DEMAND PLANNING OPTIMIZATION AT POULTRY INDUSTRY

GÜLSÜM ÖZER

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Approval of the Graduate School of Natural and Applied Sciences

____

(Prof. Dr. Abbas Kenan Çiftçi)

Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

____

(Assoc. Prof. Dr. Selin Özpeynirci)

Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

____

Asst. Prof. Dr. Kamil Erkan Kabak

Supervisor

____

Asst. Prof. Dr. Mahmut Ali Gökçe

Co-Supervisor

Examining Committee Members Date: 15.05.2018

Asst. Prof. Dr. Kamil Erkan Kabak	__________
Asst. Prof. Dr. Mahmut Ali Gökçe	__________
Prof. Dr. Sermet Anagün	__________
Assoc. Prof. Dr. Selin Özpeynirci	__________
Asst. Prof. Dr. Erdinç Öner	__________

ABSTRACT

DEMAND PLANNING OPTIMIZATION AT POULTRY INDUSTRY

ÖZER, Gülsüm

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Poultry industry has a dynamic production environment and fierce competition. Proficiency at fulfilling the demand and customer satisfaction are the main factors in being at forefront at the market and strategically at the right position. Poultry industry provides an interesting and challenging production problem mainly because it is on disassembly (rather than assembly), the raw material is live and final products have short shelf-lives.

Poultry industry has a rather long breeding period. Livestock from breeding comes in different weight distributions. A carefully designed planning cycle that needs to be well synchronized is needed to ensure that the cuts are taken in the most appropriate process alternatives according to demand.

This study proposes two mathematical models that aim to maximize profits could be applied for demand planning in poultry industry. The proposed models take into account the daily available livestock distribution, demand, customer priorities / constraints and finally production constraints. The models are tested with real data derived from one of the largest poultry producers of Turkey. The results are further discussed under different demand scenarios.

Keywords: disassembly production, mathematical modeling, demand planning, poultry

ÖZ

BİR TAVUK ETİ ENTEGRE TESİSİNDE SİPARİŞ PLANLAMA OPTİMİZASYONU PROBLEMİ

ÖZER, Gülsüm

Endüstri Mühendisliği Yüksek Lisans Programı

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Piliç eti endüstrisi dinamik bir üretim ortamına ve yoğun rekabete sahiptir. Müşteri siparişlerini karşılama becerisi ile müşteri memnuniyeti piliç eti pazarında öne çıkmada ve stratejik olarak doğru pozisyonda bulunmada başlıca faktörlerdir. Piliç eti endüstrisi ayrışma (birleştirmeden ziyade) üzerine olduğundan, hammaddenin canlı olmasından ve son ürünlerin kısa raf ömürlerine sahip olmasından dolayı ilginç ve zor bir üretim problemi sunmaktadır.

Piliç eti üretimi uzun bir yetiştirme dönemine sahiptir. Yetiştirmeden canlılar farklı ağırlık dağılımlarıyla gelmektedir. Taleplere göre en uygun süreç alternatiflerinde kesimlerin yapılmasını sağlamak için iyi senkronize edilmesi gereken dikkatlice dizayn edilmiş bir planlama döngüsüne ihtiyaç vardır.

Bu çalışma piliç eti endüstrisinde talep planlamasında uygulanabilecek kar ençoklamasını amaçlayan iki matematiksel model önermektedir. Önerilen modeller günlük mevcut hayvan dağılımını, talepleri, müşteri önceliklerini/kısıtlarını ve son olarak üretim kısıtlarını dikkate almaktadır. Bu modeller, Türkiye’nin en büyük piliç eti üreticilerinden birinden alınan gerçek verilerle test edilmiştir. Sonuçlar daha sonra farklı talep senaryoları ile tartışılmıştır.

Anahtar Kelimeler: demontaj, matematiksel modelleme, talep planlama, piliç eti

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Introduction

1.1 Research Motivation

The terms poultry farming or poultry industry are used to define meat obtained by raising poultry and generally regarded as in the agro-industrial sector (Ribeiro et al., 2018; p.1). In the world, 54 % of the poultry production is by the countries like Brazil, China, and the USA. To illustrate the production rates, the chicken meat was produced as 13.146 million tons in Brazil in 2015. This rate is together with an increase of 450,000 tons compared to the amount produced in 2014 (ABPA, 2016; p.11). With regard to China and the USA, chicken meat was produced as 13.025 and 17.966 million tons, respectively (ABPA, 2016; p.41). In addition, the consumption of chicken meat in 2016 was estimated as 43.25 kg per capita, and there is an increase of 1.1% according to the consumption in 2015, and an increase of 17.96% according to the consumption in the previous decade (ABPA, 2016; p.13).

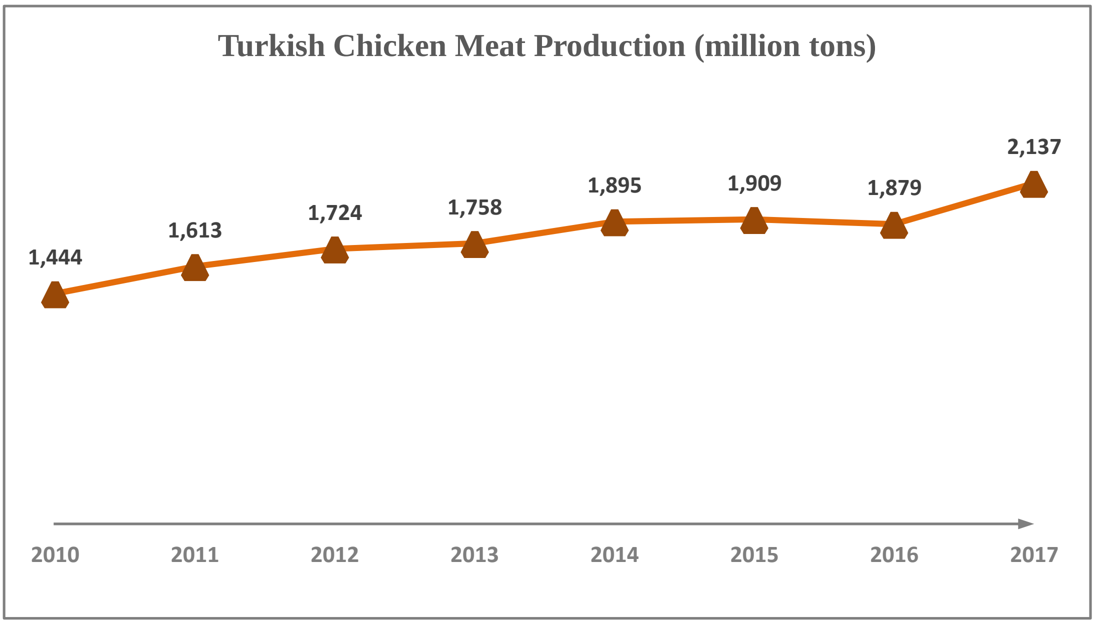


Figure 1: Turkish chicken meat production from 2010 to 2017 (million tons)

As in Turkey, Turkish poultry meat industry is the world's 8th largest poultry industry and grown up around 49%. That is, an increase of production from 1.44 million tons' poultry meat in 2010 to 2.14 million tons in year 2017 according to Turkish Statistical Institute (TUIK) (see Figure 1). Also, a significant increase of poultry products such as hen eggs, slaughtered chicken, chicken meat, slaughtered turkey and turkey meat is reported in comparison to previous year in 2017 (TUIK, 2017).

Poultry meat has advantages such as being low cost and broadly obtainable. Also, preparation of it is not slow and simple. According to its nutritional content, it has higher protein levels (22-24 percent) than red meat has (Prabarakan, 2003; p.7). Therefore, the demand of poultry meat is increased every year (see ABPA, 2016; TUIK, 2017). Parallel to this increasing demand, there is also increasing competition in the industry. In this challenging environment, customers place great emphasis on order fulfillment. For this reason, poultry companies also have to improve their services while paying great attention to their cost policy.

Poultry meat production is a lengthy process. The preparation of a final product takes approximately 2 months, starting from hatching of a chick to processing of the carcass for final product and delivering it to a customer for consumption (Minegushi, 2000). Thus, companies have to manage supply chain operations attentively to minimize possible risks along the way. As a result, planning has a vital role to synchronize all processes.

Managing poultry meat production is challenging due to number of reasons relating to the nature of production and industry. Main reasons are:

1. Short shelf life of the product

Quality standards dictate that fresh chicken meat should be dispatched in two days. Otherwise the meat should be frozen and stored in a special atmosphere controlled. As freezing and storage is an extra cost (less profitable), the planner is to sustain the balance between two (Minegushi, 2000).

2. Volatility of demand and long production process

Demand volatility based on product group is one of the main challenging factors while dealing with the fresh meat (Satır, 2003). Companies have to estimate demand as accurately as possible, because the earliest possible reaction to any new action comes almost after two months. If produced batch is more than the demand, companies have to deal with a great deal of inventory costs, while bearing the product's decreased value (as frozen product is less desirable) (Satır, 2003; p.16). If not, companies would have to backorder, causing the customer to have dissatisfaction that may result in decreased loyalty and search for alternative suppliers.

3. Disassembly production

Poultry meat production process is significantly different from a classical production. Classical production would usually put together parts to form up the final product. Poultry products are obtained by cutting up (disassembling) a whole chicken (Satır, 2003; p.17). When the chickens arrive at the slaughterhouse, they are received according to the disassembling plan to meet the demand of parts (wings, legs, breast etc.). If the one group of product order is high, it is not possible to produce in a very large quantities because, there are two wings, two legs and a breast in every single whole chicken. Poultry planner has to sustain a product balance.

4. Seasonality

There is strong seasonality for poultry meat (see TUIK, 2017). Demand varies according to the official holidays of the country and weather condition. For instance, demand for chicken meat decrease on the Muslim Sacrifice Holiday in Turkey. However, seasonality can be affected by unpredictable causes like the false bird flu news or country's economic situation.

5. Keen competition in the market

Poultry meat industry has a few but big players in the market place. In this challenging nature, companies should always have an eye on customer satisfaction while managing their profits.

6. Product Variability

More than 260 different products can be produced when a whole chicken is cut up (Satır, 2003). Different customers can order various products in a variety of specs. As the raw material has a relatively short shelf life, a delicate and flexible production is crucial.

In addition to above challenges, Boonmee and Sethanan (2016) emphasize that poultry industry has varying, heterogeneous and restricted capacities for the facilities such as pullet houses, hatcheries and slaughter houses. Therefore, imbalances among the capacities of these facilities result in partial allocation of demands. Such difficulties also lead to increase in production costs. This is the reason that chick ordering is crucial for the short-term planning (Boonmee and Sethanan, 2016; p.1-2)

This study is conducted in the production company which is one of the leading poultry company in Turkey which has a capacity of processing approximately 330.000 chickens/day on its continuous production lines. The company also has a “further processing line”, where it produces further process products like nuggets, sausages, kebab and marinated chicken meat.

The main contribution of this thesis is solving a real life production planning problem of one of the largest poultry producers in Turkey. The proposed mathematical models that represent this real life planning problem and demonstrate its contributions with results from experimentation using real life data. Accordingly, this section is organized as follows. Section 1.1 presents the process flow of poultry meat production, this is followed by description of product information in Section 1.2. After, Section 1.3 explains the problem definition of this study. Section 1.4 summarizes the outline of next chapters briefly.

1.2 Process Flow of Poultry Meat Production

The company provides broiler breeder chicks from suppliers. Chicks that are bred at chicken breeding farm, produce chicken eggs. Daily produced eggs are dispatched to hatcheries. Chicks that are hatched after incubation period (approximately 21 days) are sent to producing coops (see Figure 2). A normal industrial chicken to be used as a poultry meat is raised between 36 and 45 days (Broiler Guide, 2015). During complete duration of raising period, chickens are categorized according to their Average Body Weight (ABW) (Broiler Guide, 2015). ABW shows a tendency to change based on chickens’ age, conditions of coop and the quality of veterinary services. But there is enough reliable statistical data that allows for prediction of ABW distribution of a coop based on past data already in the system.

Chickens in coops are counted and weighed every day. With this information, planner decides on which coop to harvest on a daily basis. A planner determines the pickup day and hour from each coop, considering the weight and the travel time from coop to the slaughterhouse. The slaughterhouse is the main focus of this study (see Figure 2).

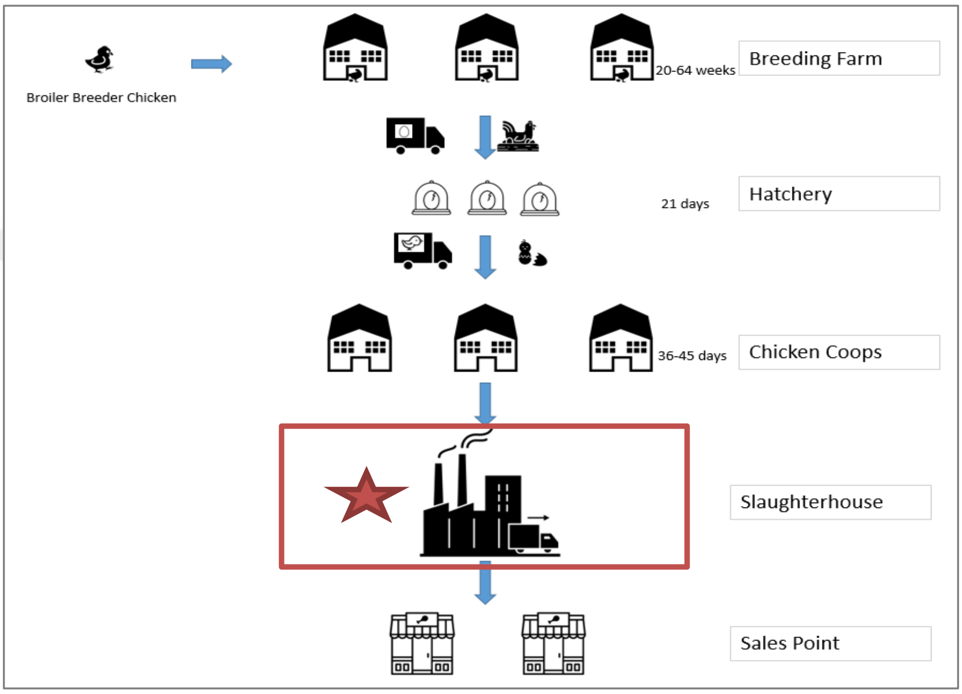


Figure 2: Process flow of poultry meat production.

When a coop arrives to the slaughterhouse, chickens are first hanged to vertical conveyor and go through a number of pre-preparing processes; like stunning, slaughter, scalding, defeathering, head remover, vent opener, eviscenator, giblet harvest, viscera removal, neck breaker. After the pre-preparation, giblets and carcass (usable meat) are washed, chilled, cut up and packed, after which, saleable meat is produced (Dixit, 2016). If packed products are for export or excess of production (cannot be sold fresh), they are sent to freezing line (see Figure 3).

The cutting process is the principle of this study. In the cutting process, there are 2 lines, named whole chicken and cut up line. Products are either packed as whole chickens or cut up according to received demand to be satisfied demand.

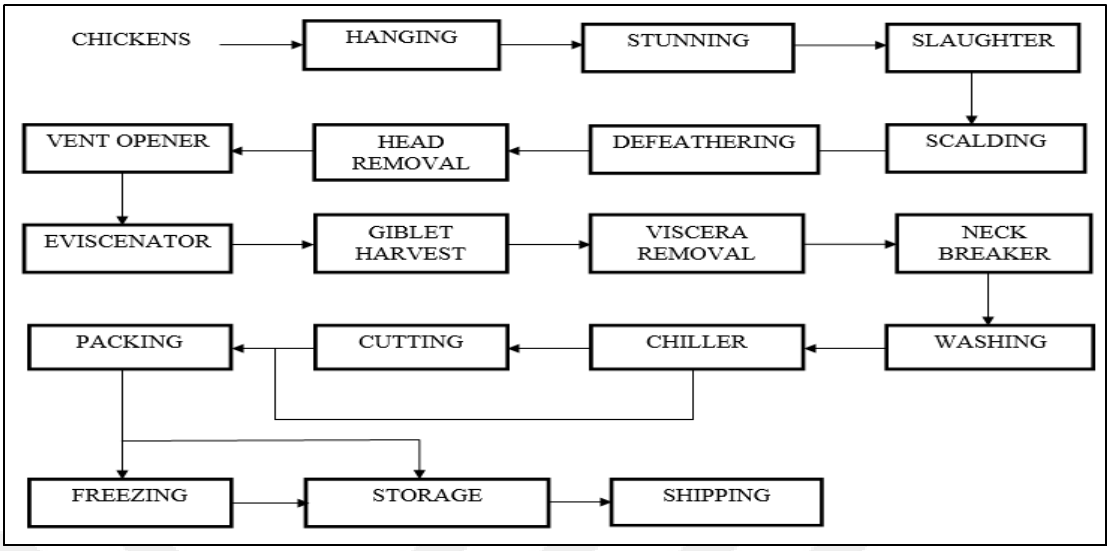


Figure 3: Process flow of slaughterhouse.

1.3 Product Information

When an industrial chicken is processed, two types of product can be acquired: whole chicken and chicken parts. When talking about production, one would think of putting parts together (assemble) according to a BOM to obtain a final product. However, industrial chicken meat production is prepared by cutting up (disassembling) a whole chicken (Satır, 2003; p. 17). Products can be grouped as follows:

1. Whole Chicken

2. Legs, Breast, Wings (Chicken parts)

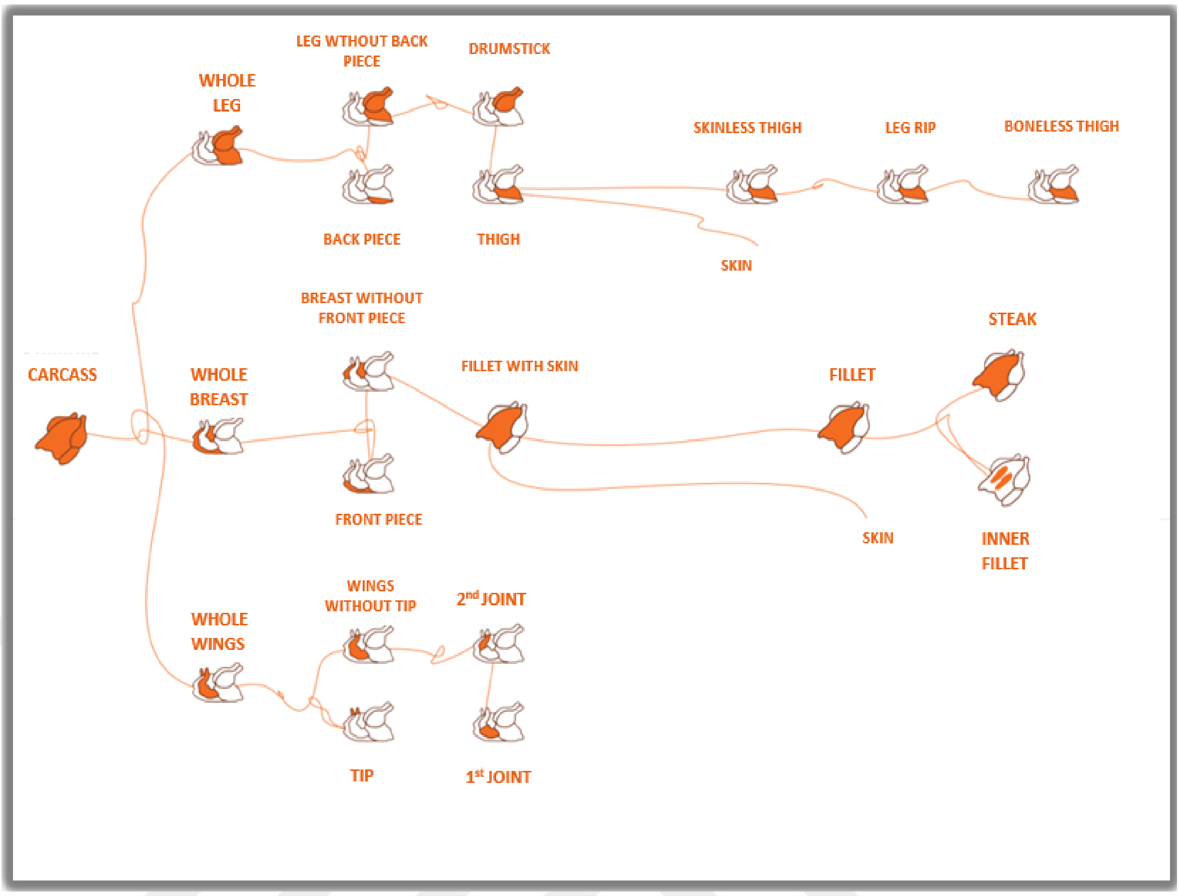


Figure 4: Product tree.

Figure 4 shows the branching of products obtained from a carcass. Accordingly, 260 different products could emerged. This diversification is based on the features below:

1 Packaging:

The products can be packed in three different containers (nylon bag, tray, and crate).

2 Shelf Life:

Fresh products' shelf life is 9 days, while frozen ones' are up to one year.

3 Weight:

The products can be sold in different weight such as 300 grams fillet or 330 grams fillets in a crate.

1.4 Problem Definition

This section defines the thesis problem according to product and process description given in previous Sections 1.1 and 1.2. Accordingly, the demand planning problem statement of thesis is defined.

Thus, the main objective of this thesis is to maximize planning profits by fulfilling customer demand and developing mathematical programming models. Also, it aims to assist in having a systematic demand planning process.

With regard to fulfilling customer demand, there are 2.5 hours between the deadline for daily demand and finalizing the planning process, though currently it takes 4-6 hours for a planner to do the daily planning. As expected, in such brief period, more than 260 products are to be sorted out according to their profitabilities. Approximately 1500 separate demands per day arrive. For these reasons, meeting all customer demands are challenging and it affects profitability of the company.

With regard to planning profits, the current planning process depends on the personal experience of the planner, and no systematic planning process exists within the organization. Therefore, excess operational costs (inventory costs, low utility, overtime etc.) originating are not monitored. Also, profits of products are not considered when deciding which demand is to be met during the planning. This is the reason that the objective of the planning process targets the profit maximization in this study.

Further, actual planning process requires to determine which demands to meet for maximizing profits by considering customer priority, product balance and capacity constraints. Together with these constraints, the demand planning gets a more difficult problem and complex.

Thus, the company needs a planning method which helps the planner to choose the most profitable, effective and reconfigurable planning alternative for such environment. Next section presents the outline of this study.

1.5 Thesis Outline

The remaining part of the thesis is organized as follows:

Chapter 2 presents the literature review of the topic.

Chapter 3 describes the stages of production planning in poultry industry and explains the flow of information in the company of interest.

Chapter 4 presents types of data collected for this study and analyses of them to describe the demand planning environment and to present its characteristics. The collected data is further used as input for the mathematical models given in Chapter 5.

Chapter 5 describes the methodology used in the design of the experiments and introduces mathematical model for demand planning optimization.

Chapter 6 calculates input data of the proposed model by using real life data and presents the experimental results. Then, it extends the output analysis.

Chapter 7 summarizes the main conclusions of this thesis and presents an outlook for future work.

Chapter 2

Literature Review

2.1 Introduction

This section reviews the relevant literature for poultry industry in Section 2.2. Then, the survey of the literature is summarized in a table (see Table 1), and then it is discussed in Section 2.3.

2.2 Literature Research

Poultry meat has advantages such as being low cost and broadly obtainable. Therefore, the demand of poultry meat are increasing every year (see ABPA, 2016; TUIK, 2017). This is the reason that there are many studies in relation to poultry meat industry. When the word "poultry" is searched on Web of Knowledge (WOS) database, approximately 39000 items appear, however, the most of these studies is related to the subject on the live chicken such as "avian influence effect", "bioenergy life cycle", "alarm due to antimicrobial resistance".

The subject of this thesis is the optimization of demand planning at a poultry industry. Therefore, the relevant literature is surveyed with the following keywords: disassembly, poultry planning, demand planning and poultry processing. Accordingly, this literature research surveys first the disassembly studies, then summarizes the main studies among the few available in the poultry production literature.

With regard to disassembly, a review of disassembly scheduling literature is presented by Kim et al. (2007). In this study, disassembly scheduling is defined as follows.

"The problem of determining the quantity and timing of disassembling end-of-use/life products and their subassemblies in order to satisfy the demand of their parts or components." (Kim et al., 2007; p. 4466).Disassembly scheduling is regarded as the reversed version of assembly lot-sizing problem, and main difference of disassembly scheduling is defined by the properties of the convergence and divergence (Kim et al., 2007; p. 4466). In other words, a single demand source of finished product is to be converged by the parts or components in the assembly system, however, multiple demand sources of parts or components are to be diverged by the products in the disassembly system (Kim et al., 2007; p. 4466). In addition, they present an integer programming (IP) formulation as well as the discussion of effects of divergent property, and problem extensions such as capacitated problems, capacitated problems with setup time, problems with storage capacity, problems with product returns, problems with backlogging, and integration with other decision problems (Kim et al., 2007).

To illustrate studies in the disassembly scheduling, Gasimov (2006) presents a capacitated disassembly scheduling problem is formulated by a mixed-integer linear programming (MIP) model (Gasimov, 2006; p. 19-21). He points out that disassembling of EOL (or root) items is required to have sell or re-usable items. Each item that is not a root item can be used during the remanufacturing process together with having, if necessary, excess parts either in the inventory or at the dispose (Gasimov, 2006; p.18).

Similarly, Kang and Hong (2012) develop a MIP model for dynamic disassembly planning to obtain an optimum disassembly plan for the parts at different levels. In this study, they consider the disassembly of returned products, specifically end-of-line products, in order to remanufacture them efficiently (Kang, 2012; p. 6236). Their study assumes deterministic demand and flows in the remanufacturing, and they show a case study on the remanufacturing of a printer fuser assembly for numerical representation (Kang, 2012; p. 6242).

In a recent study, Ji et al. (2016) present a MIP model with Lagrangian heuristic for the capacitated disassembly scheduling with parts commonality and start up costs, and also sensitivity analyses on these properties. In this study, a study by Lu and Qi (2011), discussed next paragraphs, is referred to as an example of successful application of disassembly scheduling on the poultry slaughtering scheduling (Ji et al., 2016; p. 1).

With regard to the mathematical models defined in the literature of poultry industry, Gokce et al. (2010) propose a MIP model that aims to find optimal cutting plan and minimize remnant amount by determining necessary number of chickens with weight specifications for daily demand at Keskinoglu Company, which is one of the biggest poultry company in Turkey. The distribution of chicken weights over long run is evaluated in this study, and this distribution is applied to decide the total number of chickens for a particular chicken type based on 50 grams intervals (Gokce et al., 2010; p. 233). In addition, all cutting scenarios with regard to the product groups (or chicken parts) are specified. This follows the conversion of weights by considering the rates of product groups (Gokce et al., 2010).

As highlighted by Ji et al. (2016), Lu and Qi (2011) present a dynamic lot sizing problem with multiple products. They highlight that their problem is a different version of disassembly scheduling with regard to having a single-level sub product disassembly structure (Lu and Qi, 2011; p.75). This property of the problem is explained by a joint replenishment of all products when a production order is placed, in which output products has a fixed ratio. In this regard, the problem is defined as producing a virtual ‘‘composite’’ product and decomposing it into the other products using the fixed ratio (Lu and Qi, 2011; p.74). Therefore, the problem is similar to single product dynamic lot sizing model (Lu and Qi, 2011; p.75). This is also a reason that proposed algorithms works efficiently. In this study, Lu and Qi (2011) define mathematical formulations of the two versions of this problem according to lost sales. In former version called Problem P allows the lost sales, and the latter version is the problem without lost sales (Lu and Qi, 2011).

Boonmee and Sethanan (2016) consider a MIP model for the production planning of hen egg. In this study, problem is defined as a multi-level capacitated lot-sizing and scheduling problem. Also, they point out that the problem could be a general lot-sizing and scheduling problem (GLSP) since it solves lot-sizing and scheduling concurrently (Boonmee and Sethanan, 2016; p. 653). In the model, they formulate the hen egg production with the objective of the minimization of the total cost. They apply the mathematical model to solve for small-size problems. However, they use a particle swarm optimization (PSO) and its variants such as PSO combined with gbest, lbest and nbest social structures, which are called GLNPSO, for large-size problems (Boonmee and Sethanan, 2016; p. 654). They report that GLNPSO is better than PSO for the total costs as well as the increasing the efficiency of managing the poultry production (Boonmee and Sethanan, 2016.).

Apart from above studies, there are some other studies in the literature that consider poultry production together with financial planning, integrated production planning, simulation modelling of poultry supply chain as well as reversed supply chain and shelf life of the products.

Satır (2003) uses mathematical modelling techniques in order to propose a production and financial model for integrated poultry organizations. The business issues like buying breeder, chick entrances to coops, etc are managed by this general production and financial plan with a set of decisions (Satır, 2003; p. 3). At peak time, that demand for poultry market (total of all multiple products) gets more than twice of the demand for produced meat (Satır, 2003; p.16). In order to prevent unsold parts of the chicken carcass, the supply of excess demand is not possible. It is possible to cover the demands by providing under acceptable limits in poultry industry. For instance, an acceptable demand range for 100 kg meat of customer demand is between 90 and 110 kg (Satır, 2003; p. 42). The aspect of purchases of customers in the acceptable limits is reflected within the constraints of mathematical model (Satır, 2003). The aim of the model is to have requirements like effective chicks and breeder plans for production planning (Satır, 2003).

Taube-Netto (1996) present the chicken production extensively and discuss an integrated planning environment for the poultry industry called PIPA (Portuguese acronym for Integrated Planning for Poultry Production) at Sadia that is referred to as the biggest poultry producer in Brazil. The integrated system has three levels as strategically, tactical and operational levels and these levels encapsulate different modules (Taube-Netto, 1996). In this study, they identify main advantages the PIPA system are improved feed conversion, increased value of product, quick reaction to market variations, and sensitivity on market opportunities (Taube-Netto, 1996).

Minegishi and Thiel (2000) show a system dynamic simulation modelling of poultry supply chain. Such an analysis is particularly crucial for the logistic control of these types of agro-food supply chains. To define the simulation model, they present the dynamics of a fresh food supply chain that is structured based on qualitative research such as interviews and questionnaires with 17 companies. For this reason, they regard their model is a representative for many small- and medium-sized firm in the poultry industry (Minegishi and Thiel, 2000; p.324). Simulation results with respect to the dioxin infection effect on the supply chain show that adaptation of the MPS to real orders, variations in the ratios between whole chicken and carved chicken orders, variations in the stock levels of whole slaughtered chicken, adaptation to real orders due to subsidiary activities and variations in the inventory levels of carved products (Minegishi and Thiel, 2000).

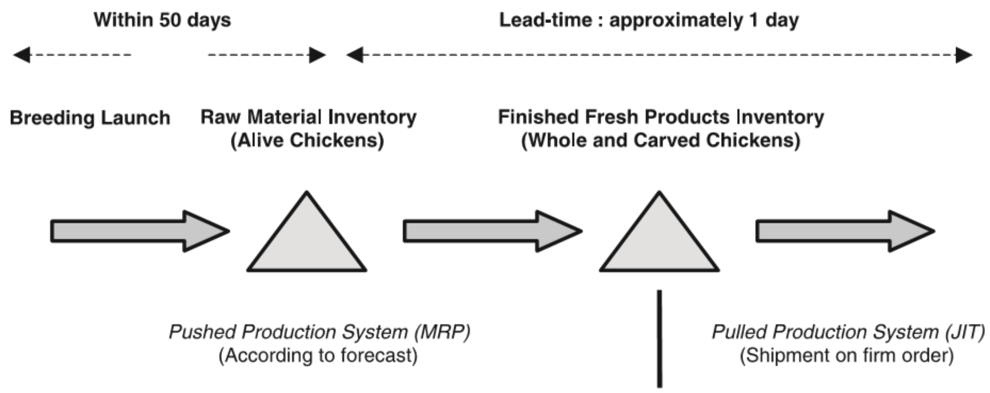


Figure 5: The principle of the poultry supply chain.

Shamsuddoha (2011) develops a reverse supply chain process model for the Bangladesh poultry industry. He point out that due to the perishability property of chicken products, there is no possibility to reuse or retrieve such products. However, he states that this situation is not the case for the wastes of them fuel so that that can be used for fertilizer, bio gas, charcoal and fish feed (Shamsuddoha, 2011; p.8)

Bruckner et al. (2013) present a tool called common predictive shelf life model with statistical analyses to determine the optimum shelf life. They state that such predictive information could be useful for decision making such as the FIFO concept (First-In First-Out) or the LSFO concept (Least Shelf life, First Out) storage management policies (Bruckner et al., 2013).

In his book, Entrup (2005) implements a shelf life dependent revenue component for the shelf life of the poultry products to maximize total profit. The objective function takes revenues from selling fresh and frozen product, and product cost into account. Two types of cutting method are described. These methods are rough cutting which is defined as cutting up whole carcass into its major component, and fine cutting which includes an extra step in processing (Entrup, 2005; p. 202). His study focuses on the fine cutting products due to the existence of sensitive microbial spoilage with the parameters of actual demands, forecasted demand, set up cost and available capacity in his model. Thus, the problem is defined as a cutting stock problem with the purpose of minimizing the scrap (Entrup, 2005).

2.3 Discussion on the Literature Research

According to aforementioned studies above, there is little research in poultry industry with regard to analysis of its effectiveness through its supply network, demand planning or production planning. Table 1 summarizes the literature for the poultry industry in the following.

Accordingly, there are four studies which are closely related with the subject of this thesis. These relevant studies are by Gokce et. al. (2010), Lu and Qi (2011), Boonmee and Sethanan (2016) and Satır (2003). The problem approach and some parts of the study by Gokce et. al. (2010) are used in the thesis. The rest of the selected studies approach are used partially.

While the disassembly planning literature covers various cases of optimal disassembly plans (Kim et al., 2017), there are only a few studies that focus on the problem, defined as a special version of disassembly scheduling (see Lu and Qi, 2011), in this thesis. The subject of this thesis is to increase effectiveness of disassembly based poultry production planning. With this purpose, this study fills a gap in poultry related literature (see Table 1).

Table 1 Summary table for the poultry industry literature.

Author	Objective	Methodology	Analysis
Gokce et al. (2010)	Minimize amount of remnant for product by satisfying weighted demand fully	MIP	Number of chickens with weight specifications for the optimal cutting plan
Lu and Qi (2011)	Minimize total cost for dynamic lot sizing problem with multiple products	MIP	Relative loss in profit, average demand fill rates for expensive and cheap products
Boonmee and Sethanan (2016)	Minimize total cost for multi-level capacitated lot-sizing and scheduling problem	MIP	Total cost and performance results by the comparison of traditional PSO and GLNPSO for 12 problem instances
Satır (2003)	Minimize annual inventory level	Mathematical Model	Effective chicks and breeder plans
Taube-Netto (1996)	Increase efficiencies by integrated production planning system	PIPA system	Feed-to-live weight conversion improvement and discussion of integrated production planning
Minegishi and Thiel (2000)	Analyze the Effects of dioxin infection in poultry supply chain	Systems Dynamics	Adaptation of the MPS to real orders, variations in the ratios between whole chicken and carved chicken orders, variations in the stock levels, adaptation to real orders due to subsidiary activities and variations in the inventory levels of carved products
Shamsuddoha (2011)	Analyze social, economic and environmental issues in poultry industry	Reverse supply chain process model	Evaluations on reverse supply chain process model
Bruckner et al. (2013)	To determine optimum shelf life	Common predictive shelf life mode	Results for the observed and predicted shelf lives for fresh pork and fresh poultry at different non-isothermal temperature scenarios
Entrup (2005)	The total profit by considering revenues and variable costs with analyzing shelf life integration in Poultry Processing	Mathematical Model	The total revenue for the considered planning period comprises the revenue from selling fresh and frozen products as well as the shelf life dependent revenue component

Chapter 3

Poultry Production Planning

3.1 Introduction

In this chapter, Section 3.2 describes the stages of production planning in poultry industry, these stages are strategical, tactical and operational. Then, Section 3.3 explains the flow of information in the company of interest. Finally, this chapter is ended with the concluding remarks in Section 3.4.

3.2 The Stages of Production Planning in Poultry Industry

In the chicken meat industry, production planning is performed by three stages. These stages are: strategic, tactical and operational planning (Boonmee et al., 2016). Figure 6 shows these stages in the following. It is noted that Figure 6 is adapted by the study of Boonmee et al. (2016) according to the planning process of the company of interest. Similar to other industries, strategic planning is a long term planning. This stage consists of three actions. Long term demand forecasting, resource planning and marketing strategy, respectively (Boonmee et al., 2016).

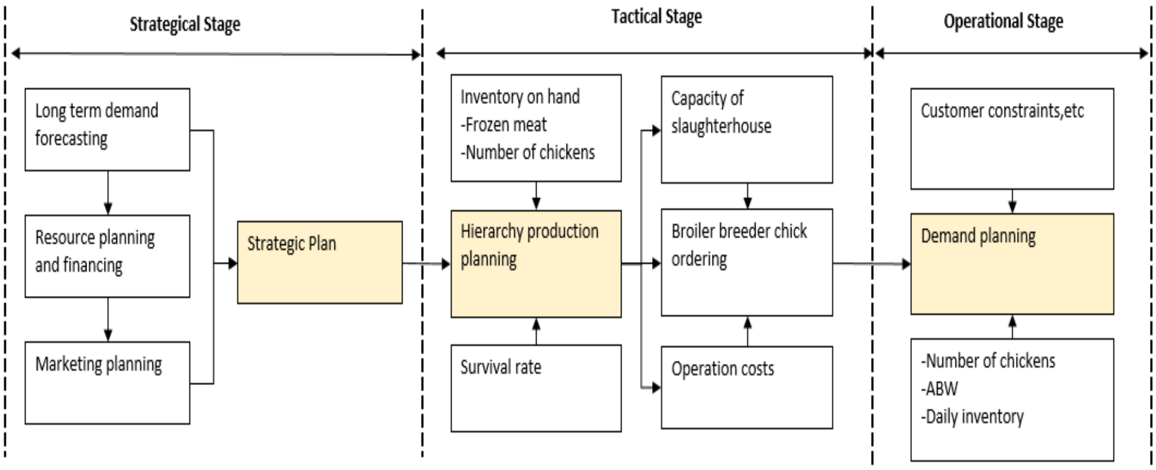


Figure 6: Production planning stages.

With regard to the strategic planning, companies aim to fulfill their missions. At the tactical stage, hierarchy of production planning is applied. This hierarchy of production planning is denoted by Figure 7 below.

Figure 7: Hierarchy of production planning at a tactical stage.

It is noted that Figure 7 is adapted by the study of Boonmee et al. (2016) for the hierarchical planning system of the company of interest. Accordingly, the tactical stage starts with demand forecasting, then number of chickens and their ABWs are determined, and then number of coops and total space required for breeding are calculated. Finally, amount of broiler breeder chicks is ordered to suppliers (see Figure 7).

With regard to operational stage, it deals with daily short term planning at its simplest, i.e., demand planning. Planner needs to decide how to distribute the available carcass among the demands. Next section explains this stage for the company of the interest.

3.3 Demand Planning in the Poultry Company

Main inputs of an operational plan is veterinary information (ABW, total number of chickens to be processed), initial inventory (turnover inventory of the previous day), daily orders and minimum and maximum level of frozen meat. These inputs are shown in Figure 8. First step of demand planning is to calculate the expected total weight of carcasses (usable meat) by multiplying to the number of chicken and ABW. In addition, according to customer orders based on SKU, the planner calculates the amount of carcass weight to be cut up to meet full order of customers based on product group (see step 2 in Figure 8). Then, the planner determines the amount of carcasses cut up or packed as a whole chicken taking into line capacities account (see step 3 in Figure 8).

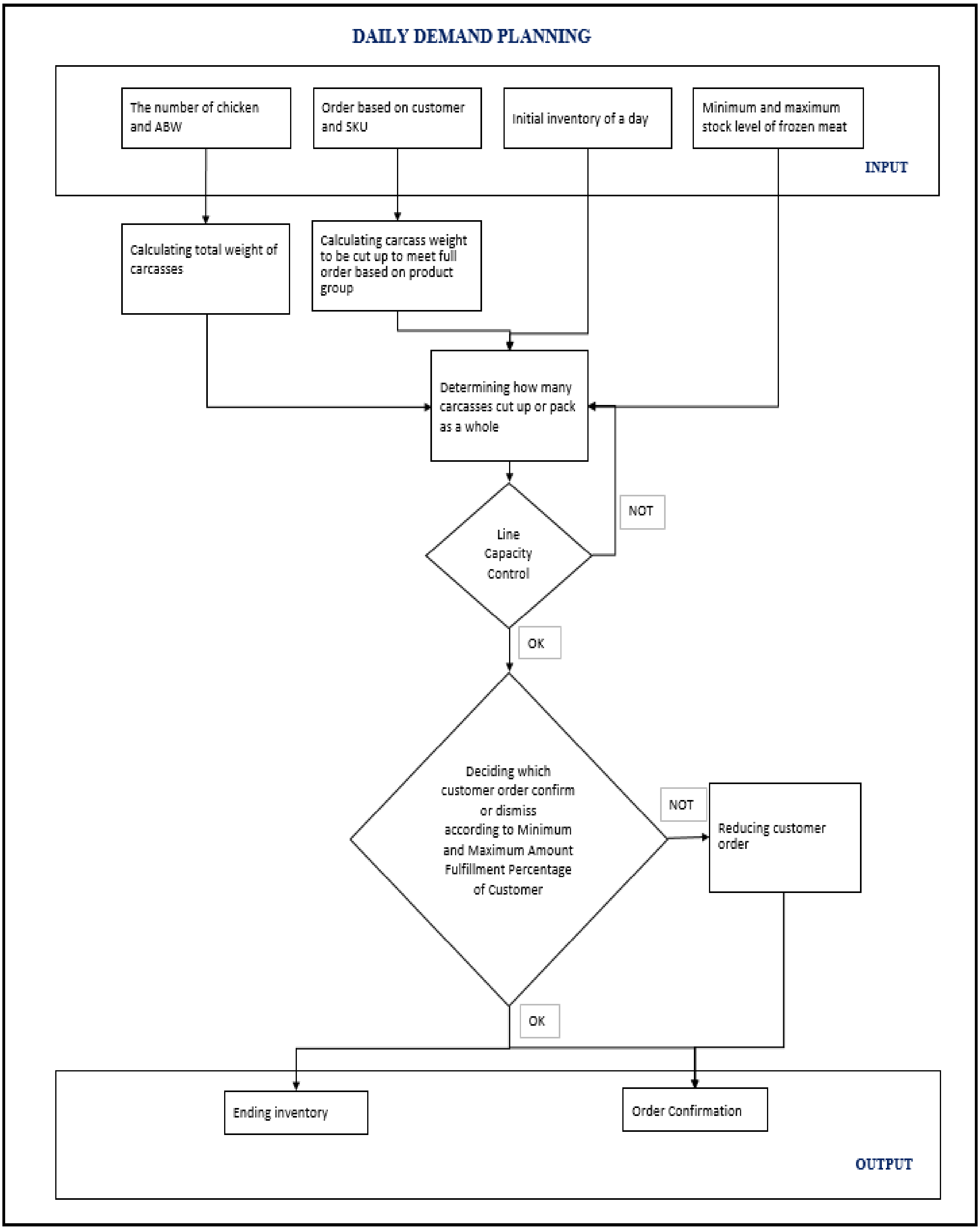


Figure 8: Flow of daily demand planning process.

After step 3, the planner chooses from which customer order is to be met fully and which customer order is to meet partially because of industry challenges explained in Chapter 1. The constraints which the planner faces while deciding either to confirm or dismiss demand are as follows:

Customer priority: Customers are classified according to the sales performance for each product. This classification helps planner when deciding which demand to backorder and which demand to fully meet. So, high-performance-customer is conserved when needed (Satır, 2003).

Excess product balance (disassembly production): There are two wings, two legs and a breast in every single whole chicken, the poultry production planner has to sustain product balance as well (Minegishi and Thiel, 2000; p.324-325).

Relative value of the product: Changing through season, processes or sales channel; product value differs.

Capacity: As in other industries, planner is bound by production capacities in chicken meat industry too.

At the end of the demand planning process, the ending inventories for each product groups and confirmed orders are obtained (see outputs in Figure 8).

3.4 Concluding Remarks

In this chapter, first three stages of production planning in poulty industry are explained. Then, the steps of demand planning for the company of the interest are described by presenting a schematic diagram that is derived from the poultry company.. It is believed that it assists to form a structural and systematic demand planning process.

According to Figure 8, main input data required for the demand planning is the data for number of chicken, ABW, customer orders, initial inventories, and minimum and maximum levels of frozen meat. These input data are collected and analyzed to characterize the demand planning. The analyses of collected input data are given in the next chapter.

CHAPTER 4

Data Analysis

4.1 Introduction

In this chapter, data analyses for the collected data are categorized into two parts. The first part includes data analyses of demand and sales for the company of interest in Section 4.2. The second part represents the data collected for main inputs of demand planning process (see Section 3.2) and analyses of these input data in Section 4.3.

4.2 Data Analyses of Sales and Customer Demand

In this section, the following data is analyzed to show the balance of demand and sales for the company of interest. Accordingly, Section 4.2.1 presents customer demand analysis for legs, breast and wings. Section 4.2.2 shows the analysis total sales of chicken meat, this is followed by the analysis of amount of product groups sold in Section 4.2.3, and Section 4.2.4 presents the carcass weight to be cut up to meet full order based on product group (see Table 2).

Table 2: Data Analyses for Customer Demand and Sales.

Section No	Data Analysis
4.2.1	Customer Demand Analysis for Legs, Breast and Wings
4.2.2	Total Sales of Chicken Meat
4.2.3	Amount of Product Group Sold
4.2.4	Carcass Weight to Be Cut Up to Meet Full Order Based on Product Group

4.2.1 Customer Demand Analysis for Legs, Breast and Wings

Two years of data for the demand of chicken meat is collected and analyzed. Figure 9 presents fluctuations of customer demand of legs, breast and wings.

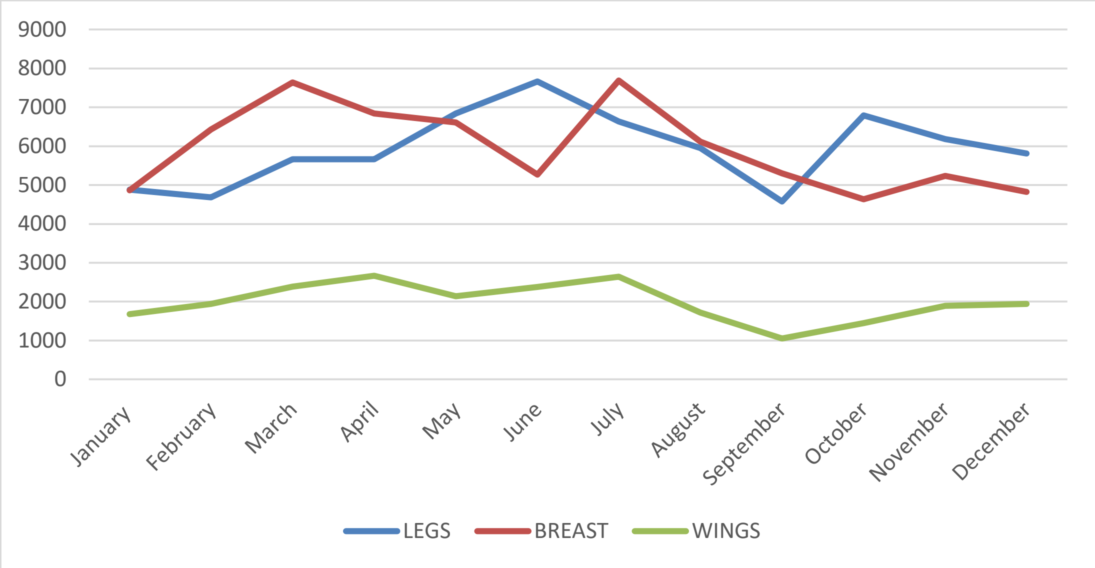


Figure 9: Customer orders for legs, breast and wings.

The mean of product groups (legs, breast and wings) is calculated by using demand data from 2016 to 2017. Then, coefficient of variance is found using the formula CV=(SD/Mean)*100. With 95% of probability, demand of legs is not less than 5489 and more than 6401 tons. Likewise, demand of breast is between 5381 and 6528 tons, and demand of wings is between 1770 and 2209 tons. According to descriptive statistical results, wings have the highest coefficient of variance. Thus, it shows high demand fluctuations based on mean demand levels over 12 months (see Figure 9).

Table 3: Statistical Analysis of Demand

Product Group	Mean	Coefficient of Variance	Confidence Interval	
LEGS	5945	1,9	5489	6401
BREAST	5955	2,4	5381	6528
WINGS	1989	2,8	1770	2209

4.2.2 Total Sales of Chicken Meat

There is a strong seasonality for poultry meat (see TUIK, 2017). It can be caused by various factors such as weather and holidays. Figure 10 shows monthly demands for three years. The analysis represents the similar trend except for the 2015. In 2015, the false rumors of bird flu went viral and caused the demand to decrease.

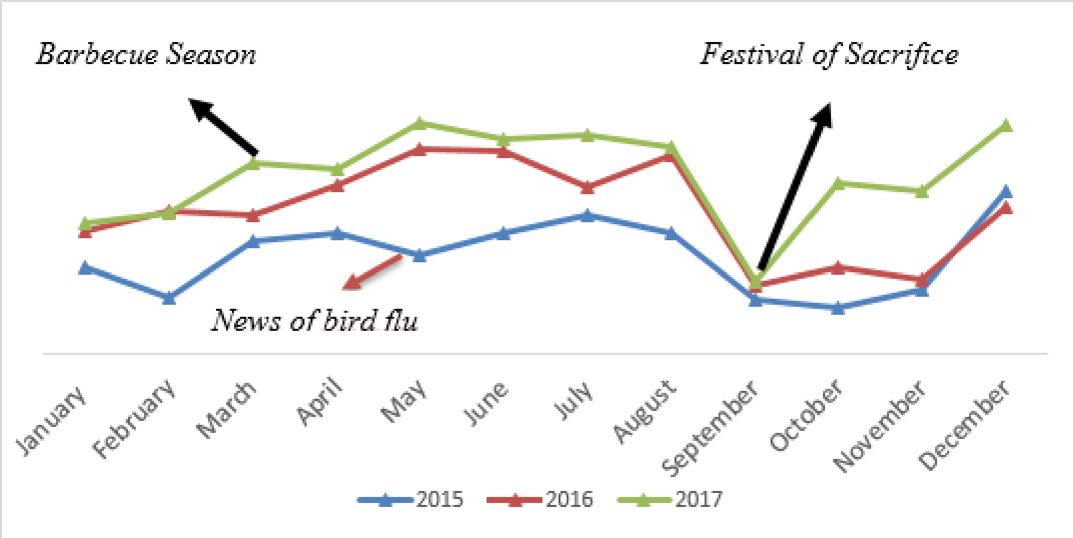


Figure 10: Total sales of chicken meat

Besides, the Figure 10 shows another insight about the volatility of demand. That is, sales volumes of the separate months in a same year differentiate in large scales. For example, for the years 2015, 2016 and 2017, September is the month when most people consume livestock and meet their meat demands by beef due to the Muslim Sacrifice Holiday, therefore demands for chicken meat fall significantly. On the other hand, the months starting from March until August represent the highest demands since these months are referred to as barbeque season.

4.2.3 Amount of Product Group Sold

With regard to total sales data, there is also seasonality in some product groups, unless there is an external factor. The following figure shows volatility of the wing sales. Sales of wings increase on March because of the barbecue season. The highest demand is observed in July.

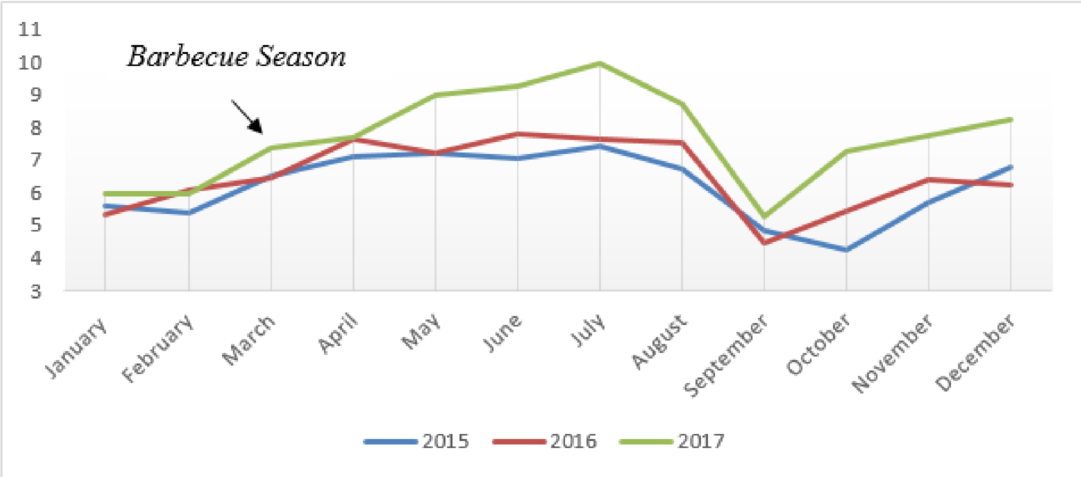


Figure 11: Sales of wings.

With regard to the drumsticks, sales of drumstick increases almost every month during a year. During the Ramadan, sales have a rising trend every year.

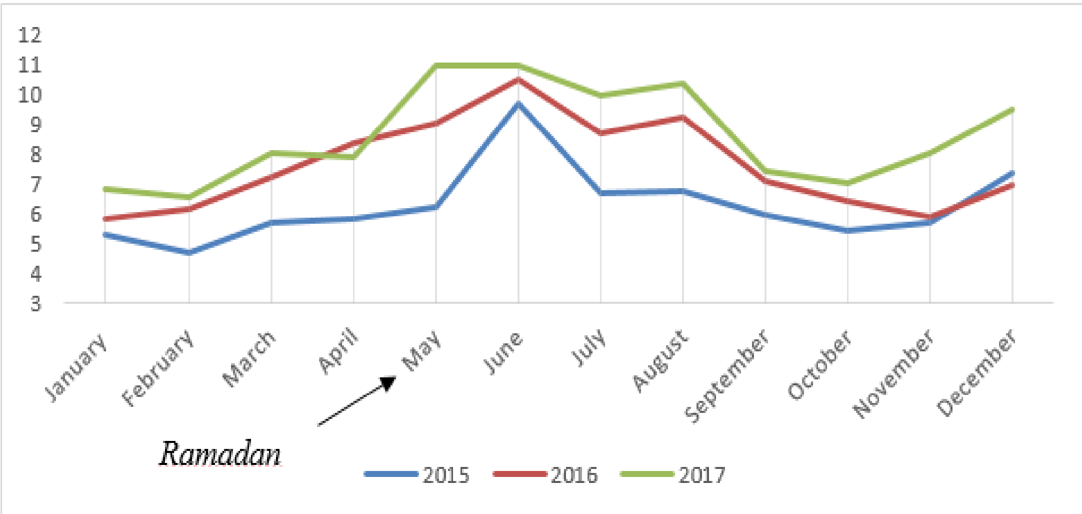


Figure 12: Sales of drumsticks.

Demand volatility based on product group is a difficult situation for the planner that has to balance product groups because of disassembly production system.

4.2.4 Carcass Weight to Be Cut Up to Meet Full Order Based on Product Group

The Figure 13 shows that total amount of carcass in tons that has to be cut up to meet orders of legs, breast and wings.

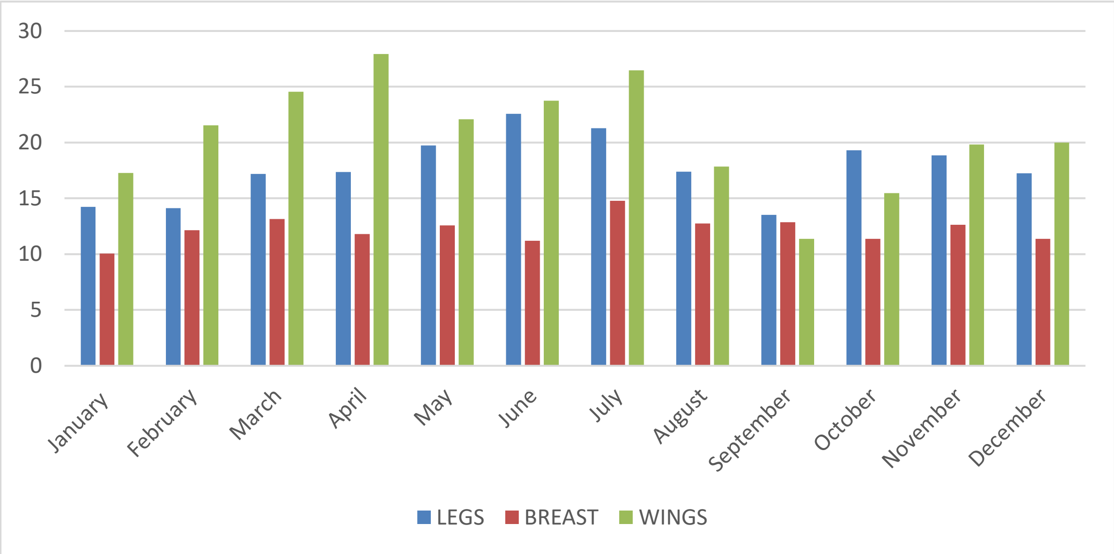


Figure 13: Carcass weight to be cut up to meet full order based on product group.

Figure 13 reveals that customer orders for each month have an irregular pattern based on the product groups of legs, breast and wings. For instance, it is not possible to produce chicken wings in very large quantities. If whole chickens are cut up as much as the demand of wings, the other parts must be produced to inventory. As there are two wings, two legs and a breast in every single whole chicken, the poultry production planner should sustain a balance between meeting demand and accepting the inventory costs. Thus, the planner can sometimes choose partially meeting the demand for wings for a customer based on a number of factors. Highlighted decisions are given for planning amount of carcass. This affects inventory levels and profit. This decision is subject to capacity and satisfying customer demand such that lost demand and inventory levels need to be minimized. According to Figure 13, customer demands for wings and legs are higher than the demands for breast over a year. This characteristics of customer demands can used to justify the solutions of the proposed mathematical models.

4.3 Collected Data Types for Parameters

A variety of parameters are defined in the proposed model. Some of these are defined as sales data of past years and some are based on the daily data (mostly of veterinary information). Table 4 lists the collected data types that are the parameters used in the proposed mathematical models in Chapter 5.

Table 4: Collected data types for parameters.

Section No	Collected Data
4.3.1	Available Carcass
4.3.2	Product Group
4.3.3	Process
4.3.4	The Minimum and Maximum Demand Fulfillment Percentage
4.3.5	Capacity of Lines
4.3.6	Profit

4.3.1 Available Carcass

After slaughtering a live chicken, the remains (the skeleton, meat and skin) are called the carcass. Carcass weight is calculated from live weight by the following calculations.

$$\textit{Carcass Weight} = (\textit{Yield} * \textit{Live Weight}) \quad (1)$$

$$\textit{Live Weight} = (\textit{Number of Chicken} * \textit{ABW}) \quad (2)$$

With regard to calculations given in (1) and (2), first live weight is calculated as the number of chickens multiplied by the ABW in (2), then total amount of available carcass weight is calculated by multiplying the live weight by yield factor in (1). Based on available long-run statistical data, the carcass weight for chickens is very close to 74% of the live weight (Bernacki, 2008). This is accepted as almost like a standard in poultry meat industry and is called the ‘yield’.

4.3.2 Product Group

Product groups represent the type of product that one would buy, sell or further process. However, SKUs differ mostly based on the packaging and customer. There are 24 product groups and 265 SKUs (Stock Keeping Unit: Product identification code) corresponding to these product groups. Appendix-2 lists these product groups and the corresponding SKUs in detail.

The weight of each product group is determined as a ratio to the weight of one unit of carcass based on long statistical studies. Table 5 below presents the ratio of product groups on one unit of carcass.

Table 5: Product groups and weights.

NUMBER	PRODUCT GROUP	RATIO OF WEIGHT
1	WHOLE CHICKEN	1,00
2	FILLET	0,33
3	WHOLE LEG	0,44
4	BREAST WITHOUT FRONT PIECE	0,39
5	WHOLE WINGS	0,11
6	DRUMSTICK	0,14
7	BONELESS THIGH	0,16
8	BACK PIECE	0,11
9	STEAK	0,27
10	INNER FILLET	0,05
11	SKIN	0,05
12	LEG RIP	0,18
13	WHOLE BREAST	0,45
14	WHOLE LEG 2	0,44
15	2nd JOINT	0,04
16	DRUMSTICK WITHOUT PAWPIECE	0,12
17	TIPS	0,01
18	FRONT PIECE	0,06
19	THIGH WITH BACK PIECE	0,30
20	LEG WITHOUT BACK PIECE	0,32
21	THIGH	0,18
22	SKINLESS THIGH	0,15
23	WINGS WITHOUT TIP	0,09
24	1st JOINT	0,06

4.3.3 Process

There are 2 lines in the slaughterhouse (whole chicken and cut up line). Products are either produced as a whole chickens or chicken parts. A carcass can be cut up in many different ways. Depending on how cutting operation is performed, varying numbers and combinations of parts are obtained from a carcass. The machines in two production lines at the slaughterhouse can be configured easily to perform any one of 157 different cutting operations. Each one of these operations are referred to as a “process” hereafter. The complete list of these 157 processes, along with the percentage and variety of parts (product groups) that can be produced using the processes are listed in Appendix 3.

Table 6: Examples of process.

Process No	WHOLE CHICKEN	FILLET	WHOLE LEG	BREAST WITHOUT FRONT PIECE	WHOLE WINGS	...	WHOLE LEG 2	2nd JOINT	DRUMSTICK WITHOUT PAWPIECE	TIPS	FRONT PIECE
1	1	0	0	0	0	...	0	0	0	0	0
28	0	0,3258	0	0	0,1066	...	0,4379	0	0	0	0,0638

To produce a certain product, the planner is to concede the by-products that come with it. For example, if a certain number of drumsticks demand is chosen to be met, after production there are idle thighs at the same amount left when drumsticks are separated from thighs.

Table 7: Example of process efficiency.

Process No	WHOLE CHICKEN	FILLET	WHOLE LEG	BREAST WITHOUT FRONT PIECE	WHOLE WINGS	DRUMSTICK	BONELESS THIGH	BACK PIECE	STEAK	INNER FILLET	SKIN	LEG RIP	WHOLE BREAST	WHOLE LEG 2	2nd JOINT	DRUMSTICK WITHOUT PAWPIECE	TIPS	FRONT PIECE	THIGH WITH BACK PIECE	LEG WITHOUT BACK PIECE	THIGH	SKINLESS THIGH	WINGS WITHOUT TIP	1st JOINT	Efficiency
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
28	0	0,32	0	0	0,10	0	0	0	0	0	0	0	0	0,44	0	0	0	0,06	0	0	0	0	0	0	0,93

Through the processes, some of the weight is lost (unusable bones, trim loss etc.). This directly affects what is called the process efficiency. Process efficiency represents the percentage weight of the output of the process as compared to carcass. Table 7 represents an example for the process efficiency for process numbers of 1 and 28. To illustrate, to get a fillet, the breast cage is cut up right to the trashcan.

Thus, there is a loss of 0, 06 kg out of 1 kg of carcass. There are usually more than one processes to get the same product type with varying by-products with different efficiencies. Therefore, process efficiency should be taken into account when deciding how much carcass is forwarded to each process.

4.3.4 The Minimum and Maximum Demand Fulfillment Percentage

Since the production is based on disassembly, in case of being high demand for one product group at certain times, it is therefore inevitable that some orders are not met fully. Deciding how much of whose orders are met is a decision that should be identified in the model. For instance, in Ramadan, demand of drumsticks increases (Appendix 1). When 100 units of carcass cut up, 14 units drumsticks, 30 units of thigh, 45 units breasts and 11 units wings are produced (Figure 14). If demand of thigh is less than 30, thigh must be produced to inventory to meet drumstick demand fully. It is much more desirable, though practically impossible to satisfy all demand. It is in the company's best interest to satisfy as much as demand possible as long as it increase profit.

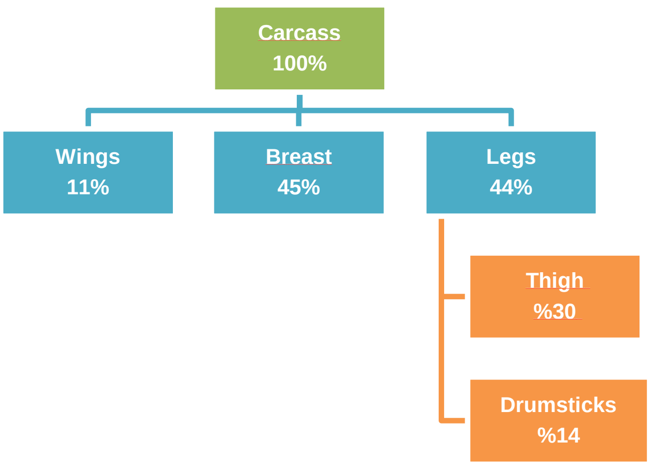


Figure 14: Example of product tree.

In the proposed models, limits for demand confirmation are defined. Minimum and maximum confirmation rate are two key parameters kept for each customer. The limits are used to guide the model to define the amount of demand to be met for each product group and are determined based on customers' regular sales volumes (calculated with the moving average of 3 months' sales) and customer priority.

A customer who consistently orders a certain amount of a product group is considered as it has a constant sales strategy on that product so, backordering the customer on that product group is thought as more harmful. Thus, with these limitations, the model is constricted. Table 8 below shows an example of a customer's demand limitations for each product group.

Min. Confirmation Kg = (3-Month Average Sales) x (Minimum Confirmation Rate)

Max. Confirmation Kg = (3-Month Average Sales) x (Maximum Confirmation Rate)

Table 8: Minimum and maximum demand fulfillment percentages of first customer.

Customer	Product Group No	Product Group	Min. Order Confirmation Rate	3-Month Average Sales (kg)	Minimum Confirmation (kg)	Max. Order Confirmation Rate	Maximum Confirmation (kg)
1	1	WHOLE CHICKEN	40%	7431	2972	110%	8174
	2	FILLET	40%	511	205	110%	562
	3	WHOLE LEG	40%	439	176	110%	483
	4	BREAST WITHOUT FRONT PI	40%	112	45	110%	123
	5	WHOLE WINGS	40%	279	112	110%	307
	6	DRUMSTICK	40%	1107	443	110%	1218
	7	BONELESS THIGH	40%	979	392	110%	1077
	8	BACK PIECE	40%	35	14	110%	39
	9	STEAK	40%	282	113	110%	310
	10	INNER FILLET	40%	335	134	110%	368
	11	SKIN	40%	0	0	110%	0
	12	LEG RIP	40%	763	305	110%	839
	13	WHOLE BREAST	40%	39	16	110%	43
	14	WHOLE LEG 2	40%	0	0	110%	0
	15	2nd JOINT	40%	302	121	110%	332
	16	DRUMSTICK WITHOUT PAW	40%	7	3	110%	8
	17	TIPS	40%	99	39	110%	109
	18	FRONT PIECE	40%	1392	557	110%	1531
	19	THIGH WITH BACK PIECE	40%	690	276	110%	759
	20	LEG WITHOUT BACK PIECE	40%	1230	492	110%	1353
	21	THIGH	40%	165	66	110%	181
	22	SKINLESS THIGH	40%	0	0	110%	0
	23	WINGS WITHOUT TIP	40%	89	35	110%	98
	24	1st JOINT	40%	809	323	110%	889

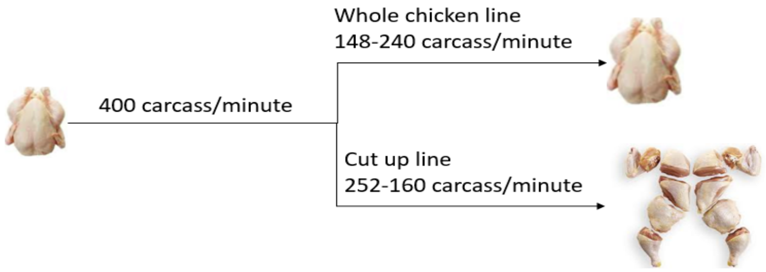
In addition to the min-max confirmation constraints given to customers on a product group basis, there are additional constraints are also defined for each SKU. Because, the model should work to maximize profitability, it tries to fulfill all demand with the most profitable SKU. This eventually causes an imbalance between what is demanded and what is more profitable. To correct this, two additional parameters are added as below.

α ("Alpha"): The least demand confirmation level for each SKU,

β ("Beta"): The upper bound of demand confirmation for each SKU.

4.3.5 Capacity of Lines

Total capacity of two lines is 400 chickens per minute; cut up line and whole chicken line. There is a transfer point that distributes 400 chickens from the chilling line to whole chicken and cut up line. This point can send maximum 252 chickens to the cut up line because of number of the shackles. Thus, transfer point have to send minimum 148 chickens to the whole chicken line. Moreover, on the whole chicken line, there are 12 packaging units and the capacity of each unit is 20 carcass per minute, so maximum number of carcass to be sent to the whole chicken line is 240.



4.3.6 Profit

Maximizing profitability is the utmost goal of this study. In the chosen market, profitability changes are time dependent, based on SKU and customer. Excess inventory can sometimes be decreased by issuing a discount to some customer groups. The proposed models are tested against current production planning practice using real life profit data in next chapter

Chapter 5

Mathematical Models for Demand Planning

5.1 Introduction

This chapter introduces two mathematical models that are proposed for optimization of poultry demand planning. The models are represented as proposed mathematical model-I and proposed mathematical model-II. Before introducing the mathematical models, notation used for the models are defined in Section 5.1. The first proposed mathematical model is given in Section 5.2 and then the alternative version of the second model is defined in Section 5.3.

5.2 Notation for Mathematical Models

Notations that are used for the mathematical models are given in the following.

Indices and Sets

s : Index for SKUs, $s=1,\ldots,S$

k : Index for product groups, $k=1,\ldots,K$

j : Index for customers, $j=1,\ldots,J$

p : Index for cutting processes, $p=1,\ldots,P$

Parameters

M_{sj} : Unit profit for customer j for SKU s (TRY/kg)

d_{sj} : Demand for customer j for SKU s (kg)

P_{sk} : 1 if SKU s is under for product group k, 0 otherwise

C_{pk} : Weight for cutting process efficiency p for product group k

A : Available amount of carcass (kg),

P_p : Efficiency of cutting process *p*

I_k^0 : Initial inventory of product group *k* (kg)

Min_{jk} : Minimum amount of product *k* allocated to customer *j*

Max_{jk} : Maximum amount of product *k* allocated to customer *j*

α_{sj}: Minimum demand satisfaction ratio of SKU *s*

β_{sj} : Maximum demand satisfaction ratio of SKU *s*

Decision Variables

I_k^1 : Ending inventory of product group *k* (kg)

r_p : Ratio of incoming carcass sent to process *p*

x_{sj} : Amount of SKU *s* allocated to customer *j* (kg)

5.2 Proposed Mathematical Model-I

The purpose of the first proposed model is to maximize the profit by optimizing the demand confirmation under the specified constraints. The output of the model are given in the following.

1. Amount of carcass in kilograms is sent to each process
2. Demands to meet and their ratios
3. Proposed turnover inventory for the day

The objective function and its constraints are given as follows.

$$Maximize \quad \sum_{s \in S} \sum_{\forall j} M_{sj} x_{sj} \tag{1}$$

$Subject\ to$

$$\sum_{p \in P} r_p = 1 \tag{2}$$

$$I_k^0 + \sum_{p \in P} A r_p C_{pk} P_p = I_k^1 + \sum_{j \in J} \sum_{s \in S} x_{sj} \qquad \forall k \tag{3}$$

$$Min_{jk} \leq \sum_{s \in S} x_{sj} \leq Max_{jk} \qquad \forall\ (j,k) \tag{4}$$

$$d_{sj}\alpha_{sj} \leq x_{sj} \leq d_{sj}\beta_{sj} \qquad \forall\ (s,j) \tag{5}$$

$$\sum_{k\in K} I_k^1 \leq 150.000 \quad (6)$$

$$0.37 \leq r_1 \leq 0.6 \quad (7)$$

$$x_{sj}, r_p, I_k^1 \geq 0 \quad (8)$$

The objective function (1) and constraints (2) to (7) are formulated. Total profit (1) is maximized in the objective function. In the chosen market, profitability changes are time dependent, based on SKU and customer. The proposed model will be tested against current production planning practice using real life data profit. Constraint (2) guarantee that all carcass definitely enters a process *p*. Constraint (3) is inventory balance constraint. Constraint (4) binds the model that weight of product group which allocated to customer *j* cannot exceed the maximum and minimum weight of product *k*. Constraint (5) makes sure that SKU-based-confirmation rates are between alpha and beta. With constraint (6), ending inventory cannot exceed 150.000 kg. The company has an ending inventory policy that forces the planner to keep daily turnover inventory maximum 150.000 kgs. This can be arbitrary but it is the current practice. Constraint (7) is a capacity of whole chicken line constraint.

The mathematical model maximizes total profit while obeying disassembly structure, process, customer satisfaction and other production constraints. According to the literature, this model considers multi-processes or more than one processes that can be applied to obtain different product groups. Determination of which processes to be used to handle total number of carcasses depends on the process efficiencies. Accordingly, the mathematical model calculates relative amounts of production at each process level and product levels.

Given order information, process information along with capacities and efficiencies, customers information, with their minimum and maximum demand fulfillment limit, profitability information based on SKU, veterinary information (ABW, number of chickens), initial inventory, the problem is to find how much of daily available carcass to send which process to satisfy the determine level of each demand such that total planning profit is maximized subject to product balance, capacity and customer priority constraints.

5.3 Proposed Mathematical Model-II

This second model adds a secondary penalty for unmet demand to the objective function. Although the profit maximizing objective function penalizes unmet demand by not being able to obtain the profit, additional penalty cost is subtracted from the objective function in the amount of SKU profit. Also holding cost for inventory leftover to the next time period is added to the objective function. Necessary updates to the constraints are made to accommodate these changes. Therefore, this model can be referred to as an alternative version of the previous model in the constraints and the objective function. The mathematical model proposed has the following assumptions.

1. Total available carcass is equal to or less than total available production capacity and amount of carcasses are inserted as number of carcasses, not in kilograms. Conversion to weight is performed after cutting up processes.
2. Profits are dependent on the customers and SKUs, they are assigned independently from the holding and penalty costs.
3. Penalty costs are assumed to be dependent only for the unsatisfied demand levels for customers and SKUs.
4. Holding cost for the inventory level is assumed as a single value that represents only one day inventory carriage to next day.
5. Range for customer orders for each SKU is kept similar from the previous model as model minimizes inventories on product group levels.
6. Backorders are not allowed.

The notation for additional parameters and decision variables are given in the following (see the other notations in previous section).

Parameters

U_{sj} : Unit penalty cost of unmet demand for customer j and SKU s (TRY/kg)

h_k : Daily per unit holding cost of inventory for product group k (TRY/kg-unit)

r_1 : Ratio of amount of whole chicken to total available carcass, i.e., 0.37

A : Number of carcasses available per day

ABW : Average body weight used for converting carcass into weight, i.e., 2.60

$Yield$: Weight of carcass after cut up, i.e., 0.74

Decision Variables

H_p : Number of carcasses sent to process *p*

G_{pk} : Amount of carcass sent to process *p* for product group *k* (kg)

Z_{sj} : Amount of unmet demand for customer *j* for SKU *s* (kg)

$$Maximize \quad \sum_{s=1}^{S}\sum_{j=1}^{J} M_{sj}X_{sj} - \sum_{j=1}^{J}\sum_{s=1}^{S} U_{sj}Z_{sj} - \sum_{k=1}^{K} h_k I_k^1 \quad (1)$$

$Subject\ to$

$$\sum_{s=1}^{S}\sum_{j=1}^{J} d_{sj}P_{sk} + I_k^1 = \sum_{p=1}^{P} G_{pk} + I_k^0 + \sum_{j=1}^{J}\sum_{s=1}^{S} Z_{sj}P_{sk} \qquad \forall k \qquad (2)$$

$$\sum_{p=2}^{P} H_p \le [A(1-r_1)] \qquad \forall p | p \ge 2 \qquad (3)$$

$$\sum_{p=1}^{P} H_p \le A \qquad \forall p \qquad (4)$$

$$\sum_{s=1}^{S}\sum_{j=1}^{J} d_{sj}P_{sk} \ge \sum_{p=1}^{P} G_{pk} \qquad \forall k | k = 1 \qquad (5)$$

$$C_{pk}H_p(ABW)(Yield) = G_{pk} \qquad \forall\ p, k \qquad (6)$$

$$\sum_{s=1}^{S}\sum_{j=1}^{J} X_{sj}P_{sk} \le \sum_{p=1}^{P} G_{pk} \qquad \forall k \qquad (7)$$

$$\alpha d_{sj} \le X_{sj} \le \beta d_{sj} \qquad \forall\ (s, j) \qquad (8)$$

$$Z_{sj} \le d_{sj} \qquad \forall\ (s, j) \qquad (9)$$

$$H_p, G_{pk}, X_{sj}, Z_{sj}, I_k^1 \ \ge 0\ and\ H_p\ integer \qquad (10)$$

According to above mathematical model, the objective function (1) maximizes the total profit by subtracting total penalty costs and total inventory holding costs from total profit obtained for all customers and products on SKU levels. Constraint (2) represents the inventory balance in which total demand for a product group *k* is added to inventory leftover for product *k*. This summation is balanced with the summation of total of production amount for product *k*, initial inventory level for product *k* and total unmet demand amount for product *k*. Constraint (3) restricts the total number of carcasses to be cut up for all cutting processes *p* by the total number of available carcasses sent for processing. Constraint (4) presents the restriction of total number of carcasses to be process by including the whole chicken amount and uses total number of carcasses to be less than it. Constraint (5) presents the constraint for whole chicken amount that should be equal or less than total demand of whole chicken. Constraint (6) converts number of carcasses cut up into amount of carcasses by taking ABW and Yield values into account for each process and product group. Constraint (7) restricts total amount of production for each product group *k* by the total amount of product group available for product group *k*. Constraining (8) shows the range of production amounts sent to each customer *j* and SKU s with alpha and beta parameters. Constraints (9) represents unmet demand restriction by the maximum amount of demand for customer *j* and SKU *s*. Constrains (10) is the sign restrictions for decision variables.

When compared to the proposed mathematical model-I, main difference is in the objective function. The second model includes an additional penalty for unmet demand in the exact amount of SKU profit and a holding cost for the end of period inventory. Also the limit for the end of period inventory is removed because there is a cost associated with it in the objective function.

Chapter 6

Experimental Results

6.1 Introduction

In this chapter, results from experimentation with the proposed model are presented. Experimentation is performed only with proposed model I. Before presenting the results, this chapter first describes the input data used for proposed model I in Section 6.2. Alpha and beta analysis for both models are shown in Section 6.3.

6.2 Input Data for Experimental Analyses

In the following, the parameters of input data for experimental analyses is described using a real industry dataset derived from the company of interest. Carcass weight is calculated for 5 different days. Table 9 shows all the input data. According to the number of carcasses, ABW and yield, the weight of carcass is calculated to be processed.

Table 9 Input parameters for mathematical models.

	First Day	Second Day	Third Day	Fourth Day	Fifth Day
The number of Carcasses	331.601	292.512	310.633	272.915	290.889
ABW(kg)	2,6	2,005	2,505	2,041	2,425
Yield	74%	74%	74%	74%	74%
Carcass Weight(kg)	638.000	434.000	575.821	412.194	522.000
Initial Inventory (kg)	83.808	182.783	130.121	178.067	92.411

In the Section 6.3, the limits of demand satisfaction using alpha and beta values for each SKU are analyzed to determine best values for initial experimentation solution. Three different scenarios are created by performing parameter analysis. Then, the models are run with different scenarios, and all three scenarios are compared to decide which limits to be chosen. With the chosen Alpha and Beta values, the model is run for real industry data in Section 6.2. Each output is compared with the actual planning data to compare the improvements of models.

In the Section 6.3, profits of customers based on each SKU are analyzed to re-assess the alpha values, and the models are run with the new alpha values. A significant improvement is observed with the same confirmation rates.

6.3 Alpha and Beta Analysis

Alpha and beta values are identified to help the model to determine the SKU based confirmation rates while maximizing the profitability, as before, these rates were set based on the personal experience of the planner. It is seen that before the model-run-planning, the SKU based confirmation rates vary between 0% and %600, while average value is between 25% and 130%.

Emerging from the actual rates, three different scenarios with different alpha and beta values (Table 10) are applied by narrowing the gap between the values. It is noted that the gap width is inversely proportional with the customer satisfaction.

Table 11 shows the outputs of the scenarios in the first mathematical model. With regard to the first model, Scenario 3 is chosen even though there can be seen a decline in total profit, as the gap is narrowest. In Scenario 3, the minimum customer demand fulfillment based on SKU, is the largest compared to the other scenarios. Alpha value, which is 25% in the real case, has been increased to 60% and also beta value, which is 120% in the real, has been decreased to 110%. It means, over sending and under sending at acceptable limits become more ideal for customer.

Table 10: Input parameters for the scenarios

	Actual	Scenario 1	Scenario 2	Scenario 3
Alpha	25%	40%	40%	60%
Beta	130%	150%	120%	120%
Min Kg	38%	40%	40%	40%
Max Kg	120%	110%	110%	110%

Table 11: Outputs of Scenarios in the First Mathematical Model.

	Actual	Scenario 1	Improvement	Scenario 2	Improvement	Scenario 3	Improvement
Profit(TRY)	58885	148013	**151%**	108576	**84%**	100016	**70%**
Demand Confirmation Rate	73%	89%	**22%**	88%	**21%**	87%	**19%**

Table 12: Outputs of Scenarios in the Second Mathematical Model.

	Actual	Scenario 1	Improvement	Scenario 2	Improvement	Scenario 3	Improvement
Profit(TRY)	58885	176727	**200%**	137506	**134%**	108473	**84%**
Demand Confirmation Rate	59%	72%	**22%**	63%	**7%**	73%	**23%**

With regard to the second model, the results are significantly different for both profit values and demand confirmation rates. Accordingly, Scenario 1 is the best scenario from the total profits. However, Scenario 3 is the best scenario according to demand confirmation rates. There are significant drops in the profit values in the second model.

6.4 Experimentation Solution

Mathematical model is solved by using IBM ILOG CPLEX 12.7.1 (2.6 GHz CPU with 8 GB RAM.) (Appendix-4) The model has 15.021 decision variables and 32.395 constraints (Figure 15). An optimal solution is obtained in a relatively short time that is approximately 34 seconds.

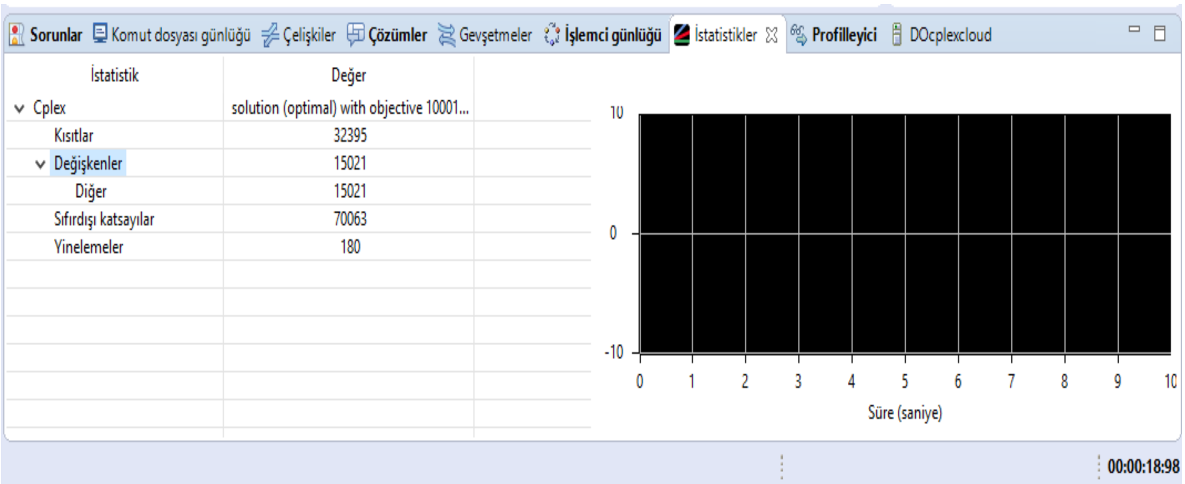


Figure 15 OPL model, number of constraints and variables for first day

The model is run with five separate days' actual planning data. When we compare the model profit with actual plan profit, significant improvement is seen average 88% (minimum %50, maximum 148%). The model presents better results with improvements in both profitability and demand confirmation. It is noted that the second proposed model gives relaxed solutions and it takes more than 5 minutes in some days to obtain results. Since there are comparable differences between these two models and due to the running time and relaxed solutions the other results related with the second proposed models is not given herein. The extension of this model is left for future research.

Table 13: Improvement of profitability in the first model.

	First Day	Second Day	Third Day	Fourth Day	Fifth Day
Realized Profit	58.885	69.615	26.557	84.136	37.827
Model Profit	100.016	126.204	51.378	126.518	93.969
Difference %	**70%**	**81%**	**93%**	**50%**	**148%**

Total number of customers are 56. Demand confirmation rate between 90% and 110% is acceptable limits for customers. According to first day data, the number of customers among the acceptable limits is 17 in the realized planning, while there are 22 in the model results. Also, the other days, improvement is observed except second day. Although, the number of customers within limit, are less than the realized planning result in second day, it is observed that good results are obtained considering the improvement in profitability and the number of customer within limit being 22.

Table 14: Improvement of Demand Confirmation

	First Day		Second Day		Third Day		Fourth Day		Five Day	
	Realized	**Model**	**Realized**	**Model**	**Realized**	**Model**	**Realized**	**Model**	**Realized**	**Model**
Total Number of Customer	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**
%89 and less	**37**	**26**	**14**	**13**	**36**	**11**	**17**	**18**	**21**	**12**
%109 and more	**2**	**8**	**16**	**21**	**3**	**13**	**19**	**17**	**14**	**23**
%90-%110	**17**	**22**	**26**	**22**	**17**	**32**	**20**	**21**	**21**	**21**

Table 15: Ending Inventory

	First Day	Second Day	Third Day	Fourth Day	Fifth Day
Realized Ending Inventory	182.783	130.121	178.067	92.411	213.411
Model Ending Inventory	149.996	149.993	149.994	149.995	149.995

6.5 Output Analysis

In this subsection, we analyze and categorize customers based on SKU-profitability. As can be seen in Tables 13-14-15, proposed model shows a significant improvement in profitability, demand confirmation rate and ending inventory value.

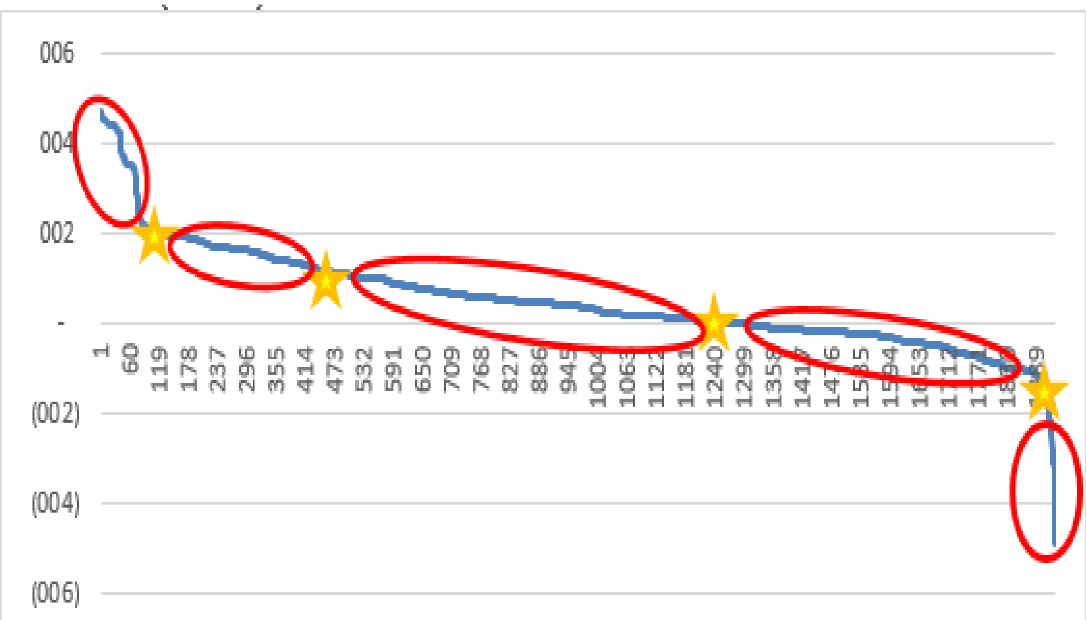


Figure 16 Profitability based on Customer-SKU (TRY/kg)

The model has its alpha values the same for every customer. Later when customer based profitability is analyzed because profitability of every customer is not the same. Customers are categorized in 5 levels of SKU-profitability and different Alpha values are defined for each level (Table 16).

Table 16: New Alpha Value

	# of SKU-Customer	Profit Range (TRY/kg)		Alpha
Profitless	16	-2 and less		**20%**
Low Performing	918	-2	0	**40%**
Average	13070	0	1	**50%**
Profitable	631	1	2	**60%**
High Profitable	205	2 and more		**70%**

The model is run again for 5 days and result is more profitable when the alpha value changes according to customer profitability, as shown in the following Table 17. When we compared the before model output (same alpha parameter) with after model output (different alpha parameter), significant improvement is seen.

Table 17: The output analysis results of profitability

	First Day	Second Day	Third Day	Fourth Day	Fifth Day
Realized Profit	58.885	69.615	26.557	84.136	37.827
Before (Profit)	100.016	126.204	51.378	126.518	93.969
After (Profit)	109.130	137.367	90.090	140.073	94.760
Further Improvement %	**9%**	**9%**	**75%**	**11%**	**1%**
Total Improvement %	**85%**	**97%**	**239%**	**66%**	**151%**

Chapter 7

Conclusions and Future Work

The poultry meat industry is enlarging in a short period because poultry meat is both healthier and cheaper (ABPA, 2016). However, in the poultry meat industry companies deal with challenging in planning due to a number of reasons like short shelf lives, volatility of demand, stiff competition in the market place and seasonality (see Chapter 1). Also, from veterinary services, vaccination and food choice, through weather conditions, logistics, and cutting efficiency, a poultry meat planner should sustain a delicate balance among a great numbers of factors to deliver healthy chicken fillet to food industry (see Chapter 1). In the poultry meat market, customer loyalty is low, so demand should be ready on time in full order sizes. Planning department manages customer satisfaction and company' cost policies. In this point, planning department has a crucial role to manage all these challenges.

Planner has to take these constraints (capacity, product balance, customer priority and profit) into account. In a short time, planner sustains a balance all constraints to find a feasible plan with all complexity.

Results from the experimental analyses show that the use of proposed models provide significant improvements in both profitability and customer satisfaction. The models can be easily reconfigured based on changing demand and parameters. It is noted that the use of the second proposed model needs to be extended for the analyses too.

In this thesis, model is run using five days' real data. The model results and the real plan made by the planner, are compared according to their demand confirmation rates and profitabilities. Severe improvement is observed. In addition, with the model proposed in this study, the time allotted for planning is reduced 83%. It is observed that when customers are classified according to their SKU-based profitability, more profitable distribution plans can be achieved. (Section 5.3 Output Analysis)

As a future study, model can be run for longer periods using SKU-based sales forecasts. In addition, the analyses and results from the second proposed model can be added in a future study. With more scientific sales forecasts, raw material supply (living birds) can be managed and so can be amended daily, which would positively effect inventory control and distribution plans..

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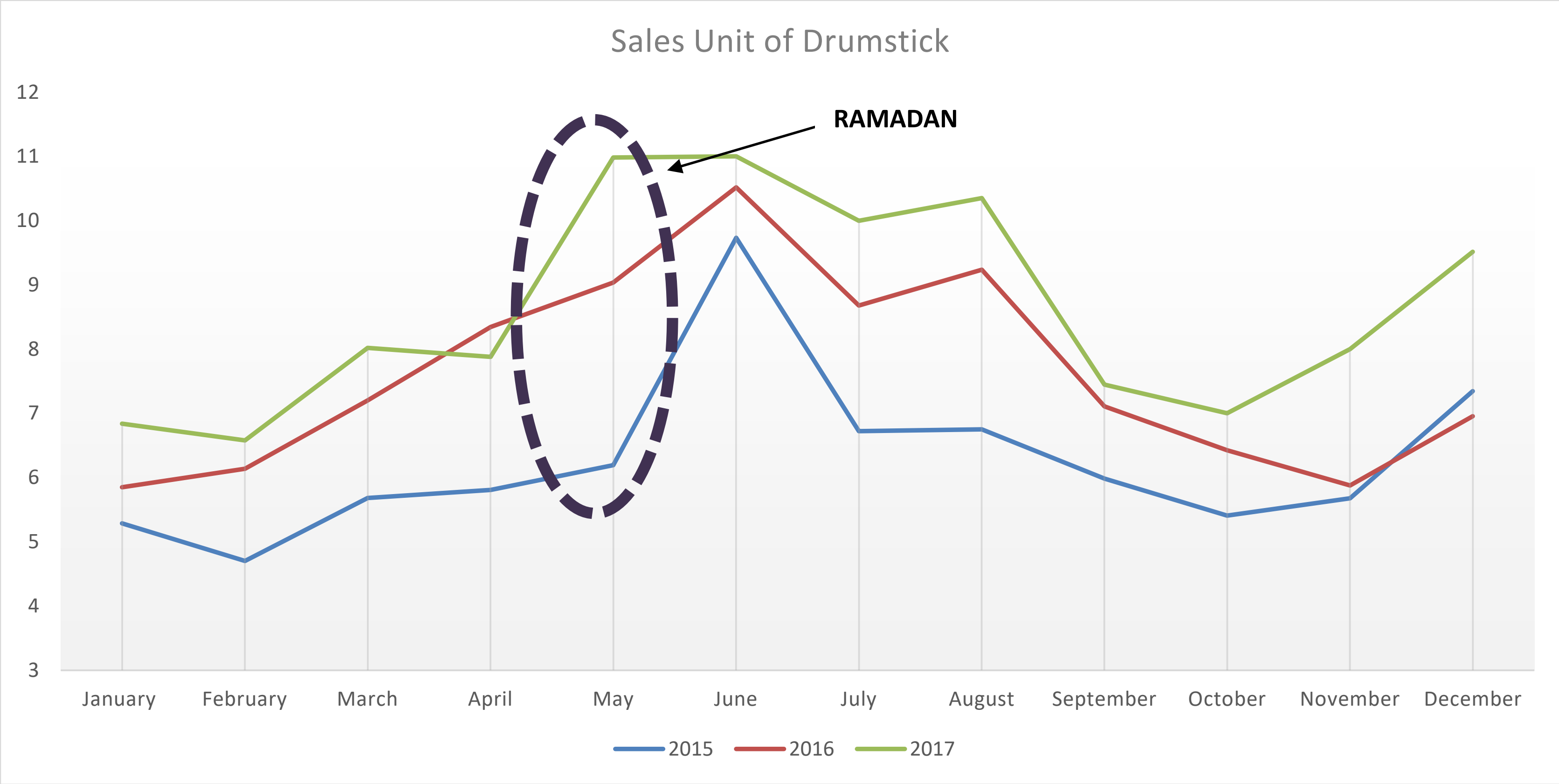
APPENDICES

APPENDIX – 1. Sales Unit of Drumstick



APPENDIX – 2. SKU-Product Group Table

SKU / Product Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
16	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
20	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
23	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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28	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
42	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
52	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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221	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
222	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
223	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
224	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
226	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
227	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
228	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
229	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
231	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
232	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
233	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
234	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
236	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
237	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
238	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
239	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
240	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
241	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
244	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
245	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
246	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
247	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
248	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
249	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
250	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
251	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
252	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
253	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
254	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
255	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
256	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
257	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
258	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
259	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
260	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
261	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

262	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
263	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
264	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
265	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX – 3. Process-Product Group Table

Process/Product Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Product Efficiency
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100,0%
2	0	0	0	0	0,11	0	0	0	0	0	0	0	0,45	0,44	0	0	0	0	0	0	0	0	0	0	99,6%
3	0	0	0,44	0	0,11	0	0	0	0	0	0	0	0,45	0	0	0	0	0	0	0	0	0	0	0	99,5%
4	0	0	0	0	0,11	0	0	0,11	0	0	0	0	0,45	0	0	0	0	0	0	0,32	0	0	0	0	99,5%
5	0	0	0	0	0,11	0,14	0	0	0	0	0	0	0,45	0	0	0	0	0	0,3	0	0	0	0	0	98,9%
6	0	0	0	0	0,11	0,14	0	0,11	0	0	0	0	0,45	0	0	0	0	0	0	0	0,18	0	0	0	98,9%
7	0	0	0	0	0,11	0,14	0	0,11	0	0	0	0,18	0,45	0	0	0	0	0	0	0	0	0	0	0	98,8%
8	0	0	0	0	0,11	0,14	0,16	0,11	0	0	0	0	0,45	0	0	0	0	0	0	0	0	0	0	0	96,5%
9	0	0	0	0	0,11	0	0	0,11	0	0	0,05	0	0,45	0	0	0,12	0	0	0	0	0	0,15	0	0	99,3%
10	0	0	0	0	0,11	0,14	0	0	0	0	0	0	0,45	0	0	0	0	0	0,3	0	0	0	0	0	98,9%
11	0	0	0	0	0,11	0	0	0,11	0	0	0	0	0,45	0	0	0,12	0	0	0	0	0,18	0	0	0	97,2%
12	0	0	0	0	0,11	0	0	0,11	0	0	0	0,18	0,45	0	0	0,12	0	0	0	0	0	0	0	0	97,2%
13	0	0	0	0	0,11	0	0,16	0,11	0	0	0	0	0,45	0	0	0,12	0	0	0	0	0	0	0	0	94,8%
14	0	0	0	0	0,11	0	0	0,11	0	0	0,05	0	0,45	0	0	0,12	0	0	0	0	0	0,15	0	0	99,3%
15	0	0	0	0,39	0,11	0	0	0	0	0	0	0	0	0,44	0	0	0	0,06	0	0	0	0	0	0	99,6%
16	0	0	0,44	0,39	0,11	0	0	0	0	0	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0	99,5%
17	0	0	0	0,39	0,11	0	0	0,11	0	0	0	0	0	0	0	0	0	0,06	0	0,32	0	0	0	0	99,5%
18	0	0	0	0,39	0,11	0,14	0	0	0	0	0	0	0	0	0	0	0	0,06	0,3	0	0	0	0	0	98,9%

19	0	0	0	0,39	0,11	0,14	0	0,11	0	0	0	0	0	0	0	0	0	0,06	0	0	0,18	0	0	0	98,9%
20	0	0	0	0,39	0,11	0,14	0	0,11	0	0	0	0,18	0	0	0	0	0	0,06	0	0	0	0	0	0	98,8%
21	0	0	0	0,39	0,11	0,14	0,16	0,11	0	0	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0	96,5%
22	0	0	0	0,39	0,11	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0	0,06	0	0	0	0,15	0	0	99,3%
23	0	0	0	0,39	0,11	0,14	0	0	0	0	0	0	0	0	0	0	0	0,06	0,3	0	0	0	0	0	98,9%
24	0	0	0	0,39	0,11	0	0	0,11	0	0	0	0	0	0	0	0,12	0	0,06	0	0	0,18	0	0	0	97,2%
25	0	0	0	0,39	0,11	0	0	0,11	0	0	0	0,18	0	0	0	0,12	0	0,06	0	0	0	0	0	0	97,2%
26	0	0	0	0,39	0,11	0	0,16	0,11	0	0	0	0	0	0	0	0,12	0	0,06	0	0	0	0	0	0	94,8%
27	0	0	0	0,39	0,11	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0	0,06	0	0	0	0,15	0	0	99,3%
28	0	0,33	0	0	0,11	0	0	0	0	0	0	0	0	0,44	0	0	0	0,06	0	0	0	0	0	0	93,4%
29	0	0,33	0,44	0	0,11	0	0	0	0	0	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0	93,3%
30	0	0,33	0	0	0,11	0	0	0,11	0	0	0	0	0	0	0	0	0	0,06	0	0,32	0	0	0	0	93,3%
31	0	0,33	0	0	0,11	0,14	0	0	0	0	0	0	0	0	0	0	0	0,06	0,3	0	0	0	0	0	92,7%
32	0	0,33	0	0	0,11	0,14	0	0,11	0	0	0	0	0	0	0	0	0	0,06	0	0	0,18	0	0	0	92,7%
33	0	0,33	0	0	0,11	0,14	0	0,11	0	0	0	0,18	0	0	0	0	0	0,06	0	0	0	0	0	0	92,6%
34	0	0,33	0	0	0,11	0,14	0,16	0,11	0	0	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0	90,3%
35	0	0,33	0	0	0,11	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0	0,06	0	0	0	0,15	0	0	93,1%
36	0	0,33	0	0	0,11	0,14	0	0	0	0	0	0	0	0	0	0	0	0,06	0,3	0	0	0	0	0	92,7%
37	0	0,33	0	0	0,11	0	0	0,11	0	0	0	0	0	0	0	0,12	0	0,06	0	0	0,18	0	0	0	91,0%
38	0	0,33	0	0	0,11	0	0	0,11	0	0	0	0,18	0	0	0	0,12	0	0,06	0	0	0	0	0	0	91,0%
39	0	0,33	0	0	0,11	0	0,16	0,11	0	0	0	0	0	0	0	0,12	0	0,06	0	0	0	0	0	0	88,7%
40	0	0,33	0	0	0,11	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0	0,06	0	0	0	0,15	0	0	93,1%
41	0	0	0	0	0,11	0	0	0	0,27	0,05	0	0	0	0,44	0	0	0	0,06	0	0	0	0	0	0	93,6%
42	0	0	0,44	0	0,11	0	0	0	0,27	0,05	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0	93,5%
43	0	0	0	0	0,11	0	0	0,11	0,27	0,05	0	0	0	0	0	0	0	0,06	0	0,32	0	0	0	0	93,5%
44	0	0	0	0	0,11	0,14	0	0	0,27	0,05	0	0	0	0	0	0	0	0,06	0,3	0	0	0	0	0	92,9%

45	0	0	0	0	0,11	0,14	0	0,11	0,27	0,05	0	0	0	0	0	0	0	0,06	0	0	0,18	0	0	0	92,9%
46	0	0	0	0	0,11	0,14	0	0,11	0,27	0,05	0	0,18	0	0	0	0	0	0,06	0	0	0	0	0	0	92,8%
47	0	0	0	0	0,11	0,14	0,16	0,11	0,27	0,05	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0	90,5%
48	0	0	0	0	0,11	0	0	0,11	0,27	0,05	0,05	0	0	0	0	0,12	0	0,06	0	0	0	0,15	0	0	93,4%
49	0	0	0	0	0,11	0,14	0	0	0,27	0,05	0	0	0	0	0	0	0	0,06	0,3	0	0	0	0	0	92,9%
50	0	0	0	0	0,11	0	0	0,11	0,27	0,05	0	0	0	0	0	0,12	0	0,06	0	0	0,18	0	0	0	91,3%
51	0	0	0	0	0,11	0	0	0,11	0,27	0,05	0	0,18	0	0	0	0,12	0	0,06	0	0	0	0	0	0	91,2%
52	0	0	0	0	0,11	0	0,16	0,11	0,27	0,05	0	0	0	0	0	0,12	0	0,06	0	0	0	0	0	0	88,9%
53	0	0	0	0	0,11	0	0	0,11	0,27	0,05	0,05	0	0	0	0	0,12	0	0,06	0	0	0	0,15	0	0	93,4%
54	0	0	0	0	0	0	0	0	0	0	0	0	0,45	0,44	0,04	0	0,01	0	0	0	0	0	0	0,06	99,5%
55	0	0	0,44	0	0	0	0	0	0	0	0	0	0,45	0	0,04	0	0,01	0	0	0	0	0	0	0,06	99,4%
56	0	0	0	0	0	0	0	0,11	0	0	0	0	0,45	0	0,04	0	0,01	0	0	0,32	0	0	0	0,06	99,4%
57	0	0	0	0	0	0,14	0	0	0	0	0	0	0,45	0	0,04	0	0,01	0	0,3	0	0	0	0	0,06	98,8%
58	0	0	0	0	0	0,14	0	0,11	0	0	0	0	0,45	0	0,04	0	0,01	0	0	0	0,18	0	0	0,06	98,8%
59	0	0	0	0	0	0,14	0	0,11	0	0	0	0,18	0,45	0	0,04	0	0,01	0	0	0	0	0	0	0,06	98,7%
60	0	0	0	0	0	0,14	0,16	0,11	0	0	0	0	0,45	0	0,04	0	0,01	0	0	0	0	0	0	0,06	96,4%
61	0	0	0	0	0	0	0	0,11	0	0	0,05	0	0,45	0	0,04	0,12	0,01	0	0	0	0	0,15	0	0,06	99,2%
62	0	0	0	0	0	0,14	0	0	0	0	0	0	0,45	0	0,04	0	0,01	0	0,3	0	0	0	0	0,06	98,8%
63	0	0	0	0	0	0	0	0,11	0	0	0	0	0,45	0	0,04	0,12	0,01	0	0	0	0,18	0	0	0,06	97,1%
64	0	0	0	0	0	0	0	0,11	0	0	0	0,18	0,45	0	0,04	0,12	0,01	0	0	0	0	0	0	0,06	97,1%
65	0	0	0	0	0	0	0,16	0,11	0	0	0	0	0,45	0	0,04	0,12	0,01	0	0	0	0	0	0	0,06	94,7%
66	0	0	0	0	0	0	0	0,11	0	0	0,05	0	0,45	0	0,04	0,12	0,01	0	0	0	0	0,15	0	0,06	99,2%
67	0	0	0	0,39	0	0	0	0	0	0	0	0	0	0,44	0,04	0	0,01	0,06	0	0	0	0	0	0,06	99,5%
68	0	0	0,44	0,39	0	0	0	0	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	99,4%
69	0	0	0	0,39	0	0	0	0,11	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0,32	0	0	0	0,06	99,4%
70	0	0	0	0,39	0	0,14	0	0	0	0	0	0	0	0	0,04	0	0,01	0,06	0,3	0	0	0	0	0,06	98,8%

71	0	0	0	0,39	0	0,14	0	0,11	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0	0,18	0	0	0,06	98,8%
72	0	0	0	0,39	0	0,14	0	0,11	0	0	0	0,18	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	98,7%
73	0	0	0	0,39	0	0,14	0,16	0,11	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	96,4%
74	0	0	0	0,39	0	0	0	0,11	0	0	0,05	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0,15	0	0,06	99,2%
75	0	0	0	0,39	0	0,14	0	0	0	0	0	0	0	0	0,04	0	0,01	0,06	0,3	0	0	0	0	0,06	98,8%
76	0	0	0	0,39	0	0	0	0,11	0	0	0	0	0	0	0,04	0,12	0,01	0,06	0	0	0,18	0	0	0,06	97,1%
77	0	0	0	0,39	0	0	0	0,11	0	0	0	0,18	0	0	0,04	0,12	0,01	0,06	0	0	0	0	0	0,06	97,1%
78	0	0	0	0,39	0	0	0,16	0,11	0	0	0	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0	0	0,06	94,7%
79	0	0	0	0,39	0	0	0	0,11	0	0	0,05	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0,15	0	0,06	99,2%
80	0	0,33	0	0	0	0	0	0	0	0	0	0	0	0,44	0,04	0	0,01	0,06	0	0	0	0	0	0,06	93,3%
81	0	0,33	0,44	0	0	0	0	0	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	93,2%
82	0	0,33	0	0	0	0	0	0,11	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0,32	0	0	0	0,06	93,2%
83	0	0,33	0	0	0	0,14	0	0	0	0	0	0	0	0	0,04	0	0,01	0,06	0,3	0	0	0	0	0,06	92,6%
84	0	0,33	0	0	0	0,14	0	0,11	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0	0,18	0	0	0,06	92,6%
85	0	0,33	0	0	0	0,14	0	0,11	0	0	0	0,18	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	92,5%
86	0	0,33	0	0	0	0,14	0,16	0,11	0	0	0	0	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	90,2%
87	0	0,33	0	0	0	0	0	0,11	0	0	0,05	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0,15	0	0,06	93,0%
88	0	0,33	0	0	0	0,14	0	0	0	0	0	0	0	0	0,04	0	0,01	0,06	0,3	0	0	0	0	0,06	92,6%
89	0	0,33	0	0	0	0	0	0,11	0	0	0	0	0	0	0,04	0,12	0,01	0,06	0	0	0,18	0	0	0,06	90,9%
90	0	0,33	0	0	0	0	0	0,11	0	0	0	0,18	0	0	0,04	0,12	0,01	0,06	0	0	0	0	0	0,06	90,9%
91	0	0,33	0	0	0	0	0,16	0,11	0	0	0	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0	0	0,06	88,6%
92	0	0,33	0	0	0	0	0	0,11	0	0	0,05	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0,15	0	0,06	93,0%
93	0	0	0	0	0	0	0	0	0,27	0,05	0	0	0	0,44	0,04	0	0,01	0,06	0	0	0	0	0	0,06	93,5%
94	0	0	0,44	0	0	0	0	0	0,27	0,05	0	0	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	93,4%
95	0	0	0	0	0	0	0	0,11	0,27	0,05	0	0	0	0	0,04	0	0,01	0,06	0	0,32	0	0	0	0,06	93,4%
96	0	0	0	0	0	0,14	0	0	0,27	0,05	0	0	0	0	0,04	0	0,01	0,06	0,3	0	0	0	0	0,06	92,8%

97	0	0	0	0	0	0,14	0	0,11	0,27	0,05	0	0	0	0	0,04	0	0,01	0,06	0	0	0,18	0	0	0,06	92,8%
98	0	0	0	0	0	0,14	0	0,11	0,27	0,05	0	0,18	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	92,7%
99	0	0	0	0	0	0,14	0,16	0,11	0,27	0,05	0	0	0	0	0,04	0	0,01	0,06	0	0	0	0	0	0,06	90,4%
100	0	0	0	0	0	0	0	0,11	0,27	0,05	0,05	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0,15	0	0,06	93,3%
101	0	0	0	0	0	0,14	0	0	0,27	0,05	0	0	0	0	0,04	0	0,01	0,06	0,3	0	0	0	0	0,06	92,8%
102	0	0	0	0	0	0	0	0,11	0,27	0,05	0	0	0	0	0,04	0,12	0,01	0,06	0	0	0,18	0	0	0,06	91,2%
103	0	0	0	0	0	0	0	0,11	0,27	0,05	0	0,18	0	0	0,04	0,12	0,01	0,06	0	0	0	0	0	0,06	91,1%
104	0	0	0	0	0	0	0,16	0,11	0,27	0,05	0	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0	0	0,06	88,8%
105	0	0	0	0	0	0	0	0,11	0,27	0,05	0,05	0	0	0	0,04	0,12	0,01	0,06	0	0	0	0,15	0	0,06	93,3%
106	0	0	0	0	0	0	0	0	0	0	0	0	0,45	0,44	0	0	0,01	0	0	0	0	0	0,09	0	99,6%
107	0	0	0,44	0	0	0	0	0	0	0	0	0	0,45	0	0	0	0,01	0	0	0	0	0	0,09	0	99,5%
108	0	0	0	0	0	0	0	0,11	0	0	0	0	0,45	0	0	0	0,01	0	0	0,32	0	0	0,09	0	99,5%
109	0	0	0	0	0	0,14	0	0	0	0	0	0	0,45	0	0	0	0,01	0	0,3	0	0	0	0,09	0	98,9%
110	0	0	0	0	0	0,14	0	0,11	0	0	0	0	0,45	0	0	0	0,01	0	0	0	0,18	0	0,09	0	98,9%
111	0	0	0	0	0	0,14	0	0,11	0	0	0	0,18	0,45	0	0	0	0,01	0	0	0	0	0	0,09	0	98,8%
112	0	0	0	0	0	0,14	0,16	0,11	0	0	0	0	0,45	0	0	0	0,01	0	0	0	0	0	0,09	0	96,5%
113	0	0	0	0	0	0	0	0,11	0	0	0,05	0	0,45	0	0	0,12	0,01	0	0	0	0	0,15	0,09	0	99,3%
114	0	0	0	0	0	0,14	0	0	0	0	0	0	0,45	0	0	0	0,01	0	0,3	0	0	0	0,09	0	98,9%
115	0	0	0	0	0	0	0	0,11	0	0	0	0	0,45	0	0	0,12	0,01	0	0	0	0,18	0	0,09	0	97,2%
116	0	0	0	0	0	0	0	0,11	0	0	0	0,18	0,45	0	0	0,12	0,01	0	0	0	0	0	0,09	0	97,2%
117	0	0	0	0	0	0	0,16	0,11	0	0	0	0	0,45	0	0	0,12	0,01	0	0	0	0	0	0,09	0	94,8%
118	0	0	0	0	0	0	0	0,11	0	0	0,05	0	0,45	0	0	0,12	0,01	0	0	0	0	0,15	0,09	0	99,3%
119	0	0	0	0,39	0	0	0	0	0	0	0	0	0	0,44	0	0	0,01	0,06	0	0	0	0	0,09	0	99,6%
120	0	0	0,44	0,39	0	0	0	0	0	0	0	0	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	99,5%
121	0	0	0	0,39	0	0	0	0,11	0	0	0	0	0	0	0	0	0,01	0,06	0	0,32	0	0	0,09	0	99,5%
122	0	0	0	0,39	0	0,14	0	0	0	0	0	0	0	0	0	0	0,01	0,06	0,3	0	0	0	0,09	0	98,9%

123	0	0	0	0,39	0	0,14	0	0,11	0	0	0	0	0	0	0	0	0,01	0,06	0	0	0,18	0	0,09	0	98,9%
124	0	0	0	0,39	0	0,14	0	0,11	0	0	0	0,18	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	98,8%
125	0	0	0	0,39	0	0,14	0,16	0,11	0	0	0	0	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	96,5%
126	0	0	0	0,39	0	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0,01	0,06	0	0	0	0,15	0,09	0	99,3%
127	0	0	0	0,39	0	0,14	0	0	0	0	0	0	0	0	0	0	0,01	0,06	0,3	0	0	0	0,09	0	98,9%
128	0	0	0	0,39	0	0	0	0,11	0	0	0	0	0	0	0	0,12	0,01	0,06	0	0	0,18	0	0,09	0	97,2%
129	0	0	0	0,39	0	0	0	0,11	0	0	0	0,18	0	0	0	0,12	0,01	0,06	0	0	0	0	0,09	0	97,2%
130	0	0	0	0,39	0	0	0,16	0,11	0	0	0	0	0	0	0	0,12	0,01	0,06	0	0	0	0	0,09	0	94,8%
131	0	0	0	0,39	0	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0,01	0,06	0	0	0	0,15	0,09	0	99,3%
132	0	0,33	0	0	0	0	0	0	0	0	0	0	0	0,44	0	0	0,01	0,06	0	0	0	0	0,09	0	93,4%
133	0	0,33	0,44	0	0	0	0	0	0	0	0	0	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	93,3%
134	0	0,33	0	0	0	0	0	0,11	0	0	0	0	0	0	0	0	0,01	0,06	0	0,32	0	0	0,09	0	93,3%
135	0	0,33	0	0	0	0,14	0	0	0	0	0	0	0	0	0	0	0,01	0,06	0,3	0	0	0	0,09	0	92,7%
136	0	0,33	0	0	0	0,14	0	0,11	0	0	0	0	0	0	0	0	0,01	0,06	0	0	0,18	0	0,09	0	92,7%
137	0	0,33	0	0	0	0,14	0	0,11	0	0	0	0,18	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	92,6%
138	0	0,33	0	0	0	0,14	0,16	0,11	0	0	0	0	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	90,3%
139	0	0,33	0	0	0	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0,01	0,06	0	0	0	0,15	0,09	0	93,1%
140	0	0,33	0	0	0	0,14	0	0	0	0	0	0	0	0	0	0	0,01	0,06	0,3	0	0	0	0,09	0	92,7%
141	0	0,33	0	0	0	0	0	0,11	0	0	0	0	0	0	0	0,12	0,01	0,06	0	0	0,18	0	0,09	0	91,0%
142	0	0,33	0	0	0	0	0	0,11	0	0	0	0,18	0	0	0	0,12	0,01	0,06	0	0	0	0	0,09	0	91,0%
143	0	0,33	0	0	0	0	0,16	0,11	0	0	0	0	0	0	0	0,12	0,01	0,06	0	0	0	0	0,09	0	88,7%
144	0	0,33	0	0	0	0	0	0,11	0	0	0,05	0	0	0	0	0,12	0,01	0,06	0	0	0	0,15	0,09	0	93,1%
145	0	0	0	0	0	0	0	0	0,27	0,05	0	0	0	0,44	0	0	0,01	0,06	0	0	0	0	0,09	0	93,6%
146	0	0	0,44	0	0	0	0	0	0,27	0,05	0	0	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	93,5%
147	0	0	0	0	0	0	0	0,11	0,27	0,05	0	0	0	0	0	0	0,01	0,06	0	0,32	0	0	0,09	0	93,5%
148	0	0	0	0	0	0,14	0	0	0,27	0,05	0	0	0	0	0	0	0,01	0,06	0,3	0	0	0	0,09	0	92,9%

149	0	0	0	0	0	0,14	0	0,11	0,27	0,05	0	0	0	0	0	0	0,01	0,06	0	0	0,18	0	0,09	0	92,9%
150	0	0	0	0	0	0,14	0	0,11	0,27	0,05	0	0,18	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	92,8%
151	0	0	0	0	0	0,14	0,16	0,11	0,27	0,05	0	0	0	0	0	0	0,01	0,06	0	0	0	0	0,09	0	90,5%
152	0	0	0	0	0	0	0	0,11	0,27	0,05	0,05	0	0	0	0	0,12	0,01	0,06	0	0	0	0,15	0,09	0	93,4%
153	0	0	0	0	0	0,14	0	0	0,27	0,05	0	0	0	0	0	0	0,01	0,06	0,3	0	0	0	0,09	0	92,9%
154	0	0	0	0	0	0	0	0,11	0,27	0,05	0	0	0	0	0	0,12	0,01	0,06	0	0	0,18	0	0,09	0	91,3%
155	0	0	0	0	0	0	0	0,11	0,27	0,05	0	0,18	0	0	0	0,12	0,01	0,06	0	0	0	0	0,09	0	91,2%
156	0	0	0	0	0	0	0,16	0,11	0,27	0,05	0	0	0	0	0	0,12	0,01	0,06	0	0	0	0	0,09	0	88,9%
157	0	0	0	0	0	0	0	0,11	0,27	0,05	0,05	0	0	0	0	0,12	0,01	0,06	0	0	0	0,15	0,09	0	93,4%

APPENDIX – 4. Proposed Model I

```
int nCustomer=...;        //j
int nSKU=...;             //s
int nProductgroup=...;    //k
int nProcess=...;         //p

range customer=1..nCustomer;
range SKU=1..nSKU;
range productgroup=1..nProductgroup;
range process=1..nProcess;

float profit[SKU][customer]=...;
float demand[SKU][customer]=...;
float Minkg[customer][productgroup]=...;
float Maxkg[customer][productgroup]=...;
int set[SKU,productgroup]=...;
int availablecarcass=...;
float efficiency[process]=...;
float weight[process][productgroup]=...;
int initialinventory[productgroup]=...;
float alpha[SKU][customer]=...;
float beta [SKU][customer]=...;

dvar float+ endinginventory[productgroup];
dvar float+ x[SKU,customer];
dvar float+ ratio[process];

maximize sum(s in SKU,j in customer)(x[s,j]*profit[s,j]);

subject to {
```

```
c1:
 sum (p in process)ratio[p]==1;


forall(k in productgroup)
    c2:
initialinventory[k]+(sum(p in process)availablecarcass*ratio[p]*efficiency[p]*weight[p,k])==endinginventory[k]+(sum(j in
customer,s in SKU:set[s,k]==1)x[s,j]);

forall(j in customer,k in productgroup)
c3:
Minkg[j,k]<= sum(s in SKU:set[s,k]==1)x[s,j];

 forall (k in productgroup,j in customer)
c4:
 sum(s in SKU:set[s,k]==1)x[s,j]<=Maxkg[j,k];

forall(s in SKU,j in customer)
c5:
  demand[s,j]*alpha[s,j]<= x[s,j];

forall(s in SKU,j in customer)

c6:

      x[s,j]<=demand[s,j]*beta[s,j];
c7:

sum(k in productgroup)endinginventory[k]<=150000;

c8:

0.6>=ratio[1]>=0.37;
}
```

Data-Proposed Model I

```
SheetConnection par("input.xls");
SheetConnection res("output.xls");
nCustomer=56;
nProductgroup=24;
nSKU=265;
nProcess=157;
set from SheetRead (par,"set");
profit from SheetRead (par,"profit");
demand from SheetRead (par,"demand");
Minkg from SheetRead (par,"Minkg");
Maxkg from SheetRead (par,"Maxkg");
availablecarcass from SheetRead (par,"availablecarcass");
efficiency from SheetRead (par,"efficiency");
weight from SheetRead (par,"weight");
initialinventory from SheetRead (par,"initialinventory");
alpha from SheetRead (par,"alpha");
beta from SheetRead (par,"beta");

x to SheetWrite(res,"result");
```

```
//Indices
int nCustomer=...;
int nSKU=...;
int nProductgroup=...;
int nProcess=...;
float ABW=...;
float Yield=...;
float alfa=...;
float beta=...;

//Sets
range customer=1..nCustomer;
range SKU=1..nSKU;
range productgroup=1..nProductgroup;
range process=1..nProcess;

//Parameters
float profit[SKU,customer]=...;
float demand[SKU,customer]=...;
float Minkg[productgroup][customer]=...;
float Maxkg[productgroup][customer]=...;
int set[SKU,productgroup]=...;
int availablecarcass=...;
float weight[process,productgroup]=...;
float efficiency[process]=...;
int initialinventory[productgroup]=...;
float penalty[SKU,customer]=...;
float holding[productgroup]=...;
float wholechickencap=...;
float priority[customer]=...;
int M1=...;
int M2=...;
```

APPENDIX – 5. Proposed Model II

```
//Decision Variables
dvar float+ endinginventory[productgroup];
dvar float+ x[SKU,customer];
dvar float+ g[process,productgroup];
dvar float+ z[SKU,customer];
dvar int+ h[process];

maximize (sum(s in SKU,j in customer)(x[s,j]*profit[s,j]))-(sum(s in SKU,j in customer)penalty[s,j]*z[s,j])-(sum(k in productgroup)holding[k]*endinginventory[k]);

subject to {

c2://inventory balance constraint
forall(k in productgroup){
   sum(s in SKU,j in customer)demand[s,j]*set[s,k]+endinginventory[k]==sum(p in process)g[p,k]+initialinventory[k]+sum(s in SKU,j in customer)z[s,j]*set[s,k];
}

c3://available carcass constraints
 sum(p in process:p>=2)h[p]<=ftoi(round(availablecarcass*(1-wholechickencap)));

c4:
 sum(p in process)h[p]<=availablecarcass;

c5://whole chicken constraint
forall(k in productgroup:k==1)
  sum(s in SKU,j in customer)demand[s,j]*set[s,k]>=sum(p in process)g[p,k];

c6://convertion of number of carcasses into weights for each product group
forall(p in process,k in productgroup)
  weight[p,k]*h[p]*ABW*Yield==g[p,k];
```

```
c7://Total demand constraint for all customers and SKUS on each product group
 forall(k in productgroup)
   sum(s in SKU, j in customer)x[s,j]*set[s,k]<=sum(p in process)g[p,k];

c8://Order confirmation range for each product and customer
 forall(s in SKU, j in customer)
   demand[s,j]*alfa<=x[s,j]<=demand[s,j]*beta;

c9://lost sales constraint
 forall(s in SKU, j in customer)
  z[s,j]<=demand[s,j];
}
```

Data-Proposed Model II

```
nCustomer=56;
nProductgroup=24;
nSKU=265;
nProcess=157;
ABW=2.60;
Yield=0.74;
alfa=0.4;
beta=1.6;

SheetConnection par("input2.xls");
SheetConnection res("output.xls");


availablecarcass from SheetRead (par,"availablecarcass"); //Inputs Kaynak-A
wholechickencap from SheetRead (par,"wholechickencap");  //Inputs Kaynak-A
priority from SheetRead (par,"priority"); //Inputs Kaynak-A
M1 from SheetRead (par,"MONE"); //Inputs Kaynak-A
```

```
M2 from SheetRead (par,"MTWO"); //Inputs Kaynak-A

profit from SheetRead (par,"profit"); //Inputs Karlilik Matrisi-M

initialinventory from SheetRead (par,"initialinventory"); //Inputs Devir-I
holding from SheetRead (par,"holding"); //Inputs Devir-I

demand from SheetRead (par,"demand"); //Inputs Talep Matrisi-d

set from SheetRead (par,"set"); //Inputs Urun Eslesme Matrisi

Minkg from SheetRead (par,"Minkg"); //Inputs GrupMin Matrisi
Maxkg from SheetRead (par,"Maxkg"); //Inputs GrupMax Matrisi

weight from SheetRead (par,"weight"); //Inputs weights and efficiency
efficiency from SheetRead (par,"efficiency"); //Inputs weights and efficiency

penalty from SheetRead (par,"penalty"); //Inputs penalty


x to SheetWrite(res,"result"); //output-output
```

APPENDIX – 5. Demand Confirmation Rate

	Demand Confirmation Rate %									
	First Day		Second Day		Third Day		Fourth Day		Fifth Day	
Customer No	Actual/ Demand Rate %	Model/ Demand Rate %	Actual/ Demand Rate %	Model/ Demand Rate %	Actual/ Demand Rate %	Model/ Demand Rate %	Actual /Demand Rate %	Model/ Demand Rate %	Actual /Demand Rate %	Model/ Demand Rate %
1	82%	80%	106%	93%	71%	106%	96%	100%	94%	109%
2	88%	79%	123%	101%	74%	95%	92%	98%	88%	103%
3	47%	72%	106%	106%	83%	149%	101%	92%	89%	109%
4	72%	80%	223%	113%	88%	179%	108%	93%	93%	110%
5	91%	77%	108%	97%	0%	0%	138%	103%	95%	99%
6	88%	78%	80%	96%	102%	153%	77%	96%	83%	99%
7	85%	93%	109%	117%	84%	107%	108%	87%	102%	101%
8	77%	93%	104%	112%	74%	106%	89%	89%	94%	105%
9	78%	80%	106%	113%	95%	119%	94%	100%	109%	113%
10	61%	78%	94%	114%	69%	100%	108%	98%	100%	116%
11	87%	94%	101%	108%	0%	0%	88%	86%	100%	118%
12	145%	112%	98%	104%	84%	108%	91%	104%	95%	104%

13	93%	94%	126%	109%	86%	152%	93%	82%	108%	110%
14	76%	100%	112%	119%	93%	109%	0%	0%	0%	0%
15	69%	85%	139%	90%	67%	107%	92%	88%	102%	116%
16	44%	66%	0%	0%	73%	136%	108%	85%	0%	0%
17	104%	102%	0%	0%	34%	145%	100%	120%	0%	0%
18	75%	114%	0%	0%	88%	85%	94%	115%	0%	0%
19	32%	97%	108%	89%	91%	111%	96%	85%	103%	105%
20	81%	84%	157%	121%	88%	75%	121%	109%	75%	105%
21	41%	58%	40%	67%	49%	84%	64%	76%	108%	38%
22	82%	81%	93%	150%	49%	137%	97%	111%	97%	105%
23	91%	78%	303%	72%	136%	87%	45%	78%	43%	67%
24	81%	77%	95%	105%	90%	109%	97%	113%	100%	114%
25	73%	88%	92%	170%	44%	91%	103%	160%	127%	177%
26	88%	77%	91%	103%	83%	77%	89%	94%	84%	113%
27	96%	80%	146%	91%	42%	101%	98%	92%	100%	115%
28	78%	85%	178%	94%	77%	98%	92%	97%	107%	107%
29	61%	95%	91%	103%	0%	0%	89%	85%	120%	112%
30	73%	84%	74%	148%	0%	0%	123%	110%	91%	196%
31	82%	105%	94%	148%	39%	36%	71%	146%	100%	149%
32	62%	80%	120%	109%	88%	90%	99%	64%	125%	146%
33	43%	96%	96%	114%	62%	104%	65%	61%	88%	101%
34	79%	71%	85%	149%	62%	89%	69%	108%	87%	148%
35	88%	90%	98%	117%	0%	0%	89%	101%	98%	123%

36	58%	90%	92%	103%	100%	110%	98%	99%	85%	118%
37	84%	92%	92%	105%	100%	120%	94%	111%	81%	101%
38	103%	108%	93%	96%	0%	0%	95%	109%	96%	100%
39	83%	113%	95%	119%	0%	0%	139%	112%	0%	0%
40	92%	91%	96%	99%	165%	120%	96%	108%	100%	109%
41	94%	84%	0%	0%	58%	105%	90%	119%	0%	0%
42	98%	98%	120%	113%	64%	96%	101%	113%	126%	115%
43	84%	93%	97%	104%	72%	108%	93%	113%	95%	109%
44	89%	100%	75%	109%	67%	101%	98%	84%	110%	181%
45	85%	96%	117%	141%	98%	118%	99%	140%	96%	174%
46	94%	108%	113%	132%	88%	102%	90%	103%	123%	151%
47	67%	82%	107%	110%	0%	0%	141%	110%	88%	110%
48	100%	162%	114%	108%	84%	82%	100%	106%	114%	111%
49	100%	167%	0%	0%	241%	200%	0%	0%	0%	0%
50	100%	110%	136%	156%	0%	0%	100%	113%	100%	150%
51	100%	103%	104%	113%	0%	0%	100%	95%	100%	109%
52	100%	109%	0%	0%	71%	104%	0%	0%	0%	0%
53	100%	98%	0%	0%	43%	93%	100%	111%	100%	210%
54	100%	200%	0%	0%	84%	99%	0%	0%	0%	0%
55	249%	184%	0%	0%	71%	83%	0%	0%	0%	0%
56	0%	0%	148%	109%	54%	88%	139%	113%	113%	108%
Result	**73%**	**87%**	**110%**	**113%**	**84%**	**108%**	**104%**	**100%**	**102%**	**121%**

APPENDIX – 6. Ending Inventory

		Model Ending Inventory				
Product No	Product Group	First Day	Second Day	Third Day	Fourth Day	Fifth Day
1	WHOLE CHICKEN	15742				0
2	FILLET	44943	42943		40576	49487
3	WHOLE LEG					
4	BREAST WITHOUT FRONT			10099		4040
5	WHOLE WINGS					
6	DRUMSTICK		7	13832	13296	
7	BONELESS THIGH	25321	22807	25		29810
8	BACK PIECE	35195	25298	26665	37629	29232
9	STEAK		1529			
10	INNER FILLET	1667		2234	1263	375
11	SKIN					
12	LEG RIP			10903		
13	WHOLE BREAST					
14	WHOLE LEG 2		899	31220	21043	244
15	2nd JOINT	2275	2763			
16	DRUMSTICK WITHOUT	19800	23921	22305	20772	21676
17	TIPS	3075	10198	2243	2879	2383
18	FRONT PIECE					

19	THIGH WITH BACK PIECE		568			568
20	LEG WITHOUT BACK PIECE		3695			
21	THIGH			19043	857	11930
22	SKINLESS THIGH		3452			250
23	WINGS WITHOUT TIP		337		1329	
24	1st JOINT	1978	11576	11425	10351	
Sum		149996	149993	149994	149995	149995