjectivity that provides a high service level, we will use the peer model. However, due to the peer estimation involved, the processing time will be very long. The difference between the ZF model and the peer model is the peer estimation and the maximization deviation method used in the peer model. That is why the peer model gives a small improvement in the ABC classification over the ZF model. Since we classify products in two classes, namely make-to-stock and make-to-order, rather than three classes, the peer estimation will add even less value. Therefore, due to the trade-off that we have made we will use the peer model, by removing the peer estimation and retaining the maximization deviation method, to rank the end products.

3.3 Parameter setting of inventory control policies in food processing industry

Product characteristics determine the appropriate inventory control model of an item. Most inventory models assume that stock items can be stored indefinitely to meet future demands. However, this is not the case in food processing industries. In food processing industries, the impact of perishability on inventory management can not be disregarded. Perishable inventory models is an attractive topic to researchers, since the importance of perishable inventories in food, chemical and pharmaceutical industries. Inventory models that describe perishability are different from the general inventory models and are generally quite complex due to the extra dimension (Nahmias & Olsen, 2015). In addition, in most food processing industries the demand is uncertain. Demand uncertainty and fixed life perishability combined to result in challenging and complex problems (Nahmias, 2011).

Academic literature of inventory control (for perishables) with deterministic lifetime can be categorized into various classes depending on (i) whether the inventory is reviewed periodically or continuously, (ii) whether replenishment orders arrive instantaneously or after a positive lead time, (iii) the cost components considered (Kouki et al., 2015).

In general, there are four inventory control policies (Silver et al., 2017). These control policies are represented in table 3.3. An explanation of the inventory control policies is explained below the table.

Table 3.3: Existing inventory control policies

	Continuous review	Periodic review
Fixed lot size	(r, Q)	(R, s, Q)
Variable lot size	(r, S)	(R, s, S)

(r, Q) policy: an order of size Q (> 0) is placed whenever the inventory position IP (on hand inventory plus on order) drops to the reorder point r.
(r, S) policy: a variable order lot size S - IP is placed whenever the inventory position drops to the reorder point r.
(R, s, Q) policy: we review IP every R periods and an order of size Q (> 0) is placed whenever the inventory position drops to the reorder point s at review.
(R, s, S) policy: we review IP every R periods and a variable lot size S-IP is placed whenever the inventory position drops to the reorder point s at review.

In case the items can be stored indefinitely, the reorder point r (and s) refers to the expected lead time demand plus safety stock. The safety stock should cover uncertainty in demand during the lead time. Therefore, the reorder point is equal to $r(ors) = \mu_L + safetyfactor * \sigma_L$. (Silver et al., 2017) The Q can be approached by the EOQ. Calculating parameter S is much more complex, and is not important for this literature review, so we leave it at that.

Since the above calculations of the policy parameters are based on the assumption that items can be stored indefinitely, we can not apply these model to our case. Therefore, this literature review focuses on inventory models for perishables to find a suitable inventory control model. The literature review focuses on inventory models for perishables with fixed lifetimes, a continuous review period, stochastic demand, and replenishment orders with positive lead times. This is because these models cover the real-case at most. In all models from the literature that cover these requirements, the optimal inventory control policy parameters are determined based on minimizing the total cost, which includes ordering, inventory holding, outdating and shortage costs.

Nahmias and Wang (1979) developed a heuristic (Q, r) perishable model under the assumption of at most one order outstanding. Chiu (1995) re-examines the (Q, r) model of Nahmias and Wang (1979) and improves his own approximation of the (Q, r) model in Chiu (1999) by replacing the extremely rough approximation by a good approximation. Tekin et al (2001) consider a continuous review perishable inventory system operating under a modified lotsize-reorder control policy which also takes into account the remaining lifetime of the items in stock and the required service level. They develop a (Q, r, T) policy, where a replenishment order Q is placed either when the inventory drops to r, or when T units of time have elapsed since the last instance at which the inventory level hit Q. The model included a service level constraint that requires the fraction of unmet demand not to exceed a prespecified value (Tekin et al., 2001). Their findings indicate that the age-based policy is superior to the stock level policy for slow moving perishable inventory systems with high service levels. Berk and GÃ¼rler (2008) compared their model to Chiu (1995) with lost sales and Poisson demand and showed that the model of Chiu (1995) performs worse than the traditional (r, Q) policy. Kouki et al. (2015) also improved the model of Chiu (1995); their approach is based on determining upper bounds rather than average values. The model differs from existing models by considering an (r, Q) inventory system with continuous demand distribution, constant lifetime and constant lead time. Kouki et al. (2015) give also a detailed literature review for perishable inventory systems and show that compared to similar existing studies, including the above models discussed, the proposed model performs very well. However, the model does not consider the required service level.

There is one model that does not meet our inventory models characteristics, but still can be a good model to use in our case. Purohit and Rathore (2012) developed a multi-item inventory control model for perishable items in which production (or supply) is instantaneous with no lead time. Even though the model considers deterministic demand and no lead time, the model can be a good approximation to use on for decisions on strategic level.

Concluding, in all cases the model of Kouki et al. (2015) gives the best and realistic results. Moreover, the model description and assumptions made are close to our case. Therefore, although the model does not consider required service levels, we will use the model of Kouki et al. (2015) to determine the optimal inventory policies. To still deal with the required service levels we will make some adjustments to the model of Kouki et al. (2015).

Chapter 4

Solution design

This chapter describes the proposed framework, and answers therefore the third sub question: *"How can a framework be built to select and assign a CODP and corresponding inventory control policy in food processing industry?"*. The goal of the proposed framework is to assign a CODP and the corresponding inventory control policy to each end product in the food processing industry, which will be input for the inventory control and planning system Slimstock to create a well-functioning Slimstock that will lead to an improvement in service level and a reduction in cost by balancing the inventory. The framework considers the perishability of the items, the limited inventory capacity, and the required service level. Figure 4.1 represents the flow diagram of the proposed framework. An arrow is defined as input for the next step. As can be seen, the framework consists of four steps: ranking the end products, match CODP's with inventory control policies, finding parameter values of the given inventory control policies, and assigning of a CODP and corresponding inventory control policy to the end products.

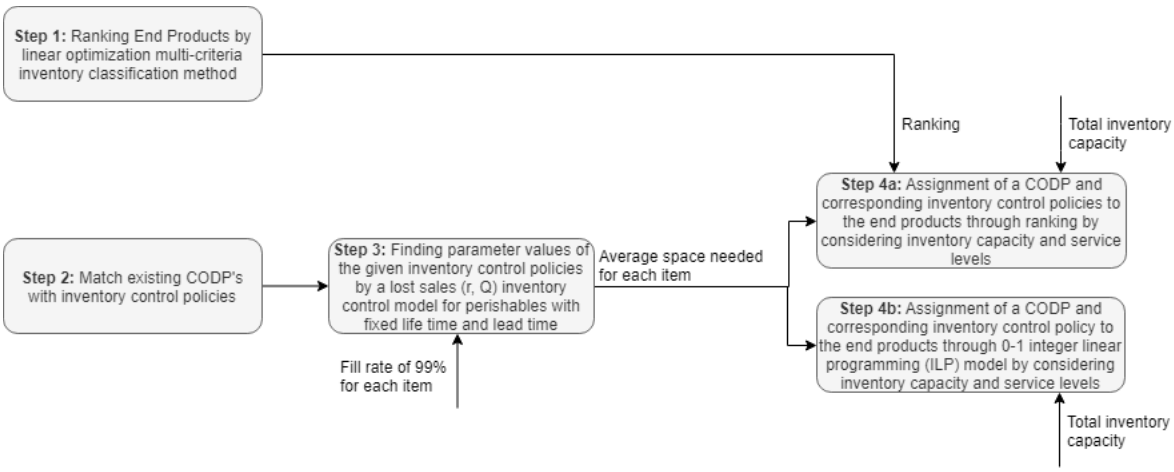


Figure 4.1: Flow diagram of proposed framework

Assigning of a CODP and corresponding inventory control policy to the end products can be done by both using the ranking (step 4a) and the 0-1 ILP model (step 4b). As can be seen, step 1 is only needed for step 4a. Both models will be implemented and compared in chapter 5.

Ranking the end products (step 1) will be carried out by a linear optimization multi-criteria inventory classification method. The higher the overall performance of an item, the more likely that the item will be produced according to the make-to-stock strategy. Therefore, step 1 provides a list, where the items are ranked from high to low. To be able to deal with the limited inventory capacity, the average inventory space needed per item is needed. This requires step 2 and 3. Note that only the make-to-stock items need inventory space. However, we do not know which item becomes a make-to-stock item in advance. Therefore, we have to calculate the average inventory space needed for all items. In step 2 we define the existing CODP's and match the CODP's with inventory control policies. Finding the parameter values of the inventory control policy that corresponds to make-to-stock decoupling point ensures that we can define the required inventory space needed for each item, which will be done in step 3. In this case, the parameter values of the given inventory control policy will be found by an (r, Q) inventory control model. To be able to calculate these parameter values, the service level of each item is needed as input. The inventory control model gives the parameter values (r, Q) and the expected average inventory space needed per item as result. The expected average inventory space for each item is an input for step 4. Finally, in step 4 a CODP and corresponding inventory control policy can be assigned to each end product by using either step 4a and 4b. In step 4a, the assigning to each end product is done by using the ranking (step 1), the average inventory space needed per item (step 3), and the total inventory capacity. In step 4b, the assigning to each end product is done by a 0-1 ILP model, the average inventory space needed per item (step 3), and the total inventory capacity. The 0-1 ILP model has as objective minimizing the total cost subject to the limited inventory capacity. 0 and 1 refers to a make-to-order and make-to-stock item, respectively.

In the end, the CODP and the corresponding inventory control policy of each item is input for the inventory control and planning system Slimstock. The steps of the framework are elaborated in detail below.

4.1 Step 1: Ranking end products

Step 1 performs a ranking of the performances of the end products. The higher the overall performance, the more likely the end product will be produced according to the make-to-stock strategy. As mentioned in section 3.2, the ranking is performed through a linear optimization multi-criteria inventory classification model of Chen (2011), except without the peer estimation. The model needs as input the data of each selected criterion for all items. The criteria selection is a managerial decision.

Below, the criteria selection is explained first, followed by the explanation of the model. For a detailed explanation and proofs we refer you to the paper of Chen (2011).

Criteria selection

In order to get a ranking of the end products, criteria selection is a crucial decision, since this decision will influence the ranking. Each company is different and is changing constantly, so criteria selection is company and time dependent. Therefore, before ranking the end products, the criteria selection has to be reconsidered. The criteria selection for the food processing company will be elaborated below. This criteria selection is based on table 3.1 from section 3.1.

For the food processing company, the following criteria will be included in the model:

- Annual usage (Sales Volumes * Cost per unit)
- Demand variability
- Best-before date
- Order lead time (customer commitment)
- Ratio of best-before date and average time between orders

According to section 3.1, annual usage is the most common criteria used in ABC classification, and should also be an important criterion for ranking end products of the food processing company. In this case, we will use the average weekly usage, since each product is introduced at a different time, which means that some products have been produced since a year and other since one month. Besides, demand variability is included because it says something about how fluctuations in demand influence the optimal amount of stock at a particular moment. Items with high variability for which an average amount of stock is held at all times can result in both high cost and low service levels; when demand is low, items might expire after costs have been made already for storage and production. When demand peaks, there is likely not enough stock for the upcoming, resulting in dissatisfied customers. Moreover, the best-before date is the critical aspect in food processing industry and should therefore be included. The commitment order lead time per customer also has to be included, since the food processing company has customer commitment about the delivery lead time and the food processing company has to meet a service level of 99%. Furthermore, we included a ratio; the ratio of best-before date and average time between orders. Since there are many items that are not sold every day, which creates risk of perishability of products, the ratio of best-before date and average time between orders is another included criterion.

The remaining criteria of table 3.1 are not included, since these criteria are either company related rather than product related or the values of a specific criterion is the same for all products.

Model explanation

Briefly, the order of the ranking method is as follows: self-estimation in most and least favorable sense, normalization in most and least favorable sense, determination of weight coefficients for the most and least favorable sense using the maximization deviation method, normalization of the weight coefficients, and aggregation of the two normalized performance scores to calculate the overall performance score of an item.

The first step is solving the self-estimation models by using the R-model (most favorable sense) and the ZF-model (least favorable sense) as mentioned in section 3.2. The R-model and the ZF-model are represented in model (4) and (5), respectively. The following parameters and decision variables are used in the models: ρ_o and δ_o, w_{io}, and $y_{io}(y_{im})$, and means the aggregated performance score, the weight of the oth item in terms of the ith criterion, and the performance score of the oth (mth) item in terms of the ith criterion, respectively.

R-model:

$$max\ \rho_o = \sum_{i=1}^{N} y_{io} w_{io} \tag{4}$$

$$\begin{aligned} \text{s.t.} \quad & \sum_{i=1}^{N} y_{im} w_{io} \leq 1, \quad m = 1,2,...,M, \\ & w_{io} \geq 0, \quad i = 1,2,...,N, \end{aligned}$$

ZF-model:

$$min\ \delta_o = \sum_{i=1}^{N} y_{io} w_{io} \tag{5}$$

$$\begin{aligned} \text{s.t.} \quad & \sum_{i=1}^{N} y_{im} w_{io} \geq 1, \quad m = 1,2,...,M, \\ & w_{io} \geq 0, \quad i = 1,2,...,N, \end{aligned}$$

By solving these models repeatedly for each item, we obtain a set of aggregated performance scores in most and least favorable sense, which can be used to classify the M inventory items.

Since ρ_o and δ_o have different definitions in that ρ_o is in the most favorable sense and δ_o in the least favorable sense, these averaged performance scores have to be normalized. For normalization, the following variables are used: $\rho^{+*} = \max(\rho_m^+$, i = 1,2,...,M), $\rho_-^+ = \min(\rho_m^+$, i = 1,2,...,M), $\delta^{-*} = \max(\delta_m^-$, i = 1,2,...,M), $\delta_-^- = \min(\delta_m^-$, i = 1,2,...,M). The averaged performance scores can then be normalized as follows:

$$\Theta_o^+ = ((\rho_o^+ - \rho_-^+)/((\rho^{+*} - \rho_-^+)), \tag{6}$$

$$\Theta_o^- = ((\delta_o^- - \delta_-^-)/((\delta^{-*} - \delta_-^-)), \tag{7}$$

For aggregation of the two averaged performance scores Θ_o^+ and Θ_o^-, the maximizing deviations method is used to identify a unique set of weight coefficients. The maximizing deviations method is explained below.

Let t_1 and t_2 be the weights of the most favorable sense and least favorables sense, respectively. And assume that t_1 and t_2 satisfy the unitization constraint condition

$\mathrm{t}_1^2 + \mathrm{t}_2^2 = 1$

Then the maximizing deviations method can be defined as follows:

$$\begin{aligned} maxD = \quad & \sum_{i=1}^{M}\sum_{j=1}^{M} \mid \Theta_i^+ - \Theta_j^+ \mid * \mathrm{t}_1 + \sum_{i=1}^{M}\sum_{j=1}^{M} \mid \Theta_i^- - \Theta_j^- \mid * \mathrm{t}_2 \\ \text{s.t.} \quad & \mathrm{t}_1^2 + \mathrm{t}_2^2 = 1, \\ & \mathrm{t}_1, \mathrm{t}_2 \geq 0. \end{aligned} \tag{8}$$

The result of the maximizing deviations method are the weights t_1^* and t_2^*. These weights have to be normalized as follows:

$$\mathrm{T}_1^* = \mathrm{t}_1^*/(\mathrm{t}_1^* + \mathrm{t}_2^*) \tag{9}$$

$$\mathrm{T}_2^* = \mathrm{t}_2^*/(\mathrm{t}_1^* + \mathrm{t}_2^*) \tag{10}$$

The weights T_1^* and T_2^* ensure that the two averaged performance scores of an item can be aggregated. So, finally, the overall performance of an item can be calculated by equation (14) in order to rank the end products:

$$\phi_o = \mathrm{T}_1^* * \Theta_o^+ + \mathrm{T}_2^* * \Theta_o^- \tag{11}$$

Concluding, this step provides a ranking of the end products based on their performance (ϕ_o). The higher the overall performance, the more likely the end product will be produced according a make-to-stock strategy. Note that, in contrast to the framework of Perona, only a ranking is performed in this step rather than group classification. The framework of Perona (2009) determines the decoupling point based on assigning the different groups to the different points, e.g. the most important groups are assigned to make-to-stock. However, like many papers about make-to-order/make-to-stock decision, they do not consider limited inventory capacity. The number of make-to-stock products could ensure that the inventory capacity will be exceeded. Therefore, we have to consider this constraint, which makes the classification not that simple. Therefore, the classification can only be done in the last step.

4.2 Step 2: Match existing CODP's with inventory control policies

Food processing companies have to deal with inventory and production capacity constraints. To be able to meet the required service level, food processing companies want to produce many items according to the make-to-stock strategy. However, the inventory capacity is limited, which makes that the food processing company is forced to switch to make-to-assembly or even to make-to-order. On the other hand, food processing companies have to deal with perishability of items. Some items have a very short best-before date, which ensures that the food processing company is forced to produce a item according to the make-to-order strategy. However, the production capacity is limited, which can ensure that all orders of the make-to-order items can not be produced within the time limit. Therefore, a balance in the number of make-to-stock and make-to-order items is needed.

To deal with the inventory capacity constraint, which is the bottleneck in our case, the required inventory space per item has to be considered. The required inventory space is based on the inventory control policy of the make-to-stock items. Therefore, in this step we already have to match inventory control policies to the several decoupling points to be able to consider the inventory capacity constraint.

First, the existing CODP's in the company are explained followed by the matching inventory control policies.

4.2.1 Existing CODP's

The process of food processing companies is roughly the same (Soman et al., 2002). Figure 4.2 represents this process. First, the raw materials go into production. The produced products will be stocked at the intermediate stock point. These products will be packaged and stocked at the finished stock point. As can be seen, food processing companies have three decoupling points, namely make-to-order, make-to-assembly, and make-to-stock.

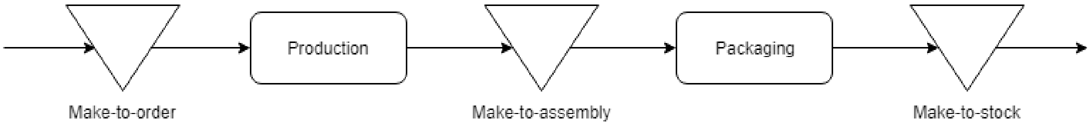


Figure 4.2: Rough process of food processing companies

However, as can be seen in section 2.1, the supply chain process of the food processing company can be divided into two processes: the production and packaging process. This is due to the fact that the food processing company sells the same product to many customers only with different packages. Moreover, the perishability of the items start from this point. Therefore, the production and packaging processes can be seen as separate processes, which means that we have only to deal with two decoupling points for the end products, namely make-to-order and make-to-stock. Figure 4.3 represents the CODP's of the packaging process of the food processing company. Note that there is basically not a CODP per process, but per item.

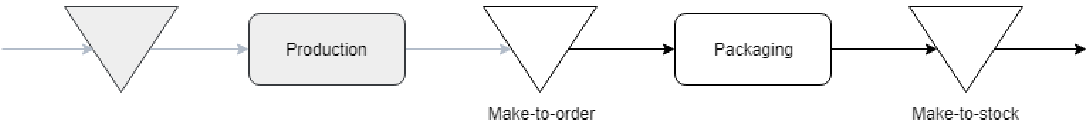


Figure 4.3: CODP's at the food processing company

4.2.2 Match existing CODP's with inventory control policies

The used CODP's and corresponding inventory control policies can be seen in table 4.1. The L4L policy is the inventory control policy of the make-to-order products. which means that the supply chain will be triggered when an order is placed. The size of the order determines the size of the replenishment.

The (r, Q) policy is the inventory control policy of the make-to-stock products, since the food processing company uses Slimstock as inventory control system, and Slimstock uses as inventory control policy a (r, Q) policy.

Table 4.1: Selected CODP's and matching inventory control policies

CODP	Inventory replenishment policy
Make-to-order	L4L
Make-to-stock	(r, Q) policy

To deal with the limited inventory capacity, we have to calculate the inventory space needed for each item in case that each item is produced according a make-to-stock strategy. Therefore, the parameter values for each item have to be calculated, which is explained in the next step.

4.3 Step 3: Finding parameter values of the (r, Q) inventory control model

This step calculates the parameters of the given inventory control policies to be able to calculate the inventory space needed for each item. In contrast to the framework of Perona, finding the parameter values is on strategical/tactical level rather than operational level. Note that this step will not give the final result. We do not select and assign a CODP and corresponding inventory control policy to each item. Finding the parameter values is only needed to consider the inventory capacity rather than finding the optimals. Therefore, an indication of the inventory space needed per item will be calculated instead of updating the parameters constantly. Note that the inventory space needed is calculated for all items, since we do not know which item becomes a make-to-stock item in advance. Moreover, the perishability of the items have to be included in the calculations.

Since make-to-stock items need storage space, the parameter values of the (r, Q) policy have to be calculated for all items. To calculate the parameters of the (r, Q) policy, we will use a modified version of the problem of Kouki et al. (2015) that ignores the impact of perishability during lead time, which refers to Model 1 in the paper of Kouki et al. (2015). Although the model that includes the impact of perishability during lead time gives more accurate estimation of the parameters (r, Q), the model provides performance similar to the model that ignores the impact of perishability during lead time. Moreover, the model that ignores the impact of perishability during lead time is much less complex, and therefore a lower computation time. Besides, the lead time is low, so the impact of perishability during lead time is not that high. And, in our case the parameter setting is on strategical/tactical level rather than operational level, which implies that a reasonable estimation of parameters (r, Q) is sufficient. This is because an estimation of the inventory space needed per item is only required in contrast to an accurate estimation of the parameters (r, Q).

Model description
We define a continuous review (r, Q) inventory control policy system, which means that an order of size Q (> 0) is placed whenever the inventory position (on hand inventory plus on order) drops to the reorder point r. The model is a single-stage perishable product inventory system. The assumptions of the model are described below.

Model assumptions:

- Stochastic demand;
- Continuous demand distribution (normal distribution)
- Items have fixed lifetime;
- Items have constant replenishment lead time;

- Unfilled demands are lost;
- Aging of items begins just at the time when replenishment orders are delivered;
- During the usable lifetime of an item, there is no decrease in the value of the item;
- The item is discarded if the item is not used during its lifetime;
- FIFO issuing policy is used;
- The impact of perishability during the lead time is ignored;
- All necessities for packaging are always available
- There are no errors at the packaging lines

To be able to define the model, the following notations are used:

x	Demand per unit of time; nonnegative continuous random variable
$f(x), F(x)$	pdf and cdf of x, $f(x) \geq 0 for x \geq 0 and f(x) = 0 for x \leq 0$
μ, σ	Mean demand rate, standard deviation of demand
$x_n, n \geq 1$	Demand during n units of time; nonnegative random variable
$f_n, Fn, n \geq 1$	pdf and cdf of the random variable x_n
K	Fixed ordering cost per order (set-up cost)
h	Holding cost per unit held in stock per unit of time
c	Purchase cost per unit
p	Lost sales cost per unit
w	Outdate cost per unit that perishes
m	Product lifetime
L	Replenishment lead time
$E[O]$	Expected outdating quantity associated with an order per cycle
$E[S]$	Expected lost sales quantity per cycle
$E[I]$	Expected inventory level per unit of time
$E[T]$	Expected cycle length, i.e. the expected units of time that elapse between two successive instances where the inventory level reaches r
α	The maximum permissible fraction of unmet demand
$r*, Q*$	The best reorder level and order quantity
$TC*$	Total optimal cost

The expected outdating quantity $E[O]$ is an upper bound and is computed when order Q is delivered. $E[O]$ is an approximation, since the impact of perishability is ignored during the order lead times. The expected lost sales $E[S]$ is also an upper bound. This upper bound is based on the assumption that the inventory level is zero when an order is delivered. By making this assumption, we are assuming that only one age category is on hand at delivery (Kouki et al., 2015). Besides, we assume that the products do not perish during lead time. By calculating the expected inventory level $E[I]$ during the cycle length, we assume $E[O] < s$. ($E[O] > s$ is extremely unlikely) and $E[O]$ will be ignored to owing with the difficulty of tracking the age of items in stock.

To determine $r*$ and $Q*$, Kouki et al. (2015) formulate an optimization problem by minimizing the total cost for an item. The optimization problem does not consider meeting a certain service level. Therefore, by solving the optimization problem of Kouki et al. (2015) the cost will be minimized, which means that a certain service level is not taken into account. Therefore, we adjust the optimization problem of Kouki et al. (2015) by adding the fill rate constraint. The optimization problem of minimizing the expected total cost $TC(r,Q)$ $(\frac{\text{Expected Cycle Cost}}{\text{Expected Cycle Length}})$ for an item, subject to the service level constraint, can then be formulated as:

$$minTC(r,Q) = \frac{K + cQ + pE[S] + wE[O]}{E[T]} + hE[I] \tag{13}$$

$$\text{s.t.} \quad \frac{E[S]}{\mu * E[T]} \leq \alpha,$$

$$r, Q \geq 0.,$$

where α is the maximum permissible fraction of lost sales, and

$$E[O] = \int_0^Q F_m(x_m)dx_m + \int_0^r F_m(r+Q-x_L)F_L(x_L)dx_L, \tag{14}$$

$$E[I] = \frac{Q + r - E[O] + \int_0^r F_L(x_L)dx_L}{2} - \frac{\mu L}{2}, \tag{15}$$

$$E[S] = \mu L - r + \int_0^r F_L(x)dx_L, \tag{16}$$

$$E[T] = \frac{Q + E[S] - E[O]}{\mu}. \tag{17}$$

For clarification, Eq. (13), (14), (15), (16), and (17) are explained below. For a detailed explanation and proofs of the equations we refer you to the paper of Kouki et al. (2015).

The objective is minimizing the cost of a specific item. By solving the optimization problem for each item separately we find the parameter values (r, Q) for each item and therefore also the average inventory level (space) per item $E[I]$. The cost function is equal to the long run expected total cost per unit of time $(\frac{\text{Expected Cycle Cost}}{\text{Expected Cycle Length}})$ and consists of the set-up cost, the purchase cost, the lost sales cost, the outdate cost, and the inventory cost. The total cost is divided by the cycle length to get a cost per unit of time. Note that the inventory cost is already given as per unit of time.

The constraint ensures that the maximum permissible fraction of unmet demand, which is equal to 1 - service level, will be met. In our case, there is no service level differentiation. The food processing company treats all items equally and strives for a service level of 99% for each item. Therefore, α is equal to 0.01 (1-0.99). The maximum permissible fraction of unmet demand is equal to the total lost sales divided by total sales. The maximum permissible fraction of unmet demand per unit of time can then be calculated by the lost sales per cycle divided by the mean demand per cycle, which can be expressed in $\frac{E[S]}{\mu * E[T]}$. To meet the service level, this expression has to be lower than the maximum permissible fraction α.

Since we ignore perishability during lead time, $E[O]$ is an approximation of the outdating quantity from the batch Q. $E[O]$ can be expressed in $E[(Q+(r-x_L)-x_m)]$, which leads to Eq. (13).

The inventory held per cycle $E[I]$ consists of two parts: before and after a new order Q is triggered (Kouki et al., 2015). To understand this Kouki et al. (2015) clarifies the expected inventory level with a figure, which is shown in figure 4.4. Area A1 + A2 refers to the first part of the equation and A3 to the second part. We assume that all items do not perish during lead time. Therefore, the second part is only the demand during lead time.

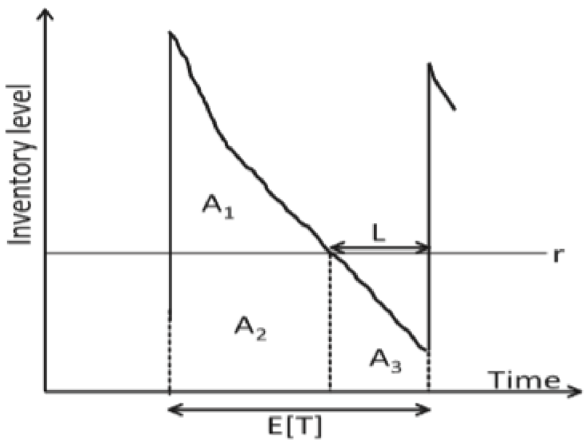


Figure 4.4: The expected inventory level

The equation of $E[S]$ is derived from the equation $\int_r^\infty (x_L - r)F_L(x)dx_L$, which makes $E[S]$ understandable.

Figure 4.4 represents the length of $E[T]$. The equation of the expected cycle length $E[T]$ when excess demands are lost is then straightforward.

To be able to calculate the integrals, the mean demand (μ) and the standard deviation (σ) are needed. We calculate the mean demand and standard deviation by $\frac{\sum_{i=1}^{N} \mu_i}{N}$ and $\sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N}}$, respectively.

By solving the model above for each item, we get the optimal parameters (r, Q) for each item and therefore, the inventory space needed for each item. Note that we use the average inventory space needed per item rather than the maximum, since we want take advantage of the total inventory capacity. However, due to the hard service level constraint and the relative large standard deviation of the mean, the r and Q becomes very large to meet the constraint, which leads to many outdating items. Slimstock deals with the same problem, and solved it by setting a maximum number of outdating items per unit of time. Therefore, we will also implemented this rule to limit the average outdating percentage. This results in fill rates below 99% for some items.

4.4 Step 4: CODP and inventory control policy assignment

The fourth and last step assigns a CODP and the corresponding inventory control policy to each item. This decision is based on either the ranking model (step 4a)or the 0-1 ILP model (step 4b), the average inventory space needed per item, and the total capacity. The way of assigning a CODP and the corresponding inventory policy to each item is explained for both cases below.

To clarify the framework, table 4.2 and 4.3 visualize a simple example of the results of the model by using step 4a and 4b, respectively. The example contains six items in total, and the maximum storage capacity in finished goods warehouse is equal to 100.

4.4.1 Step 4a: Solving by using the ranking model

We walk through the ranking list from step 1a from the top to the bottom and stop when the total available capacity will be exceeded, which is represented in table 4.2. Make-to-stock and the (r, Q) policy will be assigned to the items above the line, and make-to-order and the L4L policy will be assigned to the items below the line.

Table 4.2: Visualization of results by using step 4a

Item	Inventory space needed	CODP	Inventory control policy
Item 1	25	MTS	(r, Q)
Item 2	25	MTS	(r, Q)
Item 3	25	MTS	(r, Q)
Item 4	25	MTS	(r, Q)
Item 5	25	MTO	L4L
Item 6	25	MTO	L4L

Infinite inventory capacity
Many food processing industry companies have to deal with a limited inventory capacity. Therefore, this model will be added value in the food processing industry. However, in some cases the inventory capacity will be infinite or high enough. In case of the ILP model there will be no problem. In the case of the ranking model, all or many items will be a make-to-stock item, which is probably not optimal, i.e. slow movers will also be an make-to-stock item. Therefore, you have to draw the line by yourself. Since the food processing company has multiple items with a relative high annual usage rather than few items, we will use the 70/30 rule from Pareto, which means that 70% of use is derived from 30% of the items. This rule exactly fits the situation at the food processing company. The first 30% of the ranking list will be a make-to-stock item. Note that you always have to consider whether this rule fits to the company specific situation. For example, when the annual usage of many items are quite high, then a 80/20 rule could fit better. Finally, you have to always consider whether applying the 70/30 rule is better than the result by using the limited inventory capacity.

4.4.2 Step 4b: Solving by using the 0-1 ILP model

This step solves the problem by a 0-1 ILP model. The 0-1 ILP model is set up by minimizing the total cost subject to the limited inventory capacity.

The goal of this model is to determine which item will be produced according to a make-to-stock or make-to-order strategy. Therefore, the model is a 0-1 ILP model. The model can be described as:

Minimize total costs
subject to:
capacity needed for all MTS items $\leq$ maximum available capacity

This 0-1 ILP model is made by ourselves. The expected total cost is the sum of the costs of all make-to-stock items and the costs of all make-to-order items. To be able to define the model, we use assumptions and notations from step 3 and the following additional notations:

μ	Mean demand of the mixed distribution
ϕ	Mean demand of the normal distribution
N	Number of orders per year
OLT	Order lead time per unit
x	Packaging time (lead time); nonnegative continuous random variable
$F(x)$	Cdf of x (Normal Distribution)
$c(r_i, Q_i)$	Average inventory space needed for item i (results of step 3)
C	Total maximum inventory capacity

The mathematical model can then be formulated as follows:

$$minTC = \sum_{i=1}^{N}((\frac{K_i + c_iQ_i + p_iE[S]_i + w_iE[O]_i}{E[T]_i} + h_iE[I]_i) * 365)X_i + \sum_{i=1}^{N}(1 - X_i) * N * (k_i + c_i\phi_i + p_i * \phi_i * (1 - F(OLT))) \quad (12)$$

$$\text{s.t.} \quad \sum_{i=1}^{N} c(r_i, Q_i)X_i \leq C,$$

$$X_i \in 0, 1 \qquad \forall i,$$

where i denotes a specific item, and

$$[\mathcal{X}_i] = \begin{cases} \text{If item i is a make-to-stock item} & 1 \\ \text{Else} & 0 \end{cases}$$

The first equation of the objective function defines the expected long run cost per year of a make-to-stock item, which implies $\frac{\text{Expected Cycle Cost}}{\text{Expected Cycle Length}}$*365. These costs can be divided into ordering cost, purchase cost, lost sales cost, outdating cost, and inventory cost. This cost function is defined by Kouki et al. (2015).

The second equation of the objective function defines the expected long run cost per year of an make-to-order item, which implies the ordering cost, purchase cost, and lost sales cost for each order. This equation is made by ourselves. The long run cost of a make-to-order item can be defined as the ordering cost per order, the purchase cost per order and the lost sales cost per order multiplied by the total number of orders in a year (N). Note that the ϕ is the mean demand of the normal distribution rather than the mix distribution (which is a mix of two distributions; a normal distribution and a constant distribution of zero demands), since this refers to the mean demand per order. The lost sales cost of a make-to-order item can be defined as the total lost sales cost times the probability that an order is not ready before the required order lead time. Since we want to take into account some uncertainty for the make-to-order items, the lead time is not deterministic, so the lead time is approximated by a normal distribution, and we assume a lead time standard deviation of one day. The probability that the lead time is higher than the order lead time can be calculated by $1 - \int_0^{OLT} f(x)$, which is represented in figure 4.5. The grey area represented in figure 4.5 is equal to 1 - F(OLT). Therefore, the lost sales cost are equal to the probability that the lead time is higher than the order lead time multiplied by the mean demand per order multiplied by the lost sales per item. The mean lead time of a make-to-order item is two days. We make the assumption that all necessities for packaging are always available, e.g. semi-finished products and sleeves. Note that we ignore the holding cost of the short storage time of the make-to-order items, since this can be neglected.

The capacity constraint indicates that the sum of the average inventory space needed for all make-to-stock items have to be lower than the maximum inventory capacity. Note that we use the average inventory space needed per item rather than the maximum inventory space needed per item, since we want take full advantage of the inventory capacity.

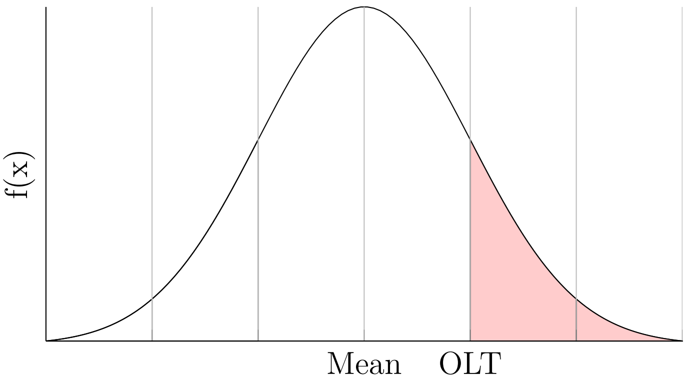


Figure 4.5: Pdf of lead time of make-to-order items

By solving the 0-1 ILP model, the results are directly available, where items with a 0 and 1 indicates a make-to-order and make-to-stock item, respectively. Table 4.3 visualizes the result of this model. Note that the model is not exact, since the model includes approximations and assumptions, i.e. the lost sales, the set-up cost, and the standard deviation of the order lead time.

Table 4.3: Visualization of results by using step 4b

Item	Inventory space needed	CODP (1 = MTS, 0 = MTO)	Inventory control policy
Item 1	25	0	L4L
Item 2	25	1	(r, Q)
Item 3	25	1	(r, Q)
Item 4	25	0	L4L
Item 5	25	1	(r, Q)
Item 6	25	1	(r, Q)

Finally, the proposed framework/tool produces the results and performance of both models. The performance of the model is divided in the total cost per year, the total average number of pallets in stock, and the average service level. The average service level is calculated by $\frac{\sum_{i=1}^{n} \mu_i * servicelevel_i}{\sum_{i=1}^{n} \mu_i}$, where i indicates to an item. The service level for each make-to-stock and make-to-order item is equal to the fill rate and $1 - \int_0^{OLT} f(x)$, respectively. After evaluating and comparing the results, the final CODP and the corresponding inventory control policy for each item can be implemented in the planning and inventory control system Slimstock, which will lead to an improvement of the service level and a reduction in cost by balancing the inventory.

Chapter 5

Solution test

This chapter represents an experimental study of the framework described in chapter 4, and answers therefore the last two sub questions: *"How can the proposed framework be applied to the food processing company?"* and *"What is the effect of implementing the proposed framework on the performance of the supply chain of the food processing company?"*. In section 5.1 the model is tested. Section 5.2 evaluates the model and its performance. Finally, in section 5.3 a conclusion about the performance of the model is drawn.

5.1 Model test

This section elaborates the test of the framework. Section 5.1.1 represents the data that is used to come up with a solution. Section 5.1.2 describes the verification and validation of the proposed framework. Section 5.1.3 explains the tool and represents the results of both the ranking model and 0-1 ILP model. In addition, a comparison between both models is made. Section 5.1.4 represents a sensitivity analysis, followed by a comparison of the proposed framework to the current situation in section 5.1.5.

5.1.1 Data used

The purpose of the proposed framework is to determine which end product will be produced according to a make-to-order or make-to-stock strategy. This decision will be made on the 224 end products from the food processing company. The data that is used is explained below.

- *One year of data*
  The data used is from week 15 2018 to week 15 2019. Note that new items are constantly being introduced throughout the year.

- *The total inventory capacity is equal to 1000 pallets*
  The total inventory capacity is equal to 1000 pallets, but we have to keep in mind that make-to-order items can also be saved in stock for a few days.

- *5% of the total inventory capacity is reserved for make-to-order items*
  In agreement with the supply chain manager, we assume that 5% of the total inventory capacity is needed for the make-to-order items.

- *The end products relating to customer X are stored at an external warehouse*
  All end products for customer X go to an external warehouse even though these products will be produced according to a make-to-stock or make-to-order strategy. Before transport, these end products are stored at the food processing company for a maximum of one day. Since these items are stored as part of the make-to-order inventory space, they do not have to be included in the capacity constraint.

- *The non-working days are filtered out when calculating the mean of μ, σ, μ_L, and σ_L, which are needed for the inventory model*
  The food processing company does not pack and deliver on non-working days. Therefore, the non-working days are filtered out when calculating the mean of μ, σ, μ_L, and σ_L. Note that this does not apply to μ_m, and σ_m, since items perish also on the non-working days.

- *An indication is given for all cost parameters*
  Since the cost parameters are too confidential and therefore we do not have the custom made planning tool to this data, an indication is given. The values of the cost parameters are the same for all items. These indications have been established together with the financial CEO. Note that lost sales and set-up cost are unknown. Together with the financial CEO and the supply chain manager we have made assumptions for these two parameters. The following parameters values are used:

  CONFIDENTIAL

5.1.2 Verification and validation

In this section the verification and validation is elaborated, respectively. Verification and validation is required to check whether the model meets the requirements and specifications, and whether the model fulfills its intended purpose.

5.1.2.1 Verification

We verify the proposed tool, the limited inventory capacity, ranking method, and the normal distribution approximation used in the inventory model, which are elaborated below.

The tool
Due to the constantly changing environment in food processing industry, the optimal CODP and inventory control policy decision are changing constantly. Therefore, recalculating the CODP and corresponding inventory control policy for each item periodically is necessary, which means that an user-friendly tool has to be made.

The proposed framework is implemented in Excel by using Visual Basic for Applications (VBA). The reason for implementing in Excel, is that there are already several programs Excel based at the food processing company, which ensures that employees will work in a familiar environment. Next to that, the manual of the tool is described in the tool itself. Users only have to insert data (for example: historical sales volumes per item) and press solve to get a solution. The solution from excel can be implemented in Slimstock. Therefore, the tool is user-friendly and can easily be used by employees of the food processing company.

The limited inventory capacity
Both models take into account the limited inventory capacity. In any case, the results of both models do not exceed the total inventory capacity.

Ranking method
As mentioned in section 3.2, in food processing industry multi-criteria inventory classification method is required rather than the traditional ABC classification, which is widely used in practice. However, it is useful to check whether a multi-criteria inventory classification method really adds value in analyses in the food processing industry. Therefore, we compare these two methods below. Appendix A represents the difference in classification in case of the ranking model and the traditional ABC classification.

The traditional ABC classification classifies, just as the ranking model, 68 items as make-to-stock, since the 70/30 rule is also applied to the traditional ABC classification. As can be seen in A, there are 30 items that the traditional ABC classification would classify different. The 15 items that are classified as make-to-stock according to the ranking model, but classified as make-to-order according to the traditional ABC classification, have all a short lead time, high best before date, a medium/high number of orders per year, and a high ratio of the best before date and the number of days between order. On the other hand, the 15 items that are classified as make-to-order according to the ranking model, but classified as make-to-stock according to the traditional ABC classification, have all the opposite values of the just mentioned criteria.

We also compare the service levels in both cases. Table 5.1 represents the service levels of both cases. The service levels in case of the multi-criteria inventory classification is higher in case of the traditional ABC classification.

Table 5.1: Service levels in case of multi-criteria inventory classification and traditional ABC classification

	Average service level of MTS items (%)	Average service level of MTO items (%)	Overall average service level (%)
Multi-criteria inventory classification	84	88	85
Traditional ABC classification	81	86	83

Concluding, in food processing industry a multi-criteria inventory classification is required to rank the items in a correct way. The traditional ABC classification does not taken into account the best before date, the order lead time and the number of orders per year for each item, which are critical criteria in food processing industry to get better performances.

Normal distribution approximation used in the inventory model
The used inventory control model assumes a normal distribution for the demand. Therefore, we have to check whether the demand of the food processing company actually follows also a normal distribution. Note that there will also be items with intermittent demand, which do not follow a normal distribution, and the used inventory model can not be applied to our case. However, in all likelihood most of the items with intermittent demand will be make-to-order items, which means that the average inventory space for those items is not necessary anymore and the inventory model is not applied to those items. Therefore, we have only checked the demand distribution of the items with non-intermittent demand. Note that this verification is actually done before we choose an inventory model.

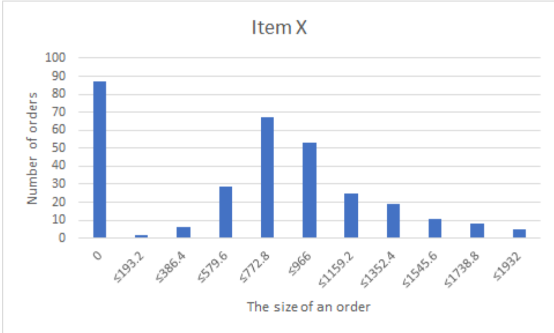
Figure 5.1a represents the schematic distribution pattern of the items with non-intermittent demand with one big peak at demand equal to zero. We can conclude that the demand of those items follows on the one hand a normal distribution (see figure 5.1b) and on the other hand a constant (see figure 5.1c). Therefore, we mix these two to calculate the mean and standard deviation in the following way:

probability that the demand is zero $* 0 +$ (1$-$probability that the demand is zero) $*$ mean of the normal distribution (or standard deviation).

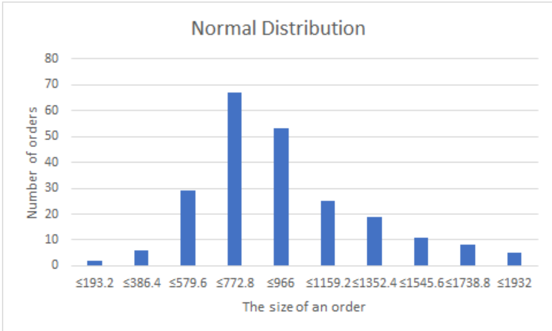
Since we multiply a constant by a normal distribution, the mix distribution can be approximated by a normal distribution. Therefore, the proposed inventory control model can be used.

5.1.2.2 Validation

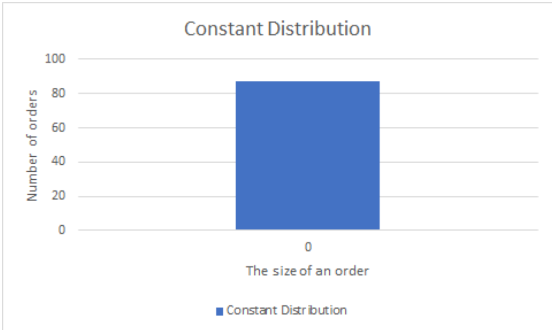
We validate on the policy parameters and the classification, which are elaborated below.



(a) Schematic distribution pattern of items with non-intermittent demand



(b) Normal distribution



(c) A constant

Figure 5.1: Demand distribution

Policy parameters

The policy parameters from the inventory model used in both the ranking model and 0-1 ILP model should not be too different from the suggestions from Slimstock. Otherwise, the expected average inventory space per item does not match with the real average inventory space per item, which means that the results from the model are not applicable in practice. Therefore, we have to compare the policy parameters from the model with the policy parameters from Slimstock. However, unfortunately, the project about implementing new supply chain systems is behind schedule, which means that the policy parameters from Slimstock are unknown. Moreover, Slimstock has no test environment. We can compare the proposed policy parameters to the current policy parameters in the custom made planning tool, but these policies are on common sense and they do not work with these policies. Besides, comparing our suggestions to the current situation by using the average inventory levels from the current systems is also not possible, since the inventory levels from the system usually do not correspond to reality. To be able to validate the policy parameters, we use expert opinion. Therefore, the supply chain manager has assessed the average inventory space per item calculated by the inventory model. Moreover, he gave us the average inventory of five items. These five items are make-to-stock items anyway, since these items are make-to-stock items in both the current situation and proposed models. Since the supply chain manager is familiar with these items, he knows the average inventory for these items. Note that the average inventory is still an indication. Table 5.2 represents the comparison of the average inventory of the current situation to the proposed model, which validates the policy parameters indirectly. Note that it does not matter whether the proposed r and Q differ from the reality. The point is that the proposed average inventory per item corresponds to reality to take into account the limited inventory capacity. As can be seen in the figure, the proposed average inventory for each item does not differ much from reality.

Table 5.2: Validation: the average inventory per item from the current situation and the proposed model

Item	**Average pallets in stock proposed model**	**Average pallets in stock current situation**	**Difference**
Item 1	11	12	1
Item 2	15	16	1
Item 3	11	14	3
Item 4	17	13	4
Item 5	14	11	3

Based on expert opinion and the above figure, we can conclude that the proposed inventory model obtains results that are close to reality. It seems that we used good indications and assumptions. Keep in mind that Slimstock can give other suggestions, and that the cost parameters of the proposed inventory model are still indications. Therefore, when Slimstock is implemented, it can be useful to run the model with the right values of the cost parameters and compare this to the suggestions from Slimstock. Unfortunately, currently, this validation method is not possible.

Classification

The CODP decision (classification) and the corresponding inventory control policy for each item is the final result of the model. Therefore, we have to validate the results to check whether the model fulfills its intended purpose. By using Slimstock, we can validate the classification. As mentioned above, unfortunately, this is not possible. Therefore, by asking expert opinion and putting the current situation in the 0-1 ILP model, we will determine whether the CODP decision and the corresponding inventory control policy for each item is justified.

Appendix E represents the results of putting the current situation in the proposed 0-1 ILP model. As can be seen, there are only 23 items classified as make-to-order, which are the in/out items. Note that the food processing company uses a hybrid MTS/MTO decision per item, which means that the current hard classification in appendix E is not really correct. To be able to do a validation and comparison with the current situation, we assume that the food processing company complies with the classification.

As can be seen in appendix E, the total average number of pallets on hand needed is equal to 690 pallets, which means that the total inventory capacity will not be exceeded. However, since the food processing company uses a hybrid MTO/MTS decision per item and they do not follow the suggested policies, the total average number of pallets on hand can become higher. Next to that, at first sight, the overall service level (83%) seems low in comparison to the current service level (96%) mentioned in section 1.3. However, the service level mentioned in section 1.3 is based on all end products, e.g. bulk, frozen, and fresh products. Since the bulk and frozen products have high service levels, the service level of the fresh products will be lower than the service level mentioned in section 1.3. Besides, the service level from appendix E is too low due to the hard classification. In addition, we use a standard deviation of the lead time of the make-to-order items of one day to cover some uncertainties, which means that the service levels of the make-to-order items may be higher in reality. Concluding, the overall service level will be higher than 83%. Overall, the results seem to be logical, although we can not validate them exactly.

Next to the validation above, we validate on the classification of the ranking model and the 0-1 ILP model. The results of both the ranking model and the 0-1 ILP model are represented in Appendix B. The last two columns of these appendices represent the CODP of the other model and whether the item is classified different by the other model, respectively. Note that the 0-1 ILP model represents a dividing line between the make-to-stock and make-to-order products rather than a ranking. A summary of those tables are given in tables 5.3 and 5.4.

Table 5.3: Summary of results of ranking model

1. Items with high demand, high best before date, low order lead time, and high number of orders per year	MTS
2. Items with low best before date, medium order lead time, and medium number of orders per year	MTS
3. Items with high best before date, low/medium order lead time, and low number of orders	MTS
4. Items with medium demand, high best before date, low order lead time, and medium/high number of orders per year	MTO
5. Items with low/medium demand, medium/high best before date, low/medium order lead time, and medium number of orders per year	MTO
6. Items with low demand, high best before date, high order lead time, and low number of orders per year	MTO
7. In/out items	MTO

Table 5.4: Summary of results of 0-1 ILP model

1. Items with high demand, high best before date, low order lead time, and high number of orders per year	MTS
2. Items with medium demand, high best before date, low/medium order lead time, and medium/high number of orders per year	MTS
3. Items with low best before date, medium order lead time, and medium number of orders per year	MTO
4. Items with high best before date, low/medium order lead time, and low number of orders	MTO
5. Items with low/medium demand, medium/high best before date, low/medium order lead time, and medium number of orders per year	MTO
6. Items with low demand, high best before date, high order lead time, and low number of orders per year	MTO
7. In/out items	MTO

By using the average inventory space needed per item, the total inventory space needed for all items is equal to 736 pallet places, which means that the total inventory capacity at the food processing company will not exceeded in case all items will be produced according to a make-to-stock strategy. Therefore, according to the ranking model, all end products have to be produced according to the make-to-stock strategy. Therefore, as mentioned in section 4.4.1, we apply then the 70/30 rule to the ranking model. Therefore, the first 68 end products of the ranking will be produced according to a make-to-stock strategy.

The results of the models are slightly different. First of all, according to the 0-1 ILP model, from the 224 end products 70 end products have to be produced according to the make-to-stock strategy, where according to the ranking model 68 end products have to be produced according to the make-to-stock strategy.

Furthermore, there is a difference in classification. 22 make-to-stock items from the ranking model are classified as make-to-order by the 0-1 ILP model. On the other hand, 24 make-to-stock items from the 0-1 ILP model are classified as make-to-order by the ranking model.

Together with the supply chain manager, we have evaluated the results and compared the models. Most of the classifications of both models makes sense. As can be seen in the tables, mainly, both models agreed on the classifications of the items on the top and the bottom of the ranking list. However, there are a number of striking classifications. Mainly in the make-to-stock list of the ranking model (the second point of table 5.3). Based on the short best before date and in comparison to the best before date a relative high order lead time, we would classify 11 items as make-to-order items rather than make-to-stock. For example, the best before date and the order lead time are equal to 3 and 4 days, respectively, which means that when the item is kept in stock, each 2 or 3 days a few items have to be produced, while the mean lead time of make-to-order items is lower than the order lead time of the item. Therefore, classifying them as make-to-order would be cheaper, while the service levels will be reached. The remarkable thing about these 11 items is that these items are exactly the items which are make-to-order products according to the 0-1 ILP model. Another remarkable thing about these items is the relative low fill rate, which makes sense since the probability of perish items is high, which means that only a few items can be kept in stock to avoid a high outdating percentage, and therefore the customer demand can not be met.

The other 11 make-to-stock items in the ranking list, which are classified as make-to-order items by the 0-1 ILP model, all have quite a low number of orders per year, but a relative low order lead time of 3 or 4 days and a relative high best before date around 10 days (point 3 of table 5.3). Therefore, we understand these classifications of the ranking model. However, since the number of orders per year is low and the mean lead time is lower than the order lead time, the cost will be lower in case of a make-to-order item and therefore the 0-1 ILP model classifies these 11 items as a make-to-order item. Besides, the service levels of these items are higher or equal in case of make-to-order. Therefore, for these 11 items, we agree on the classification of the 0-1 ILP model. Note that the mean and standard deviation of the make-to-order lead time have to be correct, else in case the lead time is higher, the service levels of the make-to-order items will drop drastically, and classifying as make-to-stock will then be better. A few examples of these items where this would be the case are product 20, 43, and 47. The mean demand and best before date of these items are relatively high, and the order lead time is equal to 3, which means that when the mean make-to-order lead time of 2 days will be higher, the overall average service levels of these items drop drastically, since the demand is high. In this case, the mean of the make-to-order lead time is known. On the other hand, the standard deviation is unknown. Therefore, a sensitivity analysis on the standard deviation of the make-to-order lead time is needed. This sensitivity analysis is done in section 5.1.4.4.

24 make-to-stock items from the 0-1 ILP model, is classified as make-to-order by

the ranking model. These items all have a quite low order lead time between 1 and 3 days and a relatively high number of orders per year (point 2 from table 5.3). Therefore, classifying them as make-to-stock makes sense, and we agree on the 0-1 ILP model. The ranking model classifies these 24 items as make-to-order, since the mean demand is relatively low.

Moreover, in both models, a few items with a short lead time, relative high best before date, and a medium number of orders per year are classified as make-to-order. However, at first sight, it seems to be logical to classify them as make-to-stock. At the end, we still agree with the classification of the models, since the short order lead time is just above the mean lead time. Thereby, classifying these items as make-to-order is less expensive. In case the lead time will increase, the classification will be change, since the make-to-stock cost will decrease.

Concluding, in general, the CODP decision and the corresponding inventory control policy for the end products are justified for both models. Although, the 0-1 ILP model is more justified. Next to that, the calculations of the policy parameters and the service levels seem to be right. Therefore, the proposed framework has been successfully validated.

5.1.3 Results

The proposed framework contains two different models: the ranking model and the 0-1 ILP model. Therefore, a comparison has to be made to define whether there is a difference in results of both models. Note that ranking models and 0-1 ILP models are heuristics and exact methods respectively, and an exact method is always preferred over a heuristic. In that case, a comparison of these two models is not needed. However, in our case the 0-1 ILP model is not exact, since we use approximations for lost sales, set-up cost, and standard deviation of the lead time. Therefore, both models are heuristics and a comparison is useful. In this section, we compare both models.

5.1.3.1 The tool

The results of both models can be produced by using the tool. Appendix C represents the tool and figure 5.2 represents the manual of the tool for explanation. The tool is made in Excel. The sheet 'Model Explanation' represents the manual of the tool. The user only have to use the sheets with a green label. The user has to insert the right data in these sheets. After inserting data, by pressing the 'Solve 4a' and 'Solve 4b' button the results of, respectively, the ranking model and the 0-1 ILP model are generated. After running, the sheet 'Solution' represents the results, which means a CODP and the corresponding inventory control policy for each item. Next to that, the sheet 'Solution' represents other relevant data and the performance measures. As mentioned in chapter 4, the performance measures consists of the total cost per year, the average number of pallets in stock, and the overall average service level.

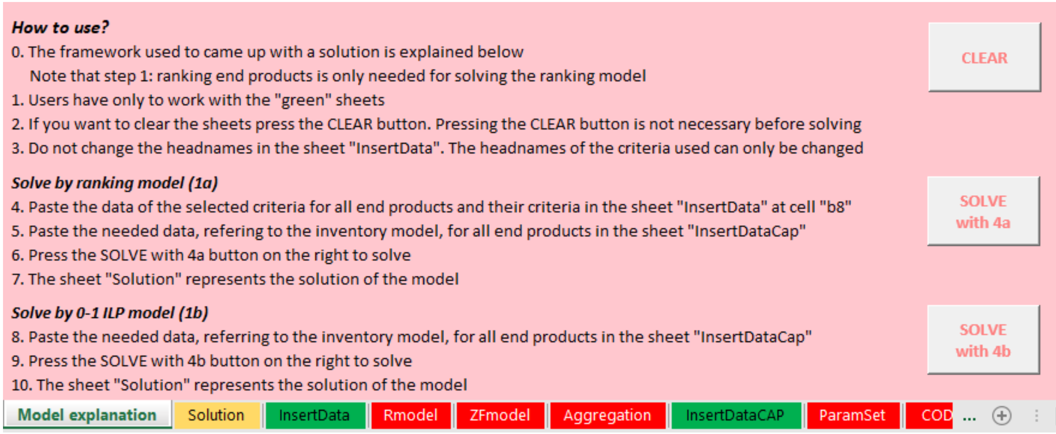


Figure 5.2: Manual of the tool

5.1.3.2 Comparison of ranking model to the 0-1 ILP model

The maximum computation time of the ranking model and the 0-1 ILP model are 10 and 5 minutes, respectively. The computation time of the inventory model is equal to 4 minutes, which means that the computation time of the ranking model and the 0-1 ILP model is 6 and 1 minutes, respectively.

We asked the supply chain manager for expert opinion. A kind of comparison is already done in section 5.1.2.2, since we validate the results of the two proposed models together with the supply chain manager. In general, the classifications of both models makes sense to the supply chain manager. However, there are a few striking classifications, which is discussed in section 5.1.2.2.

Next to the classification comparison, we compare both models on the total cost and service levels. Tables 5.5 and 5.6 represent the total cost per year, the total number of pallets on hand needed, and the service levels of both the results of the ranking model and the 0-1 ILP model.

Table 5.5: Total cost per year and average number of pallets in stock in case of the ranking model and the 0-1 ILP model

	Total cost per year (€)	**Total average number of pallets on hand needed**
Ranking model	21,917,944	491
0-1 ILP model	17,785,066	527
Difference	4,132,879	36

Table 5.6: Service levels in case of the ranking model and the 0-1 ILP model

	Average service level of MTS items (%)	**Average service level of MTO items (%)**	**Overall average service level (%)**
Ranking model	84	88	85
0-1 ILP model	99	89	94
Difference	15	1	9

As can be seen in tables 5.5 and 5.6, the total cost per year in case of the 0-1 ILP model is around €3,360,000 lower than in case of the ranking model. Moreover, the overall average service level in case of the 0-1 ILP model is as much as 9% higher than in case of the ranking model. The low average service level of the make-to-stock items in case of the ranking model can be explained by the extreme low service levels of some items. The low service levels of these items can be explained by the high probability of perishability of these items, which means that only a low quantity per item is in stock, and therefore the customer demand can not be covered.

Concluding, in general the classification of both models makes sense. However, the results are slightly different. The ranking model classifies items with a short best before date and in comparison to the best before date a relatively high order lead time, and where the order lead time is just above the mean order lead time, as a make-to-stock item. This is a big disadvantage of the model. Other disadvantages of the ranking model are the high computation time and the relatively low overall service level and total cost in comparison to the 0-1 ILP model. On the other hand, the classifications of all items of the 0-1 ILP model makes sense, the computation time of the 0-1 ILP model is twice as fast as the ranking model, and the overall service level is relatively high with 93%, where the overall service level of the make-to-stock items is equal to rounded 99%. In addition, the proposed 0-1 ILP model is a near to exact method, and therefore the results will be close to optimal. Therefore, we prefer the 0-1 ILP model over the ranking model.

Finally, we can conclude that, even though the 0-1 ILP model is not entirely exact, the 0-1 ILP model is still better than a heuristic approach, which refers to the ranking model. Note that the accuracy of the values of the input is a strict requirement of the 0-1 ILP model. In case of doubt about the accuracy of the values of the input, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results. Even though the 0-1 ILP model performs better, we do not eliminate the ranking model, since the results are not significantly worse, and can be even better than the current situation. In addition, model comparison adds value to the results. The results become more reliable.

5.1.4 Sensitivity analysis

We want to find out how and to what extent the solution depends on the input parameters. In order to do so, we run several experiments to see how the parameter inputs influence the solutions. We run several experiments by using the maximum inventory space needed per item rather than the average inventory space needed, varying the criteria selection of the ranking model, the lost sales parameter of the (r, Q) inventory model, and the standard deviation of the lead time of the make-to-order items used in the 0-1 ILP model.

5.1.4.1 Maximum inventory space needed per item

As mentioned in section 4.3, we calculate the average inventory space needed per item to take into account the limited inventory capacity. We take the average, since we want take full advantage of the total inventory capacity. On the other hand, we could have used the maximum inventory space needed per item. Therefore, it is interesting to compare the results to the results by using the maximum inventory space needed per item. The maximum inventory space needed per item can be calculated by $(r - x_L) + Q - E[O]$ (Kouki et al., 2015).

By using the maximum inventory space needed per item, the ranking model classifies the first 86 items of the ranking as make-to-stock, since the maximum inventory capacity is reached. Therefore, the results are the same as by using the average inventory space needed. The result of the 0-1 ILP model is exactly the same as the result by using the average inventory space; 70 items are classified as make-to-stock items.

Concluding, taking the maximum inventory space per item rather than the average inventory space per item does not influence the final results.

5.1.4.2 Criteria selection in the ranking model

As mentioned in section 4.1, criteria selection in the ranking model is a crucial decision, since this decision will influence the ranking. Therefore, a sensitivity analysis on criteria selection is required. Just as in the proposed ranking, the 70/30 rule is applied to all other cases.

We leave the details of the sensitivity analysis to appendix D. The impact of adding one criteria is analyzed. In the proposed ranking model we have used five criteria: weekly usage, standard deviation of the demand, the best before date, the order lead time, and the ratio of the best before date and the average number of days between two orders. In appendix D the proposed result of the ranking model is represented, where the last columns are the results of the ranking model with different criteria selection. In each result, one criteria is removed. So, the column "Without order lead time" means that weekly usage, standard deviation, and best before date are included criteria. The ratio and the order lead time are removed. Table 5.7 summarizes appendix D.

Table 5.7: Summary of sensitivity analysis on criteria selection

	Without ratio	**Without order lead time**	**Without best before date**
Difference in classification to current situation	2	8	22

As can be seen, the ratio does not really add value. Two items are classified differently. On the other hand, by also removing the order lead time, eight items are classified differently. These eight items have a relatively low or a relatively high order lead time, so these items switch to make-to-stock and make-to-order, respectively. By also removing the best before date, twenty-two items are classified differently. The items with an extremely low and high best before date switch to make-to-order and make-to-stock, respectively.

Next to the classification comparison, we compare the service levels. Figure 5.3 represents the service levels in case of different criteria selections. We can conclude that adding criteria, which are crucial in food processing industry, adds indeed value. The more food processing industry related criteria we remove, the lower the service levels.

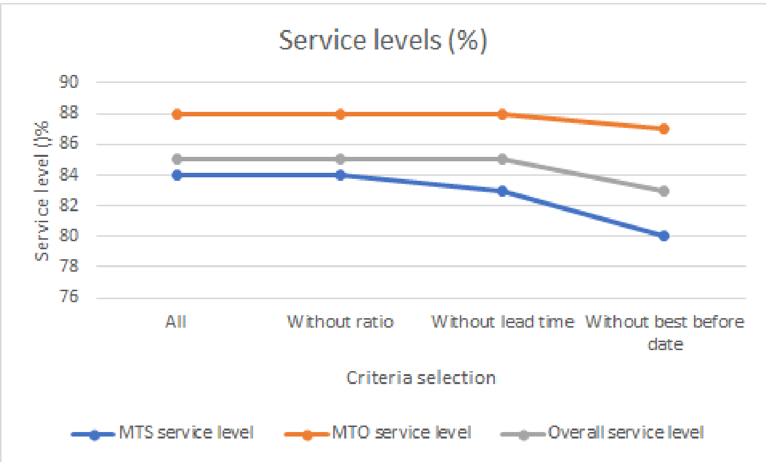


Figure 5.3: Sensitivity analysis: Criteria selection

Finally, the results are sensitive to the criteria selection. Therefore, criteria selection is a crucial decision. By choosing the wrong criteria, the results can be worse. Therefore, the sensitivity to criteria selection makes the ranking model less powerful.

5.1.4.3 Lost sales

The value of the lost sales parameter is unknown to the food processing company, which means that we have made an assumption. However, lost sales is a crucial parameter, since this parameter does significantly influence the total cost. Therefore, a sensitivity analysis is required.

We used the 0-1 ILP model to do the sensitivity analysis, since both the cost function of the 0-1 ILP model and the cost function of the inventory model is included, which are influenced both by the lost sales. The ranking model contains only the average space needed per item that is influenced by the lost sales cost. Therefore, the impact of lost sales cost will not have that much influence on the ranking model and certainly not whenever a large part of the inventory capacity is not used. Therefore, the influence of the lost sales cost on the 0-1 ILP model is more interesting. Moreover, the trend of the performance that will be found also applies to the ranking model.

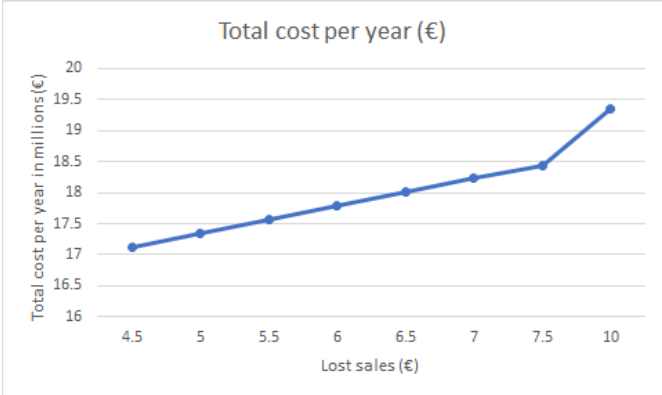
Figure 5.4 represents the results of the sensitivity analysis. We vary the lost sales cost from 4.5 to 7.5 euro with steps of 0.5 euro. In addition, we include one outlier of the lost sales cost, which is equal to 10 euros, to see the impact whenever the lost sales cost is quite high. The total cost per year, total average number of pallets in stock, and the service levels are used as measures to evaluate the sensitivity analysis.

As can be seen in figures 5.4a and 5.4b, both the total cost and the total average number of pallets in stock increase when lost sales cost increase. These increasing costs makes sense, since whenever the lost sales cost increase, the cost of both the make-to-stock and make-to-order production will increase. The increasing total average number of pallets in stock can be explained by the faster rising make-to-order cost than the make-to-stock cost, which means that some items becomes make-to-stock rather than make-to-order. Therefore, the total average number of pallets in stock will be higher. Table 5.8 confirmed this observation. The higher the lost sales cost, the higher the number of make-to-stock items. The make-to-order cost rise faster than the make-to-stock cost, since the optimal r and Q values will be find to minimize the cost. The items with a relatively high demand switch to a make-to-stock item. The service levels remain the same when the lost sales cost increase. On the other hand, the cost will increase.

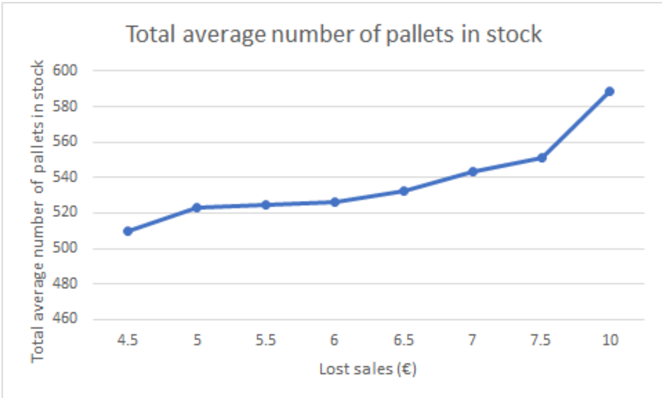
Table 5.8: Sensitivity analysis: lost sales cost- number of make-to-stock and make-to-order items

Lost sales cost (€)	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**10**
Number of MTS items	66	69	69	70	72	74	77	91
Number of MTO items	158	155	155	154	152	150	147	133

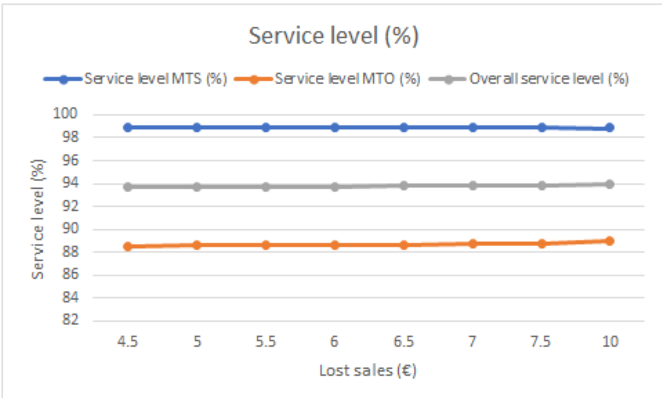
Concluding, the lost sales cost do influence the result of the 0-1 ILP model. The



(a) Total cost per year



(b) Total average number of pallets



(c) Service levels

Figure 5.4: Sensitivity analysis: lost sales cost

higher the lost sales cost, the more items will be classified as make-to-stock, since an out-of-stock item is more expensive. This ensures a higher total average number of pallets in stock. Note that when the lost sales cost will be so high that many items becomes a make-to-stock item, at a certain point the limited inventory capacity will influence the result, since the limited capacity is reached. Then, the classification will be constant by increasing the lost sales from that point onwards. In addition, the higher the lost sales cost, the higher the total cost. The service levels will drop, since the optimal can not be realized due to the fact that the maximum inventory capacity is used.

Lost sales cost will not influence the result of the ranking model, but it does influence the measures. In all cases, the sum of the space needed for all items does not exceeded the limited inventory capacity, which means that, in all cases, we apply the 70/30 rule to the ranking model. Therefore, the lost sales cost will not have impact on the results of the ranking model. However, the total cost and the service level become higher and lower, respectively, since no item will switch from make-to-order to make-to-stock.

Since the results of both models are sensitive to lost sales, it is crucial to make good assumptions.

Note that we made an assumption for the set-up costs too. However, the set-up cost does not influence the total cost as much as the lost sales. The set-up cost will influence the results whenever the set-up cost are much higher, and the assumption made for the set-up cost will not deviate much from reality.

5.1.4.4 Standard deviation of the lead time of the make-to-order items

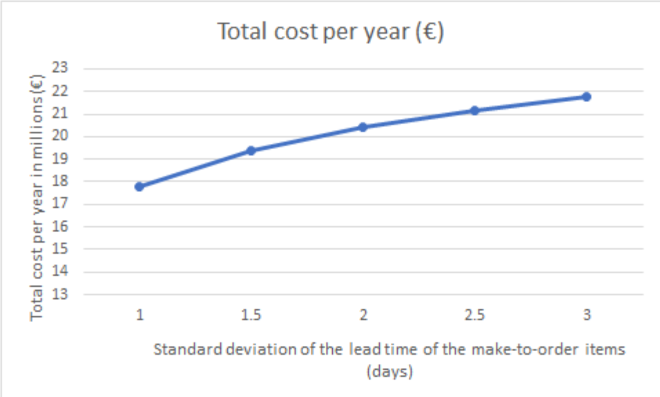
As mentioned in section 5.1.3, it is interesting to find out how and to what extent the solution depends on the standard deviation of the lead time of the make-to-order items. The result of the 0-1 ILP model can be sensitive to different standard deviations of the lead time of the make-to-order items, since the lead time does quite influence the cost of the make-to-order items, which can result in a classification switch from an item, i.e. from a make-to-order to a make-to-stock item. Therefore, a sensitivity analysis is represented below.

Figure 5.5 represents the results of the sensitivity analysis. We vary the standard deviation from 1 to 3 days with steps of 0.5 day. The total cost per year, total average number of pallets in stock, and the service levels are used as measures to evaluate the sensitivity analysis. Table 5.9 represent the total number of make-to-stock and make-to-order items in case of the different standard deviations.

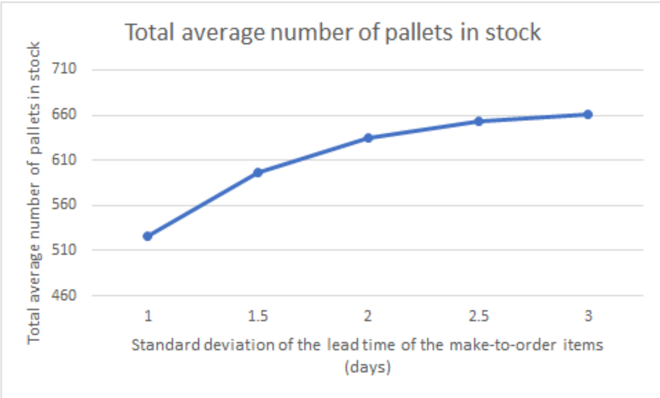
Table 5.9: Sensitivity analysis: standard deviation - number of make-to-stock and make-to-order items

Standard deviation (days)	**1**	**1.5**	**2**	**2.5**	**3**
Number of MTS items	70	99	119	128	135
Number of MTO items	154	125	105	96	89

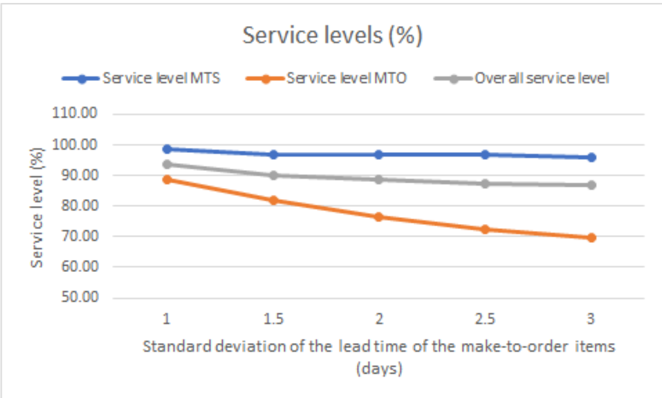
The higher the standard deviation, the more items will be classified as make-to-stock, and the total average number of pallets in stock will therefore be higher. Moreover, the higher the standard deviation, the higher the cost. This makes



(a) Total cost per year



(b) Total average number of pallets in stock



(c) Service levels

Figure 5.5: Sensitivity analysis: standard deviation of lead time of the make-to-order items

sense, since the make-to-order cost will increase, and therefore a make-to-order item can switch to a make-to-stock item. The items with a relatively high demand and low order lead time switch to a make-to-stock item. In addition, the higher the standard deviation, the lower the service levels. The average service level of the make-to-order items drops drastically, which makes sense since the higher the standard deviation of the lead time, the higher the probability that an item is too late. Concluding, the results of the 0-1 ILP model are sensitive to the standard deviation of the lead time of the make-to-order items. Therefore, it is crucial to make good assumptions.

5.1.5 Comparison of proposed framework to current situation

In this section, we compare the proposed framework to the current situation. By implementing the inventory control and planning system Slimstock with the right input, the service levels have to be improved and the cost have to be reduced by balancing the inventory. Therefore, by entering the CODP and corresponding inventory control policy for each item in Slimstock, we can compare the new situation to the current situation. Unfortunately, since the project on implementing new supply chain systems is behind schedule, Slimstock is not implemented yet. Moreover, Slimstock has no test environment, which means that an application based comparison to the current situation is not possible. To be able to compare the the proposed framework to the current situation, we compare the classification from the proposed framework to the current situation. Moreover, in section 5.1.2.2, we put the current situation in the proposed 0-1 ILP model, and therefore we can compare the total cost per year and the service levels by assuming that the food processing company uses the policies from the proposed inventory model.

Table 5.10 and 5.11 represent the total cost per year, the total average number of pallets on hand needed, and the service levels. The high total number of pallets on hand needed in the current situation can be explained by the high number of make-to-stock items. The high total cost can be explained by the fact that many items are classified as make-to-stock, while classifying these items as make-to-order will be cheaper.

Table 5.10: Total cost per year and average number of pallets in stock of both models and current situation

	Total cost per year (€)	**Total average number of pallets on hand needed**
Current situation	24,952,469	690
Ranking model	21,917,944	491
Difference to current situation	3,034,524	199
0-1 ILP model	17,785,066	527
Difference to current situation	7,167,403	163

The total cost per year of the current situation is much higher than the cost per year in case of both the ranking model and the 0-1 ILP model. The overall average service level of the current situation is lower than overall service level in case of

Table 5.11: Service levels of both models and current situation

	Average service level of MTS items (%)	Average service level of MTO items (%)	Overall average service level (%)
Current situation	83	93	83
Ranking model	84	88	85
Difference to current situation	1	5	2
0-1 ILP model	99	89	94
Difference to current situation	16	4	11

both the ranking model and 0-1 ILP model. In addition, in the current situation the total average number of pallets on hand needed is much higher than in case of both models. Note that the food processing company uses a hybrid MTS/MTO decision per item and different policies, which means that the performances of the current situation can slightly differ from the performance in tables 5.10 and 5.11.

Next to the comparison based on the performance measures, we compare the models to the current situation based on the classification. Appendix E represents this comparison. It makes sense that many items are classified differently, since in the current situation there are many items classified as make-to-stock. However, the ones that are classified as make-to-order are all classified as make-to-order in the ranking model as well and, except from 4 items, also in the 0-1 ILP model. However, it makes sense that the four items just mentioned are classified as make-to-stock, since the mean demand, the best before date, and the number of orders per year are high, and the order lead time is relatively low for these four items.

Concluding, based on the performance measures, both the ranking model and the 0-1 ILP model perform better than the current situation. In addition, in the current situation many items are classified different in comparison to both models. However, the ones that are classified as make-to-order according to the current situation, except from four items, seem to be right.

5.2 Evaluation

This section describes the advantages and disadvantages of the proposed model/tool.

Advantages

Results based on calculations and two different models
In comparison to the current situation, the tool uses calculations to determine the CODP and the corresponding inventory control policy of each item. We proved that both models perform better than the current situation. Moreover, we proved that the 0-1 ILP model performs better than the ranking model. However, in case

of doubt about the accuracy of the values of the input, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results.

Easily applicable in practice
The framework is easily applicable in practice. The framework is not that complex as in CODP determination models in the literature.

User-friendly and reuse
The proposed tool is user-friendly and easy to reuse. It is a matter of inserting data and pressing the button. The tool contains a manual that clearly explains the functioning of the tool. In addition, the tool is programmed in that way that adjustments can be made easily.

Production planning
The proposed tool is developed for the end products, which refers to the packaging department. This tool can also be applied easily to the production department, where make-to-order and make-to-stock refer to the raw materials and semi-finished products, respectively.

New products
When a new product is introduced, many parameters are unknown. To still determine whether the new product will be a make-to-stock or make-to-order product, we can approximate the unknown parameters by using the parameters of the similar products. At the same time, this is also a disadvantage, since parameters of similar products have to be used.

Disadvantages

Computation time
The tool is implemented in Excel to make it user-friendly. A disadvantage of Excel is the longer computation time than other software, e.g. AIMMS. The computation time of the proposed tool is 5 and 10 minutes for running the 0-1 ILP model and ranking model, respectively. The high computation time is mainly due to the several integrals included in the inventory model. Note that the inventory model is included in both the ranking model and 0-1 ILP model. The computation time depends on the precision of calculating the integral. However, the tool will be used once every quarter or once every week. Therefore, computational efficiency is less important.

Ranking model; criteria selection
A disadvantage of the ranking model is the subjectivity involved; the criteria selection. In general, the classifications of the items are correct. However, the classification of some items are incorrect or doubtable, since the subjectivity is involved.

5.3 Conclusion

With the results of this chapter, the fifth research question can be answered: *What is the effect of implementing the proposed framework on the performance of the supply chain of the food processing company?*

The proposed framework/tool is implemented well. We prefer the 0-1 ILP model, since this model performs better than the ranking model. However, in case of doubt about the accuracy of the values of the input, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results. By using the 0-1 ILP model the total cost per year will decrease with around €7,167,403 per year to €17,785,066, and therefore the inventory will be balanced. Moreover, the overall average service level will increase to 94%. Note that the overall average service level can never reach the 99% in the proposed framework and may be higher in real case, since we use a standard deviation of the lead time of the make-to-order items of one day to cover some uncertainties, which means that the service levels of the make-to-order items may be higher in real case. Next to that, the average service level of the make-to-stock items is equal to 99%.

Concluding, the results of the proposed tool have a positive impact on the service level and total cost per year. By feeding Slimstock with the results of the tool, the service level will be improved and the cost will be reduced by balancing the inventory. By using the 0-1 ILP model, the target values of the supply chain performances will be reached; the make-to-stock items will have a service level of 99% (increase of 19.3%) and the cost will reduced by 29%, which is equal to one third. In addition, the overall average service level is equal to 94%. Note that these values are based on the proposed model rather than on Slimstock, since Slimstock is not implemented yet. Note also that we assume that the rest of all input for Slimstock is implemented well.

Chapter 6

Conclusions and recommendations

This final chapter concludes the research. In section 6.1, we will answer the main research question, followed by the recommendations for the implementation of the proposed model in section 6.2. In section 6.2.1, an implementation plan is elaborated. Finally, section 6.3 provides suggestions for further research.

6.1 Conclusion

The companies producing food have to consider the enormous growth and changes in the market. The food processing company has to meet a service level of 99% to satisfy her customers, while cost have to be reduced. Therefore, to be able to be competitive, striving for an optimal supply chain is required for the food processing company. However, the supply chain of the food processing company is not optimal; the service levels are below target and the costs can be reduced by one third by balancing the inventory. To fulfill this aim, the food processing company started with the implementation of the forecasting and inventory management system called Slimstock. The basis for a well-functioning system is having the correct values of all inputs, which is missing at the moment. Since the inventory management part of the system is new, the inputs related to the inventory management, which includes the CODP determination and the inventory control policy for each item, are the important ones. We focus on the end products, since starting from the customer viewpoint, the demand of end products is most important, and therefore the start point. Moreover, in food processing industry, perishability of items is most challenging. Therefore, this research focuses on the fresh end product from the food processing company. Therefore, this research answers the following main research question:

How can a framework that selects and assigns a CODP and corresponding inven-

tory control policy to different end products in food processing industry be created and implemented?

Currently, from the 224 end products, 201 end products are assigned as a make-to-stock item. The CODP for each end product is based on common sense. In addition, most items are treated as either make-to-stock or make-to-order. The food processing company uses a hybrid MTO/MTS system for each item. The CODP partition is crucial as input for Slimstock, since Slimstock does calculations based on these inputs to decide how much and when production will take place to fulfill the customer demand in time. Moreover, an optimal partition of the make-to-order/make-to-stock items provides cost reduction in inventory while the delivery reliability will be met (van Donk, 2001). Concluding, an optimal determination of the CODP and corresponding inventory control policy adds value in implementing Slimstock to improve the service levels and reduce the cost.

We develop a framework that selects and assigns a CODP and corresponding inventory control policy to different end products in food processing industry to improve service levels and reduce cost. The framework considers the perishability of the items, the limited inventory capacity, and the required service levels. The framework contains two different models: a ranking model and a 0-1 ILP model, which are both heuristics since we made assumptions. Both models assign a CODP and corresponding inventory control policy to each end product. The models can be compared to get more reliable results. To be able to consider the limited inventory capacity, the framework includes matching existing CODP's with inventory control policies and parameter setting of the inventory control policies that matches with the make-to-stock CODP. Note that the inventory level (space) needed have to be calculated for all items, since we do not know which item is assigned to a make-to-order or make-to-stock item, in advance. A L4L policy is assigned to the make-to-order items, and a (r, Q) policy considering perishability is assigned to the make-to-stock items, since Slimstock uses that policy.

The ranking method and the inventory model included in the framework is from the literature. To take into account meeting a service level, we add a service level constraint to the inventory model. The 0-1 ILP model is made by ourselves. The framework contributes to the literature, since the literature lacks a user-friendly quantitative model to decide the CODP of item in the food processing industry.

Due to the constantly changing environment the framework is implemented in Excel by using Visual Basic for Applications (VBA) to be able to reuse the framework easily. The results from both models can be produced by using this tool. Employees have to only insert the needed data and press the button to get the solution. Therefore, the tool is user-friendly.

When comparing the ranking model to the 0-1 ILP model, we can conclude that, even though the 0-1 ILP model is not entirely exact, the 0-1 ILP model is still better than the heuristic approach, which refers to the ranking model. In case of the 0-1 ILP model, the total cost per year and overall service level are equal to

€17,785,066 and 94%, respectively. In case of the ranking model, the total cost per year and the overall service level are, respectively, €4,132,879 higher and 8% lower. In addition, based on the classification, the 0-1 ILP model classifies better. Moreover, the total computation time from the 0-1 ILP model is twice as fast as the ranking model.

To find out how and to what extent the solution depends on the input parameters, we did sensitivity analysis. Using the maximum inventory space needed per item rather than the average inventory space needed does not influence the results. On the other hand, the criteria selection, lost sales and standard deviation of the lead time of the make-to-order items do influence the results. By removing food processing industry related criteria, the service levels become lower. The higher the lost sales and standard deviation, the higher the cost and the lower the overall average service level. Moreover, the classification will be different in all cases.

We compare the results of the proposed framework to the current situation. The results of both models are better than the current situation. The total costs per year in case of the ranking model and 0-1 ILP model are, respectively, 24% and 29% lower than in case of the current situation. The overall average service level in case of the ranking model and 0-1 ILP model are, respectively, 2.4% and 13.3% higher than in case of the current situation.

Concluding, the results of the proposed tool have a positive impact on the service level and total cost per year. By feeding Slimstock with the suggested CODP and corresponding inventory control policy for each end product, the service level will be improved and the cost will be reduced by balancing the inventory. By using the 0-1 ILP model, the target values of the supply chain performances will be reached; the make-to-stock items will have a service level of 99% and the cost will reduced by 29%, which is equal to one third. In addition, the overall average service level is equal to 94%. Note that these values are based on the proposed model rather than on Slimstock, since Slimstock is not implemented yet. Note also that the accuracy of the values of the input is a strict requirement of the 0-1 ILP model. In case of doubt about the accuracy of the values of the input, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results.

6.2 Recommendations

This section provides recommendations for the supply chain department of the food processing company. These recommendations are related to the implementations and uses of the model.

- *Standardizing logistics tasks*
  The basis of a well-functioning inventory control system, in this case Slimstock, is having the right input. At the moment, a real problem is the many

differences in inventory levels. The actual inventory levels do not match with the inventory levels that are in the system. Therefore, this problem has to be solved first before Slimstock can be implemented. The main cause of the many differences in inventory levels is the infrequent check ins and outs of the products in the systems by the logistic employees. Besides, if stock differences are found, this is usually not solved. By standardizing tasks and motivating the employees, this problem will be solved. This is a real problem, since without solving this problem, Slimstock has no value at all. Therefore, solving this problem is crucial.

- *Use of one ERP system and standardize new data implementation*
  There is no system that contains all data. The food processing company uses many systems to collect data. Moreover, now and then data is missing for several products for several parameters. Besides, the food processing company has unwritten rules for some parameters. An example is the order lead time. We recommend to use one system for all data, standardize new data implementation, and to have no longer unwritten rules. This will ensure effectiveness and efficiency. At the moment, we have spent quite a lot of time to collect all data, either to collect it from several systems or to convert the data to the correct format. Therefore, in our opinion data consistency has to be improved to reuse the framework and generate credible outcomes.

- *Download OpenSolver for Excel*
  The OpenSolver is needed to be able to use the tool. OpenSolver can handle bigger problems than the general solver for Excel. The IT department has to ensure that the OpenSolver is available in Excel. The OpenSolver can be downloaded for free and it is safe and widely accepted.

- *Run the tool frequently*
  We recommend to run the tool at least each quarter. At the moment, it takes a lot of time to gather all data in the right format. When this will be easier, we recommend to run the tool each month or when a new product is introduced. Note that the criteria selection of the ranking model and the value of the parameters of the (r, Q) inventory model have to be reconsidered.

- *Implementing results in Slimstock*
  We recommend to implement the results of the 0-1 ILP model in Slimstock. This is because the 0-1 ILP model performs better than the ranking model. However, in case of doubt about the accuracy of the input, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results.

- *Inventory policy parameters*
  Although the inventory policy parameters seem quite good, we have to keep in mind that we used indications and assumptions for the input parameters of the inventory model. Using indications can give less precise results. Therefore, we recommend to run the tool with the right input parameters. Note that this will also affect the cost function of the 0-1 ILP model.

- *Implementing inventory policy parameters in the custom made planning tool*
  Since Slimstock is not implemented on the packaging part yet, the inventory policy parameters of the proposed model can be implemented in the custom made planning tool. The custom made planning tool is the current inventory control system, where the inventory policy parameters are based on common sense. Therefore, implementing the inventory policy parameters of the proposed model in the custom made planning tool ensures for an improvement of the service level and a balanced inventory level. Note that the proposed tool has to run with the right input parameters rather than indications.

- *Compare when Slimstock is implemented*
  Unfortunately, we were unable to implement the suggestions in a test environment of Slimstock to check the results. Moreover, we were also unable to compare the policy parameters to the policy parameters suggested by Slimstock. Therefore, we recommend to still do this comparison/validation whenever Slimstock is implemented completely.

- *Production planning*
  We recommend to apply the proposed tool also to the production planning. Note that the inventory capacity of the raw materials and the semi-finished products are much higher than the end products, since there is flexible external warehousing capacity available.

6.2.1 Implementation Plan

The proposed framework gives as final result a CODP and the corresponding inventory control policy for each end product. This result is a crucial input for the inventory control system called Slimstock, since Slimstock makes calculations based on all inputs. The implementation plan sounds simple: put the CODP and the corresponding inventory control policy for each end product suggested by the proposed framework in Slimstock, and Slimstock does the calculations. However, finally, Slimstock gives suggestions about when and how much has to be produced for each item. The employees have to follow these suggestions to create efficiency and effectiveness. To ensure that employees follow the suggestions from Slimstock, they have to support the input decisions. Therefore, it is important that the employees accept the proposed framework and agree on the results.

To implement the plan correctly, we have to explain the proposed framework to the employees who will work with the suggestions from Slimstock. Although the proposed framework is user-friendly and knowledge about the subjects is not a necessity, it is good to have some background about the models to understand them, in order to potentially spot flaws and incorrect outcomes of calculations. This will prevent people from uninformed copying of the outcomes and instead support informed decisions are taken. Therefore, we will explain the framework and its use to the employees to convince them of the CODP and corresponding inventory control policy for each end product suggested by the proposed framework. When this is succeeded, the CODP and corresponding inventory control policy for each end product can be implemented in Slimstock and the model can be used periodically by the employees.

The framework contains the ranking model and the 0-1 ILP model, which gives slightly different results. Since the 0-1 ILP model performs better, we recommend to implement the CODP and corresponding inventory control policy for each end product suggested by the 0-1 ILP model. In case of doubt about the accuracy of the values of the input parameters, we recommend to run both the ranking model and the 0-1 ILP model and compare and evaluate the results.

To be able to use the framework periodically, the criteria selection and input parameters have to be reconsidered constantly. In addition, the inventory space needed per item calculated by the inventory model of the proposed framework have to be compared to the real world, since this may not differ much from each other.

6.3 Further research

The proposed model focuses on customer satisfaction and inventory capacity. However, another important aspect can be the production capacity. As mentioned in section 2.1, the inventory capacity is a bottleneck as well as time limitations for this research. Therefore, the production capacity has been left out. For further research, considering production capacity can be useful. Moreover, we make a few assumptions, i.e. the lost sales, all necessities for packaging are always available, and there are no errors on the packaging lines. Since, as mentioned in 5.1.4, lost sales influence the total cost and the policy parameters, a good approximation of lost sales should add value. Due to the fact that we assume that all necessities for packaging are always available and there are no errors on the packaging lines, we ignore some risk of out of stock. Out of stocks of packaging materials potentially result in longer lead time, which results in risk of out of stocks for end products. Therefore, it can be useful to reconsider the lead time. Since longer lead time for make-to-stock items will result in higher safety stocks, this will also influence working capital and increased inventory capacity.

References

Berk, E., & Gurler, U. (2008). Analysis of the (q, r) inventory model for perishables with positive lead times and lost sales. , *56*(5), 1238-1246.

Chalotra, V. (2013). Inventory management and small firms growth: An analytical study in supply chain. , *17*(3), 213-222.

Chen, J. (2011). Peer-estimation for multiple criteria abc inventory classification. , *38*, 1784-1791.

Chiu, H. (1995). An approximation to the continuous review inventory model with perishable items and lead times. , *87*, 93-108.

Douissa, M., & Jabeur, K. (2016). A new model for multi-criteria abc inventory classification: Proaftn method. , *96*, 550-559.

Elbaz, M., & Abdelsalam, G. (2017). A decision mathematical model for selection production strategy. , *8*(1).

Flores, B., & Whybark, D. (1987). Implementing multiple criteria abc analysis. , *7*(1), 79-85.

FMI. (2018). Meat substitutes market: Global industry analysis 2012 - 2016 and opportunity assessment 2017 - 2026.

Hadi-Vencheh, A. (2010). An improvement to multiple criteria abc inventory classification. , *201*, 962-965.

Hoekstra, S., & Romme, J. (1992). Integral logistic structures: Developing customer-oriented goods flow.

Kouki, C., et al. (2015). A lost sales (r, q) inventory control model for perishables with fixed lifetime and lead time. , *168*, 143-157.

Menkveld, N. (2018). *Nichemarkt vleesvervangers groeit snel.* ABN AMRO.

Nagib, A., et al. (2016). The role of hybrid make-to-stock (mts) - make-to-order (mto) and economic order quantity (eoq) inventory control models in food and beverage processing industry. , *160*.

Nahmias, S. (2011). *Perishable inventory systems* (1st ed.). Springer.

Nahmias, S., & Olsen, T. (2015). *Production and operations analysis* (7th ed.). Waveland Press.

Nahmias, S., & Wang, S. (1979). A heuristic lot size reorder point model for decaying inventories. , *25*, 90-97.

Ng, W. (2007). A simple classifier for multiple criteria abc analysis. , *177*, 344-353.

Perona, M., et al. (2009). Combining make-to-order and make-to-stock inventory policies: an empirical application to a manufacturing sme. , *20*(7), 559-575.

Purohit, G., & Rathore, H. (2012). Multi item inventory control model with space constraints for deteriorable items. , *11*(1), 35-41.

Rafiei, H., & Rabbani, M. (2011). Capacity coordination in hybrid make-to-stock/ make-to-order production environments. , *50*(3), 773-789.

Ramanathan, R. (2006). Abc inventory classification with multiple-criteria using weighted linear optimization. , 695-700.

Seyedi, I., et al. (2016). An inventory model with reworking and setup time to consider effect of inflation and time value of money. , *13*(3), 416-430.

Silver, E., et al. (2017). *Inventory and production management in supply chains* (4th ed.). CRC Press.

Soman, C., van Donk, D., & Gaalman, G. (2002). Combined make-to-order and make-to-stock in a food production system. , *90*, 223-235.

Sun, X., et al. (2008). Positioning multiple decoupling points in a supply network. , *113*, 943-956.

Tekin, E., et al. (2001). Age-based vs. stock level control policies for a perishable inventory system. , *134*, 309-329.

Teunter, R., et al. (2009). Abc classification: Serivce levels and inventory costs. , 1-10.

van Donk, D. (2001). Make to stock or make to order: The decoupling point in the food processing industries. , *69*, 297–306.

van Kampen, T., et al. (2012). Sku classification: a literature review and conceptual framework. , *32*(7), 850-876.

Zaerpour, N., et al. (2008). Make-to-order or make-to-stock decision by novel hybrid approach. , *22*, 186-201.

Zhou, P., & Fan, L. (2007). A note on multi-criteria abc inventory classification using weighted linear optimization. , 1488-1491.

Appendices

Appendix A

Comparison of ranking model to ABC classification

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP ABC classification	Difference
1	636.25	9	3	226.24	0.90	28.17	MTS	(s, Q) policy	100.00	MTS	YES
2	493.81	9	3	235.29	0.71	13.75	MTS	(s, Q) policy	99.45	MTS	YES
3	153.54	32	2	222.22	0.70	28.92	MTS	(s, Q) policy	100.00	MTS	YES
4	404.26	6	2	246.35	0.66	10.62	MTS	(s, Q) policy	100.00	MTS	YES
5	455.96	12	3	306.68	0.64	29.32	MTS	(s, Q) policy	100.00	MTS	YES
6	339.18	6	2	242.33	0.63	10.63	MTS	(s, Q) policy	100.00	MTS	YES
7	395.64	12	3	214.17	0.63	9.27	MTS	(s, Q) policy	92.52	MTS	YES
8	554.42	9	3	306.68	0.59	27.08	MTS	(s, Q) policy	100.00	MTS	YES
9	429.61	12	3	308.69	0.58	15.07	MTS	(s, Q) policy	99.82	MTS	YES
10	458.37	4	4	102.56	0.58	0.00	MTS	(s, Q) policy	38.00	MTS	YES
11	307.63	7	4	96.53	0.57	7.53	MTS	(s, Q) policy	100.00	MTS	YES
12	142.83	13	3	253.47	0.57	14.00	MTS	(s, Q) policy	100.00	MTS	YES
13	343.69	12	3	299.64	0.55	17.15	MTS	(s, Q) policy	100.00	MTS	YES
14	180.42	13	3	246.35	0.54	14.67	MTS	(s, Q) policy	100.00	MTS	YES
15	321.09	12	3	306.68	0.54	16.05	MTS	(s, Q) policy	100.00	MTS	YES
16	109.66	12	3	225.95	0.54	9.35	MTS	(s, Q) policy	100.00	MTS	YES
17	2378.09	13	3	151.69	0.53	0.00	MTS	(s, Q) policy	99.91	MTS	YES
18	298.21	12	3	302.66	0.53	16.61	MTS	(s, Q) policy	100.00	MTS	YES
19	137.49	12	3	225.23	0.52	7.82	MTS	(s, Q) policy	100.00	MTS	YES
20	1931.95	12	3	109.60	0.52	0.00	MTS	(s, Q) policy	65.19	MTS	YES
21	250.79	12	3	307.69	0.52	15.73	MTS	(s, Q) policy	100.00	MTS	YES
22	77.88	13	3	201.10	0.52	14.51	MTS	(s, Q) policy	100.00	MTS	YES
23	1463.94	10	3	136.75	0.51	0.00	MTS	(s, Q) policy	53.47	MTS	YES
24	264.04	12	3	259.42	0.51	16.65	MTS	(s, Q) policy	100.00	MTS	YES
25	239.90	12	3	295.62	0.50	12.13	MTS	(s, Q) policy	100.00	MTS	YES
26	217.66	4	6	99.55	0.50	1.51	MTS	(s, Q) policy	83.26	MTS	YES
27	94.91	12	3	191.05	0.50	6.29	MTS	(s, Q) policy	100.00	MTS	YES
28	229.94	3	4	104.57	0.49	0.37	MTS	(s, Q) policy	59.85	MTS	YES
29	1279.61	12	3	93.51	0.49	0.00	MTS	(s, Q) policy	99.34	MTS	YES
30	191.95	4	6	101.56	0.49	1.16	MTS	(s, Q) policy	88.85	MTS	YES
31	31.48	24	3	102.20	0.48	5.13	MTS	(s, Q) policy	99.75	MTO	NO
32	111.33	10	5	217.03	0.48	5.09	MTS	(s, Q) policy	100.00	MTS	YES
33	323.96	4	3	270.48	0.48	1.61	MTS	(s, Q) policy	67.54	MTS	YES
34	161.37	12	3	256.40	0.48	8.22	MTS	(s, Q) policy	100.00	MTS	YES
35	662.03	16	3	70.39	0.48	0.00	MTS	(s, Q) policy	42.31	MTS	YES
36	79.33	13	3	198.09	0.48	9.77	MTS	(s, Q) policy	100.00	MTS	YES
37	157.39	4	6	102.56	0.48	1.14	MTS	(s, Q) policy	74.31	MTS	YES
38	139.05	12	3	302.66	0.48	8.51	MTS	(s, Q) policy	100.00	MTS	YES
39	1076.65	16	3	95.99	0.47	0.00	MTS	(s, Q) policy	92.64	MTS	YES
40	69.39	13	3	195.07	0.47	10.02	MTS	(s, Q) policy	100.00	MTS	YES
41	54.35	13	3	187.02	0.47	8.00	MTS	(s, Q) policy	100.00	MTS	YES
42	91.53	10	3	198.09	0.47	9.43	MTS	(s, Q) policy	100.00	MTS	YES
43	1037.85	12	3	91.50	0.47	0.00	MTS	(s, Q) policy	80.24	MTS	YES
44	215.66	4	4	108.60	0.47	0.39	MTS	(s, Q) policy	60.47	MTS	YES
45	198.03	8	3	269.48	0.47	7.67	MTS	(s, Q) policy	100.00	MTS	YES
46	140.61	10	3	243.33	0.47	3.37	MTS	(s, Q) policy	97.36	MTS	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP ABC classification	Difference
47	420.44	6	3	206.13	0.47	0.00	MTS	(s, Q) policy	48.34	MTS	YES
48	47.71	13	3	188.03	0.47	8.10	MTS	(s, Q) policy	100.00	MTO	NO
49	47.44	13	3	185.01	0.47	8.07	MTS	(s, Q) policy	100.00	MTO	NO
50	52.63	12	1	208.14	0.46	4.05	MTS	(s, Q) policy	100.00	MTO	NO
51	923.38	13	3	124.34	0.46	0.00	MTS	(s, Q) policy	39.85	MTS	YES
52	104.79	13	3	197.08	0.46	2.56	MTS	(s, Q) policy	93.30	MTS	YES
53	40.38	13	3	176.97	0.46	6.90	MTS	(s, Q) policy	100.00	MTO	NO
54	403.94	16	3	68.28	0.46	0.00	MTS	(s, Q) policy	92.03	MTO	NO
55	46.48	12	1	207.13	0.46	4.09	MTS	(s, Q) policy	100.00	MTO	NO
56	115.74	7	4	91.50	0.46	2.35	MTS	(s, Q) policy	99.69	MTS	YES
57	91.01	8	3	191.05	0.46	5.25	MTS	(s, Q) policy	100.00	MTS	YES
58	34.79	13	3	167.16	0.46	6.35	MTS	(s, Q) policy	99.90	MTO	NO
59	107.85	4	3	270.48	0.46	2.36	MTS	(s, Q) policy	99.68	MTS	YES
60	884.00	4	3	163.88	0.45	0.00	MTS	(s, Q) policy	67.77	MTS	YES
61	79.96	12	3	253.39	0.45	5.99	MTS	(s, Q) policy	100.00	MTO	NO
62	380.51	10	3	112.31	0.45	0.00	MTS	(s, Q) policy	87.31	MTS	YES
63	538.63	12	3	69.38	0.45	0.00	MTS	(s, Q) policy	82.76	MTO	NO
64	75.78	12	3	300.65	0.45	3.90	MTS	(s, Q) policy	100.00	MTO	NO
65	87.39	7	4	79.44	0.45	3.53	MTS	(s, Q) policy	100.00	MTS	YES
66	29.01	12	1	206.13	0.45	2.67	MTS	(s, Q) policy	99.95	MTO	NO
67	31.88	12	1	205.12	0.45	1.87	MTS	(s, Q) policy	99.74	MTO	NO
68	252.51	16	3	62.81	0.45	0.00	MTS	(s, Q) policy	99.80	MTO	NO
69	93.39	13	3	187.02	0.45	2.35	MTO	L4L	91.98	MTO	YES
70	64.89	12	3	263.44	0.45	4.14	MTO	L4L	100.00	MTO	YES
71	26.42	12	1	206.13	0.45	2.51	MTO	L4L	100.00	MTO	YES
72	24.60	12	1	205.12	0.44	1.94	MTO	L4L	96.54	MTO	YES
73	85.30	13	3	171.94	0.44	1.84	MTO	L4L	85.32	MTO	YES
74	23.24	12	1	202.11	0.44	2.00	MTO	L4L	100.00	MTO	YES
75	1009.80	10	3	114.95	0.44	0.00	MTO	L4L	31.78	MTS	NO
76	74.27	13	3	169.93	0.44	2.46	MTO	L4L	96.16	MTO	YES
77	70.22	10	3	114.63	0.44	1.65	MTO	L4L	83.34	MTO	YES
78	86.25	12	3	184.01	0.44	1.88	MTO	L4L	85.80	MTO	YES
79	67.07	13	3	183.00	0.44	2.46	MTO	L4L	97.27	MTO	YES
80	23.16	13	3	126.69	0.44	4.08	MTO	L4L	99.27	MTO	YES
81	15.04	12	1	203.11	0.44	1.36	MTO	L4L	99.78	MTO	YES
82	48.97	12	3	213.17	0.44	2.99	MTO	L4L	100.00	MTO	YES
83	13.97	12	1	206.13	0.44	1.31	MTO	L4L	99.90	MTO	YES
84	63.04	13	3	166.91	0.44	2.69	MTO	L4L	99.26	MTO	YES
85	62.65	13	3	165.91	0.44	2.06	MTO	L4L	93.04	MTO	YES
86	59.16	13	3	190.04	0.44	2.18	MTO	L4L	94.67	MTO	YES
87	20.57	13	3	142.78	0.44	3.48	MTO	L4L	99.97	MTO	YES
88	12.68	12	1	204.12	0.44	1.22	MTO	L4L	100.00	MTO	YES
89	69.07	6	3	170.94	0.44	1.89	MTO	L4L	92.54	MTS	NO
90	48.83	13	3	188.03	0.44	2.63	MTO	L4L	100.00	MTO	YES
91	14.34	12	1	195.07	0.44	1.30	MTO	L4L	99.82	MTO	YES
92	51.82	13	3	182.00	0.44	2.08	MTO	L4L	94.99	MTO	YES
93	81.20	9	3	255.40	0.44	3.91	MTO	L4L	100.00	MTO	YES
94	23.84	12	1	138.76	0.43	1.77	MTO	L4L	100.00	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP ABC classification	Difference
95	20.87	10	1	170.94	0.43	1.82	MTO	L4L	100.00	MTO	YES
96	79.23	6	3	127.70	0.43	2.27	MTO	L4L	97.29	MTS	NO
97	43.10	9	3	190.04	0.43	1.97	MTO	L4L	96.47	MTO	YES
98	40.19	13	3	174.96	0.43	2.13	MTO	L4L	98.40	MTO	YES
99	180.65	5	4	100.55	0.43	1.37	MTO	L4L	94.85	MTS	NO
100	17.02	13	3	111.61	0.43	3.10	MTO	L4L	99.98	MTO	YES
101	59.68	12	4	52.29	0.43	1.98	MTO	L4L	99.97	MTO	YES
102	23.56	13	5	94.15	0.43	2.11	MTO	L4L	99.10	MTO	YES
103	28.88	12	3	195.07	0.43	2.11	MTO	L4L	100.00	MTO	YES
104	93.18	4	4	71.39	0.43	0.79	MTO	L4L	88.17	MTS	NO
105	107.10	4	4	90.38	0.43	1.19	MTO	L4L	97.77	MTS	NO
106	51.47	12	3	93.86	0.43	2.95	MTO	L4L	100.00	MTO	YES
107	40.84	12	3	174.96	0.43	1.48	MTO	L4L	99.97	MTO	YES
108	44.11	12	3	131.95	0.43	2.70	MTO	L4L	100.00	MTO	YES
109	25.64	10	3	120.66	0.43	3.73	MTO	L4L	100.00	MTO	YES
110	57.40	5	3	171.33	0.43	4.09	MTO	L4L	99.77	MTS	NO
111	47.73	12	3	152.17	0.43	1.71	MTO	L4L	89.44	MTO	YES
112	44.90	5	3	115.46	0.43	1.73	MTO	L4L	100.00	MTO	YES
113	65.23	12	4	51.28	0.43	1.83	MTO	L4L	100.00	MTO	YES
114	102.15	4	6	101.56	0.43	0.75	MTO	L4L	82.45	MTS	NO
115	13.04	13	3	69.52	0.43	2.69	MTO	L4L	100.00	MTO	YES
116	27.54	12	3	158.87	0.43	1.64	MTO	L4L	95.36	MTO	YES
117	63.23	10	3	179.99	0.43	1.29	MTO	L4L	92.92	MTO	YES
118	12.57	13	3	83.65	0.42	2.63	MTO	L4L	100.00	MTO	YES
119	120.43	10	5	96.53	0.42	1.89	MTO	L4L	98.12	MTO	YES
120	10.86	13	3	56.31	0.42	1.98	MTO	L4L	99.93	MTO	YES
121	45.63	12	4	51.28	0.42	1.78	MTO	L4L	100.00	MTO	YES
122	20.85	12	3	98.54	0.42	1.31	MTO	L4L	100.00	MTO	YES
123	9.63	13	3	76.97	0.42	1.74	MTO	L4L	99.73	MTO	YES
124	14.94	10	3	103.57	0.42	2.34	MTO	L4L	99.82	MTO	YES
125	20.59	10	3	116.64	0.42	2.84	MTO	L4L	99.71	MTO	YES
126	48.56	5	3	164.90	0.42	4.25	MTO	L4L	100.00	MTO	YES
127	48.00	10	3	184.01	0.42	1.57	MTO	L4L	100.00	MTO	YES
128	23.53	10	3	118.65	0.42	3.26	MTO	L4L	100.00	MTO	YES
129	110.89	8	4	90.06	0.42	2.30	MTO	L4L	99.79	MTO	YES
130	46.03	7	4	78.43	0.42	1.24	MTO	L4L	100.00	MTO	YES
131	92.66	10	3	126.69	0.42	0.66	MTO	L4L	69.41	MTO	YES
132	44.88	13	3	76.42	0.42	6.13	MTO	L4L	100.00	MTO	YES
133	183.50	12	3	53.29	0.42	0.00	MTO	L4L	99.14	MTO	YES
134	102.71	11	5	91.50	0.42	1.41	MTO	L4L	92.04	MTO	YES
135	46.07	8	4	75.41	0.42	1.17	MTO	L4L	100.00	MTO	YES
136	5.59	13	3	52.14	0.42	1.02	MTO	L4L	99.67	MTO	YES
137	96.74	8	4	94.81	0.42	2.39	MTO	L4L	100.00	MTO	YES
138	7.02	12	3	131.72	0.42	0.52	MTO	L4L	98.99	MTO	YES
139	6.52	13	3	46.35	0.42	1.34	MTO	L4L	100.00	MTO	YES
140	83.83	9	5	102.55	0.42	2.23	MTO	L4L	100.00	MTO	YES
141	96.09	10	5	98.54	0.42	1.49	MTO	L4L	94.73	MTO	YES
142	52.12	6	3	129.71	0.42	4.40	MTO	L4L	100.00	MTS	NO

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP ABC classification	Difference
143	34.22	5	3	139.05	0.42	2.79	MTO	L4L	99.54	MTO	YES
144	151.64	5	4	98.54	0.41	0.91	MTO	L4L	83.20	MTO	YES
145	92.07	6	5	102.56	0.41	1.58	MTO	L4L	98.30	MTO	YES
146	60.38	10	5	86.47	0.41	1.62	MTO	L4L	99.73	MTO	YES
147	9.20	12	3	73.00	0.41	0.56	MTO	L4L	99.00	MTO	YES
148	30.15	9	3	161.89	0.41	1.17	MTO	L4L	99.49	MTO	YES
149	699.04	2	3	144.79	0.41	0.00	MTO	L4L	35.67	MTO	YES
150	77.32	8	4	90.06	0.41	1.23	MTO	L4L	99.40	MTO	YES
151	49.41	10	5	96.53	0.41	1.10	MTO	L4L	92.83	MTO	YES
152	83.97	4	6	96.53	0.41	0.62	MTO	L4L	79.29	MTS	NO
153	299.93	12	3	200.00	0.41	7.64	MTO	L4L	99.69	MTS	NO
154	93.79	5	3	169.93	0.41	0.38	MTO	L4L	63.68	MTO	YES
155	50.33	9	5	99.07	0.41	1.31	MTO	L4L	98.48	MTO	YES
156	72.31	5	4	93.51	0.41	1.08	MTO	L4L	99.65	MTO	YES
157	123.39	5	4	95.52	0.41	0.98	MTO	L4L	98.24	MTO	YES
158	36.21	10	5	97.53	0.41	1.06	MTO	L4L	100.00	MTO	YES
159	79.86	4	6	54.30	0.41	0.63	MTO	L4L	83.03	MTS	NO
160	19.54	6	1	107.59	0.41	1.12	MTO	L4L	100.00	MTO	YES
161	28.15	9	5	85.78	0.40	0.83	MTO	L4L	99.94	MTO	YES
162	38.60	5	3	164.90	0.40	0.72	MTO	L4L	95.32	MTO	YES
163	75.15	4	6	54.30	0.40	0.52	MTO	L4L	76.79	MTS	NO
164	61.30	5	4	87.48	0.40	0.95	MTO	L4L	99.77	MTO	YES
165	5.88	10	3	4.02	0.40	0.42	MTO	L4L	100.00	MTO	YES
166	71.72	4	6	55.30	0.40	0.55	MTO	L4L	79.60	MTO	YES
167	13.26	7	4	98.54	0.40	0.49	MTO	L4L	100.00	MTO	YES
168	51.10	4	3	191.05	0.40	0.86	MTO	L4L	93.98	MTO	YES
169	13.19	4	1	164.90	0.40	0.36	MTO	L4L	91.10	MTO	YES
170	116.42	6	3	118.65	0.40	0.21	MTO	L4L	52.61	MTO	YES
171	50.26	7	5	98.54	0.40	0.98	MTO	L4L	100.00	MTO	YES
172	9.52	12	3	1.01	0.40	0.57	MTO	L4L	91.43	MTO	YES
173	101.42	13	3	169.46	0.40	3.33	MTO	L4L	100.00	MTO	YES
174	9.89	4	1	171.94	0.40	0.20	MTO	L4L	78.73	MTO	YES
175	46.57	5	4	83.46	0.40	0.74	MTO	L4L	98.52	MTO	YES
176	47.71	5	4	79.44	0.40	0.59	MTO	L4L	87.05	MTO	YES
177	6.29	4	1	158.87	0.40	0.24	MTO	L4L	98.99	MTO	YES
178	45.03	5	4	83.46	0.40	1.00	MTO	L4L	100.00	MTO	YES
179	62.85	4	6	52.29	0.40	0.49	MTO	L4L	77.39	MTO	YES
180	16.53	6	3	68.37	0.40	1.45	MTO	L4L	99.86	MTO	YES
181	100.10	13	3	149.91	0.39	5.40	MTO	L4L	100.00	MTO	YES
182	29.81	7	5	93.51	0.39	0.70	MTO	L4L	99.29	MTO	YES
183	8.41	4	3	77.42	0.39	0.59	MTO	L4L	99.90	MTO	YES
184	23.86	7	5	86.47	0.39	0.54	MTO	L4L	97.51	MTO	YES
185	32.69	6	6	97.53	0.39	0.55	MTO	L4L	99.60	MTO	YES
186	21.88	6	5	95.52	0.39	0.52	MTO	L4L	100.00	MTO	YES
187	41.15	4	5	99.55	0.39	0.75	MTO	L4L	100.00	MTO	YES
188	17.15	4	4	98.54	0.39	0.32	MTO	L4L	99.19	MTO	YES
189	27.38	6	6	96.53	0.39	0.52	MTO	L4L	100.00	MTO	YES
190	14.87	6	5	97.53	0.39	0.34	MTO	L4L	99.73	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP ABC classification	Difference
191	27.91	3	4	87.48	0.39	0.25	MTO	L4L	83.30	MTO	YES
192	38.67	4	6	78.21	0.39	0.50	MTO	L4L	81.42	MTO	YES
193	24.63	5	4	53.29	0.39	0.49	MTO	L4L	100.00	MTO	YES
194	24.13	6	6	92.51	0.39	0.31	MTO	L4L	90.66	MTO	YES
195	42.65	5	4	86.47	0.39	0.35	MTO	L4L	94.12	MTO	YES
196	91.77	13	3	130.36	0.39	3.33	MTO	L4L	100.00	MTO	YES
197	13.73	4	4	81.45	0.39	0.21	MTO	L4L	93.59	MTO	YES
198	18.74	5	4	41.23	0.39	0.25	MTO	L4L	99.67	MTO	YES
199	29.39	6	3	39.21	0.38	0.78	MTO	L4L	100.00	MTO	YES
200	16.63	4	4	94.52	0.38	0.32	MTO	L4L	98.11	MTO	YES
201	11.62	3	4	95.52	0.38	0.23	MTO	L4L	100.00	MTO	YES
202	8.38	3	4	89.49	0.38	0.13	MTO	L4L	98.99	MTO	YES
203	18.03	2	5	67.37	0.37	0.17	MTO	L4L	96.34	MTO	YES
204	5.13	4	6	40.22	0.37	0.13	MTO	L4L	98.99	MTO	YES
205	3.38	13	15	16.09	0.37	0.28	MTO	L4L	99.96	MTO	YES
206	7.12	2	5	51.28	0.37	0.03	MTO	L4L	68.20	MTO	YES
207	2.17	4	6	2.01	0.37	0.03	MTO	L4L	99.40	MTO	YES
208	7.90	13	15	58.66	0.37	1.54	MTO	L4L	99.81	MTO	YES
209	47.79	12	3	59.59	0.37	2.99	MTO	L4L	100.00	MTO	YES
210	7.10	13	15	44.69	0.36	1.30	MTO	L4L	98.99	MTO	YES
211	40.47	10	3	31.29	0.36	1.70	MTO	L4L	100.00	MTO	YES
212	0.82	29	30	2.01	0.36	0.18	MTO	L4L	99.22	MTO	YES
213	6.15	29	30	3.02	0.36	1.32	MTO	L4L	99.17	MTO	YES
214	1.64	29	30	2.01	0.35	0.37	MTO	L4L	100.00	MTO	YES
215	9.23	29	30	3.02	0.33	2.01	MTO	L4L	100.00	MTO	YES
216	1.62	13	30	2.01	0.33	0.10	MTO	L4L	92.92	MTO	YES
217	205.33	13	30	52.14	0.31	5.06	MTO	L4L	100.00	MTO	YES
218	2.15	13	30	2.01	0.30	0.17	MTO	L4L	100.00	MTO	YES
219	10.51	19	30	3.02	0.30	1.31	MTO	L4L	100.00	MTO	YES
220	3.95	13	30	1.01	0.29	0.29	MTO	L4L	100.00	MTO	YES
221	6.26	13	30	1.01	0.27	0.41	MTO	L4L	99.00	MTO	YES
222	34.82	12	30	18.10	0.24	2.03	MTO	L4L	100.00	MTO	YES
223	20.19	13	30	1.01	0.23	1.37	MTO	L4L	98.22	MTO	YES
224	125.83	13	30	7.04	0.03	6.02	MTO	L4L	100.00	MTS	NO

Appendix B

Results

B.1 Results of ranking model

Average Service Level of MTS items =	83.54
Average Service Level of MTO items =	88.46
Overall average service level =	84.88

Total Pallet Capacity	900
Total cost per year	21917944
Total Pallets Needed	491

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP 0-1 ILP model	Difference
1	636.25	9	3	226.24	0.90	28.17	MTS	(s, Q) policy	100.00	MTS	YES
2	493.81	9	3	235.29	0.71	13.75	MTS	(s, Q) policy	99.45	MTS	YES
3	153.54	32	2	222.22	0.70	28.92	MTS	(s, Q) policy	100.00	MTS	YES
4	404.26	6	2	246.35	0.66	10.62	MTS	(s, Q) policy	100.00	MTS	YES
5	455.96	12	3	306.68	0.64	29.32	MTS	(s, Q) policy	100.00	MTS	YES
6	339.18	6	2	242.33	0.63	10.63	MTS	(s, Q) policy	100.00	MTS	YES
7	395.64	12	3	214.17	0.63	9.27	MTS	(s, Q) policy	92.52	MTS	YES
8	554.42	9	3	306.68	0.59	27.08	MTS	(s, Q) policy	100.00	MTS	YES
9	429.61	12	3	308.69	0.58	15.07	MTS	(s, Q) policy	99.82	MTS	YES
10	458.37	4	4	102.56	0.58	0.00	MTS	(s, Q) policy	38.00	MTO	NO
11	307.63	7	4	96.53	0.57	7.53	MTS	(s, Q) policy	100.00	MTO	NO
12	142.83	13	3	253.47	0.57	14.00	MTS	(s, Q) policy	100.00	MTS	YES
13	343.69	12	3	299.64	0.55	17.15	MTS	(s, Q) policy	100.00	MTS	YES
14	180.42	13	3	246.35	0.54	14.67	MTS	(s, Q) policy	100.00	MTS	YES
15	321.09	12	3	306.68	0.54	16.05	MTS	(s, Q) policy	100.00	MTS	YES
16	109.66	12	3	225.95	0.54	9.35	MTS	(s, Q) policy	100.00	MTS	YES
17	2378.09	13	3	151.69	0.53	0.00	MTS	(s, Q) policy	99.91	MTS	YES
18	298.21	12	3	302.66	0.53	16.61	MTS	(s, Q) policy	100.00	MTS	YES
19	137.49	12	3	225.23	0.52	7.82	MTS	(s, Q) policy	100.00	MTS	YES
20	1931.95	12	3	109.60	0.52	0.00	MTS	(s, Q) policy	65.19	MTO	NO
21	250.79	12	3	307.69	0.52	15.73	MTS	(s, Q) policy	100.00	MTS	YES
22	77.88	13	3	201.10	0.52	14.51	MTS	(s, Q) policy	100.00	MTS	YES
23	1463.94	10	3	136.75	0.51	0.00	MTS	(s, Q) policy	53.47	MTO	NO
24	264.04	12	3	259.42	0.51	16.65	MTS	(s, Q) policy	100.00	MTS	YES
25	239.90	12	3	295.62	0.50	12.13	MTS	(s, Q) policy	100.00	MTS	YES
26	217.66	4	6	99.55	0.50	1.51	MTS	(s, Q) policy	83.26	MTO	NO
27	94.91	12	3	191.05	0.50	6.29	MTS	(s, Q) policy	100.00	MTS	YES
28	229.94	3	4	104.57	0.49	0.37	MTS	(s, Q) policy	59.85	MTO	NO
29	1279.61	12	3	93.51	0.49	0.00	MTS	(s, Q) policy	99.34	MTS	YES
30	191.95	4	6	101.56	0.49	1.16	MTS	(s, Q) policy	88.85	MTO	NO
31	31.48	24	3	102.20	0.48	5.13	MTS	(s, Q) policy	99.75	MTO	NO
32	111.33	10	5	217.03	0.48	5.09	MTS	(s, Q) policy	100.00	MTO	NO
33	323.96	4	3	270.48	0.48	1.61	MTS	(s, Q) policy	67.54	MTO	NO
34	161.37	12	3	256.40	0.48	8.22	MTS	(s, Q) policy	100.00	MTS	YES
35	662.03	16	3	70.39	0.48	0.00	MTS	(s, Q) policy	42.31	MTO	NO
36	79.33	13	3	198.09	0.48	9.77	MTS	(s, Q) policy	100.00	MTS	YES
37	157.39	4	6	102.56	0.48	1.14	MTS	(s, Q) policy	74.31	MTO	NO
38	139.05	12	3	302.66	0.48	8.51	MTS	(s, Q) policy	100.00	MTS	YES
39	1076.65	16	3	95.99	0.47	0.00	MTS	(s, Q) policy	92.64	MTS	YES
40	69.39	13	3	195.07	0.47	10.02	MTS	(s, Q) policy	100.00	MTS	YES
41	54.35	13	3	187.02	0.47	8.00	MTS	(s, Q) policy	100.00	MTS	YES
42	91.53	10	3	198.09	0.47	9.43	MTS	(s, Q) policy	100.00	MTS	YES
43	1037.85	12	3	91.50	0.47	0.00	MTS	(s, Q) policy	80.24	MTO	NO

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP 0-1 ILP model	Difference
44	215.66	4	4	108.60	0.47	0.39	MTS	(s, Q) policy	60.47	MTO	NO
45	198.03	8	3	269.48	0.47	7.67	MTS	(s, Q) policy	100.00	MTS	YES
46	140.61	10	3	243.33	0.47	3.37	MTS	(s, Q) policy	97.36	MTS	YES
47	420.44	6	3	206.13	0.47	0.00	MTS	(s, Q) policy	48.34	MTO	NO
48	47.71	13	3	188.03	0.47	8.10	MTS	(s, Q) policy	100.00	MTS	YES
49	47.44	13	3	185.01	0.47	8.07	MTS	(s, Q) policy	100.00	MTS	YES
50	52.63	12	1	208.14	0.46	4.05	MTS	(s, Q) policy	100.00	MTS	YES
51	923.38	13	3	124.34	0.46	0.00	MTS	(s, Q) policy	39.85	MTO	NO
52	104.79	13	3	197.08	0.46	2.56	MTS	(s, Q) policy	93.30	MTO	NO
53	40.38	13	3	176.97	0.46	6.90	MTS	(s, Q) policy	100.00	MTS	YES
54	403.94	16	3	68.28	0.46	0.00	MTS	(s, Q) policy	92.03	MTS	YES
55	46.48	12	1	207.13	0.46	4.09	MTS	(s, Q) policy	100.00	MTS	YES
56	115.74	7	4	91.50	0.46	2.35	MTS	(s, Q) policy	99.69	MTO	NO
57	91.01	8	3	191.05	0.46	5.25	MTS	(s, Q) policy	100.00	MTS	YES
58	34.79	13	3	167.16	0.46	6.35	MTS	(s, Q) policy	99.90	MTS	YES
59	107.85	4	3	270.48	0.46	2.36	MTS	(s, Q) policy	99.68	MTS	YES
60	884.00	4	3	163.88	0.45	0.00	MTS	(s, Q) policy	67.77	MTO	NO
61	79.96	12	3	253.39	0.45	5.99	MTS	(s, Q) policy	100.00	MTS	YES
62	380.51	10	3	112.31	0.45	0.00	MTS	(s, Q) policy	87.31	MTO	NO
63	538.63	12	3	69.38	0.45	0.00	MTS	(s, Q) policy	82.76	MTO	NO
64	75.78	12	3	300.65	0.45	3.90	MTS	(s, Q) policy	100.00	MTS	YES
65	87.39	7	4	79.44	0.45	3.53	MTS	(s, Q) policy	100.00	MTO	NO
66	29.01	12	1	206.13	0.45	2.67	MTS	(s, Q) policy	99.95	MTS	YES
67	31.88	12	1	205.12	0.45	1.87	MTS	(s, Q) policy	99.74	MTS	YES
68	252.51	16	3	62.81	0.45	0.00	MTS	(s, Q) policy	99.80	MTS	YES
69	93.39	13	3	187.02	0.45	2.35	MTO	L4L	91.98	MTO	YES
70	64.89	12	3	263.44	0.45	4.14	MTO	L4L	100.00	MTS	NO
71	26.42	12	1	206.13	0.45	2.51	MTO	L4L	100.00	MTS	NO
72	24.60	12	1	205.12	0.44	1.94	MTO	L4L	96.54	MTS	NO
73	85.30	13	3	171.94	0.44	1.84	MTO	L4L	85.32	MTO	YES
74	23.24	12	1	202.11	0.44	2.00	MTO	L4L	100.00	MTS	NO
75	1009.80	10	3	114.95	0.44	0.00	MTO	L4L	31.78	MTO	YES
76	74.27	13	3	169.93	0.44	2.46	MTO	L4L	96.16	MTO	YES
77	70.22	10	3	114.63	0.44	1.65	MTO	L4L	83.34	MTO	YES
78	86.25	12	3	184.01	0.44	1.88	MTO	L4L	85.80	MTO	YES
79	67.07	13	3	183.00	0.44	2.46	MTO	L4L	97.27	MTO	YES
80	23.16	13	3	126.69	0.44	4.08	MTO	L4L	99.27	MTO	YES
81	15.04	12	1	203.11	0.44	1.36	MTO	L4L	99.78	MTS	NO
82	48.97	12	3	213.17	0.44	2.99	MTO	L4L	100.00	MTS	NO
83	13.97	12	1	206.13	0.44	1.31	MTO	L4L	99.90	MTS	NO
84	63.04	13	3	166.91	0.44	2.69	MTO	L4L	99.26	MTO	YES
85	62.65	13	3	165.91	0.44	2.06	MTO	L4L	93.04	MTO	YES
86	59.16	13	3	190.04	0.44	2.18	MTO	L4L	94.67	MTO	YES
87	20.57	13	3	142.78	0.44	3.48	MTO	L4L	99.97	MTS	NO
88	12.68	12	1	204.12	0.44	1.22	MTO	L4L	100.00	MTS	NO
89	69.07	6	3	170.94	0.44	1.89	MTO	L4L	92.54	MTO	YES
90	48.83	13	3	188.03	0.44	2.63	MTO	L4L	100.00	MTO	YES
91	14.34	12	1	195.07	0.44	1.30	MTO	L4L	99.82	MTS	NO
92	51.82	13	3	182.00	0.44	2.08	MTO	L4L	94.99	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP 0-1 ILP model	Difference
93	81.20	9	3	255.40	0.44	3.91	MTO	L4L	100.00	MTS	NO
94	23.84	12	1	138.76	0.43	1.77	MTO	L4L	100.00	MTS	NO
95	20.87	10	1	170.94	0.43	1.82	MTO	L4L	100.00	MTS	NO
96	79.23	6	3	127.70	0.43	2.27	MTO	L4L	97.29	MTO	YES
97	43.10	9	3	190.04	0.43	1.97	MTO	L4L	96.47	MTO	YES
98	40.19	13	3	174.96	0.43	2.13	MTO	L4L	98.40	MTO	YES
99	180.65	5	4	100.55	0.43	1.37	MTO	L4L	94.85	MTO	YES
100	17.02	13	3	111.61	0.43	3.10	MTO	L4L	99.98	MTO	YES
101	59.68	12	4	52.29	0.43	1.98	MTO	L4L	99.97	MTO	YES
102	23.56	13	5	94.15	0.43	2.11	MTO	L4L	99.10	MTO	YES
103	28.88	12	3	195.07	0.43	2.11	MTO	L4L	100.00	MTO	YES
104	93.18	4	4	71.39	0.43	0.79	MTO	L4L	88.17	MTO	YES
105	107.10	4	4	90.38	0.43	1.19	MTO	L4L	97.77	MTO	YES
106	51.47	12	3	93.86	0.43	2.95	MTO	L4L	100.00	MTS	NO
107	40.84	12	3	174.96	0.43	1.48	MTO	L4L	99.97	MTO	YES
108	44.11	12	3	131.95	0.43	2.70	MTO	L4L	100.00	MTO	YES
109	25.64	10	3	120.66	0.43	3.73	MTO	L4L	100.00	MTS	NO
110	57.40	5	3	171.33	0.43	4.09	MTO	L4L	99.77	MTO	YES
111	47.73	12	3	152.17	0.43	1.71	MTO	L4L	89.44	MTO	YES
112	44.90	5	3	115.46	0.43	1.73	MTO	L4L	100.00	MTO	YES
113	65.23	12	4	51.28	0.43	1.83	MTO	L4L	100.00	MTO	YES
114	102.15	4	6	101.56	0.43	0.75	MTO	L4L	82.45	MTO	YES
115	13.04	13	3	69.52	0.43	2.69	MTO	L4L	100.00	MTO	YES
116	27.54	12	3	158.87	0.43	1.64	MTO	L4L	95.36	MTO	YES
117	63.23	10	3	179.99	0.43	1.29	MTO	L4L	92.92	MTO	YES
118	12.57	13	3	83.65	0.42	2.63	MTO	L4L	100.00	MTO	YES
119	120.43	10	5	96.53	0.42	1.89	MTO	L4L	98.12	MTO	YES
120	10.86	13	3	56.31	0.42	1.98	MTO	L4L	99.93	MTO	YES
121	45.63	12	4	51.28	0.42	1.78	MTO	L4L	100.00	MTO	YES
122	20.85	12	3	98.54	0.42	1.31	MTO	L4L	100.00	MTO	YES
123	9.63	13	3	76.97	0.42	1.74	MTO	L4L	99.73	MTO	YES
124	14.94	10	3	103.57	0.42	2.34	MTO	L4L	99.82	MTO	YES
125	20.59	10	3	116.64	0.42	2.84	MTO	L4L	99.71	MTO	YES
126	48.56	5	3	164.90	0.42	4.25	MTO	L4L	100.00	MTO	YES
127	48.00	10	3	184.01	0.42	1.57	MTO	L4L	100.00	MTO	YES
128	23.53	10	3	118.65	0.42	3.26	MTO	L4L	100.00	MTO	YES
129	110.89	8	4	90.06	0.42	2.30	MTO	L4L	99.79	MTO	YES
130	46.03	7	4	78.43	0.42	1.24	MTO	L4L	100.00	MTO	YES
131	92.66	10	3	126.69	0.42	0.66	MTO	L4L	69.41	MTO	YES
132	44.88	13	3	76.42	0.42	6.13	MTO	L4L	100.00	MTS	NO
133	183.50	12	3	53.29	0.42	0.00	MTO	L4L	99.14	MTS	NO
134	102.71	11	5	91.50	0.42	1.41	MTO	L4L	92.04	MTO	YES
135	46.07	8	4	75.41	0.42	1.17	MTO	L4L	100.00	MTO	YES
136	5.59	13	3	52.14	0.42	1.02	MTO	L4L	99.67	MTO	YES
137	96.74	8	4	94.81	0.42	2.39	MTO	L4L	100.00	MTO	YES
138	7.02	12	3	131.72	0.42	0.52	MTO	L4L	98.99	MTO	YES
139	6.52	13	3	46.35	0.42	1.34	MTO	L4L	100.00	MTO	YES
140	83.83	9	5	102.55	0.42	2.23	MTO	L4L	100.00	MTO	YES
141	96.09	10	5	98.54	0.42	1.49	MTO	L4L	94.73	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP 0-1 ILP model	Difference
142	52.12	6	3	129.71	0.42	4.40	MTO	L4L	100.00	MTS	NO
143	34.22	5	3	139.05	0.42	2.79	MTO	L4L	99.54	MTO	YES
144	151.64	5	4	98.54	0.41	0.91	MTO	L4L	83.20	MTO	YES
145	92.07	6	5	102.56	0.41	1.58	MTO	L4L	98.30	MTO	YES
146	60.38	10	5	86.47	0.41	1.62	MTO	L4L	99.73	MTO	YES
147	9.20	12	3	73.00	0.41	0.56	MTO	L4L	99.00	MTO	YES
148	30.15	9	3	161.89	0.41	1.17	MTO	L4L	99.49	MTO	YES
149	699.04	2	3	144.79	0.41	0.00	MTO	L4L	35.67	MTO	YES
150	77.32	8	4	90.06	0.41	1.23	MTO	L4L	99.40	MTO	YES
151	49.41	10	5	96.53	0.41	1.10	MTO	L4L	92.83	MTO	YES
152	83.97	4	6	96.53	0.41	0.62	MTO	L4L	79.29	MTO	YES
153	299.93	12	3	200.00	0.41	7.64	MTO	L4L	99.69	MTS	NO
154	93.79	5	3	169.93	0.41	0.38	MTO	L4L	63.68	MTO	YES
155	50.33	9	5	99.07	0.41	1.31	MTO	L4L	98.48	MTO	YES
156	72.31	5	4	93.51	0.41	1.08	MTO	L4L	99.65	MTO	YES
157	123.39	5	4	95.52	0.41	0.98	MTO	L4L	98.24	MTO	YES
158	36.21	10	5	97.53	0.41	1.06	MTO	L4L	100.00	MTO	YES
159	79.86	4	6	54.30	0.41	0.63	MTO	L4L	83.03	MTO	YES
160	19.54	6	1	107.59	0.41	1.12	MTO	L4L	100.00	MTS	NO
161	28.15	9	5	85.78	0.40	0.83	MTO	L4L	99.94	MTO	YES
162	38.60	5	3	164.90	0.40	0.72	MTO	L4L	95.32	MTO	YES
163	75.15	4	6	54.30	0.40	0.52	MTO	L4L	76.79	MTO	YES
164	61.30	5	4	87.48	0.40	0.95	MTO	L4L	99.77	MTO	YES
165	5.88	10	3	4.02	0.40	0.42	MTO	L4L	100.00	MTO	YES
166	71.72	4	6	55.30	0.40	0.55	MTO	L4L	79.60	MTO	YES
167	13.26	7	4	98.54	0.40	0.49	MTO	L4L	100.00	MTO	YES
168	51.10	4	3	191.05	0.40	0.86	MTO	L4L	93.98	MTO	YES
169	13.19	4	1	164.90	0.40	0.36	MTO	L4L	91.10	MTS	NO
170	116.42	6	3	118.65	0.40	0.21	MTO	L4L	52.61	MTO	YES
171	50.26	7	5	98.54	0.40	0.98	MTO	L4L	100.00	MTO	YES
172	9.52	12	3	1.01	0.40	0.57	MTO	L4L	91.43	MTO	YES
173	101.42	13	3	169.46	0.40	3.33	MTO	L4L	100.00	MTS	NO
174	9.89	4	1	171.94	0.40	0.20	MTO	L4L	78.73	MTO	YES
175	46.57	5	4	83.46	0.40	0.74	MTO	L4L	98.52	MTO	YES
176	47.71	5	4	79.44	0.40	0.59	MTO	L4L	87.05	MTO	YES
177	6.29	4	1	158.87	0.40	0.24	MTO	L4L	98.99	MTO	YES
178	45.03	5	4	83.46	0.40	1.00	MTO	L4L	100.00	MTO	YES
179	62.85	4	6	52.29	0.40	0.49	MTO	L4L	77.39	MTO	YES
180	16.53	6	3	68.37	0.40	1.45	MTO	L4L	99.86	MTO	YES
181	100.10	13	3	149.91	0.39	5.40	MTO	L4L	100.00	MTS	NO
182	29.81	7	5	93.51	0.39	0.70	MTO	L4L	99.29	MTO	YES
183	8.41	4	3	77.42	0.39	0.59	MTO	L4L	99.90	MTO	YES
184	23.86	7	5	86.47	0.39	0.54	MTO	L4L	97.51	MTO	YES
185	32.69	6	6	97.53	0.39	0.55	MTO	L4L	99.60	MTO	YES
186	21.88	6	5	95.52	0.39	0.52	MTO	L4L	100.00	MTO	YES
187	41.15	4	5	99.55	0.39	0.75	MTO	L4L	100.00	MTO	YES
188	17.15	4	4	98.54	0.39	0.32	MTO	L4L	99.19	MTO	YES
189	27.38	6	6	96.53	0.39	0.52	MTO	L4L	100.00	MTO	YES
190	14.87	6	5	97.53	0.39	0.34	MTO	L4L	99.73	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Policy	Service Level	CODP 0-1 ILP model	Difference
191	27.91	3	4	87.48	0.39	0.25	MTO	L4L	83.30	MTO	YES
192	38.67	4	6	78.21	0.39	0.50	MTO	L4L	81.42	MTO	YES
193	24.63	5	4	53.29	0.39	0.49	MTO	L4L	100.00	MTO	YES
194	24.13	6	6	92.51	0.39	0.31	MTO	L4L	90.66	MTO	YES
195	42.65	5	4	86.47	0.39	0.35	MTO	L4L	94.12	MTO	YES
196	91.77	13	3	130.36	0.39	3.33	MTO	L4L	100.00	MTS	NO
197	13.73	4	4	81.45	0.39	0.21	MTO	L4L	93.59	MTO	YES
198	18.74	5	4	41.23	0.39	0.25	MTO	L4L	99.67	MTO	YES
199	29.39	6	3	39.21	0.38	0.78	MTO	L4L	100.00	MTO	YES
200	16.63	4	4	94.52	0.38	0.32	MTO	L4L	98.11	MTO	YES
201	11.62	3	4	95.52	0.38	0.23	MTO	L4L	100.00	MTO	YES
202	8.38	3	4	89.49	0.38	0.13	MTO	L4L	98.99	MTO	YES
203	18.03	2	5	67.37	0.37	0.17	MTO	L4L	96.34	MTO	YES
204	5.13	4	6	40.22	0.37	0.13	MTO	L4L	98.99	MTO	YES
205	3.38	13	15	16.09	0.37	0.28	MTO	L4L	99.96	MTO	YES
206	7.12	2	5	51.28	0.37	0.03	MTO	L4L	68.20	MTO	YES
207	2.17	4	6	2.01	0.37	0.03	MTO	L4L	99.40	MTO	YES
208	7.90	13	15	58.66	0.37	1.54	MTO	L4L	99.81	MTO	YES
209	47.79	12	3	59.59	0.37	2.99	MTO	L4L	100.00	MTO	YES
210	7.10	13	15	44.69	0.36	1.30	MTO	L4L	98.99	MTO	YES
211	40.47	10	3	31.29	0.36	1.70	MTO	L4L	100.00	MTO	YES
212	0.82	29	30	2.01	0.36	0.18	MTO	L4L	99.22	MTO	YES
213	6.15	29	30	3.02	0.36	1.32	MTO	L4L	99.17	MTO	YES
214	1.64	29	30	2.01	0.35	0.37	MTO	L4L	100.00	MTO	YES
215	9.23	29	30	3.02	0.33	2.01	MTO	L4L	100.00	MTO	YES
216	1.62	13	30	2.01	0.33	0.10	MTO	L4L	92.92	MTO	YES
217	205.33	13	30	52.14	0.31	5.06	MTO	L4L	100.00	MTO	YES
218	2.15	13	30	2.01	0.30	0.17	MTO	L4L	100.00	MTO	YES
219	10.51	19	30	3.02	0.30	1.31	MTO	L4L	100.00	MTO	YES
220	3.95	13	30	1.01	0.29	0.29	MTO	L4L	100.00	MTO	YES
221	6.26	13	30	1.01	0.27	0.41	MTO	L4L	99.00	MTO	YES
222	34.82	12	30	18.10	0.24	2.03	MTO	L4L	100.00	MTO	YES
223	20.19	13	30	1.01	0.23	1.37	MTO	L4L	98.22	MTO	YES
224	125.83	13	30	7.04	0.03	6.02	MTO	L4L	100.00	MTO	YES

B.2 Results of 0-1 ILP model

Average Service Level of MTS items =	98.89
Average Service Level of MTO items =	88.65
Overall average service level =	93.77

Total Pallet Capacity	900
minTC (per year)	17785065
Total Pallets Needed	527

Product	Mean demand	Best before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP ranking	Difference
39	1076.65	16	3	95.99	0.00	92.64	114268	133239	114268	1	MTS	(s, Q) policy	MTS	YES
17	2378.09	13	3	151.69	0.00	99.91	183090	295704	183090	1	MTS	(s, Q) policy	MTS	YES
22	77.88	13	3	201.10	14.51	100.00	144828	194407	144828	1	MTS	(s, Q) policy	MTS	YES
94	23.84	12	1	138.76	1.77	100.00	17188	51371	17188	1	MTS	(s, Q) policy	MTO	NO
173	101.42	13	3	169.46	3.33	100.00	133040	170294	133040	1	MTS	(s, Q) policy	MTO	NO
196	91.77	13	3	130.36	3.33	100.00	139081	153680	139081	1	MTS	(s, Q) policy	MTO	NO
181	100.10	13	3	149.91	5.40	100.00	144846	167775	144846	1	MTS	(s, Q) policy	MTO	NO
36	79.33	13	3	198.09	9.77	100.00	128546	159040	128546	1	MTS	(s, Q) policy	MTS	YES
48	47.71	13	3	188.03	8.10	100.00	65473	96906	65473	1	MTS	(s, Q) policy	MTS	YES
40	69.39	13	3	195.07	10.02	100.00	114709	139509	114709	1	MTS	(s, Q) policy	MTS	YES
53	40.38	13	3	176.97	6.90	100.00	66506	82347	66506	1	MTS	(s, Q) policy	MTS	YES
58	34.79	13	3	167.16	6.35	99.90	59963	71027	59963	1	MTS	(s, Q) policy	MTS	YES
142	52.12	6	3	129.71	4.40	100.00	92483	104483	92483	1	MTS	(s, Q) policy	MTO	NO
41	54.35	13	3	187.02	8.00	100.00	70502	109888	70502	1	MTS	(s, Q) policy	MTS	YES
42	91.53	10	3	198.09	9.43	100.00	125370	160525	125370	1	MTS	(s, Q) policy	MTS	YES
109	25.64	10	3	120.66	3.73	100.00	43508	49289	43508	1	MTS	(s, Q) policy	MTO	NO
14	180.42	13	3	246.35	14.67	100.00	178075	253050	178075	1	MTS	(s, Q) policy	MTS	YES
12	142.83	13	3	253.47	14.00	100.00	199077	318600	199077	1	MTS	(s, Q) policy	MTS	YES
132	44.88	13	3	76.42	6.13	100.00	70368	96198	70368	1	MTS	(s, Q) policy	MTO	NO
7	395.64	12	3	214.17	9.27	92.52	528796	585340	528796	1	MTS	(s, Q) policy	MTS	YES
2	493.81	9	3	235.29	13.75	99.45	498483	730009	498483	1	MTS	(s, Q) policy	MTS	YES
6	339.18	6	2	242.33	10.63	100.00	325148	1025916	325148	1	MTS	(s, Q) policy	MTS	YES
27	94.91	12	3	191.05	6.29	100.00	126128	177819	126128	1	MTS	(s, Q) policy	MTS	YES
19	137.49	12	3	225.23	7.82	100.00	126697	206147	126697	1	MTS	(s, Q) policy	MTS	YES
1	636.25	9	3	226.24	28.17	100.00	734378	1172945	734378	1	MTS	(s, Q) policy	MTS	YES
4	404.26	6	2	246.35	10.62	100.00	405272	1221991	405272	1	MTS	(s, Q) policy	MTS	YES
57	91.01	8	3	191.05	5.25	100.00	91071	133877	91071	1	MTS	(s, Q) policy	MTS	YES
3	153.54	32	2	222.22	28.92	100.00	309683	928896	309683	1	MTS	(s, Q) policy	MTS	YES
153	299.93	12	3	200.00	7.64	99.69	312696	451755	312696	1	MTS	(s, Q) policy	MTO	NO
18	298.21	12	3	302.66	16.61	100.00	96760	151580	96760	1	MTS	(s, Q) policy	MTS	YES
64	75.78	12	3	300.65	3.90	100.00	32059	42578	32059	1	MTS	(s, Q) policy	MTS	YES
82	48.97	12	3	213.17	2.99	100.00	23975	29057	23975	1	MTS	(s, Q) policy	MTO	NO
34	161.37	12	3	256.40	8.22	100.00	53233	83706	53233	1	MTS	(s, Q) policy	MTS	YES
49	47.44	13	3	185.01	8.07	100.00	65689	96311	65689	1	MTS	(s, Q) policy	MTS	YES
16	109.66	12	3	225.95	9.35	100.00	157893	245186	157893	1	MTS	(s, Q) policy	MTS	YES
87	20.57	13	3	142.78	3.48	99.97	29826	38864	29826	1	MTS	(s, Q) policy	MTO	NO
133	183.50	12	3	53.29	0.00	99.14	19632	23742	19632	1	MTS	(s, Q) policy	MTO	NO
29	1279.61	12	3	93.51	0.00	99.34	104238	160005	104238	1	MTS	(s, Q) policy	MTS	YES
5	455.96	12	3	306.68	29.32	100.00	187505	284778	187505	1	MTS	(s, Q) policy	MTS	YES
13	343.69	12	3	299.64	17.15	100.00	107321	173806	107321	1	MTS	(s, Q) policy	MTS	YES
67	31.88	12	1	205.12	1.87	99.74	15675	76298	15675	1	MTS	(s, Q) policy	MTS	YES
38	139.05	12	3	302.66	8.51	100.00	45450	73613	45450	1	MTS	(s, Q) policy	MTS	YES
66	29.01	12	1	206.13	2.67	99.95	39284	86305	39284	1	MTS	(s, Q) policy	MTS	YES
24	264.04	12	3	259.42	16.65	100.00	94857	134056	94857	1	MTS	(s, Q) policy	MTS	YES
71	26.42	12	1	206.13	2.51	100.00	34009	63896	34009	1	MTS	(s, Q) policy	MTO	NO
88	12.68	12	1	204.12	1.22	100.00	18045	32574	18045	1	MTS	(s, Q) policy	MTO	NO
83	13.97	12	1	206.13	1.31	99.90	17494	37135	17494	1	MTS	(s, Q) policy	MTO	NO
45	198.03	8	3	269.48	7.67	100.00	59515	89775	59515	1	MTS	(s, Q) policy	MTS	YES
21	250.79	12	3	307.69	15.73	100.00	83112	128444	83112	1	MTS	(s, Q) policy	MTS	YES
9	429.61	12	3	308.69	15.07	99.82	133543	216064	133543	1	MTS	(s, Q) policy	MTS	YES
50	52.63	12	1	208.14	4.05	100.00	25446	123605	25446	1	MTS	(s, Q) policy	MTS	YES

Product	Mean demand	Best before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP ranking	Difference
160	19.54	6	1	107.59	1.12	100.00	14571	35329	14571	1	MTS	(s, Q) policy	MTO	NO
169	13.19	4	1	164.90	0.36	91.10	29233	29269	29233	1	MTS	(s, Q) policy	MTO	NO
72	24.60	12	1	205.12	1.94	96.54	36643	59725	36643	1	MTS	(s, Q) policy	MTO	NO
8	554.42	9	3	306.68	27.08	100.00	152075	243220	152075	1	MTS	(s, Q) policy	MTS	YES
91	14.34	12	1	195.07	1.30	99.82	15121	32932	15121	1	MTS	(s, Q) policy	MTO	NO
81	15.04	12	1	203.11	1.36	99.78	19105	44793	19105	1	MTS	(s, Q) policy	MTO	NO
15	321.09	12	3	306.68	16.05	100.00	109045	162864	109045	1	MTS	(s, Q) policy	MTS	YES
55	46.48	12	1	207.13	4.09	100.00	23589	109590	23589	1	MTS	(s, Q) policy	MTS	YES
70	64.89	12	3	263.44	4.14	100.00	25833	36571	25833	1	MTS	(s, Q) policy	MTO	NO
61	79.96	12	3	253.39	5.99	100.00	38057	43771	38057	1	MTS	(s, Q) policy	MTS	YES
59	107.85	4	3	270.48	2.36	99.68	86727	97371	86727	1	MTS	(s, Q) policy	MTS	YES
93	81.20	9	3	255.40	3.91	100.00	28357	39440	28357	1	MTS	(s, Q) policy	MTO	NO
25	239.90	12	3	295.62	12.13	100.00	84631	122891	84631	1	MTS	(s, Q) policy	MTS	YES
74	23.24	12	1	202.11	2.00	100.00	13369	56576	13369	1	MTS	(s, Q) policy	MTO	NO
95	20.87	10	1	170.94	1.82	100.00	17911	50625	17911	1	MTS	(s, Q) policy	MTO	NO
46	140.61	10	3	243.33	3.37	97.36	62244	73299	62244	1	MTS	(s, Q) policy	MTS	YES
106	51.47	12	3	93.86	2.95	100.00	22508	26847	22508	1	MTS	(s, Q) policy	MTO	NO
68	252.51	16	3	62.81	0.00	99.80	21756	31980	21756	1	MTS	(s, Q) policy	MTS	YES
54	403.94	16	3	68.28	0.00	92.03	46600	50574	46600	1	MTS	(s, Q) policy	MTS	YES
218	2.15	13	30	2.01	0.17	100.00	2594	1658	1658	0	MTO	L4L policy	MTO	YES
224	125.83	13	30	7.04	6.02	100.00	152909	94868	94868	0	MTO	L4L policy	MTO	YES
216	1.62	13	30	2.01	0.10	100.00	48206	1253	1253	0	MTO	L4L policy	MTO	YES
223	20.19	13	30	1.01	1.37	100.00	66529	15222	15222	0	MTO	L4L policy	MTO	YES
219	10.51	19	30	3.02	1.31	100.00	48858	7970	7970	0	MTO	L4L policy	MTO	YES
75	1009.80	10	3	114.95	0.00	84.13	293269	111246	111246	0	MTO	L4L policy	MTO	YES
51	923.38	13	3	124.34	0.00	84.13	280049	115034	115034	0	MTO	L4L policy	MTS	NO
199	29.39	6	3	39.21	0.78	84.13	19308	11509	11509	0	MTO	L4L policy	MTO	YES
100	17.02	13	3	111.61	3.10	84.13	35431	35382	35382	0	MTO	L4L policy	MTO	YES
146	60.38	10	5	86.47	1.62	99.87	46644	24483	24483	0	MTO	L4L policy	MTO	YES
32	111.33	10	5	217.03	5.09	99.87	187520	130348	130348	0	MTO	L4L policy	MTS	NO
171	50.26	7	5	98.54	0.98	99.87	44674	20864	20864	0	MTO	L4L policy	MTO	YES
37	157.39	4	6	102.56	1.14	100.00	363577	120390	120390	0	MTO	L4L policy	MTS	NO
30	191.95	4	6	101.56	1.16	100.00	314657	146391	146391	0	MTO	L4L policy	MTS	NO
26	217.66	4	6	99.55	1.51	100.00	400442	165717	165717	0	MTO	L4L policy	MTS	NO
208	7.90	13	15	58.66	1.54	100.00	37219	6598	6598	0	MTO	L4L policy	MTO	YES
120	10.86	13	3	56.31	1.98	84.13	44144	22294	22294	0	MTO	L4L policy	MTO	YES
141	96.09	10	5	98.54	1.49	99.87	78515	38256	38256	0	MTO	L4L policy	MTO	YES
161	28.15	9	5	85.78	0.83	99.87	20836	12209	12209	0	MTO	L4L policy	MTO	YES
140	83.83	9	5	102.55	2.23	99.87	56988	35174	35174	0	MTO	L4L policy	MTO	YES
155	50.33	9	5	99.07	1.31	99.87	48316	20846	20846	0	MTO	L4L policy	MTO	YES
134	102.71	11	5	91.50	1.41	99.87	88242	40639	40639	0	MTO	L4L policy	MTO	YES
156	72.31	5	4	93.51	1.08	97.72	49861	32637	32637	0	MTO	L4L policy	MTO	YES
176	47.71	5	4	79.44	0.59	97.72	59072	21852	21852	0	MTO	L4L policy	MTO	YES
175	46.57	5	4	83.46	0.74	97.72	46830	21440	21440	0	MTO	L4L policy	MTO	YES
164	61.30	5	4	87.48	0.95	97.72	45362	27814	27814	0	MTO	L4L policy	MTO	YES
178	45.03	5	4	83.46	1.00	97.72	43317	20780	20780	0	MTO	L4L policy	MTO	YES
210	7.10	13	15	44.69	1.30	100.00	59659	8802	8802	0	MTO	L4L policy	MTO	YES
110	57.40	5	3	171.33	4.09	84.13	104530	101266	101266	0	MTO	L4L policy	MTO	YES
123	9.63	13	3	76.97	1.74	84.13	50267	20210	20210	0	MTO	L4L policy	MTO	YES
139	6.52	13	3	46.35	1.34	84.13	59177	14216	14216	0	MTO	L4L policy	MTO	YES
115	13.04	13	3	69.52	2.69	84.13	38317	26738	26738	0	MTO	L4L policy	MTO	YES
143	34.22	5	3	139.05	2.79	84.13	90603	61040	61040	0	MTO	L4L policy	MTO	YES
118	12.57	13	3	83.65	2.63	84.13	38652	26288	26288	0	MTO	L4L policy	MTO	YES
136	5.59	13	3	52.14	1.02	84.13	58465	11867	11867	0	MTO	L4L policy	MTO	YES
180	16.53	6	3	68.37	1.45	84.13	52314	33624	33624	0	MTO	L4L policy	MTO	YES
126	48.56	5	3	164.90	4.25	84.13	95999	86250	86250	0	MTO	L4L policy	MTO	YES
151	49.41	10	5	96.53	1.10	99.87	64415	24253	24253	0	MTO	L4L policy	MTO	YES

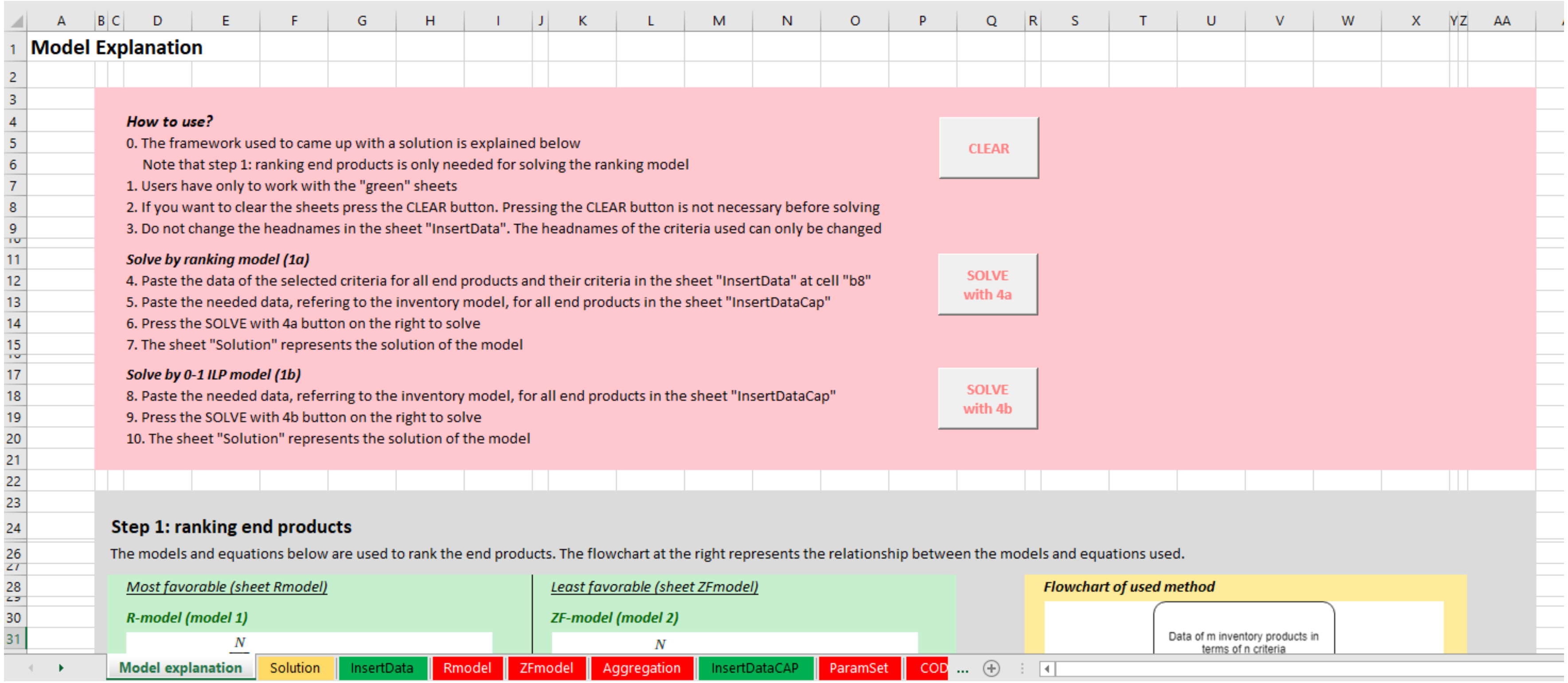
Product	Mean demand	Best before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP ranking	Difference
99	180.65	5	4	100.55	1.37	97.72	105716	66236	66236	0	MTO	L4L policy	MTO	YES
157	123.39	5	4	95.52	0.98	97.72	59276	36928	36928	0	MTO	L4L policy	MTO	YES
144	151.64	5	4	98.54	0.91	97.72	99394	45043	45043	0	MTO	L4L policy	MTO	YES
209	47.79	12	3	59.59	2.99	84.13	95118	79872	79872	0	MTO	L4L policy	MTO	YES
211	40.47	10	3	31.29	1.70	84.13	72966	62249	62249	0	MTO	L4L policy	MTO	YES
96	79.23	6	3	127.70	2.27	84.13	127492	118755	118755	0	MTO	L4L policy	MTO	YES
89	69.07	6	3	170.94	1.89	84.13	131314	104608	104608	0	MTO	L4L policy	MTO	YES
112	44.90	5	3	115.46	1.73	84.13	86484	67909	67909	0	MTO	L4L policy	MTO	YES
214	1.64	29	30	2.01	0.37	100.00	3537	2508	2508	0	MTO	L4L policy	MTO	YES
215	9.23	29	30	3.02	2.01	100.00	54232	13955	13955	0	MTO	L4L policy	MTO	YES
213	6.15	29	30	3.02	1.32	100.00	67002	9322	9322	0	MTO	L4L policy	MTO	YES
212	0.82	29	30	2.01	0.18	100.00	6496	1272	1272	0	MTO	L4L policy	MTO	YES
31	31.48	24	3	102.20	5.13	84.13	125916	94121	94121	0	MTO	L4L policy	MTS	NO
221	6.26	13	30	1.01	0.41	100.00	61717	7088	7088	0	MTO	L4L policy	MTO	YES
220	3.95	13	30	1.01	0.29	100.00	4216	2991	2991	0	MTO	L4L policy	MTO	YES
217	205.33	13	30	52.14	5.06	100.00	184219	155122	155122	0	MTO	L4L policy	MTO	YES
198	18.74	5	4	41.23	0.25	97.72	21243	8766	8766	0	MTO	L4L policy	MTO	YES
193	24.63	5	4	53.29	0.49	97.72	22779	11504	11504	0	MTO	L4L policy	MTO	YES
149	699.04	2	3	144.79	0.00	84.13	227500	88240	88240	0	MTO	L4L policy	MTO	YES
168	51.10	4	3	191.05	0.86	84.13	34600	25371	25371	0	MTO	L4L policy	MTO	YES
23	1463.94	10	3	136.75	0.00	84.13	317643	159362	159362	0	MTO	L4L policy	MTS	NO
33	323.96	4	3	270.48	1.61	84.13	234534	143774	143774	0	MTO	L4L policy	MTS	NO
154	93.79	5	3	169.93	0.38	84.13	85730	43285	43285	0	MTO	L4L policy	MTO	YES
174	9.89	4	1	171.94	0.20	15.87	29452	22826	22826	0	MTO	L4L policy	MTO	YES
63	538.63	12	3	69.38	0.00	84.13	80935	67829	67829	0	MTO	L4L policy	MTS	NO
78	86.25	12	3	184.01	1.88	84.13	60147	45592	45592	0	MTO	L4L policy	MTO	YES
108	44.11	12	3	131.95	2.70	84.13	27941	23944	23944	0	MTO	L4L policy	MTO	YES
111	47.73	12	3	152.17	1.71	84.13	37839	26079	26079	0	MTO	L4L policy	MTO	YES
107	40.84	12	3	174.96	1.48	84.13	26576	23181	23181	0	MTO	L4L policy	MTO	YES
148	30.15	9	3	161.89	1.17	84.13	25124	18446	18446	0	MTO	L4L policy	MTO	YES
92	51.82	13	3	182.00	2.08	84.13	35620	28688	28688	0	MTO	L4L policy	MTO	YES
183	8.41	4	3	77.42	0.59	84.13	51046	21189	21189	0	MTO	L4L policy	MTO	YES
184	23.86	7	5	86.47	0.54	99.87	32718	9720	9720	0	MTO	L4L policy	MTO	YES
125	20.59	10	3	116.64	2.84	84.13	43143	37426	37426	0	MTO	L4L policy	MTO	YES
158	36.21	10	5	97.53	1.06	99.87	41433	18262	18262	0	MTO	L4L policy	MTO	YES
128	23.53	10	3	118.65	3.26	84.13	61383	48259	48259	0	MTO	L4L policy	MTO	YES
102	23.56	13	5	94.15	2.11	99.87	95498	28464	28464	0	MTO	L4L policy	MTO	YES
150	77.32	8	4	90.06	1.23	97.72	65973	37264	37264	0	MTO	L4L policy	MTO	YES
129	110.89	8	4	90.06	2.30	97.72	74300	48950	48950	0	MTO	L4L policy	MTO	YES
137	96.74	8	4	94.81	2.39	97.72	66182	42998	42998	0	MTO	L4L policy	MTO	YES
195	42.65	5	4	86.47	0.35	97.72	31102	12215	12215	0	MTO	L4L policy	MTO	YES
204	5.13	4	6	40.22	0.13	100.00	32528	4898	4898	0	MTO	L4L policy	MTO	YES
192	38.67	4	6	78.21	0.50	100.00	117636	31620	31620	0	MTO	L4L policy	MTO	YES
159	79.86	4	6	54.30	0.63	100.00	90502	31055	31055	0	MTO	L4L policy	MTO	YES
163	75.15	4	6	54.30	0.52	100.00	96649	29282	29282	0	MTO	L4L policy	MTO	YES
207	2.17	4	6	2.01	0.03	100.00	4191	920	920	0	MTO	L4L policy	MTO	YES
166	71.72	4	6	55.30	0.55	100.00	88969	28008	28008	0	MTO	L4L policy	MTO	YES
179	62.85	4	6	52.29	0.49	100.00	83881	24614	24614	0	MTO	L4L policy	MTO	YES
114	102.15	4	6	101.56	0.75	100.00	217680	78767	78767	0	MTO	L4L policy	MTO	YES
152	83.97	4	6	96.53	0.62	100.00	198783	64990	64990	0	MTO	L4L policy	MTO	YES
200	16.63	4	4	94.52	0.32	97.72	33106	8833	8833	0	MTO	L4L policy	MTO	YES
190	14.87	6	5	97.53	0.34	99.87	18859	7414	7414	0	MTO	L4L policy	MTO	YES
206	7.12	2	5	51.28	0.03	99.87	30543	3363	3363	0	MTO	L4L policy	MTO	YES
203	18.03	2	5	67.37	0.17	99.87	38214	8406	8406	0	MTO	L4L policy	MTO	YES
187	41.15	4	5	99.55	0.75	99.87	39135	17424	17424	0	MTO	L4L policy	MTO	YES
145	92.07	6	5	102.56	1.58	99.87	68754	36803	36803	0	MTO	L4L policy	MTO	YES
186	21.88	6	5	95.52	0.52	99.87	19567	10038	10038	0	MTO	L4L policy	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP ranking	Difference
20	1931.95	12	3	109.60	0.00	84.13	393270	238598	238598	0	MTO	L4L policy	MTS	NO
43	1037.85	12	3	91.50	0.00	84.13	156824	128767	128767	0	MTO	L4L policy	MTS	NO
119	120.43	10	5	96.53	1.89	99.87	83646	47455	47455	0	MTO	L4L policy	MTO	YES
182	29.81	7	5	93.51	0.70	99.87	30392	11598	11598	0	MTO	L4L policy	MTO	YES
101	59.68	12	4	52.29	1.98	97.72	43610	32868	32868	0	MTO	L4L policy	MTO	YES
52	104.79	13	3	197.08	2.56	84.13	72571	67743	67743	0	MTO	L4L policy	MTS	NO
191	27.91	3	4	87.48	0.25	97.72	47994	13531	13531	0	MTO	L4L policy	MTO	YES
84	63.04	13	3	166.91	2.69	84.13	36119	33914	33914	0	MTO	L4L policy	MTO	YES
121	45.63	12	4	51.28	1.78	97.72	29078	20456	20456	0	MTO	L4L policy	MTO	YES
189	27.38	6	6	96.53	0.52	100.00	35485	12062	12062	0	MTO	L4L policy	MTO	YES
90	48.83	13	3	188.03	2.63	84.13	30960	27336	27336	0	MTO	L4L policy	MTO	YES
197	13.73	4	4	81.45	0.21	97.72	28936	6619	6619	0	MTO	L4L policy	MTO	YES
185	32.69	6	6	97.53	0.55	100.00	33500	14078	14078	0	MTO	L4L policy	MTO	YES
113	65.23	12	4	51.28	1.83	97.72	37403	28841	28841	0	MTO	L4L policy	MTO	YES
73	85.30	13	3	171.94	1.84	84.13	60245	44910	44910	0	MTO	L4L policy	MTO	YES
104	93.18	4	4	71.39	0.79	97.72	80350	36179	36179	0	MTO	L4L policy	MTO	YES
130	46.03	7	4	78.43	1.24	97.72	29716	21118	21118	0	MTO	L4L policy	MTO	YES
65	87.39	7	4	79.44	3.53	97.72	63028	42571	42571	0	MTO	L4L policy	MTS	NO
11	307.63	7	4	96.53	7.53	97.72	160455	133374	133374	0	MTO	L4L policy	MTS	NO
135	46.07	8	4	75.41	1.17	97.72	38816	21080	21080	0	MTO	L4L policy	MTO	YES
56	115.74	7	4	91.50	2.35	97.72	81239	55143	55143	0	MTO	L4L policy	MTS	NO
117	63.23	10	3	179.99	1.29	84.13	37862	30371	30371	0	MTO	L4L policy	MTO	YES
76	74.27	13	3	169.93	2.46	84.13	42982	39468	39468	0	MTO	L4L policy	MTO	YES
79	67.07	13	3	183.00	2.46	84.13	39295	36177	36177	0	MTO	L4L policy	MTO	YES
205	3.38	13	15	16.09	0.28	100.00	23972	1565	1565	0	MTO	L4L policy	MTO	YES
222	34.82	12	30	18.10	2.03	100.00	116748	39654	39654	0	MTO	L4L policy	MTO	YES
47	420.44	6	3	206.13	0.00	84.13	344921	158218	158218	0	MTO	L4L policy	MTS	NO
170	116.42	6	3	118.65	0.21	84.13	101436	44928	44928	0	MTO	L4L policy	MTO	YES
10	458.37	4	4	102.56	0.00	97.72	746420	173459	173459	0	MTO	L4L policy	MTS	NO
77	70.22	10	3	114.63	1.65	84.13	47721	32179	32179	0	MTO	L4L policy	MTO	YES
97	43.10	9	3	190.04	1.97	84.13	58035	43041	43041	0	MTO	L4L policy	MTO	YES
167	13.26	7	4	98.54	0.49	97.72	16024	8027	8027	0	MTO	L4L policy	MTO	YES
138	7.02	12	3	131.72	0.52	84.13	18459	6519	6519	0	MTO	L4L policy	MTO	YES
202	8.38	3	4	89.49	0.13	97.72	24942	5207	5207	0	MTO	L4L policy	MTO	YES
85	62.65	13	3	165.91	2.06	84.13	41514	33703	33703	0	MTO	L4L policy	MTO	YES
194	24.13	6	6	92.51	0.31	100.00	39867	10767	10767	0	MTO	L4L policy	MTO	YES
98	40.19	13	3	174.96	2.13	84.13	29221	22862	22862	0	MTO	L4L policy	MTO	YES
188	17.15	4	4	98.54	0.32	97.72	27002	8209	8209	0	MTO	L4L policy	MTO	YES
177	6.29	4	1	158.87	0.24	15.87	21505	20056	20056	0	MTO	L4L policy	MTO	YES
44	215.66	4	4	108.60	0.39	97.72	270941	82706	82706	0	MTO	L4L policy	MTS	NO
28	229.94	3	4	104.57	0.37	97.72	330982	100279	100279	0	MTO	L4L policy	MTS	NO
201	11.62	3	4	95.52	0.23	97.72	25046	6703	6703	0	MTO	L4L policy	MTO	YES
122	20.85	12	3	98.54	1.31	84.13	13673	10980	10980	0	MTO	L4L policy	MTO	YES
162	38.60	5	3	164.90	0.72	84.13	54622	36082	36082	0	MTO	L4L policy	MTO	YES
127	48.00	10	3	184.01	1.57	84.13	27795	23915	23915	0	MTO	L4L policy	MTO	YES
103	28.88	12	3	195.07	2.11	84.13	21622	17689	17689	0	MTO	L4L policy	MTO	YES
69	93.39	13	3	187.02	2.35	84.13	55544	49147	49147	0	MTO	L4L policy	MTO	YES
86	59.16	13	3	190.04	2.18	84.13	38712	32429	32429	0	MTO	L4L policy	MTO	YES
165	5.88	10	3	4.02	0.42	84.13	15581	5829	5829	0	MTO	L4L policy	MTO	YES
35	662.03	16	3	70.39	0.00	84.13	196076	82357	82357	0	MTO	L4L policy	MTS	NO
124	14.94	10	3	103.57	2.34	84.13	55427	31160	31160	0	MTO	L4L policy	MTO	YES
131	92.66	10	3	126.69	0.66	84.13	86378	47693	47693	0	MTO	L4L policy	MTO	YES
147	9.20	12	3	73.00	0.56	84.13	19191	6381	6381	0	MTO	L4L policy	MTO	YES
60	884.00	4	3	163.88	0.00	84.13	199878	124978	124978	0	MTO	L4L policy	MTS	NO
116	27.54	12	3	158.87	1.64	84.13	26170	16377	16377	0	MTO	L4L policy	MTO	YES
62	380.51	10	3	112.31	0.00	84.13	89335	83368	83368	0	MTO	L4L policy	MTS	NO
105	107.10	4	4	90.38	1.19	97.72	70013	41625	41625	0	MTO	L4L policy	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP ranking	Difference
172	9.52	12	3	1.01	0.57	84.13	19963	4680	4680	0	MTO	L4L policy	MTO	YES
80	23.16	13	3	126.69	4.08	84.13	88327	47683	47683	0	MTO	L4L policy	MTO	YES

Appendix C

The tool


Model Explanation
How to use?
0. The framework used to came up with a solution is explained below
Note that step 1: ranking end products is only needed for solving the ranking model
1. Users have only to work with the "green" sheets
2. If you want to clear the sheets press the CLEAR button. Pressing the CLEAR button is not necessary before solving
3. Do not change the headnames in the sheet "InsertData". The headnames of the criteria used can only be changed
Solve by ranking model (1a)
4. Paste the data of the selected criteria for all end products and their criteria in the sheet "InsertData" at cell "b8"
5. Paste the needed data, refering to the inventory model, for all end products in the sheet "InsertDataCap"
6. Press the SOLVE with 4a button on the right to solve
7. The sheet "Solution" represents the solution of the model
Solve by 0-1 ILP model (1b)
8. Paste the needed data, referring to the inventory model, for all end products in the sheet "InsertDataCap"
9. Press the SOLVE with 4b button on the right to solve
10. The sheet "Solution" represents the solution of the model
CLEAR
SOLVE with 4a
SOLVE with 4b
Step 1: ranking end products
The models and equations below are used to rank the end products. The flowchart at the right represents the relationship between the models and equations used.
Most favorable (sheet Rmodel)
R-model (model 1)
Least favorable (sheet ZFmodel)
ZF-model (model 2)
Flowchart of used method
Data of m inventory products in terms of n criteria
Model explanation
Solution
InsertData
Rmodel
ZFmodel
Aggregation
InsertDataCAP
ParamSet

Appendix D

Sensitivity analysis: criteria selection of ranking model

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Without ratio BBD/DBO	Difference	Without OLT	Difference	Without BBD	Difference
1	636.25	9	3	226.24	0.90	28.17	MTS	MTS	YES	MTS	YES	MTS	YES
2	493.81	9	3	235.29	0.71	13.75	MTS	MTS	YES	MTS	YES	MTS	YES
3	153.54	32	2	222.22	0.70	28.92	MTS	MTS	YES	MTS	YES	MTS	YES
4	404.26	6	2	246.35	0.66	10.62	MTS	MTS	YES	MTS	YES	MTS	YES
5	455.96	12	3	306.68	0.64	29.32	MTS	MTS	YES	MTS	YES	MTS	YES
6	339.18	6	2	242.33	0.63	10.63	MTS	MTS	YES	MTS	YES	MTS	YES
7	395.64	12	3	214.17	0.63	9.27	MTS	MTS	YES	MTS	YES	MTS	YES
8	554.42	9	3	306.68	0.59	27.08	MTS	MTS	YES	MTS	YES	MTS	YES
9	429.61	12	3	308.69	0.58	15.07	MTS	MTS	YES	MTS	YES	MTS	YES
10	458.37	4	4	102.56	0.58	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
11	307.63	7	4	96.53	0.57	7.53	MTS	MTS	YES	MTS	YES	MTS	YES
12	142.83	13	3	253.47	0.57	14.00	MTS	MTS	YES	MTS	YES	MTS	YES
13	343.69	12	3	299.64	0.55	17.15	MTS	MTS	YES	MTS	YES	MTS	YES
14	180.42	13	3	246.35	0.54	14.67	MTS	MTS	YES	MTS	YES	MTS	YES
15	321.09	12	3	306.68	0.54	16.05	MTS	MTS	YES	MTS	YES	MTS	YES
16	109.66	12	3	225.95	0.54	9.35	MTS	MTS	YES	MTS	YES	MTS	YES
17	2378.09	13	3	151.69	0.53	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
18	298.21	12	3	302.66	0.53	16.61	MTS	MTS	YES	MTS	YES	MTS	YES
19	137.49	12	3	225.23	0.52	7.82	MTS	MTS	YES	MTS	YES	MTS	YES
20	1931.95	12	3	109.60	0.52	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
21	250.79	12	3	307.69	0.52	15.73	MTS	MTS	YES	MTS	YES	MTS	YES
22	77.88	13	3	201.10	0.52	14.51	MTS	MTS	YES	MTS	YES	MTS	YES
23	1463.94	10	3	136.75	0.51	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
24	264.04	12	3	259.42	0.51	16.65	MTS	MTS	YES	MTS	YES	MTS	YES
25	239.90	12	3	295.62	0.50	12.13	MTS	MTS	YES	MTS	YES	MTS	YES
26	217.66	4	6	99.55	0.50	1.51	MTS	MTS	YES	MTS	YES	MTS	YES
27	94.91	12	3	191.05	0.50	6.29	MTS	MTS	YES	MTS	YES	MTS	YES
28	229.94	3	4	104.57	0.49	0.37	MTS	MTS	YES	MTS	YES	MTS	YES
29	1279.61	12	3	93.51	0.49	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
30	191.95	4	6	101.56	0.49	1.16	MTS	MTS	YES	MTS	YES	MTS	YES
31	31.48	24	3	102.20	0.48	5.13	MTS	MTS	YES	MTS	YES	MTO	NO
32	111.33	10	5	217.03	0.48	5.09	MTS	MTS	YES	MTS	YES	MTS	YES
33	323.96	4	3	270.48	0.48	1.61	MTS	MTS	YES	MTS	YES	MTS	YES
34	161.37	12	3	256.40	0.48	8.22	MTS	MTS	YES	MTS	YES	MTS	YES
35	662.03	16	3	70.39	0.48	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
36	79.33	13	3	198.09	0.48	9.77	MTS	MTS	YES	MTS	YES	MTS	YES
37	157.39	4	6	102.56	0.48	1.14	MTS	MTS	YES	MTS	YES	MTS	YES
38	139.05	12	3	302.66	0.48	8.51	MTS	MTS	YES	MTS	YES	MTS	YES
39	1076.65	16	3	95.99	0.47	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
40	69.39	13	3	195.07	0.47	10.02	MTS	MTS	YES	MTS	YES	MTS	YES
41	54.35	13	3	187.02	0.47	8.00	MTS	MTS	YES	MTS	YES	MTS	YES
42	91.53	10	3	198.09	0.47	9.43	MTS	MTS	YES	MTS	YES	MTS	YES
43	1037.85	12	3	91.50	0.47	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
44	215.66	4	4	108.60	0.47	0.39	MTS	MTS	YES	MTS	YES	MTS	YES
45	198.03	8	3	269.48	0.47	7.67	MTS	MTS	YES	MTS	YES	MTS	YES
46	140.61	10	3	243.33	0.47	3.37	MTS	MTS	YES	MTS	YES	MTS	YES
47	420.44	6	3	206.13	0.47	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
48	47.71	13	3	188.03	0.47	8.10	MTS	MTS	YES	MTS	YES	MTS	YES
49	47.44	13	3	185.01	0.47	8.07	MTS	MTS	YES	MTS	YES	MTS	YES
50	52.63	12	1	208.14	0.46	4.05	MTS	MTS	YES	MTS	YES	MTO	NO
51	923.38	13	3	124.34	0.46	0.00	MTS	MTS	YES	MTS	YES	MTS	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Without ratio BBD/DBO	Difference	Without OLT	Difference	Without BBD	Difference
52	104.79	13	3	197.08	0.46	2.56	MTS	MTS	YES	MTS	YES	MTO	NO
53	40.38	13	3	176.97	0.46	6.90	MTS	MTS	YES	MTS	YES	MTS	YES
54	403.94	16	3	68.28	0.46	0.00	MTS	MTS	YES	MTS	YES	MTO	NO
55	46.48	12	1	207.13	0.46	4.09	MTS	MTS	YES	MTO	NO	MTO	NO
56	115.74	7	4	91.50	0.46	2.35	MTS	MTS	YES	MTS	YES	MTS	YES
57	91.01	8	3	191.05	0.46	5.25	MTS	MTS	YES	MTS	YES	MTS	YES
58	34.79	13	3	167.16	0.46	6.35	MTS	MTS	YES	MTS	YES	MTO	NO
59	107.85	4	3	270.48	0.46	2.36	MTS	MTS	YES	MTS	YES	MTS	YES
60	884.00	4	3	163.88	0.45	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
61	79.96	12	3	253.39	0.45	5.99	MTS	MTS	YES	MTS	YES	MTO	NO
62	380.51	10	3	112.31	0.45	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
63	538.63	12	3	69.38	0.45	0.00	MTS	MTS	YES	MTS	YES	MTS	YES
64	75.78	12	3	300.65	0.45	3.90	MTS	MTO	NO	MTO	NO	MTO	NO
65	87.39	7	4	79.44	0.45	3.53	MTS	MTS	YES	MTS	YES	MTS	YES
66	29.01	12	1	206.13	0.45	2.67	MTS	MTS	YES	MTO	NO	MTO	NO
67	31.88	12	1	205.12	0.45	1.87	MTS	MTS	YES	MTO	NO	MTO	NO
68	252.51	16	3	62.81	0.45	0.00	MTS	MTS	YES	MTS	YES	MTO	NO
69	93.39	13	3	187.02	0.45	2.35	MTO	MTO	YES	MTO	YES	MTO	YES
70	64.89	12	3	263.44	0.45	4.14	MTO	MTO	YES	MTO	YES	MTO	YES
71	26.42	12	1	206.13	0.45	2.51	MTO	MTS	NO	MTO	YES	MTO	YES
72	24.60	12	1	205.12	0.44	1.94	MTO	MTO	YES	MTO	YES	MTO	YES
73	85.30	13	3	171.94	0.44	1.84	MTO	MTO	YES	MTO	YES	MTO	YES
74	23.24	12	1	202.11	0.44	2.00	MTO	MTO	YES	MTO	YES	MTO	YES
75	1009.80	10	3	114.95	0.44	0.00	MTO	MTO	YES	MTO	YES	MTS	NO
76	74.27	13	3	169.93	0.44	2.46	MTO	MTO	YES	MTO	YES	MTO	YES
77	70.22	10	3	114.63	0.44	1.65	MTO	MTO	YES	MTO	YES	MTO	YES
78	86.25	12	3	184.01	0.44	1.88	MTO	MTO	YES	MTO	YES	MTO	YES
79	67.07	13	3	183.00	0.44	2.46	MTO	MTO	YES	MTO	YES	MTO	YES
80	23.16	13	3	126.69	0.44	4.08	MTO	MTO	YES	MTO	YES	MTO	YES
81	15.04	12	1	203.11	0.44	1.36	MTO	MTO	YES	MTO	YES	MTO	YES
82	48.97	12	3	213.17	0.44	2.99	MTO	MTO	YES	MTO	YES	MTO	YES
83	13.97	12	1	206.13	0.44	1.31	MTO	MTO	YES	MTO	YES	MTO	YES
84	63.04	13	3	166.91	0.44	2.69	MTO	MTO	YES	MTO	YES	MTO	YES
85	62.65	13	3	165.91	0.44	2.06	MTO	MTO	YES	MTO	YES	MTO	YES
86	59.16	13	3	190.04	0.44	2.18	MTO	MTO	YES	MTO	YES	MTO	YES
87	20.57	13	3	142.78	0.44	3.48	MTO	MTO	YES	MTO	YES	MTO	YES
88	12.68	12	1	204.12	0.44	1.22	MTO	MTO	YES	MTO	YES	MTO	YES
89	69.07	6	3	170.94	0.44	1.89	MTO	MTO	YES	MTO	YES	MTS	NO
90	48.83	13	3	188.03	0.44	2.63	MTO	MTO	YES	MTO	YES	MTO	YES
91	14.34	12	1	195.07	0.44	1.30	MTO	MTO	YES	MTO	YES	MTO	YES
92	51.82	13	3	182.00	0.44	2.08	MTO	MTO	YES	MTO	YES	MTO	YES
93	81.20	9	3	255.40	0.44	3.91	MTO	MTO	YES	MTO	YES	MTO	YES
94	23.84	12	1	138.76	0.43	1.77	MTO	MTO	YES	MTO	YES	MTO	YES
95	20.87	10	1	170.94	0.43	1.82	MTO	MTO	YES	MTO	YES	MTO	YES
96	79.23	6	3	127.70	0.43	2.27	MTO	MTO	YES	MTO	YES	MTS	NO
97	43.10	9	3	190.04	0.43	1.97	MTO	MTO	YES	MTO	YES	MTO	YES
98	40.19	13	3	174.96	0.43	2.13	MTO	MTO	YES	MTO	YES	MTO	YES
99	180.65	5	4	100.55	0.43	1.37	MTO	MTO	YES	MTO	YES	MTS	NO
100	17.02	13	3	111.61	0.43	3.10	MTO	MTO	YES	MTO	YES	MTO	YES
101	59.68	12	4	52.29	0.43	1.98	MTO	MTO	YES	MTO	YES	MTO	YES
102	23.56	13	5	94.15	0.43	2.11	MTO	MTO	YES	MTO	YES	MTO	YES
103	28.88	12	3	195.07	0.43	2.11	MTO	MTO	YES	MTO	YES	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Without ratio BBD/DBO	Difference	Without OLT	Difference	Without BBD	Difference
104	93.18	4	4	71.39	0.43	0.79	MTO	MTO	YES	MTO	YES	MTS	NO
105	107.10	4	4	90.38	0.43	1.19	MTO	MTO	YES	MTO	YES	MTS	NO
106	51.47	12	3	93.86	0.43	2.95	MTO	MTO	YES	MTO	YES	MTO	YES
107	40.84	12	3	174.96	0.43	1.48	MTO	MTO	YES	MTO	YES	MTO	YES
108	44.11	12	3	131.95	0.43	2.70	MTO	MTO	YES	MTO	YES	MTO	YES
109	25.64	10	3	120.66	0.43	3.73	MTO	MTO	YES	MTO	YES	MTO	YES
110	57.40	5	3	171.33	0.43	4.09	MTO	MTO	YES	MTO	YES	MTS	NO
111	47.73	12	3	152.17	0.43	1.71	MTO	MTO	YES	MTO	YES	MTO	YES
112	44.90	5	3	115.46	0.43	1.73	MTO	MTO	YES	MTO	YES	MTS	NO
113	65.23	12	4	51.28	0.43	1.83	MTO	MTO	YES	MTO	YES	MTO	YES
114	102.15	4	6	101.56	0.43	0.75	MTO	MTO	YES	MTO	YES	MTS	NO
115	13.04	13	3	69.52	0.43	2.69	MTO	MTO	YES	MTO	YES	MTO	YES
116	27.54	12	3	158.87	0.43	1.64	MTO	MTO	YES	MTO	YES	MTO	YES
117	63.23	10	3	179.99	0.43	1.29	MTO	MTO	YES	MTO	YES	MTO	YES
118	12.57	13	3	83.65	0.42	2.63	MTO	MTO	YES	MTO	YES	MTO	YES
119	120.43	10	5	96.53	0.42	1.89	MTO	MTO	YES	MTO	YES	MTO	YES
120	10.86	13	3	56.31	0.42	1.98	MTO	MTO	YES	MTO	YES	MTO	YES
121	45.63	12	4	51.28	0.42	1.78	MTO	MTO	YES	MTO	YES	MTO	YES
122	20.85	12	3	98.54	0.42	1.31	MTO	MTO	YES	MTO	YES	MTO	YES
123	9.63	13	3	76.97	0.42	1.74	MTO	MTO	YES	MTO	YES	MTO	YES
124	14.94	10	3	103.57	0.42	2.34	MTO	MTO	YES	MTO	YES	MTO	YES
125	20.59	10	3	116.64	0.42	2.84	MTO	MTO	YES	MTO	YES	MTO	YES
126	48.56	5	3	164.90	0.42	4.25	MTO	MTO	YES	MTO	YES	MTO	YES
127	48.00	10	3	184.01	0.42	1.57	MTO	MTO	YES	MTO	YES	MTO	YES
128	23.53	10	3	118.65	0.42	3.26	MTO	MTO	YES	MTO	YES	MTO	YES
129	110.89	8	4	90.06	0.42	2.30	MTO	MTO	YES	MTO	YES	MTO	YES
130	46.03	7	4	78.43	0.42	1.24	MTO	MTO	YES	MTO	YES	MTO	YES
131	92.66	10	3	126.69	0.42	0.66	MTO	MTO	YES	MTO	YES	MTO	YES
132	44.88	13	3	76.42	0.42	6.13	MTO	MTO	YES	MTO	YES	MTO	YES
133	183.50	12	3	53.29	0.42	0.00	MTO	MTO	YES	MTO	YES	MTO	YES
134	102.71	11	5	91.50	0.42	1.41	MTO	MTO	YES	MTO	YES	MTO	YES
135	46.07	8	4	75.41	0.42	1.17	MTO	MTO	YES	MTO	YES	MTO	YES
136	5.59	13	3	52.14	0.42	1.02	MTO	MTO	YES	MTO	YES	MTO	YES
137	96.74	8	4	94.81	0.42	2.39	MTO	MTO	YES	MTO	YES	MTO	YES
138	7.02	12	3	131.72	0.42	0.52	MTO	MTO	YES	MTO	YES	MTO	YES
139	6.52	13	3	46.35	0.42	1.34	MTO	MTO	YES	MTO	YES	MTO	YES
140	83.83	9	5	102.55	0.42	2.23	MTO	MTO	YES	MTO	YES	MTO	YES
141	96.09	10	5	98.54	0.42	1.49	MTO	MTO	YES	MTO	YES	MTO	YES
142	52.12	6	3	129.71	0.42	4.40	MTO	MTO	YES	MTO	YES	MTO	YES
143	34.22	5	3	139.05	0.42	2.79	MTO	MTO	YES	MTO	YES	MTO	YES
144	151.64	5	4	98.54	0.41	0.91	MTO	MTO	YES	MTO	YES	MTO	YES
145	92.07	6	5	102.56	0.41	1.58	MTO	MTO	YES	MTO	YES	MTO	YES
146	60.38	10	5	86.47	0.41	1.62	MTO	MTO	YES	MTO	YES	MTO	YES
147	9.20	12	3	73.00	0.41	0.56	MTO	MTO	YES	MTO	YES	MTO	YES
148	30.15	9	3	161.89	0.41	1.17	MTO	MTO	YES	MTO	YES	MTO	YES
149	699.04	2	3	144.79	0.41	0.00	MTO	MTO	YES	MTO	YES	MTS	NO
150	77.32	8	4	90.06	0.41	1.23	MTO	MTO	YES	MTO	YES	MTO	YES
151	49.41	10	5	96.53	0.41	1.10	MTO	MTO	YES	MTO	YES	MTO	YES
152	83.97	4	6	96.53	0.41	0.62	MTO	MTO	YES	MTO	YES	MTS	NO
153	299.93	12	3	200.00	0.41	7.64	MTO	MTO	YES	MTO	YES	MTO	YES
154	93.79	5	3	169.93	0.41	0.38	MTO	MTO	YES	MTO	YES	MTO	YES
155	50.33	9	5	99.07	0.41	1.31	MTO	MTO	YES	MTO	YES	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Without ratio BBD/DBO	Difference	Without OLT	Difference	Without BBD	Difference
156	72.31	5	4	93.51	0.41	1.08	MTO	MTO	YES	MTO	YES	MTO	YES
157	123.39	5	4	95.52	0.41	0.98	MTO	MTO	YES	MTO	YES	MTO	YES
158	36.21	10	5	97.53	0.41	1.06	MTO	MTO	YES	MTO	YES	MTO	YES
159	79.86	4	6	54.30	0.41	0.63	MTO	MTO	YES	MTO	YES	MTO	YES
160	19.54	6	1	107.59	0.41	1.12	MTO	MTO	YES	MTO	YES	MTO	YES
161	28.15	9	5	85.78	0.40	0.83	MTO	MTO	YES	MTO	YES	MTO	YES
162	38.60	5	3	164.90	0.40	0.72	MTO	MTO	YES	MTO	YES	MTO	YES
163	75.15	4	6	54.30	0.40	0.52	MTO	MTO	YES	MTO	YES	MTO	YES
164	61.30	5	4	87.48	0.40	0.95	MTO	MTO	YES	MTO	YES	MTO	YES
165	5.88	10	3	4.02	0.40	0.42	MTO	MTO	YES	MTO	YES	MTO	YES
166	71.72	4	6	55.30	0.40	0.55	MTO	MTO	YES	MTO	YES	MTO	YES
167	13.26	7	4	98.54	0.40	0.49	MTO	MTO	YES	MTO	YES	MTO	YES
168	51.10	4	3	191.05	0.40	0.86	MTO	MTO	YES	MTO	YES	MTO	YES
169	13.19	4	1	164.90	0.40	0.36	MTO	MTO	YES	MTO	YES	MTO	YES
170	116.42	6	3	118.65	0.40	0.21	MTO	MTO	YES	MTO	YES	MTO	YES
171	50.26	7	5	98.54	0.40	0.98	MTO	MTO	YES	MTO	YES	MTO	YES
172	9.52	12	3	1.01	0.40	0.57	MTO	MTO	YES	MTO	YES	MTO	YES
173	101.42	13	3	169.46	0.40	3.33	MTO	MTO	YES	MTO	YES	MTO	YES
174	9.89	4	1	171.94	0.40	0.20	MTO	MTO	YES	MTO	YES	MTO	YES
175	46.57	5	4	83.46	0.40	0.74	MTO	MTO	YES	MTO	YES	MTO	YES
176	47.71	5	4	79.44	0.40	0.59	MTO	MTO	YES	MTO	YES	MTO	YES
177	6.29	4	1	158.87	0.40	0.24	MTO	MTO	YES	MTO	YES	MTO	YES
178	45.03	5	4	83.46	0.40	1.00	MTO	MTO	YES	MTO	YES	MTO	YES
179	62.85	4	6	52.29	0.40	0.49	MTO	MTO	YES	MTO	YES	MTO	YES
180	16.53	6	3	68.37	0.40	1.45	MTO	MTO	YES	MTO	YES	MTO	YES
181	100.10	13	3	149.91	0.39	5.40	MTO	MTO	YES	MTO	YES	MTO	YES
182	29.81	7	5	93.51	0.39	0.70	MTO	MTO	YES	MTO	YES	MTO	YES
183	8.41	4	3	77.42	0.39	0.59	MTO	MTO	YES	MTO	YES	MTO	YES
184	23.86	7	5	86.47	0.39	0.54	MTO	MTO	YES	MTO	YES	MTO	YES
185	32.69	6	6	97.53	0.39	0.55	MTO	MTO	YES	MTO	YES	MTO	YES
186	21.88	6	5	95.52	0.39	0.52	MTO	MTO	YES	MTO	YES	MTO	YES
187	41.15	4	5	99.55	0.39	0.75	MTO	MTO	YES	MTO	YES	MTO	YES
188	17.15	4	4	98.54	0.39	0.32	MTO	MTO	YES	MTO	YES	MTO	YES
189	27.38	6	6	96.53	0.39	0.52	MTO	MTO	YES	MTO	YES	MTO	YES
190	14.87	6	5	97.53	0.39	0.34	MTO	MTO	YES	MTO	YES	MTO	YES
191	27.91	3	4	87.48	0.39	0.25	MTO	MTO	YES	MTO	YES	MTO	YES
192	38.67	4	6	78.21	0.39	0.50	MTO	MTO	YES	MTO	YES	MTO	YES
193	24.63	5	4	53.29	0.39	0.49	MTO	MTO	YES	MTO	YES	MTO	YES
194	24.13	6	6	92.51	0.39	0.31	MTO	MTO	YES	MTO	YES	MTO	YES
195	42.65	5	4	86.47	0.39	0.35	MTO	MTO	YES	MTO	YES	MTO	YES
196	91.77	13	3	130.36	0.39	3.33	MTO	MTO	YES	MTO	YES	MTO	YES
197	13.73	4	4	81.45	0.39	0.21	MTO	MTO	YES	MTO	YES	MTO	YES
198	18.74	5	4	41.23	0.39	0.25	MTO	MTO	YES	MTO	YES	MTO	YES
199	29.39	6	3	39.21	0.38	0.78	MTO	MTO	YES	MTO	YES	MTO	YES
200	16.63	4	4	94.52	0.38	0.32	MTO	MTO	YES	MTO	YES	MTO	YES
201	11.62	3	4	95.52	0.38	0.23	MTO	MTO	YES	MTO	YES	MTO	YES
202	8.38	3	4	89.49	0.38	0.13	MTO	MTO	YES	MTO	YES	MTO	YES
203	18.03	2	5	67.37	0.37	0.17	MTO	MTO	YES	MTO	YES	MTO	YES
204	5.13	4	6	40.22	0.37	0.13	MTO	MTO	YES	MTO	YES	MTO	YES
205	3.38	13	15	16.09	0.37	0.28	MTO	MTO	YES	MTO	YES	MTO	YES
206	7.12	2	5	51.28	0.37	0.03	MTO	MTO	YES	MTO	YES	MTO	YES
207	2.17	4	6	2.01	0.37	0.03	MTO	MTO	YES	MTO	YES	MTO	YES

Product	Mean demand	Best before date	Order lead time	Number of orders per year	Overall performance index	Avg. Number of pallets on hand	CODP	Without ratio BBD/DBO	Difference	Without OLT	Difference	Without BBD	Difference
208	7.90	13	15	58.66	0.37	1.54	MTO	MTO	YES	MTO	YES	MTO	YES
209	47.79	12	3	59.59	0.37	2.99	MTO	MTO	YES	MTO	YES	MTO	YES
210	7.10	13	15	44.69	0.36	1.30	MTO	MTO	YES	MTO	YES	MTO	YES
211	40.47	10	3	31.29	0.36	1.70	MTO	MTO	YES	MTO	YES	MTO	YES
212	0.82	29	30	2.01	0.36	0.18	MTO	MTO	YES	MTS	NO	MTO	YES
213	6.15	29	30	3.02	0.36	1.32	MTO	MTO	YES	MTS	NO	MTO	YES
214	1.64	29	30	2.01	0.35	0.37	MTO	MTO	YES	MTS	NO	MTO	YES
215	9.23	29	30	3.02	0.33	2.01	MTO	MTO	YES	MTS	NO	MTO	YES
216	1.62	13	30	2.01	0.33	0.10	MTO	MTO	YES	MTO	YES	MTO	YES
217	205.33	13	30	52.14	0.31	5.06	MTO	MTO	YES	MTO	YES	MTO	YES
218	2.15	13	30	2.01	0.30	0.17	MTO	MTO	YES	MTO	YES	MTO	YES
219	10.51	19	30	3.02	0.30	1.31	MTO	MTO	YES	MTO	YES	MTO	YES
220	3.95	13	30	1.01	0.29	0.29	MTO	MTO	YES	MTO	YES	MTO	YES
221	6.26	13	30	1.01	0.27	0.41	MTO	MTO	YES	MTO	YES	MTO	YES
222	34.82	12	30	18.10	0.24	2.03	MTO	MTO	YES	MTO	YES	MTO	YES
223	20.19	13	30	1.01	0.23	1.37	MTO	MTO	YES	MTO	YES	MTO	YES
224	125.83	13	30	7.04	0.03	6.02	MTO	MTO	YES	MTO	YES	MTO	YES

Appendix E

Comparison of both the ranking model and the 0-1 ILP model to the current situation

Average Service Level of MTS items =	82.94
Average Service Level of MTO items =	92.75
Overall average service level =	83.18

Total Pallet Capacity	900
Total cost per year	24952468
Total Pallets Needed	690

Product	Mean demand	Best Before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP proposed 0-1 ILP model	Difference	CODP proposed ranking model	Difference
39	1076.65	16	3	95.99	0.00	92.64	114268	133239	114268	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
17	2378.09	13	3	151.69	0.00	99.91	183090	295704	183090	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
22	77.88	13	3	201.10	14.51	100.00	144828	194407	144828	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
94	23.84	12	1	138.76	1.77	100.00	17188	51371	17188	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
36	79.33	13	3	198.09	9.77	100.00	128546	159040	128546	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
48	47.71	13	3	188.03	8.10	100.00	65473	96906	65473	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
40	69.39	13	3	195.07	10.02	100.00	114709	139509	114709	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
53	40.38	13	3	176.97	6.90	100.00	66506	82347	66506	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
58	34.79	13	3	167.16	6.35	99.90	59963	71027	59963	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
142	52.12	6	3	129.71	4.40	100.00	92483	104483	92483	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
41	54.35	13	3	187.02	8.00	100.00	70502	109888	70502	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
42	91.53	10	3	198.09	9.43	100.00	125370	160525	125370	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
109	25.64	10	3	120.66	3.73	100.00	43508	49289	43508	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
14	180.42	13	3	246.35	14.67	100.00	178075	253050	178075	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
12	142.83	13	3	253.47	14.00	100.00	199077	318600	199077	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
7	395.64	12	3	214.17	9.27	92.52	528796	585340	528796	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
2	493.81	9	3	235.29	13.75	99.45	498483	730009	498483	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
6	339.18	6	2	242.33	10.63	100.00	325148	1025916	325148	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
27	94.91	12	3	191.05	6.29	100.00	126128	177819	126128	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
19	137.49	12	3	225.23	7.82	100.00	126697	206147	126697	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
1	636.25	9	3	226.24	28.17	100.00	734378	1172945	734378	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
4	404.26	6	2	246.35	10.62	100.00	405272	1221991	405272	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
57	91.01	8	3	191.05	5.25	100.00	91071	133877	91071	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
3	153.54	32	2	222.22	28.92	100.00	309683	928896	309683	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
153	299.93	12	3	200.00	7.64	99.69	312696	451755	312696	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
18	298.21	12	3	302.66	16.61	100.00	96760	151580	96760	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
64	75.78	12	3	300.65	3.90	100.00	32059	42578	32059	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
82	48.97	12	3	213.17	2.99	100.00	23975	29057	23975	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
34	161.37	12	3	256.40	8.22	100.00	53233	83706	53233	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
49	47.44	13	3	185.01	8.07	100.00	65689	96311	65689	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
16	109.66	12	3	225.95	9.35	100.00	157893	245186	157893	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
87	20.57	13	3	142.78	3.48	99.97	29826	38864	29826	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
133	183.50	12	3	53.29	0.00	99.14	19632	23742	19632	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
29	1279.61	12	3	93.51	0.00	99.34	104238	160005	104238	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
5	455.96	12	3	306.68	29.32	100.00	187505	284778	187505	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
13	343.69	12	3	299.64	17.15	100.00	107321	173806	107321	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
67	31.88	12	1	205.12	1.87	99.74	15675	76298	15675	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
38	139.05	12	3	302.66	8.51	100.00	45450	73613	45450	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
66	29.01	12	1	206.13	2.67	99.95	39284	86305	39284	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
24	264.04	12	3	259.42	16.65	100.00	94857	134056	94857	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
71	26.42	12	1	206.13	2.51	100.00	34009	63896	34009	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
88	12.68	12	1	204.12	1.22	100.00	18045	32574	18045	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
83	13.97	12	1	206.13	1.31	99.90	17494	37135	17494	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
45	198.03	8	3	269.48	7.67	100.00	59515	89775	59515	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
21	250.79	12	3	307.69	15.73	100.00	83112	128444	83112	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
9	429.61	12	3	308.69	15.07	99.82	133543	216064	133543	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
50	52.63	12	1	208.14	4.05	100.00	25446	123605	25446	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
160	19.54	6	1	107.59	1.12	100.00	14571	35329	14571	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
169	13.19	4	1	164.90	0.36	91.10	29233	29269	29233	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
72	24.60	12	1	205.12	1.94	96.54	36643	59725	36643	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
8	554.42	9	3	306.68	27.08	100.00	152075	243220	152075	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
91	14.34	12	1	195.07	1.30	99.82	15121	32932	15121	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
81	15.04	12	1	203.11	1.36	99.78	19105	44793	19105	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
15	321.09	12	3	306.68	16.05	100.00	109045	162864	109045	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
55	46.48	12	1	207.13	4.09	100.00	23589	109590	23589	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
70	64.89	12	3	263.44	4.14	100.00	25833	36571	25833	1	MTS	(s, Q) policy	MTS	YES	MTO	NO

Product	Mean demand	Best Before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP proposed 0-1 ILP model	Difference	CODP proposed ranking model	Difference
61	79.96	12	3	253.39	5.99	100.00	38057	43771	38057	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
59	107.85	4	3	270.48	2.36	99.68	86727	97371	86727	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
93	81.20	9	3	255.40	3.91	100.00	28357	39440	28357	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
25	239.90	12	3	295.62	12.13	100.00	84631	122891	84631	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
74	23.24	12	1	202.11	2.00	100.00	13369	56576	13369	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
95	20.87	10	1	170.94	1.82	100.00	17911	50625	17911	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
46	140.61	10	3	243.33	3.37	97.36	62244	73299	62244	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
106	51.47	12	3	93.86	2.95	100.00	22508	26847	22508	1	MTS	(s, Q) policy	MTS	YES	MTO	NO
68	252.51	16	3	62.81	0.00	99.80	21756	31980	21756	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
54	403.94	16	3	68.28	0.00	92.03	46600	50574	46600	1	MTS	(s, Q) policy	MTS	YES	MTS	YES
75	1009.80	10	3	114.95	0.00	31.78	293269	111246	293269	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
51	923.38	13	3	124.34	0.00	39.85	280049	115034	280049	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
199	29.39	6	3	39.21	0.78	100.00	19308	11509	19308	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
100	17.02	13	3	111.61	3.10	99.98	35431	35382	35431	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
146	60.38	10	5	86.47	1.62	99.73	46644	24483	46644	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
32	111.33	10	5	217.03	5.09	100.00	187520	130348	187520	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
171	50.26	7	5	98.54	0.98	100.00	44674	20864	44674	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
37	157.39	4	6	102.56	1.14	74.31	363577	120390	363577	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
30	191.95	4	6	101.56	1.16	88.85	314657	146391	314657	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
26	217.66	4	6	99.55	1.51	83.26	400442	165717	400442	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
141	96.09	10	5	98.54	1.49	94.73	78515	38256	78515	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
161	28.15	9	5	85.78	0.83	99.94	20836	12209	20836	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
140	83.83	9	5	102.55	2.23	100.00	56988	35174	56988	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
155	50.33	9	5	99.07	1.31	98.48	48316	20846	48316	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
134	102.71	11	5	91.50	1.41	92.04	88242	40639	88242	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
156	72.31	5	4	93.51	1.08	99.65	49861	32637	49861	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
176	47.71	5	4	79.44	0.59	87.05	59072	21852	59072	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
175	46.57	5	4	83.46	0.74	98.52	46830	21440	46830	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
164	61.30	5	4	87.48	0.95	99.77	45362	27814	45362	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
178	45.03	5	4	83.46	1.00	100.00	43317	20780	43317	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
110	57.40	5	3	171.33	4.09	99.77	104530	101266	104530	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
123	9.63	13	3	76.97	1.74	99.73	50267	20210	50267	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
139	6.52	13	3	46.35	1.34	100.00	59177	14216	59177	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
115	13.04	13	3	69.52	2.69	100.00	38317	26738	38317	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
143	34.22	5	3	139.05	2.79	99.54	90603	61040	90603	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
118	12.57	13	3	83.65	2.63	100.00	38652	26288	38652	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
180	16.53	6	3	68.37	1.45	99.86	52314	33624	52314	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
126	48.56	5	3	164.90	4.25	100.00	95999	86250	95999	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
151	49.41	10	5	96.53	1.10	92.83	64415	24253	64415	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
99	180.65	5	4	100.55	1.37	94.85	105716	66236	105716	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
157	123.39	5	4	95.52	0.98	98.24	59276	36928	59276	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
144	151.64	5	4	98.54	0.91	83.20	99394	45043	99394	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
209	47.79	12	3	59.59	2.99	100.00	95118	79872	95118	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
211	40.47	10	3	31.29	1.70	100.00	72966	62249	72966	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
96	79.23	6	3	127.70	2.27	97.29	127492	118755	127492	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
89	69.07	6	3	170.94	1.89	92.54	131314	104608	131314	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
112	44.90	5	3	115.46	1.73	100.00	86484	67909	86484	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
31	31.48	24	3	102.20	5.13	99.75	125916	94121	125916	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
198	18.74	5	4	41.23	0.25	99.67	21243	8766	21243	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
193	24.63	5	4	53.29	0.49	100.00	22779	11504	22779	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
149	699.04	2	3	144.79	0.00	35.67	227500	88240	227500	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
168	51.10	4	3	191.05	0.86	93.98	34600	25371	34600	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
23	1463.94	10	3	136.75	0.00	53.47	317643	159362	317643	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
33	323.96	4	3	270.48	1.61	67.54	234534	143774	234534	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
154	93.79	5	3	169.93	0.38	63.68	85730	43285	85730	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
174	9.89	4	1	171.94	0.20	78.73	29452	22826	29452	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
63	538.63	12	3	69.38	0.00	82.76	80935	67829	80935	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
78	86.25	12	3	184.01	1.88	85.80	60147	45592	60147	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
108	44.11	12	3	131.95	2.70	100.00	27941	23944	27941	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
111	47.73	12	3	152.17	1.71	89.44	37839	26079	37839	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
107	40.84	12	3	174.96	1.48	99.97	26576	23181	26576	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
148	30.15	9	3	161.89	1.17	99.49	25124	18446	25124	1	MTS	(s, Q) policy	MTO	NO	MTO	NO

Product	Mean demand	Best Before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP proposed 0-1 ILP model	Difference	CODP proposed ranking model	Difference
92	51.82	13	3	182.00	2.08	94.99	35620	28688	35620	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
183	8.41	4	3	77.42	0.59	99.90	51046	21189	51046	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
184	23.86	7	5	86.47	0.54	97.51	32718	9720	32718	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
125	20.59	10	3	116.64	2.84	99.71	43143	37426	43143	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
158	36.21	10	5	97.53	1.06	100.00	41433	18262	41433	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
128	23.53	10	3	118.65	3.26	100.00	61383	48259	61383	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
102	23.56	13	5	94.15	2.11	99.10	95498	28464	95498	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
150	77.32	8	4	90.06	1.23	99.40	65973	37264	65973	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
129	110.89	8	4	90.06	2.30	99.79	74300	48950	74300	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
137	96.74	8	4	94.81	2.39	100.00	66182	42998	66182	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
195	42.65	5	4	86.47	0.35	94.12	31102	12215	31102	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
204	5.13	4	6	40.22	0.13	98.99	32528	4898	32528	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
192	38.67	4	6	78.21	0.50	81.42	117636	31620	117636	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
159	79.86	4	6	54.30	0.63	83.03	90502	31055	90502	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
163	75.15	4	6	54.30	0.52	76.79	96649	29282	96649	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
207	2.17	4	6	2.01	0.03	99.40	4191	920	4191	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
166	71.72	4	6	55.30	0.55	79.60	88969	28008	88969	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
179	62.85	4	6	52.29	0.49	77.39	83881	24614	83881	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
114	102.15	4	6	101.56	0.75	82.45	217680	78767	217680	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
152	83.97	4	6	96.53	0.62	79.29	198783	64990	198783	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
200	16.63	4	4	94.52	0.32	98.11	33106	8833	33106	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
190	14.87	6	5	97.53	0.34	99.73	18859	7414	18859	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
206	7.12	2	5	51.28	0.03	68.20	30543	3363	30543	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
203	18.03	2	5	67.37	0.17	96.34	38214	8406	38214	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
187	41.15	4	5	99.55	0.75	100.00	39135	17424	39135	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
145	92.07	6	5	102.56	1.58	98.30	68754	36803	68754	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
186	21.88	6	5	95.52	0.52	100.00	19567	10038	19567	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
20	1931.95	12	3	109.60	0.00	65.19	393270	238598	393270	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
43	1037.85	12	3	91.50	0.00	80.24	156824	128767	156824	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
119	120.43	10	5	96.53	1.89	98.12	83646	47455	83646	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
182	29.81	7	5	93.51	0.70	99.29	30392	11598	30392	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
101	59.68	12	4	52.29	1.98	99.97	43610	32868	43610	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
52	104.79	13	3	197.08	2.56	93.30	72571	67743	72571	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
191	27.91	3	4	87.48	0.25	83.30	47994	13531	47994	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
84	63.04	13	3	166.91	2.69	99.26	36119	33914	36119	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
121	45.63	12	4	51.28	1.78	100.00	29078	20456	29078	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
189	27.38	6	6	96.53	0.52	100.00	35485	12062	35485	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
90	48.83	13	3	188.03	2.63	100.00	30960	27336	30960	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
197	13.73	4	4	81.45	0.21	93.59	28936	6619	28936	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
185	32.69	6	6	97.53	0.55	99.60	33500	14078	33500	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
113	65.23	12	4	51.28	1.83	100.00	37403	28841	37403	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
73	85.30	13	3	171.94	1.84	85.32	60245	44910	60245	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
104	93.18	4	4	71.39	0.79	88.17	80350	36179	80350	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
130	46.03	7	4	78.43	1.24	100.00	29716	21118	29716	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
65	87.39	7	4	79.44	3.53	100.00	63028	42571	63028	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
11	307.63	7	4	96.53	7.53	100.00	160455	133374	160455	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
135	46.07	8	4	75.41	1.17	100.00	38816	21080	38816	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
56	115.74	7	4	91.50	2.35	99.69	81239	55143	81239	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
117	63.23	10	3	179.99	1.29	92.92	37862	30371	37862	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
76	74.27	13	3	169.93	2.46	96.16	42982	39468	42982	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
79	67.07	13	3	183.00	2.46	97.27	39295	36177	39295	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
205	3.38	13	15	16.09	0.28	99.96	23972	1565	23972	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
47	420.44	6	3	206.13	0.00	48.34	344921	158218	344921	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
170	116.42	6	3	118.65	0.21	52.61	101436	44928	101436	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
10	458.37	4	4	102.56	0.00	38.00	746420	173459	746420	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
77	70.22	10	3	114.63	1.65	83.34	47721	32179	47721	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
97	43.10	9	3	190.04	1.97	96.47	58035	43041	58035	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
167	13.26	7	4	98.54	0.49	100.00	16024	8027	16024	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
138	7.02	12	3	131.72	0.52	98.99	18459	6519	18459	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
202	8.38	3	4	89.49	0.13	98.99	24942	5207	24942	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
85	62.65	13	3	165.91	2.06	93.04	41514	33703	41514	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
194	24.13	6	6	92.51	0.31	90.66	39867	10767	39867	1	MTS	(s, Q) policy	MTO	NO	MTO	NO

Product	Mean demand	Best Before date	Order lead time	Number of order per year	Avg. number of pallets on hand	Service Level	MTScost	MTOcost	minTCi	Xi	CODP	Policy	CODP proposed 0-1 ILP model	Difference	CODP proposed ranking model	Difference
98	40.19	13	3	174.96	2.13	98.40	29221	22862	29221	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
188	17.15	4	4	98.54	0.32	99.19	27002	8209	27002	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
177	6.29	4	1	158.87	0.24	98.99	21505	20056	21505	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
44	215.66	4	4	108.60	0.39	60.47	270941	82706	270941	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
28	229.94	3	4	104.57	0.37	59.85	330982	100279	330982	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
201	11.62	3	4	95.52	0.23	100.00	25046	6703	25046	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
122	20.85	12	3	98.54	1.31	100.00	13673	10980	13673	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
162	38.60	5	3	164.90	0.72	95.32	54622	36082	54622	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
127	48.00	10	3	184.01	1.57	100.00	27795	23915	27795	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
103	28.88	12	3	195.07	2.11	100.00	21622	17689	21622	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
69	93.39	13	3	187.02	2.35	91.98	55544	49147	55544	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
86	59.16	13	3	190.04	2.18	94.67	38712	32429	38712	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
165	5.88	10	3	4.02	0.42	100.00	15581	5829	15581	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
35	662.03	16	3	70.39	0.00	42.31	196076	82357	196076	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
124	14.94	10	3	103.57	2.34	99.82	55427	31160	55427	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
131	92.66	10	3	126.69	0.66	69.41	86378	47693	86378	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
60	884.00	4	3	163.88	0.00	67.77	199878	124978	199878	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
116	27.54	12	3	158.87	1.64	95.36	26170	16377	26170	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
62	380.51	10	3	112.31	0.00	87.31	89335	83368	89335	1	MTS	(s, Q) policy	MTO	NO	MTS	YES
105	107.10	4	4	90.38	1.19	97.77	70013	41625	70013	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
80	23.16	13	3	126.69	4.08	99.27	88327	47683	88327	1	MTS	(s, Q) policy	MTO	NO	MTO	NO
173	101.42	13	3	169.46	3.33	84.13	133040	170294	170294	0	MTO	L4L policy	MTS	NO	MTO	YES
196	91.77	13	3	130.36	3.33	84.13	139081	153680	153680	0	MTO	L4L policy	MTS	NO	MTO	YES
181	100.10	13	3	149.91	5.40	84.13	144846	167775	167775	0	MTO	L4L policy	MTS	NO	MTO	YES
132	44.88	13	3	76.42	6.13	84.13	70368	96198	96198	0	MTO	L4L policy	MTS	NO	MTO	YES
218	2.15	13	30	2.01	0.17	100.00	2594	1658	1658	0	MTO	L4L policy	MTO	YES	MTO	YES
224	125.83	13	30	7.04	6.02	100.00	152909	94868	94868	0	MTO	L4L policy	MTO	YES	MTO	YES
216	1.62	13	30	2.01	0.10	100.00	48206	1253	1253	0	MTO	L4L policy	MTO	YES	MTO	YES
223	20.19	13	30	1.01	1.37	100.00	66529	15222	15222	0	MTO	L4L policy	MTO	YES	MTO	YES
219	10.51	19	30	3.02	1.31	100.00	48858	7970	7970	0	MTO	L4L policy	MTO	YES	MTO	YES
208	7.90	13	15	58.66	1.54	100.00	37219	6598	6598	0	MTO	L4L policy	MTO	YES	MTO	YES
120	10.86	13	3	56.31	1.98	84.13	44144	22294	22294	0	MTO	L4L policy	MTO	YES	MTO	YES
210	7.10	13	15	44.69	1.30	100.00	59659	8802	8802	0	MTO	L4L policy	MTO	YES	MTO	YES
136	5.59	13	3	52.14	1.02	84.13	58465	11867	11867	0	MTO	L4L policy	MTO	YES	MTO	YES
214	1.64	29	30	2.01	0.37	100.00	3537	2508	2508	0	MTO	L4L policy	MTO	YES	MTO	YES
215	9.23	29	30	3.02	2.01	100.00	54232	13955	13955	0	MTO	L4L policy	MTO	YES	MTO	YES
213	6.15	29	30	3.02	1.32	100.00	67002	9322	9322	0	MTO	L4L policy	MTO	YES	MTO	YES
212	0.82	29	30	2.01	0.18	100.00	6496	1272	1272	0	MTO	L4L policy	MTO	YES	MTO	YES
221	6.26	13	30	1.01	0.41	100.00	61717	7088	7088	0	MTO	L4L policy	MTO	YES	MTO	YES
220	3.95	13	30	1.01	0.29	100.00	4216	2991	2991	0	MTO	L4L policy	MTO	YES	MTO	YES
217	205.33	13	30	52.14	5.06	100.00	184219	155122	155122	0	MTO	L4L policy	MTO	YES	MTO	YES
222	34.82	12	30	18.10	2.03	100.00	116748	39654	39654	0	MTO	L4L policy	MTO	YES	MTO	YES
147	9.20	12	3	73.00	0.56	84.13	19191	6381	6381	0	MTO	L4L policy	MTO	YES	MTO	YES
172	9.52	12	3	1.01	0.57	84.13	19963	4680	4680	0	MTO	L4L policy	MTO	YES	MTO	YES