DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PRODUCTION DISTRIBUTION PLANNING IN CONSUMER GOODS INDUSTRY

by
Yelda ÇELEBİ

February, 2012
İZMİR

PRODUCTION DISTRIBUTION PLANNING IN CONSUMER GOODS INDUSTRY

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We have read the thesis entitled **"PRODUCTION DISTRIBUTION PLANNING IN CONSUMER GOODS INDUSTRY"** completed by **YELDA ÇELEBİ** under supervision of **ASSOC. PROF. DR. BİLGE BİLGEN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Yelda ÇELEBİ

PRODUCTION DISTRIBUTION PLANNING IN CONSUMER GOODS INDUSTRY

ABSTRACT

In this thesis, we present a hybrid solution methodology based on a MILP formulation and a simulation for production scheduling and distribution problem in dairy industry. An efficient solution method for perishable products is developed by considering stochastic factors in food industry. A real life dairy industry producing yoghurt is studied in detail in this study.

In food industry, increasing variety of products causes more complex production process which requires flexibility and efficient assignment of resources. Production process of multiple products in more than one production sites and distribution of them involves many variables and constraints.

Shelf life is one of the significant constraints for perishable products such as dairy, meat or bakery goods in food industry. However, shelf life issues are seldom accounted for in today's production planning systems. This research is supported by an application in yoghurt production plant of a leading dairy product manufacturing company.

In analytic models proposed to solve production planning problems, operation time is assumed as fixed values. However, uncertain factors such as breakdowns, operation time, delays of real systems cannot be correctly represented in analytic model. In addition, in yoghurt production process, the products differ from each other in features such as cup size, due dates, set up times, fat content etc. This variability enforces the scheduling methodologies practical for real world applications. To overcome with this problem, hybrid analytic-simulation approach is proposed by combining the analytic and simulation model. Analytic model is developed for decreasing the cost of setup, transportation, production, inventory and overtime. Simulation model is applied to insert the stochastic factors such as operation time, delays or machine failures in the model.

In hybrid approach, operation time is considered as dynamic factor and it is adjusted by the results simulation and analytic model iteratively. Thus, more realistic solution is obtained for scheduling problem in food industry by performing the iterative hybrid analytic-simulation procedure.

Keywords: Food industry**,** perishable products, scheduling problem, MILP, yoghurt production, shelf life, simulation, hybrid approach

TÜKETİM MALLARI ENDÜSTRİSİNDE ÜRETİM DAĞITIM PLANLAMA

ÖZ

Bu tezde, süt ve süt ürünleri endüstrisinde üretim çizelgeleme ve dağıtım problemi için Karışık Tamsayılı Doğrusal Programlama ve Simülasyon modelini esas alan hibrit çözüm yöntemi ortaya koyulmuştur. Süt ve süt ürünleri endüstrisinde, kolay bozulabilen ürünler için değişken faktörleri dikkate alan etkili bir çözüm yöntemi geliştirilmiştir. Gerçek bir süt ve süt ürünleri endüstrisinde yoğurt üretimi detaylı olarak çalışılmıştır.

Gıda endüstrisinde, artan ürün çeşitliliği esneklik ve etkili kaynak yönetimi gerektiren üretim süreçlerinin daha karmaşık olmasına sebep olur. Birçok ürünün birden fazla üretim sahasındaki üretimi ve ürünlerin dağıtım süreci birçok değişken ve kısıt içermektedir.

Gıda endüstrisinde, raf ömrü süt, et ya da unlu mamuller gibi kolay bozulabilen ürünler için önemli kısıtlardan biridir. Ancak, günümüzdeki üretim planlama sistemlerinde nadiren dikkate alınmaktadır. Bu çalışma, süt ve süt ürünleri üretiminde lider şirketlerden birinde, yoğurt üretimi alanında yapılan bir uygulamayla desteklenmektedir.

Üretim planlama problemleri için önerilen analitik modellerde, operasyon süreleri sabit değerler olarak kabul edilmektedir. Bu yüzden bozulmalar, operasyon sürelerindeki değişiklikler ve gecikmeler gibi değişken faktörler analitik modelde doğru şekilde gösterilememektedir. Ek olarak, yoğurt üretim sürecinde ürünler kase boyutu, teslim süreleri, ayar süreleri ve yağ oranları gibi özellikler bakımından birbirlerinden farklılık göstermektedir. Bu çeşitlilik çizelgeleme yöntemlerini gerçek sistemlerde uygulanabilir olmaları yönünde zorlamaktadır. Bu problemle başa çıkabilmek adına analitik ve simülasyon modelini bir arada kullanan hibrit analitik-simülasyon yaklaşımı önerilmiştir. Analitik model ayar, taşıma, üretim, stok ve fazla mesai maliyetlerini minimize etmek amacıyla geliştirilmiştir. Simülasyon ise, operasyon süreleri, gecikmeler ya da makine bozulmaları gibi değişken faktörlerin modele dahil edilebilmesi başvurulmuş bir yöntemdir.

Hibrit yaklaşımında, operasyon süreleri dinamik faktörler olarak ele alınır ve ardışık olarak analitik model ve simülasyon modeli sonuçlarına göre ayarlanmaktadır. Böylece gıda endüstrisinde üretim çizelgeleme problemi için ardışık hibrit analitik-simülasyon yöntemi ile daha gerçekçi bir sonuç edilmektedir.

Anahtar Kelimeler: Gıda endüstrisi, kolay bozulabilen ürünler, çizelgeleme problemi, karışık tamsayılı doğrusal programlama, raf ömrü, simülasyon, hibrit yaklaşım

CONTENTS

Page

CHAPTER ONE
INTRODUCTION

In process industry, food production is one of the oldest types. In the beginning of the previous century, it leaped from the small, rural scale to the industrialized national and later international level (Doganis and Sarimveis, 2008). While companies aim to make profit by only selling their products at the beginning, the aggressive competition forced them to reduce production costs.

The increasing of production amounts from hundred kilos to millions of tones per year and product variability require companies to reduce costs such as labor, storage, transportation etc. to augment their profitability. Bulk product loss, long set up times, idling of machinery, nonproductive use of workforce prevent the successful respond to demand and cause the rising of costs. Therefore, scheduling tools are applied to cope with the complexity.

The benefits offered by scheduling tools (cost reduction, improved management of equipment, time, manpower) made it possible to continue meeting production targets and at the same time achieve significant cost improvements through more efficient planning and scheduling of actions (Doganis and Sarimveis, 2008). Several constraints encountered in everyday such as machine time, working hours, production targets make scheduling problem more complicated.

Another difficulty in the food industry is the limited shelf life of products that Make-to-Stock system is impractical for responding to demand. Shelf life is defined as the duration between producing a product and using it, for which the product remains safe and acceptable to user (Doganis and Sarimveis, 2008).

In food products, shelf life is a significant characteristic for the customer. The freshest one of the same products is always preferred by the customer. For that reason, retail do not display products that have different expiration date at the same time.

If a sale of product is less than its forecast, than products can be away from the expiration date and the non fresh products are separated as wastage. So the retailer and the industry determine an acceptable shelf life level that is the least remaining duration until the expiration date. The possibility to offer a higher shelf life than its competitors constitutes a pivotal competitive advantage for fresh food producers, making the provision of shelf life functions crucial for modern production planning systems (Entrup et al, 2005). In food industry, fresh products such as dairy, meat, bakery goods have a significant part. Figure 1.1 shows the distribution of milk and milk products in food industry in Turkiye.

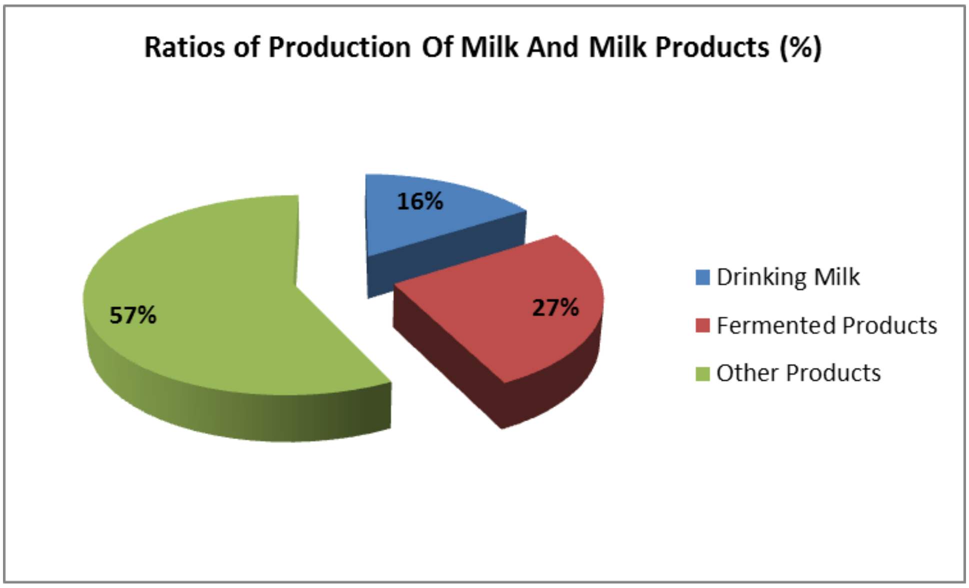


Figure 1.1 The ratios of production of milk and milk products

According to the results of the research made in 2010 January-2011 August by TUIK, %27 of milk product is belong to the fermented products. In perishable products industry including dairy, meat, or bakery goods, the consideration of shelf life has a major importance in production planning. Perishable food industries are industries that primarily produce food products with a short shelf life which is considered "short" if it is in a range from several days up to 2-3 months. Shelf life restrictions directly influence wastage, inventory levels and out-of-stock rates in the retail outlets, furthermore consumers tend to buy the product with the longest possible shelf life (Entrup et al, 2004).

Several researches have been done in food industry for perishable products. Dairy products are the most popular category in terms of consumption. Figure 1.2 shows the relative rate of perishable food production in Turkiye.

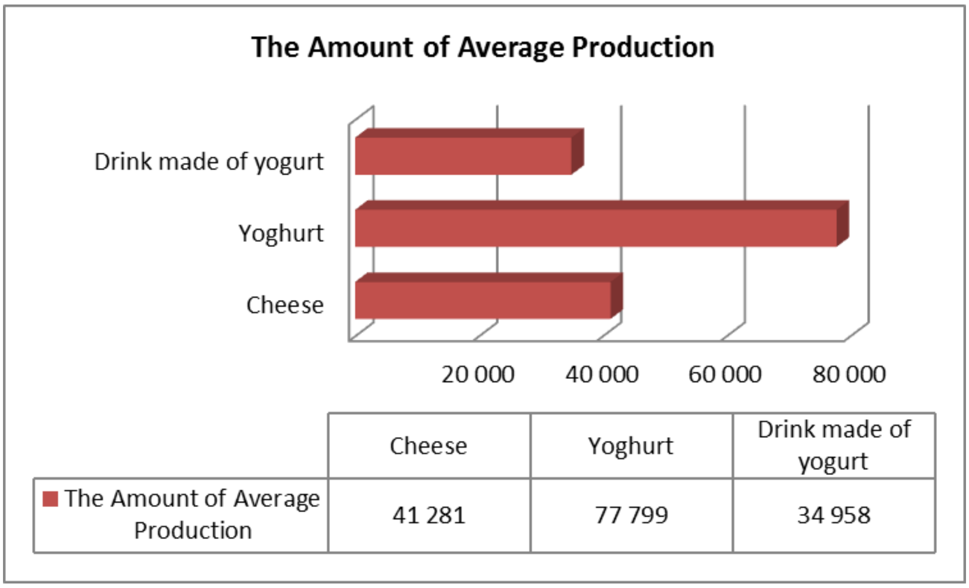


Figure 1.2 Average production of fermented products

Within the dairy fresh products, most categories belong to fermented products (Entrup et al, 2005). Milk products prepared by lactic acid and yeast fermentation are called fermented or cultured milks. The fermentation of milk is a fairly simple, cheap, and safe way to preserve milk (Walstra et al. 1999).

Yoghurt is the most popular of all cultured-milk products all over the world. Buttermilk, kefir, or sour milk also are fermented products besides yogurt. Yogurt has been a common product for years. Mostly during the previous century how-ever, production shifted from small family-run workshops that produced for local markets to large, world-scale factories that supply many national markets (Doganis and Sarimveis, 2007).

In yogurt production industry, the products have different features like fat content, the size of the container or the language on the label etc. The increasing variety of yogurt products forces the industry to respond to demands in complex scheduling which requires flexibility and an efficient coordination. Product features make harder to determine the efficient scheduling paths by increasing complexity.

In recent years, most planning techniques have examined for perishable products industry whose complexity come from short shelf life. Besides this complexity, the variability in demands, machine utilization, benefit with respect to freshness, incapacity of facility, overtime cost make harder to determine optimal scheduling program.

To implement the scheduling program in real world, the model should consist of deterministic and stochastic factors together. Most of the real problem are not appropriate to apply a solution obtained by analytic model. Because a production system can has a wide variety of dynamic behaviors. Therefore, simulation can be preferred when an analytic solution cannot give proper values for solutions.

In order to solve the problem, a hybrid method is developed by combining the analytic and simulation model. The model is formulated as an analytic model that minimizes the overall cost. The operation times of lines are considered as stochastic factors in simulation model.

A mathematical model aims to decrease the cost of set up, production, inventory, distribution and transportation. Because of stochastic factors such as unexpected delays, queuing and machine failure, operation time provided by mathematical model cannot reflect dynamic characteristic of real-world systems and optimal solution of mathematical model is not acceptable in practice (Safaei et al, 2010).

In this reseach, we design and implement a hybrid approach for solving a production planning problem that considers deterministic and stochastic factors together to minimize overall cost. In the previous scheduling related literature a scheduling problem for yoghurt production process has not been solved by hybrid analytic-simulation approach.

The outline of the thesis is explained as following. In Chapter 2, literature of production scheduling and yoghurt production process are mentioned. Problem definition is explained in Chapter 3. Chapter 4 refers to model formulation in MILP. In Chapter 5, proposed solution methodology is presented. Numerical example and computational results will be explained in Chapter 6. Conclusin is summarized in Chapter 7.

CHAPTER TWO
LITERATURE

In recent years, there has been great interest in the development of intelligent solutions for production scheduling (Doganis and Sarimveis, 2007). Production scheduling is more challenging process in food industry compared to other sectors. The features of food industry are not suitable for working unlimited product inventory and resource. For this reason, scheduling process keeps its popularity for researchers for years.

The effective factors such as strong competition in especially dairy food market, product variaty and short shelf lives force the companies for more flexible utilization of resources, faster response to product, technology or demand changes while reducing production costs, increasing throughput.

Günther and Neuhaus (2004) worked a block planning principle considering both lot sizing and scheduling. For reducing the complexity of model, several variants of a product type and recipe are integrated into a block. The sequence of batches in the block is determined by changeover features used in common, for example, from lighter colour to darker.

In literature, most models are organized as assuming unlimited storage of finished products. Approaches that ignore shelf life of product are not practical in food industry. Many authors such as Kallrath (2002), Günther and Neuhaus (2004), point out the necessity of shelf life in production planning and scheduling. Soman et al. (2004) integrate shelf life constraint into the Economic Lot Scheduling Problem. They use constant production rate in their model because of the quality problems which occur by changing the production rate. The backordering is not allowed in the model. Viswanathan and Goyal (2000) study in backordering in Economic Lot Scheduling Problem by considering shelf life.

In food industry, yoghurt is one of the most popular products that is studied on in dairy products. Yoghurt products show characteristics in two ways. The value of yoghurt decreases over time as customers give a higher value to a fresh product; on the other hand, yoghurt is almost worthless after the date of expire (Entrup et al., 2005). Entrup et al. (2005), develop an Mixed-Integer Linear Programming (MILP) model that considers shelf life issues in production planning and scheduling. Three different model formulations that rely on the principle of block planning for weekly production planning are presented for fresh food industry.

Scheduling systems usually include the following capabilities: assignment of tasks to equipment, sequencing of tasks on machines, and event timing (Doganis and Sarimveis, 2008). In food industry, transitions cause significant losses in production time and considerable costs. That is why changeover between products cannot be neglected.

The authers such as Chen et al. (2002), Gupta and Karimi (2003), Lim and Karimi (2003), Giannelos and Georgiadis (2003), Janak et al. (2004) (Doganis and Sarimveis, 2008), present methodologies that include sequence-dependent changeovers considering only set up time, ignoring the cost involved.

There are also researches that focus on side aspects of production scheduling, like environmental effects of production tasks and scheduling of workforce. For instance, Berlin et al. (2007), study a heuristic to arrange products to minimize the environmental impact of yoghurt products in their life cycle.

Doganis and Sarimveis (2007), define a study for scheduling of parallel machines by considering due dates and changeovers. Although the research includes in features of products, due dates, product-specific machine speed, minimum lot sizes, sequence dependent changeover times and costs, it ignores the freshness of product. Therefore, Doganis and Sarimveis (2008), combine their model according to minimizing time duration between production and delivery of products to the retailers.

In supply chain planning, it is common to use discrete-event simulation and mixed-integer linear programming. This procedure is applied iteratively until the difference between subsequent solutions is small enough. (Almader et al, 2009). Problems can be solved in more realistic way by using this model. Miller and Park (1998) analyze coffee production with limited shelf life by using discrete event simulation in production scheduling.

Kopanos, Puigjaner, Georgiadis (2010) focus on the lot-sizing and production scheduling problem in a multiproduct yogurt production line of a real-life dairy plant. In this research, a new mixed discrete/continuous-time mixed-integer linear programming model, based on the definition of families of products, is proposed to enhance the production capacity and flexibility of the plant by considering sequence-dependent times and costs.

Kopanos, Puigjaner, Georgiadis (2011) present an alternative MIP-based solution strategy for dealing with large-scale food processing scheduling problems and considers renewable resource constraints. The method they proposed does not guarantee global optimality but decreases the computational requirements. They represents several problems for computational performance and practical benefits of proposed method. Kopanos, Puigjaner, Georgiadis (2011) present another research on an ice-cream production process. They proposed a MIP model to optimize all processing stages by reducing the production cost for final products.

Amorim et al. (2011) studies hybrid genetic algorithm to solve two different MIP models for the multi-objective lot-sizing and scheduling problem by considering perishability constraints. Multiple objectives consist of production costs and freshness of products. They support their research with a real life application.

Ahumada and Villalobos (2009) present an integrated tactical planning model for the production and distribution of fresh produce. A mixed integer programming model is used for making planning decisions by considering the perishability of the crops in two different ways as a loss function in its objective function, and as a constraint for the storage of products.

Marinelli et al (2007) propose an exact model and a heuristic solution approach for a capacitated lot sizing and scheduling real problem in yoghurt production industry. The problem is formulated as hybrid Continuous Set-up and Capacitated Lot Sizing Problem in paper. The minimization of inventory, production, and machine setup costs are aimed in the model, however sequence-dependent costs and times are not considered. Ferreira, Morabito and Rangel (2009), present a mixed integer programming model that integrates production lot sizing and scheduling decisions in beverage industry by considering sequence dependent set-up time and cost.

CHAPTER THREE
PROBLEM DEFINITION

In this thesis we address the production scheduling and distribution planning problem in a yoghurt production line of the multi product dairy plants.

3.1 Yoghurt Production Process

Yoghurt is semisolid fermented product made from standardized milk mixed with a symbiotic blend of yoghurt culture organisms (Chandan and Shahani, 1993). Yoghurt is classified in two main types as common: set and stirred yoghurt. While Set yoghurt is incubated and fermented in the retail cups, stirred yoghurt is fermented before packaging (Entrup et al, 2005). In addition, nuts and flavors can be added to stirred yoghurt.

Besides these two main types yoghurt is typically classified as follows:

- ***Set type*** incubated and cooled in the package,
- ***Stirred type*** incubated in tanks and cooled before packing,
- ***Drinking type*** similar to stirred type, but the coagulum is “broken down” to a liquid before being packed,
- ***Frozen type*** incubated in tanks and frozen like ice cream,
- Concentrated incubated in tanks, concentrated and cooled before being packed. This type is sometimes called ***strained*** yoghurt, sometimes labneh, labaneh. (Dairy Processing Handbook/chapter 11)

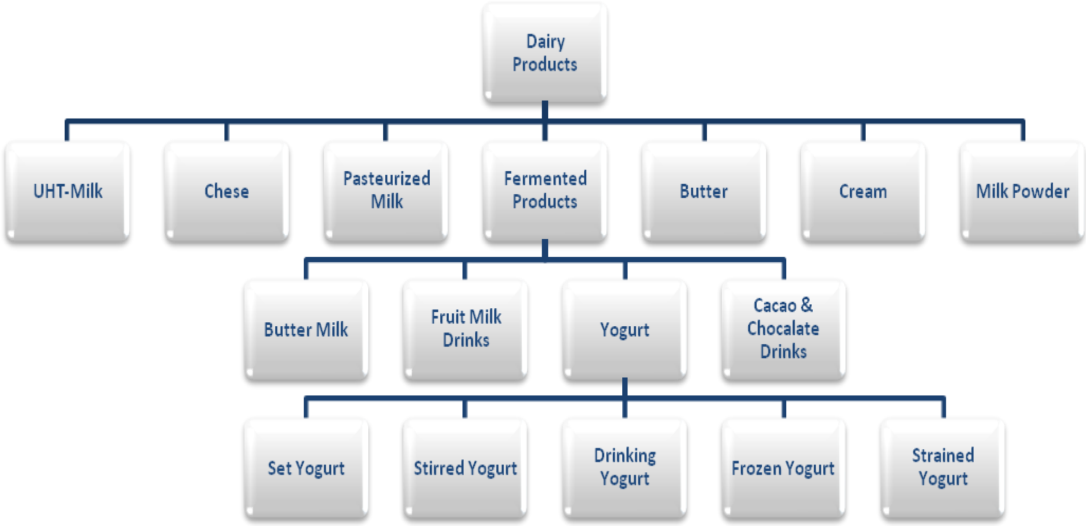


Figure 3.1 Production range in dairy food industry

The success of yogurt can be attributed to the following factors (Chandan and Shahani 1993, Tamime and Robinson 1999):

- Health-related glamour of fermented milks and increase of low fat products,
- Achievement of a desirable taste by using special sweeteners,
- High versatility of taste, color, and texture
- Intense marketing and merchandizing activities,
- Relatively low costs of the product, and
- Longer shelf life than fresh milk.

Numerous factors must be carefully controlled during the manufacturing process in order to produce a high-quality yoghurt with the required flavour, aroma, viscosity, consistency, appearance, freedom from whey separation and long shelf life (Dairy Processing Handbook/chapter 11):

- Choice of milk
- Milk standardisation
- Milk additives
- Deaeration

• Homogenisation
• Heat treatment
• Choice of culture
• Culture preparation
• Plant design

In this investigation, set yoghurt is focussed. The production process of set yoghurt is described in 8 main steps.

3.1.1 Collecting Raw Milk

Milk used for yoghurt production must have a low content of bacteria and must not contain antibiotics, bacteriophages. Therefore the dairy must collect milk from selected producers and very carefully analysed milk for yogurt production. Raw milk has several unique characteristics that make the dairy SC and production system different from other fresh food production systems (Rosenthal 1991, Tamime and Robinson 1999, Walstra et al. 1999):

- ***Highly perishable :*** Raw milk has no protection from outside contamination and is a great culture environment , which has the optimal conditions for boosting populations of microorganisms. Therefore, milk should be produced in a clean environment to prevent contamination and should be kept at a temperature of 4°C along the entire transportation chain from the farm to the dairy plant.

- ***The variation of composition of the raw milk:*** The main components of milk are water (mainly), fat, protein, lactose, and minerals (Kopanos et. al., 2010). The chemical composition of fresh milk varies from day to day depending on various factors such as the stage of lactation, age and breed of the cow, milking intervals, season of the year, climate temperature, nutrition and hormones. (e.g. with regard to fat and protein content) from day to day, even within a particular breed, depending on such factors as the breeding policy, the age of the animal, the health of the udder, the feeding management, climatic conditions and seasons of the year, and also on the intervals between milking.

- ***Varying quantities :***. As the raw milk must be processed within a very short time, processing capacity of a dairy can never be fully used during most of the year.

- ***Several components:*** that can be in various ways (e.g. cream and skim milk, powder and water etc.) so that a wide various products can be made by separating raw milk into several components (e.g. cream and skim milk, powder and water etc.)

Milk is normally collected twice a day from the cow and cold-stored at the farm in a milk tank (Rosenthal 1991). Milk is collected on a daily basis from the farms and transferred to the factory by trucks with cooled conteiners. The main components of milk are water (mainly), fat, protein, lactose, and minerals (Kopanos et. al. 2009). The chemical composition of fresh milk varies from day to day . To remove variations of the chemical compositions of fresh milk depending on the breeding policy, the age of the animal, the health of the udder, the feeding management, climatic conditions and seasons of the year, the intervals between milking and ensure better final product quality, milk collected from farms is analyzed by taking a sample for the chemical and microbiological analysis and classified according to its specialities in silos that keep milk cooled below 5°C. Milk which is suitable for fermentation is pumped into refrigerated silos, where it is stored temporarily. Silos are covered with isolation material and have an agitation system to keep milk which belong to different batches in a certain level. In some cases, the raw milk is clarified prior to storing, meaning that solid impurities are removed from the milk by filtration or centrifugal separation (Rosenthal 1991). Generally, the raw milk should not remain in the raw milk silo longer than one or two days (Walstra et al. 1999).

3.1.2 Pasteurization

The second step of yoghurt production is pasteurization process. The removal of contaminants such as straws, leaves, hair, seeds and soil from the fresh milk forms the important part of hygiene standards. Centrifugal clarification, the most common method, is used for the filtration of milk. Filtered milk continues to heat processing named Pasteurization to kill pathogenic bacteria. The pasteurization process is based on the use of different time and temperature relationships. Milk is pasteurized at 161°F (72°C) for 15 seconds which defined High-Temperature-Short-Time Treatment (HTST). Pasteurized milk is stored in silo tank temprorily for the next process.

3.1.3 Standardization

The next step of yoghurt production is standardization process. Because the variations of fat content in milk, standardization process is needed to meet the compositional standards for yoghurt. Two types of standardization method are used in order to enhance the quality of the final product:

- The fat content in the milk is standardized.
- The solids-not-fat content in the milk is standardized.

Standardization can be done by removing part of the fat content from milk, mixing full cream milk with skimmed milk, adding cream to full-fat milk or skimmed milk, addition of milk powder in order to adjust the compositional standards. Milk powder is widely used in the industry to fortify liquid milk for the manufacture of a thick smooth yogurt. Although different milk powders can be used, skim milk powder is the most widely applied (Tamime and Robinson, 1999). Standardized milk is transfered to refrigerated storage tank where the samples are analyzed for suitability of fat content, ph and density.

3.1.4 Homogenisation and Heat Treatment

Milk, which has optimal properties for yoghurt, is sent to the pasteurization process in order to destroy pathogens and other undesirable microorganisms which can be activated during standardization and transferring process. After pasteurization the sterilized milk is pressed through a homogenizer. The main reasons for homogenising milk are to prevent creaming during the incubation period and to assure uniform distribution of the milk fat.

Homogenisation process provides fat globules in milk to split into pieces and inhibites the cream accumulated surface of yoghurt.Also, homogenisation with subsequent heating at high temperature, usually 90 – 95°C for about 5 minutes, has a very good influence on the viscosity (Dairy Processing Handbook/chapter 11).

The homogenization phase contributes to;

- a whiter and more attractive milk color,
- an improved mouthfeel of the product, and
- an increased milk viscosity (Kopanos et al., 2009).

Homogenized milk is transferred to plate heat exchanger where it is again heated to 85-90°C in a holding tube, cooled and transferred to the fermentation tanks (Tamime and Robinson, 1999). The milk is heat treated before being inoculated with the starter culture in order to (Dairy Processing Handbook/chapter 11):

- improve the properties of the milk as a substrate for the bacteria culture,
- ensure that the coagulum of the finished yoghurt will be firm,
- reduce the risk of whey separation in the end product.

Homogenized milk is storaged for analyzing of homogenity and protein denaturation test.

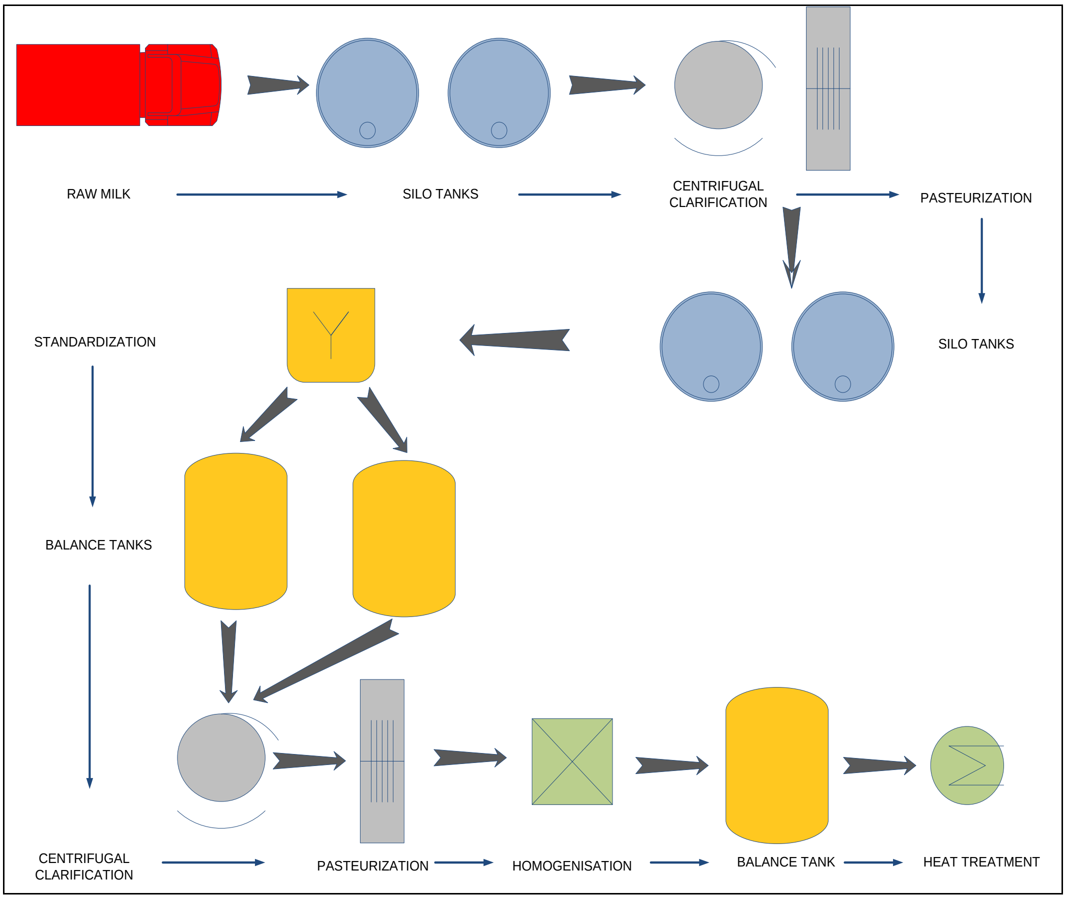


Figure 3.2 The required processes for transforming raw milk to yoghurt milk

3.1.5 Culture Addition

Culture addition process starts with the preparation of culture. Before culture is sent to line, it is mixed with water. This mixture is pasteurized and cooled in suitable temperature. The fermentation time varies according to the temperature, the final product type, and the concentration of the starter cultures in the mix. The starter culture influences not only the quality of the product, but also the fermentation time. Depending on the type of the starter concentrate (bulk or frozen), the kind of product, and the fermentation temperature, the fermentation time varies between 2.5-3.0 hours at 40-45°C and 16 hours at ca. 30°C (Tamime and Robinson, 1999).

Homogenized milk and culture are sent to the dosing pamp in order to mix the ingredients in certain percentage. The mixture including homogenized milk and culture moves in the line to the packaging machines.

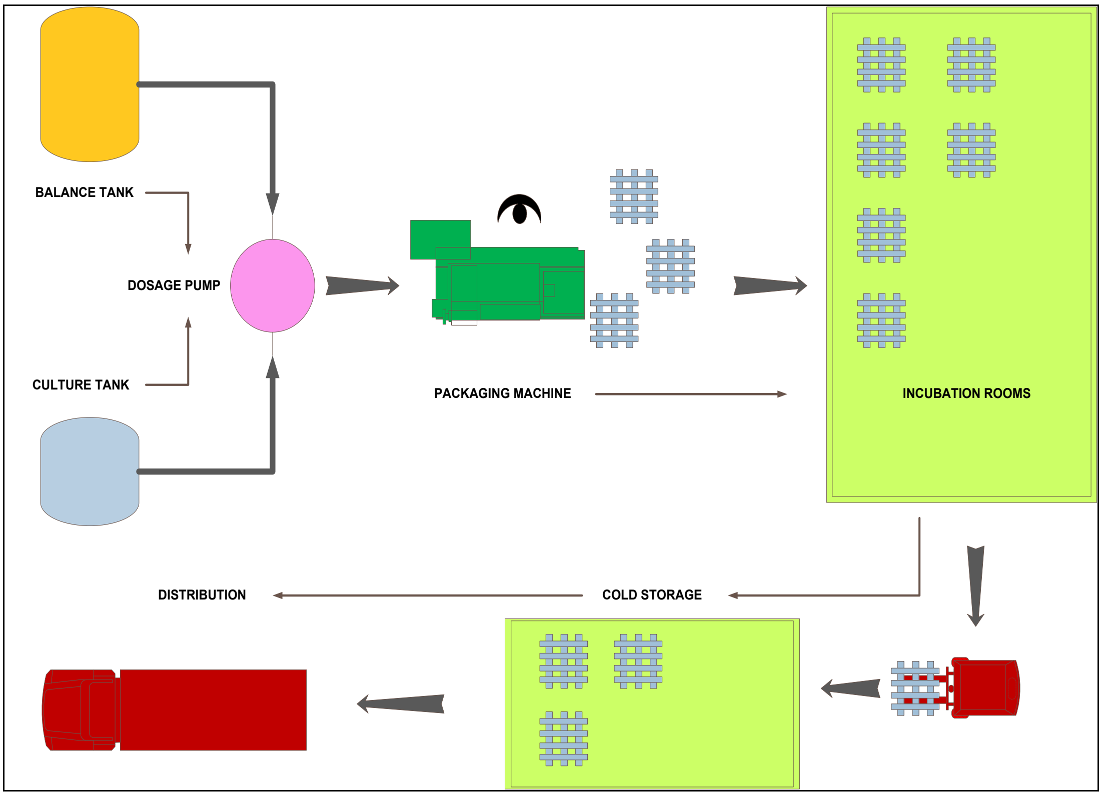


Figure 3.3 Production process of yoghurt milk for packed yoghurt products

3.1.6 Packaging

The next process is filling and packaging that are performed in parallel packaging machines. The machines can pack many different type of final products which have different characteristics depending on cup size, cup type, labeling, yogurt type, and so on. The packaging units sterilize and clean the packaging material before filling the cups with yoghurt mixture and closing them with a lid. The packaging lines differ from eachother with respect to cup size or yoghurt type such as full-fat, half-fat or light yoghurt.

3.1.7 Fermentation

The packaged milk is delivered to incubation rooms, where the fermentation process starts. The fermentation time can vary significantly depending on the temperature, the final product type, and the concentration of the starter cultures in the mix. Milk is brought to the incubation temperature (around 30–40°C) and the bacterial cultures are activated for fermentation process. The products are controlled by ph analysis periodically during the incubation. After the ideal pH-value has been reached, to stop further developement of bacteria, cooling to 15 – 22°C (from 42 – 43°C) should be accomplished within 30 minutes to attain optimum quality conditions. The packaged yoghurt products that reach the required spesifications are transferred the cold storages.

3.1.8 Cold Storage and Distribution

The last process of the final product is cooling storage operation. The final product which completes its fermentation process is sent to storages where the tempreture is below 10°C since yoghurt organisms show only limited growth below this temperature. The stored products are subjected to quality control process that is taken 2 days. The final products which achive the quality control analysis are ready for distribution.

A dairy plant could distribute final products to customers by refrigerated vehicles that transport yogurt with special recommendations, because inappropriate refrigeration and/or high shaking of the yogurt can lead to a reduction in viscosity, and thus to quality deterioration.

3.2 Production Scheduling Problem in Yoghurt Production Process

Production scheduling problem in food industry is different from other industries. In food industry, especially for perishable products, holding inventory is dangerous because of shelf life constraint. Scheduling of yoghurt production process is affected from uncontrollable factors like seasonality, suitability of raw milk, fermentation time etc. Yoghurt production process starts with collection of milk and continues with Pasteurization, standardization, homogenization, Culture addition, packaging, fermentation, Cold Storage and Distribution processes respectively. Yoghurt product types differ from each other according to fat rate of milk and cup sizes. While cup size is determined in packaging operation, fat rate is arranged with standardization operation. The packaging process is considered in scheduling problem. The other operations in process are assumed infinite.

Production scheduling is also interrelated with a part of transportation problem. The demand collected from customers is determined the quantity that the production model should produce. Although it is an important factor, it is not enough for production scheduling. Because the production system has two factories that show similar production features in different positions. The demands with certain due dates are collected from distribution centers located in different cities. They are assigned to factories according to the distance between distribution center and factory for decreasing transportation cost to maximize revenue. Moreover, all products produced in the production system are stored at storage points in the factories until they are transferred to distribution centers. Due to shelf life of perishable products, there are hard limitations about storage period. Also, storing with long time has an influence on customer preference that affects benefit adversely.

In addition, sequence dependent set up times are considered in the system. There are strong limitations for product sequence. The product order should be follow increasing low fat level on lines. For instance, light yoghurt should be produced before the full-fat yoghurt on the same line. For optimal scheduling program, a MILP formulation is applied to satisfy the customer and producer together.

The problem that is investigated in this thesis has the following structures:

1. The demand for each product in each day is collected from distribution centers respectively. The scheduling horizon is supposed as 5 days.

2. The changeover time and cost are involved for all possible transitions between products.
3. All kinds of products cannot be produced on all machines. Machines are categorized with respect to capabilities for certain products.
4. The time for quality control process is considered in the model. It is not allowed that the products are not delivered before they complete required time for quality control process.
5. The freshness that has a significant part in competition is taken into account for profitability.
6. Inventory holding cost is figured out for each line for every additional hour except regular working hours.
7. Operation cost for two products that can be produce at the same machine differs from each other. Therefore, the operation cost is computed for each product and machine one by one.
8. The available working hours for lines are defined according to shifts.
9. The production speed of each product is changeable in the same machine. It is an important factor for production scheduling.
10. Unmet demand is considered in MILP model. The unmet quantity of a demand is transferred to the following day. In addition, it causes a cost for every additional day.
11. Overtime is available for all lines in six days of a week. If it is needed, overtime can be planned for related line and product.

Key decision variables to be made are:

1. The quantities of each product are computed for every day and line.
2. The starting time and finishing time of a product type in a line is determined.
3. The inventory of each product at the end of day is obtained.
4. The unmet demand quantity can be achieved for product types.
5. The utilization of lines is acquired for regular condition.

The products are assigned related lines on MILP model. Each line has different speed for different products. In MILP model, the production speeds are set a distinct value. In real world system, operation times cannot be considered as fixed values. In MILP model, variations in operation times such as machine breakdowns and unexpected down times cannot be considered. For that reason, simulation is used for taking into consider the down times and obtain more realistic solution.

In achieving real solution, simulation and MILP model are evaluated together for production scheduling problem in yoghurt production process.

CHAPTER FOUR
MODEL FORMULATION

The mathematical model determines the optimal scheduling program to maximize the benefit by considering costs and the shelf life of products. The production scheduling and the distribution of orders among factories are considered in the model in yoghurt industry. The problem is formulated as a mixed integer linear program (MILP) explained as follows.

Indices

i	days
d	demand days
j,k,t	products
l	lines
a	distribution centers

Parametres

benefit(j)	maximum benefit for meeting the maximum shelf life of product *j*, in TL/unit
cr(j)	critical rate for shelf life that customer approve for product *j*, in % of maximum shelf life
sl(j)	shelf life of product *j*, in day
varc(j,l)	variable cost for the production of one unit of product *j* on line *l*, in TL/unit
storagecost(j)	inventory cost for one unit of product *j* for a day, in TL/unit
udc(j)	cost of unmet demand for product *j*, in TL/unit
setupcost (j,k)	changeover cost from product *j* to product *k*, in TL
oc(l)	cost for overtime of line *l* per unit of time, TL/hour

TC(a,l)	cost for transportation from plant including line *l* to distribution center *a*, in TL/unit
de(j,d,a)	demand from distribution center *a* for product *j* on demand day *d*, in unit
qq(j)	required time for quality control operation for product *j*, in day
cap(j,l)	machine speed for product *j*, in unit/hour
setup time(j,k)	changeover time from product *j* to product *k*, in hour
maxtime(i,l)	maximum available time of line *l* on day *i*, in hour
rtime(i,l)	regular in use shift of line *l* on day *i*, in hour
M	Extremely big number
p	Extremely small number

Decision Variables

x(i,j,l,d)	quantity of product *j* produced on line *l* on day *i* for demand day *d*, in unit
y(j,l,a,d)	quantity of product *j* produced on line *l* for distribution center *a* for demand day *d*, in unit
input(j)	total production of product *j* during the all period, in unit
output(j)	total demand of product *j* during the all period, in unit
ud(j,d,a)	unmet demand quantity of product *j* on demand day *d* for distribution center *a*, in unit
deu(j,d,a)	sum of demand from distribution center *a* for product *j* on demand day *d* and unmet demand from distribution center *a* for product *j* on demand day *d-1*
inv(i,j,l)	inventory of product *j* at the end of day *i* on line *l*, in unit
overtime (i,l)	overtime on day *i* on line *l*, in hour
PT(i,j,l)	utilization of line *l* for product *j* on day *i*, in hour
ST(i,j,l)	starting time for processing of product *j* on line *l* on day *i*, in hour
FT(i,j,l)	finishing time for processing of product *j* on line *l* on day *i*, in hour
lasttime(i,l)	finishing time of the last product on line *l* on day *I*

Binary Variables

b(i,j,l)	production of product *j* on line *l* on day *i*
binsetup(i,j,k,l)	changeover from product *j* to product *k* on line *l* on day *I*

Objective Function

Max

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L}\sum_{d=1}^{D} x(i, j, l, d) * benefit(j) * \frac{(1-cr(j))*sl(j)-(d-i)}{(1-cr(j))*sl(j)}$$

$$-\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L}\sum_{d=1}^{D} x(i, j, l, d) * \mathrm{var}(j, l) - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} inv(i, j, l) * storage\cos t(j)$$

$$-\sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{a=1}^{A} ud(j, d, a) * udc(j) - \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{J}\sum_{l=1}^{L} binsetup(i, j, k, l) * setup\cos t(j, k)$$

$$-\sum_{i=1}^{I}\sum_{l=1}^{L} overtime(i, l) * oc(l) - \sum_{j=1}^{J}\sum_{l=1}^{L}\sum_{a=1}^{A}\sum_{d=1}^{D} TC(a, l) * y(j, l, a, d) \qquad (1)$$

The objective function aims to maximize the benefit by considering the shelf life of products and costs such as variable cost, set up cost, storage cost, overtime cost, unmet demand cost and transportation cost. It is supposed that the manufacturer yields a financial benefit if the products have a longer residual shelf life when being delivered. (Entrup et al, 2005). The shelf life-dependent benefit increases linearly because the benefits for customer increase with every additional day of residual shelf life. For instance, if a product has shelf life of 30 days, the customers require %66 of shelf life as minimum residual shelf life (*cr(j)*=0.66). If product is delivered on 3th day of its shelf life, the benefit will be *ben(j)** 0.70, however if product is delivered on 6th day of its shelf life, the benefit will be *ben(j)** 0.41 for the product.

$$input(j) \geq output(j) \qquad \forall j, \tag{2}$$

$$input(j) = \sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{d=1}^{D} x(i,j,l,d) + \sum_{d=1}^{D}\sum_{a=1}^{A} ud(j,d,a)$$

$$\forall j,\ qq(j) \geq (d - i) or (d - i) \leq (1 - cr(j)) * sl(j), \tag{3}$$

$$output(j) = \sum_{j=1}^{J}\sum_{d=1}^{D}\sum_{a=1}^{A} deu(j,d,a) \qquad \forall j, \tag{4}$$

The variables *input(j)* and *output(j)* in Constraint(2), (3) and (4) are designed to satisfy demand of day *d* fully or partially of product *j*. Constraint (3) refers to sum of production quantity and unmet demand of product *j* for all period. Constraint (4) corresponds to the sum of demand from all distribution centers in all demand days for product *j*. Constraint (2) guaranties that sum of production and unmet demand for product *j* during the whole period should be greater than or equal to the sum of demand that comes from all distribution centers in all demand days.

$$x(i,j,l,d) = 0 \qquad \forall i \geq d, \forall j, \forall l, \tag{5}$$

The parameter *qq(j)* refers to the required time for analysis of quality control. According to Constraint (3), demand of demand day d can not be produced in the same day (*d*=i) or after the demand day (*i*>*d*). Production should be completed at least quality control time before.

Also it provides getting maximum benefit by meeting the maximum shelf life of product *j*. The benefit increases linearly between the minimum customer requirement on shelf life *(crj)* and the maximum possible shelf life *(slj)* since the benefits for the retailer increase with every additional day of residual shelf life.

$$\sum_{a=1}^{A} y(j,l,a,d) = \sum_{i=1}^{I} x(i,j,l,d) \qquad \forall j, \forall l, \forall d \, , \tag{6}$$

Constraint (6) provides the quantity of product *j* produced in all lines for the demand of day *d* to be the same with the quantity of product *j* transferred to distribution centers for demand of day *d*.

$$deu(j,\, d,\, a) \;=\; de(j,\, d,\, a) \qquad \forall j,\, \forall a,\, d \;=\; 1 \tag{7}$$

$$deu(j,\, d,\, a) \;=\; de(j,\, d,\, a) \;+\; ud(j,\, d \;-\; 1,\, a) \qquad \forall j,\, \forall a,\, \forall d \;>\; 1 \tag{8}$$

Constraint (7) and (8) consider the unmet demand for products. *deu(j,d,a)* equals to sum of demand for product *j* for demand day d and unmet demand quantity for product *j* of previous day. We assume that there is no unmet demand for product *j* on the first demand day. For that reason *deu(j,d,a)* equals to *de(j,d,a)* for *d=1* for all products as shown in Constraint (8).

$$de(j,\, d,\, a) \;=\; \sum_{l=1}^{L} y(j,\, l,\, a,\, d) \;+\; ud(j,\, d,\, a) \qquad \forall j,\, \forall a,\, d \;=\; 1 \tag{9}$$

$$deu(j,\, d,\, a) \;=\; \sum_{l=1}^{L} y(j,\, l,\, a,\, d) \;+\; ud(j,\, d,\, a) \qquad \forall j,\, \forall a,\, \forall d \;>\; 1 \tag{10}$$

According to Constraint (9) and (10), sum of unmet demand of distribution center *a* for product *j* on demand day *d* and the quantity of product *j* that transferred to distribution center *a* should be equal to demand of distribution center *a* for product *j* on demand day *d*.

$$inv(i, j, l) = \sum_{d=1}^{D} x(i, j, l, d) - \sum_{a=1}^{A} y(j, l, a, i) \qquad i = 1, \forall j, \forall l \tag{11}$$

$$inv(i, j, l) = inv(i-1, j, l) + \sum_{d=1}^{D} x(i, j, l, d) - \sum_{a=1}^{A} y(j, l, a, i) \qquad i > 1, \forall j, \forall l \tag{12}$$

Constraint (11) shows the inventory level only for the first day. The inventory of product j on line l at the end of first day is equal to the quantity of product *j* produced on line *l* during the first day minus the distributed quantity of product *j* produced on line *l* for total demand come from distribution centers.

Constraint (12) refers to the inventory level at the end of day *i* on line *l*. It is computed by adding the production quantity of product *j* produced on line *l* on day *i* to the inventory of the previous day and minus the distributed quantity of product *j* produced on line *l* for total demand come from distribution centers.

$$PT(i, j, l) = \frac{\sum_{d=1}^{D} x(i, j, l, d)}{cap(j, l)} \qquad \forall i, \forall j, \forall l \tag{13}$$

$$ST(i, j, l) = 0 \qquad \forall i, j = 1, \forall l \tag{14}$$

$$FT(i, j, l) = ST(i, j, l) + PT(i, j, l) + \sum_{k=j+1}^{J} binsetup(i, j, k, l) * setuptime(j, k) \qquad \forall i, \forall j, \forall l \tag{15}$$

$$ST(i, j, l) \geq FT(i, j-1, l) \qquad \forall i, j > 1, \forall l \tag{16}$$

Constraint (13),(14),(15) and (16) are timing constraints that define the starting and finishing time for each product in each machine and day. The starting time of the first product set to zero in each day as shown in Constraint (14). The processing time of a product depends on the production quantity and the machine speed for the product as declared by Constraint (13). The finishing time of product j is determined by adding processing and changeover time to starting time. Changeover time between products in a machine is considered in Constraint (15). The setup time required for product *k* after product *j* is added to the finishing time of product *j*. Therefore starting time of product *j* should be greater than the finishing time of the previous product as emphasized in Constraint (16).

$$lasttime(i,l) = FT(i,J,l) \qquad \forall i, \forall l \tag{17}$$

$$lasttime(i,l) \leq \max time(i,l) \qquad \forall i, \forall l \tag{18}$$

$$lasttime(i,l) \leq rtime(i,l) + overtime(i,l) \qquad \forall i, \forall l \tag{19}$$

The total machine time in a day is equal to the finishing time of the last product. It is considered in Constraint (17). last time (i,l) refers to the finishing time of the last product on line *l* on day *i*. The total machine time is bounded with the maximum time a machine can work in Constraint (18). *rtime (i,l)* corresponds to regular shift of line *l* on day *i*. Last time passing over the regular shift means over time for line *l* in day *i*. Overtime needed on line *l* on day *i* is computed in Constraint (19).

$$x(i,j,l,d) \leq b(i,j,l) * M \qquad \forall i,\ \forall j,\ \forall l,\ \forall d \tag{20}$$

$$binsetup(i,j,k,l) = 0 \qquad \forall i, j > k, \forall l \tag{21}$$

$$binsetup(i,j,k,l) \le 1 + (1 - b(i,j,l)) + (1 - b(i,k,l)) - p * \sum_{t=j+1}^{k-1} b(i,t,l) \quad \forall i, j, k > j, l \tag{22}$$

$$binsetup(i,j,k,l) \ge b(i,j,l) + b(i,k,l) - 1 - \sum_{t=j+1}^{k-1} b(i,t,l) \quad \forall i, \forall j, k > j, \forall l \tag{23}$$

$$\sum_{j=1}^{J} b(i,j,l) - \sum_{j=1}^{J}\sum_{k=1}^{J} binsetup(i,j,k,l) \le 1 \qquad \forall i, \forall l \tag{24}$$

$$binsetup(i,j,k,l) \le b(i,j,l) \qquad \forall i, \forall j, k > j, \forall l \tag{25}$$

$$binsetup(i,j,k,l) \le b(i,k,l) \qquad \forall i, \forall j, k > j, \forall l \tag{26}$$

Binary variable in Constraint (20) is equal to *1*, if and only if product *j* is produced on line *l* on day *i* for demand of day *d*. Constraint (21) ensures that only specific sequence of product is allowed on line *l*. The relationship between *b(i,j,l)* and *b(i,k,l)* is illustrated in Constraint (22) and (23). *b(i,j,k,l)* is equal to *1*, if product *j* and *k* are produced in a row. Constraint (24) shows that the number of produced items, minus the number of setups must be less than or equal to 1. Although Constraint (25) and (26) do not add new information to the model, they increase the speed of model to obtain the solution.

$$x(i,\ j,\ l,\ d),\ y(j,\ l,\ a,\ d),\ deu(j,\ d,\ a) \ \ge\ 0 \qquad \forall i,\ \forall j,\ \forall l,\ \forall d,\ \forall a$$

$$input(j),\ output(j) \ \ge\ 0 \qquad \forall j$$

$$inv(i,\ j,l),\ PT(i,\ j,l),\ ST(i,\ j,l),\ FT(i,\ j,l)\ \geq\ 0 \qquad \forall i,\ \forall j,\ \forall l$$

$$lasttime(i,\ l)\ \geq\ 0 \qquad \forall i,\ \forall l$$

$$b(i,\ j,\ l)\ \in\ \{0,1\} \qquad \forall i,\ \forall j,\ \forall l$$

$$binsetup(i,\ j,\ k,\ l)\ \in\ \{0,1\} \qquad \forall i,\ \forall j,\ \forall k,\ \forall l$$

CHAPTER FIVE
SOLUTION METHOD

The hybrid approach is preferred as solution method in problem solution. The hybrid mathematical-simulation approach consists of independent mathematical and simulation models of total system, which develop their solution procedures and use them together for problem solving. (Safaei et al, 2010)

The output is obtained from mathematical model which is optimized without consideration of stochastic factors. It is used as input values in simulation model. Then, output of the simulation model feeds back to the mathematical model. The approach goes on until the essential results are reached.

5.1 Mathematical Model

The mathematical model is used to obtain optimized scheduling program. The production quantities are determined as optimization model result. Mathematical model also gives us how much product at what factory should stock up to minimize the total cost within a certain period. The mathematical model is formulated as mixed integer linear program (MILP) as explained in Chapter 4.

5.1.1 Computational Results

The computational results of MILP model is explained in this part. Table 1 shows the production quantities of products in lines for each production day. For instance, Product 1 produces in Line 1 and Line 4. The quantity produced in Line 1 is 220 in Production Day 1, 15322 in Production Day 2. The production starts with Production Day 2 in Line 4 and the quantity is 11690. The Grand total of production is 996950 for all products in 5 production days. The detailed production quantity for products is listed in Table 5.1.

Table 5.1 Production quantity of products for MILP model (unit)

		Production Day					
Product	**Line**	**1**	**2**	**3**	**4**	**5**	**Grand Total**
1	1	220	15322	8191	7991	9386	41110
1	4	0	11690	5982	5904	6290	29866
10	9	0	30451	24662	17759	18212	91084
2	4	12408	14300	13261	13201	15056	68226
3	1	20145	19879	18986	21232	23073	103315
4	2	14144	38145	26197	27190	25616	131292
4	5	14144	18359	14975	17839	17691	83008
5	3	12474	10252	10280	9931	10104	53041
5	6	8383	8405	9168	9929	9463	45348
6	3	15723	15833	14974	15181	16203	77914
6	6	12299	12708	12689	12710	13184	63590
7	7	6046	0	7504	7388	7763	28701
7	8	9840	16075	8556	7679	7548	49698
8	7	667	25525	13744	13682	12367	65985
9	9	12376	14467	12349	12629	12951	64772
Grand Total		**138869**	**251411**	**201518**	**200245**	**204907**	**996950**

Table 5.2 Unmet demand quantities of products (unit)

Products/Days	**3**	**4**	**5**	**6**	**Grand Total**
1	13984	0	0	0	13984
3	0	0	0	0	0
4	17267	0	0	0	17267
7	1000	0	0	0	1000
8	25168	0	0	0	25168
9	4400	0	0	0	4400
10	17465	7296	0	0	24761
Grand Total	**79284**	**7296**	**0**	**0**	**86580**

Table 5.2 refers to the unmet demand of products for demand days. Demand of 6 products cannot be met on Demand Day 3. Only for Product 10, the unmet demand quantity goes on the following day.

There is no unmet demand for products after Demand Day 4. The total unmet demand quantity is 86580 for given period.

Table 5.3 Inventory levels of lines on production days

		Production Days						
Line	**Product**	**1**	**2**	**3**	**4**	**5**	**6**	**Grand Total**
1	1	2200	15542	23513	16182	17377	9386	84200
1	3	20145	40024	38865	40218	44305	23073	206630
2	4	14144	52289	64342	53387	52806	25616	262584
3	5	12474	22726	20532	20211	20035	10104	106082
3	6	15723	31556	30807	30155	31384	16203	155828
4	1	0	11690	17672	11886	12194	6290	59732
4	2	12408	26708	27561	26462	28257	15056	136452
5	4	14144	32503	33334	32814	35530	17691	166016
6	5	8383	16788	17573	19097	19392	9463	90696
6	6	12299	25007	25397	25399	25894	13184	127180
7	7	6046	6046	7504	14892	15151	7763	57402
7	8	6670	26192	39269	27426	26049	12367	137973
8	7	9840	25915	24631	16235	15227	7548	99396
9	9	12376	26843	26816	24978	25580	12951	129544
9	10	0	30451	55113	42421	35971	18212	182168
Grand Total		**146852**	**390280**	**452929**	**401763**	**405152**	**204907**	**2001883**

Table 5.3 refers the inventory levels of lines during whole period. The detailed quantity of products is analyzed in Table 5.3. The system reaches the maximum stock on Production Day 3. Product 4 has the maximum stock on Line 2 among all products during 6-day period.

Table 5.4 Overtime for lines on production days

	Production Days				
Lines	**2**	**3**	**4**	**5**	**Grand Total**
1	0.00	0.00	0.00	0.00	0.00
2	5.58	0.00	0.00	0.00	5.58
7	6.35	4.64	4.49	3.64	19.11
8	0.00	0.00	0.00	0.00	0.00
9	8.00	4.13	1.33	1.74	15.20
Grand Total	**19.93**	**8.77**	**5.82**	**5.38**	**39.89**

Overtime that the lines need is shown in Table 5.4. Overtime is computed for Production Days 2, 3, 4 and 5. The second day needs the maximum hours for overtime. On Production Day 4 and 5, overtime is planned only Line 7 and Line 9.

Table 5.5 Distributed quantities of products for demands

			Demand Day					
Product	**Line**	**Dist Center**	**3**	**4**	**5**	**6**	**7**	**Grand Total**
1	1	1	0	3202	2235	2241	1800	9478
1	1	4	0	4053	1780	2100	1810	9743
1	1	6	220	3648	2273	1900	3406	11447
1	1	7	0	4419	1903	1750	2370	10442
1	4	2	0	3529	2226	2254	1940	9949
1	4	3	0	3199	1502	2150	2570	9421
1	4	5	0	4962	2254	1500	1780	10496
10	9	1	0	3994	1963	1862	1799	9618
10	9	2	0	7247	3443	4015	4227	18932
10	9	3	0	185	10127	1981	3091	15384
10	9	4	0	3596	2271	2652	2164	10683
10	9	5	0	6717	3382	3960	3535	17594
10	9	6	0	4261	1897	1579	2007	9744
10	9	7	0	4451	1579	1710	1389	9129
2	4	1	1166	2121	2314	1668	1750	9019
2	4	2	1195	2369	2564	1492	1800	9420
2	4	3	1137	1423	1891	2391	1940	8782
2	4	4	2239	2191	1396	2150	2570	10546
2	4	6	2262	2109	1874	1500	1780	9525
2	4	7	2020	1627	1996	1900	3406	10949
3	1	1	2402	3785	2429	2461	2750	13827
3	1	2	4130	3153	3222	2857	2830	16192

Table 5.5 (cont.)

3	1	3	2211	2589	3372	2264	2927	13363
3	1	4	3111	2089	2602	3150	3570	14522
3	1	5	3360	2799	2914	4100	3810	16983
3	1	6	2785	3249	2102	3500	2780	14416
3	1	7	2146	2215	2345	2900	4406	14012
4	2	1	5637	6189	4049	5231	4953	26059
4	2	4	0	18302	9930	9156	8900	46288
4	2	6	4395	7524	6538	6903	6527	31887
4	2	7	4112	6130	5680	5900	5236	27058
4	5	2	4466	5637	5241	5316	5740	26400
4	5	3	2397	6569	5200	5780	5324	25270
4	5	5	6855	6153	4534	6743	6627	30912
4	5	6	426	0	0	0	0	426
5	3	1	1414	1522	1694	1600	1523	7753
5	3	4	3907	2117	2155	2261	2356	12796
5	3	6	3947	3813	3716	3400	3305	18181
5	3	7	3206	2800	2715	2670	2920	14311
5	6	2	2503	2070	2819	3885	3240	14517
5	6	3	2907	3117	3155	3261	3316	15756
5	6	5	2973	3218	3194	2783	2907	15075
6	3	1	4312	4222	4207	4228	4380	21349
6	3	4	3230	3264	3183	3176	3230	16083
6	3	6	4948	4673	4541	4223	4598	22983
6	3	7	3233	3674	3043	3554	3995	17499
6	6	2	3279	3549	3136	3648	3519	17131
6	6	3	4740	4839	4923	4515	4680	23697
6	6	5	4280	4320	4630	4547	4985	22762
7	7	1	2312	0	2207	2228	2514	9261
7	7	4	1230	0	1183	1176	1223	4812
7	7	6	914	0	1856	1997	1896	6663
7	7	7	1590	0	2258	1987	2130	7965
7	8	1	0	2222	0	0	0	2222
7	8	2	2779	2549	2136	1648	1937	11049
7	8	3	3739	3840	3923	3515	3427	18444
7	8	4	0	1264	0	0	0	1264
7	8	5	2323	2148	2497	2516	2184	11668
7	8	6	999	1926	0	0	0	2925
7	8	7	0	2126	0	0	0	2126
8	7	1	0	2642	1297	1225	1180	6344
8	7	2	0	4952	2347	2754	2905	12958
8	7	3	0	3218	1912	1308	1197	7635
8	7	4	667	2092	1716	1987	1638	8100
8	7	5	0	5886	3402	2927	2643	14858

Table 5.5 (cont.)

8	7	6	0	4494	2354	2967	1826	11641
8	7	7	0	2241	716	514	978	4449
9	9	1	1418	1422	1396	1324	1279	6839
9	9	2	2539	2615	2448	2855	3006	13463
9	9	3	2403	2917	2013	1409	2198	10940
9	9	4	1133	1424	1615	1886	1539	7597
9	9	5	2103	2674	2405	2816	2514	12512
9	9	6	1459	1571	1349	1123	1427	6929
9	9	7	1321	1844	1123	1216	988	6492
Grand Total			138869	251411	201518	200245	204907	996950

In Table 5.5, the distributed quantities is listed based on lines and products. As an example, Product 1 produced on Line 1 is transported to Distribution Center 1, 4, 6 and 7. Total quantities of 9478 are transferred from Line 1 to Distribution Center 1 during the period. Similarly, 9743 units of Product 1 are sent to Distribution Center 4 during whole period. We can see detailed quantities of each product transported from lines to distribution centers in Table 5.

5.2 Simulation Model

Simulation modeling and analysis has become a popular technique for analyzing the effects of the changes without actual implementation or assignment of resources. (Huda and Chung, 2002).

Simulation models, which explicitly consider randomness of exogenous and endogenous production variables, are more capable of capturing actual system behaviour. (Lee and Kim 2002, Gnoni et al. 2003).

Simulation model is preferred for problem to include the stochastic factor to solution. In mathematical model, it is not possible to add machine breakdowns to the problem. For that reason, simulation model is used for obtain more realistic solution for scheduling problem.

5.2.1 Literature Review

Miller and Park (1998) used discrete event simulation in a process industry as a day-to-day production-scheduling tool. They applied the simulation model in a coffee production process. Two simulation models were developed for weekdays and weekends because of different machine hours. They developed simulation model to evaulate the schedule created by the scheduler and to determine a new valid and feasible production schedule by taking factors such as demand, the inventory level and operational status of the machines into consideration.

Huda and Chung (2002) worked simulation modeling and analysis into high-speed combined continuous and discrete food industry manufacturing process. They combined discrete and continuous event approaches in a coffee manufacturing facility.

Musselman, O'reilly and Duket (2002) emphasized the role of simulation in advanced planning and scheduling. They argue about that actual lead times are different from the fixed lead times assumed by MRP when a system is highly utilized and dynamic. For that reason, they suggest that simulation can be used to determine wheter the start times generated by the plan will actually allow the manufacturing orders to be completed by their due dates.

Noh, Rim and Lee (2005) worked about meeting due dates in the make-to-order (MTO) based manufacturing environment. They proposed a new concept meeting due dates by reserving partial capacity in MTO firms. They prefered dicrete event simulation to examine the proposed system.

Vorst, Tromp and Zee (2008) studied about food supply chain redesign; integrated decision making on product quality, sustainability and logistics by using simulation tool. They applied their research for fresh pineapple supply chain which is an increasing market in Europa. Their objective was choosing the best design that reduces overall chain cost among alternatives.

Bottani and Montanari (2009), choosen simulation method for reproducing a fast moving consumer goods supply chain. Their purpose is assessing the effects of different supply configurations by considering total supply chain costs and bullwhip effect.

5.2.2 Conceptual Model for Simulation

In real-world system, operation times cannot be accepted as a static factor. Because of the dynamic nature of the real system, the exact solution obtained from mathematical model cannot be applied practically. Simulation models include nonlinearities, complex structure and stochasticity which are main features of real system.

The simulation model is established to represent the MILP model. It includes machine failures as different from mathematical model. It is developed by Rockwell Arena Simulation Software. The conceptual model of the system is shown in Figure 5.1

Production starts with the products on a line considering the production day row. The priority of products is important, because in MILP model, it is not allowed the product with high sequence number to produce firstly. For that reason, the simulation model always starts with the first product the program. After the desired quantity of the first product is completed, the model controls the conditions and starts the production of second product. When all program given according to MILP results for day i is completed, the model starts the production of the following day. During all program, the failures become active. Thus, we can measure the operation times required for production program given by MILP model. In order to obtain mean operations times , five independent replications are applied in simulation model.

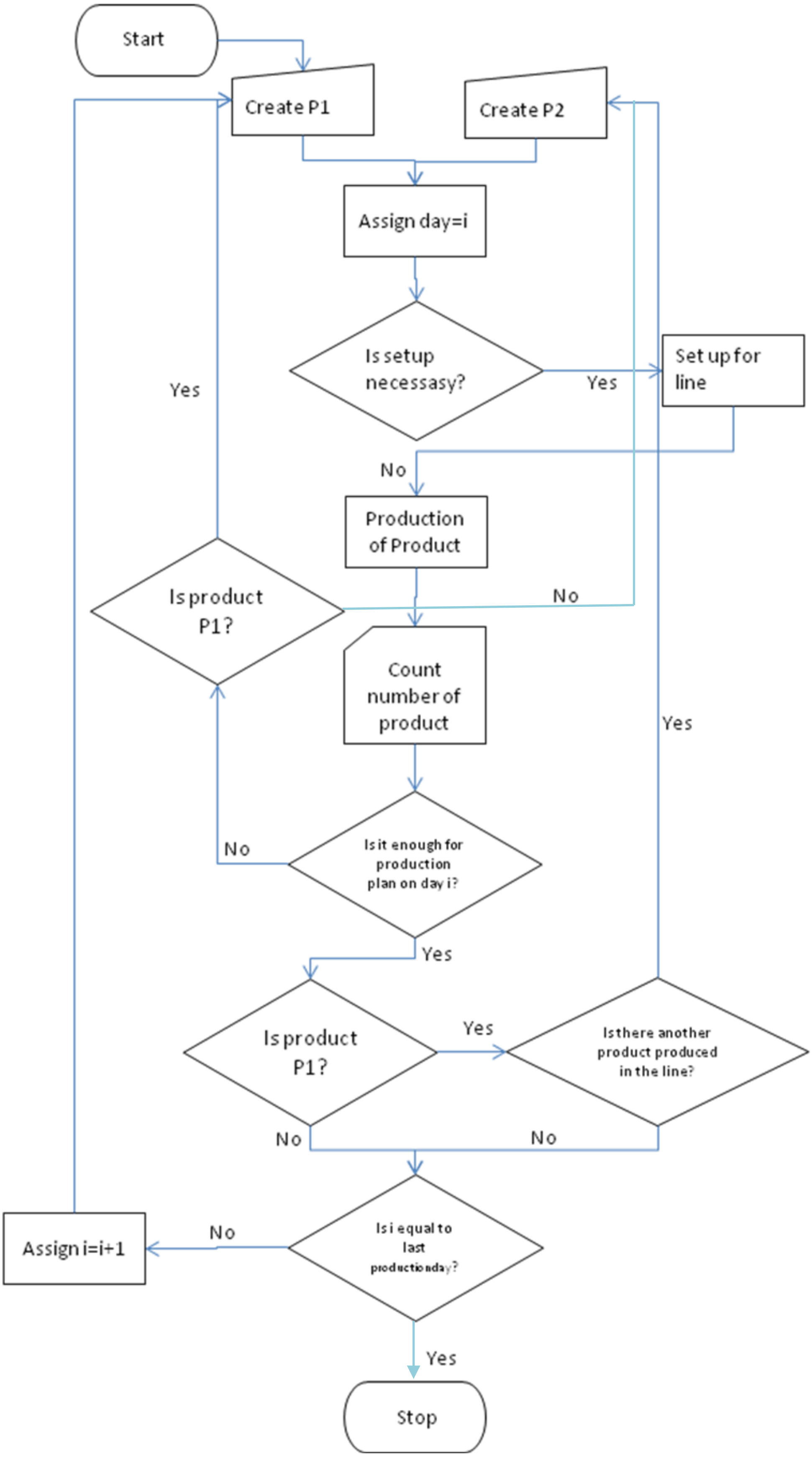


Figure 5.1 The conceptual model

5.3 The Hybrid Methodology

The hybrid simulation-analytic approach consists of building an independent analytic and simualtion model of the total system, developing their solution procedures, and using their solution procedures together for problem solving. (Lee et al., 2002).

In many researches, the capacity of system is assumed fixed or infinite. In real systems, there is a significant difference between system capacity and the required time to achive production plans. The consumed time for production plan are complex and has stochastic natures of real system. Therefore, in real world system, exact solutions that do not include variability are not enough for problem solutions.
A mathematical model gives the optimal solution that decreases the costs for set up, production, inventory, distribution. Optimal solution of mathematical model is not acceptable because the stochastic factors such as machine failures are not included in formulation. For that reason, the mathematical model cannot reflect the dynamic characteristic of real-world system. For this reason, a hybrid solution approach is developed by applying MILP formulation and simulation model.

In this thesis, hybrid approach is preferred for adjusting the capacities of production lines. According to results of hybrid approach, more realistic scheduling program is obtained, and costs and benefits are determined in practically for strategic decisions.

The goal of hybrid approach is to achieve an optimal scheduling program for production lines by combining optimization models and simulation models.

5.3.1 Literature Review

Byrne and Bakir (1999), studied a hybrid algorithm combining mathematical programming and simulation model in a manufacturing system for multi-period multi-product problem. They applied the method in a case study that considers system characteristics such as queuing and transportation delays for obtaining a result both mathematically optimal and practically feasible.

Kim and Kim (2001), applied simulation and a linear programming model iteratively to find the capacity-feasible production plan. They proposed to identify the actual workload of the jobs and utilization of the resources by optimal production plan and minimum total cost.

Lee and Kim (2000), studied hybrid approach which is a specific problem solving procedure combining analytic and simulation methods to solve production-distribution problems in supply chains. The machine capacity and distribution capacity constraints in the analytic model are considered as stochastic factors in the model and adjusted according to the results of iterations.

Hsieh (2002), dealed with hybrid analytic and simulation model in designing a multi-stage, multi-buffer electronic device assembly line.

Lee, Kim and Moon (2002), proposed hybrid approach for solving a multiperiod, multiproduct, multishop production and distribution problem in supply chain environment. They considered machine capacity and distribution capacity as stochastic factors which are adjusted according to the results from independently developed simulation model. The procedure they applied, based on imposing adjusted capacities derived from simulation model results.

Manzini et al. (2003) used discrete/continuous hybrid simulation tools in order to model and simulate several operating conditions in combination with different system configurations. They applied the tool in five significant industrial cases, which are simulated in collaboration with important enterprises and belong to different industrial sectors. The time and cost are analyzed as results of hybrid simulation tool.

Gnoni et al. (2003), studied a lot sizing and schedulig problem in a multi-site manufacturing system with capacity constraints and uncertain multi-product and multi-period demand. They proposed a hybrid modelling approach which is the integration of mixed-integer linear programming model and simulation model. They applied the method to an industrial case study concerning a supply chain producing components for both the market and aftermarket.

Byrne and Bakir (2005), also studied the hybrid algorithm with JIT approach. The model they improved, takes into account the requirement of small lot sizes of JIT approach. They try to ensure that correct quantity of product is produced in each period for minimizing any excess inventory.

Ko, Ko and Kim (2006) prefered hybrid optimization/simulation approach to design a distribution network for 3PLs . a genetic algorithm is used for the optimization model to determine dynamic distribution network structures. The simulation model is applied to capture the uncertainty in demands, order-picking time, and travel time for the capacity plans of the warehouses based on service time.

Lim et al. (2006) studied optimal distribution planning in supply chain. They proposed a distribution model with low cost and high customer satisfaction. They used a hybrid approach involving genetic algorithm (GA) and simulation to solve the problem. Simulation that considers uncertain factors such as queuing, breakdowns and repairing time in the supply chain provided more realistic solution for the problem.

Li, Gonzalez and Zhu (2008), studied optimization with simulation methods which is an effective approach in optimization of a system that possesses the characteristics described in a dedicated remanufacturing system. To overcome limitations associated with the existing simulation optimization approaches, a hybrid cell evaluated genetic algorithm (CEGA) that combines fractional factorial design (FFD) and genetic algorithm (GA) is developed for the simulation optimization of the reverse manufacturing system. They applied their study on a computer plant.

Matta (2008), used simulation model for predicting the system performance, and mathematical model for optimizing the discrete event system. They proposed three types of formulations such as mixed integer linear model, an approximate LP model and stochastic programming model in solving the buffer allocation problem in flow lines with finite buffer capacities.

Yoo, Cho and Yucesan (2010) used hybrid algorithm to minimize the number of alternatives to be evaluated and the number of replications used in the evaluation of each alternative in supply chain optimization problem. The hybrid algorithm consists of nested partitioning (NP) to evaluate the total number of alternatives and optimal computing budget allocation (OCBA) to optimize the total number of simulation replications.

Almeder (2009), emphasized an approach combining an ant-based algorithm with a mixed-integer linear programming in solving multi-level capacitated lot-sizing problems. They used two different local search method, a fast one based on shifting production and solving a linear program, and a more complex one, where the capability of a MIP solver to improve solutions for small mixed-integer problems.

Klemmt et al. (2009), presented a discrete event simulation and MIP model in a job shop problem. They developed an advanced Job Shop MIP model additional restrictions, like release dates, due dates, branches, setups, etc. which allows a modeling of practical relevant scheduling problems. Then, they used the results of MIP model in simulation model that has real-time conditions.

Safaei et al. (2010) proposed a hybrid mathematical-simulation model to solve the multi-product, multi-period, multi-side production distribution planning problem. Because the mathematical model cannot reflect dymamic factors of real world system, they combined the results with simulation model and reached the solution iteratively.

5.3.2 The Hybrid Mathematical-Simulation Approach

In real world system, it is not possible to consider operation time as static factor. The production systems generally include dymamic nature in real systems. The solution which is obtained from the mathematical model with fixed operation time cannot represent the system in reality. The simulation model provides to insert real operation times to the mathematical model.

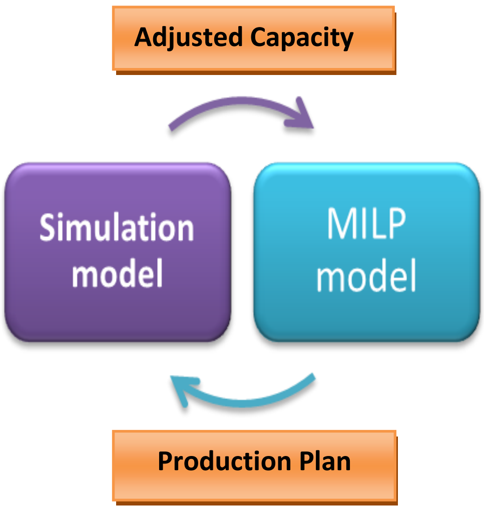


Figure 5.2 Flow of solutions between models

Operation time is defined for each product particularly in simualtion model. The scheduling program that is achieved from mathematical model is taken as input for the simulation model. The simulation model result gives us total production time for each product. The total time of a product spent in a machine is used to compute the real operation time for that product in particular machine. Thus, the required operation time is reached for the mathematical solution by simulation model. The solution of simulation model is reflected as operation time on mathematical model. Therefore, the operation time in mathematical model is adjusted by the results of the simulation model and the mathematical model regenerates new production scheduling program by the adjusted operation time (Safaei et al, 2010). The iteration ends if the difference rate between preceding simulation operation time (POT) and current simulation operation time (COT) is close enough to be acceptable. When the difference is close enough , the mathematical model is regarded as reflecting the realistic situation through the simulation model. Therefore, the scheduling program taken from mathematical model at that iteration reflects the stochastic situations and regarded as realistically optimal.

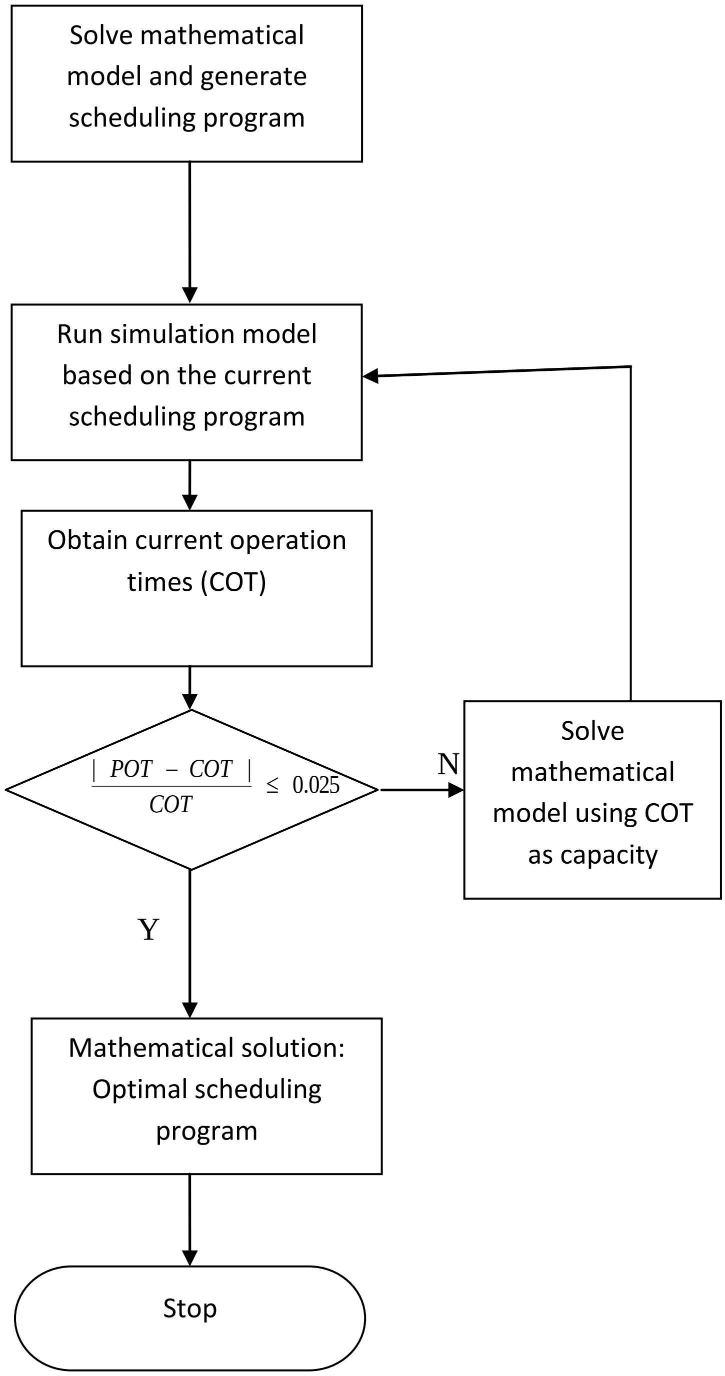


Figure 5.3 Flow diagram of hybrid method

The procedure consists of 7 steps:

Step 1: Solve the mathematical model and obtain the production plan.

Step 2: Run simulation model based on the current production plan.

Step 3: Obtain current operation times for products on each machine via simulation model (COT).

Step 4: If the difference rate between preeceding operation time (POT) and current operation time (COT) is within the rate of 0.025, then go to step 6, otherwise go to step 5.

Step 5: Solve the mathematical model using operation times for products on each machine as machine speed.

Step 6: Mathematical solution: Optimal production plan.

Step 7: Stop

A flow diagram in Figure 5.3 illustrates the solution procedure.

CHAPTER SIX
CASE STUDY AND COMPUTATIONAL RESULTS

A scheduling problem in yoghurt production lines of multiproduct dairy plants is analyzed in this research.

6.1 Case Study

The dairy firm is a milk-processing company that runs two factories located in different cities. Ten different product types are produced in factories that include nine production lines to satisfy demands of customers.

The product types differ from each other based on cup size and yoghurt type. Table 6.1 shows distribution of production capacities in factories based on product types.

Table 6.1 Distribution of production capacities in factories

Product Type	Factory 1 (%)	Factory 2 (%)
P1	50	50
P2	0	100
P3	100	0
P4	50	50
P5	50	50
P6	50	50
P7	50	50
P8	100	0
P9	0	100
P10	0	100

Five types of products are common that they can be produced in both factories. While two of them can be produced only in Factory 1, three of them can be produced in Factory 2 because of the location of production lines.

In Table 6.2, the position of lines can be seen among factories.

Table 6.2 Distribution of production capacities in factories

	L1	L2	L3	L4	L5	L6	L7	L8	L9
F1	X	X	X				X		
F2				X	X	X		X	X

Lines 1,2,3 and 7 are located in Factory 1 and Lines 4,5,6,8 and 9 are located in Factory 2. For that reason some products can only be produced in one factory.

Table 6.3 Machine – Product matrix

Product/Line	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
L1	X		X							
L2				X						
L3					X	X				
L4	X	X								
L5				X						
L6					X	X				
L7							X	X		
L8							X			
L9									X	X

Table 6.3 refers to distribution of products to lines and factories. In the table P1 refers to product type 1 and L1 refers to production line 1. While some products can be produced in more than one machine, some machines can produce more than one product. For instance, product P1 can be produced in both lines L1 and L4. In addition, L3 can produce both types P5 and P6. Because of the variations of product size, the machine capacity differs for the different product types.

Table 6.4 shows the line capacities for each product type. For common lines, features are similar in both factories. So that the capacities of lines that produce the same type of product are equal to each other in both factories. Product P1 can be produced in both factory in lines L1 and L4 with same capacity.

Table 6.4 Machine Capacities for Product Types

Product/Machine (Unit/Hr)	L1	L2	L3	L4	L5	L6	L7	L8	L9
P1	2013	0	0	2013	0	0	0	0	0
P2	0	0	0	2640	0	0	0	0	0
P3	3420	0	0	0	0	0	0	0	0
P4	0	1768	0	0	1768	0	0	0	0
P5	0	0	4615	0	0	4615	0	0	0
P6	0	0	4615	0	0	4615	0	0	0
P7	0	0	0	0	0	0	1230	1230	0
P8	0	0	0	0	0	0	1142	0	0
P9	0	0	0	0	0	0	0	0	1547
P10	0	0	0	0	0	0	0	0	2316

In multi-product machines, changeover times should be considered because in a machine, more than one product can be produced and set up times are sequence dependent. Besides the difference of cup sizes, works in process for product types are variable that changeover time is needed as cleaning and sterilization time. Table 6.5 shows the changeover times for all machines and products.

Table 6.5 Changeover times for products

Product Type(Hr)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	0	3.5	2	-	-	-	-	-	-	-
P2	-	0	-	-	-	-	-	-	-	-
P3	-	-	0	-	-	-	-	-	-	-
P4	-	-	-	0	-	-	-	-	-	-
P5	-	-	-	-	0	1.6	-	-	-	-
P6	-	-	-	-	-	0	-	-	-	-
P7	-	-	-	-	-	-	0	2.5	-	-
P8	-	-	-	-	-	-	-	0	-	-
P9	-	-	-	-	-	-	-	-	0	1.5
P10	-	-	-	-	-	-	-	-	-	0

Changeover times are not categorized for machines one by one. Although the machines are located in different factories, they have the same features that the changeover times are the same for products in all lines that produce them.

The finished goods are delivered to distribution centers from the factories. The demands for all products come from 7 different distribution centers. They are all located in different region that their distances are changeable to factories. This means that the transportation cost is an important factor that affects the total cost. Therefore, while the demands are distributed to factories, the location of distribution center should be taken into account for minimizing the total cost.

For common products that can be produced in both factory, the demands are assigned to factories by considering the distance, but for the products that can be produced in only one factory, the demands are assigned that factory without taking into consideration transportation cost.

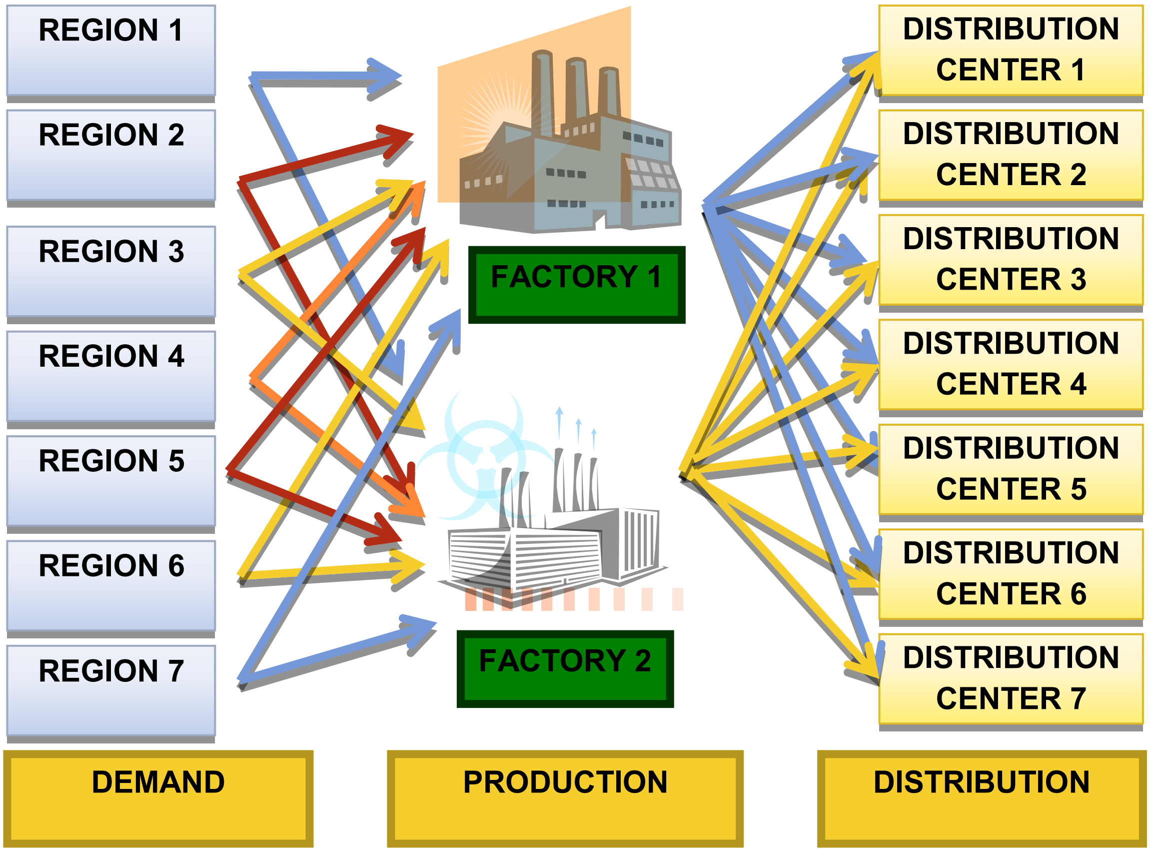


Figure 6.1 Order collection process

Figure 6.1 shows the route a demand follow in the whole system.

The time horizon of short term planning for yoghurt manufacturing is usually one week. (Nakhla 1995). A day contains three shifts which are from 07:00 to 15:00 (Shift 1), from 15:00 to 23:00 (Shift 2), from 23:00 to 07:00 (Shift 3). The regular production day consists of first and second shift. The production time in a week starts on Monday, ends on Saturday. If necessary, the production day can be proceeded with Sunday shifts and the third shifts in weekdays which are defined as overtime. On Mondays, two of shifts are reserved as ***Cleaning time*** for the production unit. The cleaning time is not flexible that it cannot be shortened and delayed, because the yoghurt is fresh and sterilized production.

Table 6.6 Scheduling horizon for yogurt production

	Monday			**Tuesday**			**Wednesday**			**Thursday**			**Friday**			**Saturday**			**Sunday**		
Shift	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***2***	***3***
Regular Working Time	X			X	X		X	X		X	X		X	X		X	X				
Overtime						X			X			X			X			X	X	X	X
Cleaning		X	X																		

In food industry, reliability of product is as important as freshness. Therefore, all products should be complete their quality control process after the production. For all yoghurt products, the quality control process is completed in 2 days. It means that, the customer should order the demands at least two days before or the demands should be produced at least 2 days before the order day.

The demands for all products come from 7 different distribution centers. The demand period is not customized that the demands can be asked everyday in a week. Also transferring of products from factories to distribution centers are carried out each day.

In this case, production period is determined as 5 days which starts on Monday. The demands of Wednesday are defined as the beginning of demand period because of the two-day-long quality process. It consists of 5 days that starts with Wednesday and ends with Sunday. All demands for each product are shown day by day in a week in Table 6.6.

Table 6.7 Demands for each product units

		Distribution Center							
Product	**Demand Day**	**DC1**	**DC2**	**DC3**	**DC4**	**DC5**	**DC6**	**DC7**	**TOTAL**
TYPE 1	**1**	1802	1701	1675	1816	2590	1908	2712	**14204**
	2	1400	1828	1524	2237	2372	1960	1707	**13028**
	3	2235	2226	1502	1780	2254	2273	1903	**14173**
	4	2241	2254	2150	2100	1500	1900	1750	**13895**
	5	1800	1940	2570	1810	1780	3406	2370	**15676**
TYPE 2	**1**	1166	1195	1137	2239	2389	2262	2020	**12408**
	2	2121	2369	1423	2191	2460	2109	1627	**14300**
	3	2314	2564	1891	1396	1226	1874	1996	**13261**
	4	1668	1492	2391	2150	2100	1500	1900	**13201**
	5	1750	1800	1940	2570	1810	1780	3406	**15056**
TYPE 3	**1**	2402	4130	2211	3111	3360	2785	2146	**20145**
	2	3785	3153	2589	2089	2799	3249	2215	**19879**
	3	2429	3222	3372	2602	2914	2102	2345	**18986**
	4	2461	2857	2264	3150	4100	3500	2900	**21232**
	5	2750	2830	2927	3570	3810	2780	4406	**23073**
TYPE 4	**1**	5637	4466	2397	9227	6855	5625	4112	**38319**
	2	6189	5637	6569	9075	6153	6720	6130	**46473**
	3	4049	5241	5200	9930	4534	6538	5680	**41172**
	4	5231	5316	5780	9156	6743	6903	5900	**45029**
	5	4953	5740	5324	8900	6627	6527	5236	**43307**
TYPE 5	**1**	1414	2503	2907	3907	2973	3947	3206	**20857**
	2	1522	2070	3117	2117	3218	3813	2800	**18657**
	3	1694	2819	3155	2155	3194	3716	2715	**19448**
	4	1600	3885	3261	2261	2783	3400	2670	**19860**
	5	1523	3240	3316	2356	2907	3305	2920	**19567**
TYPE 6	**1**	4312	3279	4740	3230	4280	4948	3233	**28022**
	2	4222	3549	4839	3264	4320	4673	3674	**28541**
	3	4207	3136	4923	3183	4630	4541	3043	**27663**
	4	4228	3648	4515	3176	4547	4223	3554	**27891**
	5	4380	3519	4680	3230	4985	4598	3995	**29387**
TYPE 7	**1**	2312	2779	3740	1230	2323	1913	1590	**15887**
	2	2222	2549	3839	1264	2148	1926	2126	**16074**
	3	2207	2136	3923	1183	2497	1856	2258	**16060**
	4	2228	1648	3515	1176	2516	1997	1987	**15067**
	5	2514	1937	3427	1223	2184	1896	2130	**15311**
TYPE 8	**1**	1319	2438	1402	1234	3102	1807	943	**12245**
	2	1323	2514	1816	1525	2784	2687	1298	**13947**

Table 6.7 (cont.)

	3	1297	2347	1912	1716	3402	2354	716	**13744**
	4	1225	2754	1308	1987	2927	2967	514	**13682**
	5	1180	2905	1197	1638	2643	1826	978	**12367**
TYPE 9	**1**	1418	2539	2403	1133	2103	1503	1321	**12420**
	2	1422	2615	2917	1424	2674	1527	1844	**14423**
	3	1396	2448	2013	1615	2405	1349	1123	**12349**
	4	1324	2855	1409	1886	2816	1123	1216	**12629**
	5	1279	3006	2198	1539	2514	1427	988	**12951**
TYPE 10	**1**	1994	3570	3379	1593	2957	2114	1858	**17465**
	2	2000	3677	4102	2003	3760	2147	2593	**20282**
	3	1963	3443	2831	2271	3382	1897	1579	**17366**
	4	1862	4015	1981	2652	3960	1579	1710	**17759**
	5	1799	4227	3091	2164	3535	2007	1389	**18212**

Because the yogurt is a perishable product, stock level should be kept in an acceptable level. It is important to determine the production quantity in every period of time properly. The shelf lives of all yogurt products are 15 days. The shortness of shelf life causes that the customer wants to buy the freshest product from the market. For this reason, the quantity of stock can be determined strategically in different period. The stock level should minimize the unmet demand with maximum freshness.

Shelf life takes a significant part in the objective function because customers tend to buy the product with a longer remaining shelf life. The financial benefit of a product increases, if the product has a longer shelf life when being delivered. The shelf life dependent benefit increases linearly between the minimum customer requirement on shelf life and the maximum possible shelf life. (Shelf Life Integration in Yogurt Production).

In this case, the acceptable rate for customer is 0,66. That means, the customer buy a product that expires maximum %66 of total shelf life. For instance, if the shelf life of a product is 15 days, it can be delivered until 10th day after the production. At the 11th day, the customer does not accept buying the product. For that reason, the benefit of a product that expired the 3 days of its shelf life is more than the benefit of a product that expired the 5 days of its shelf life. The benefit increases with every additional day of residual shelf life. It is explained by the graph shown in Figure 6.2.

The financial benefit for product types is shown in Table 6.8.

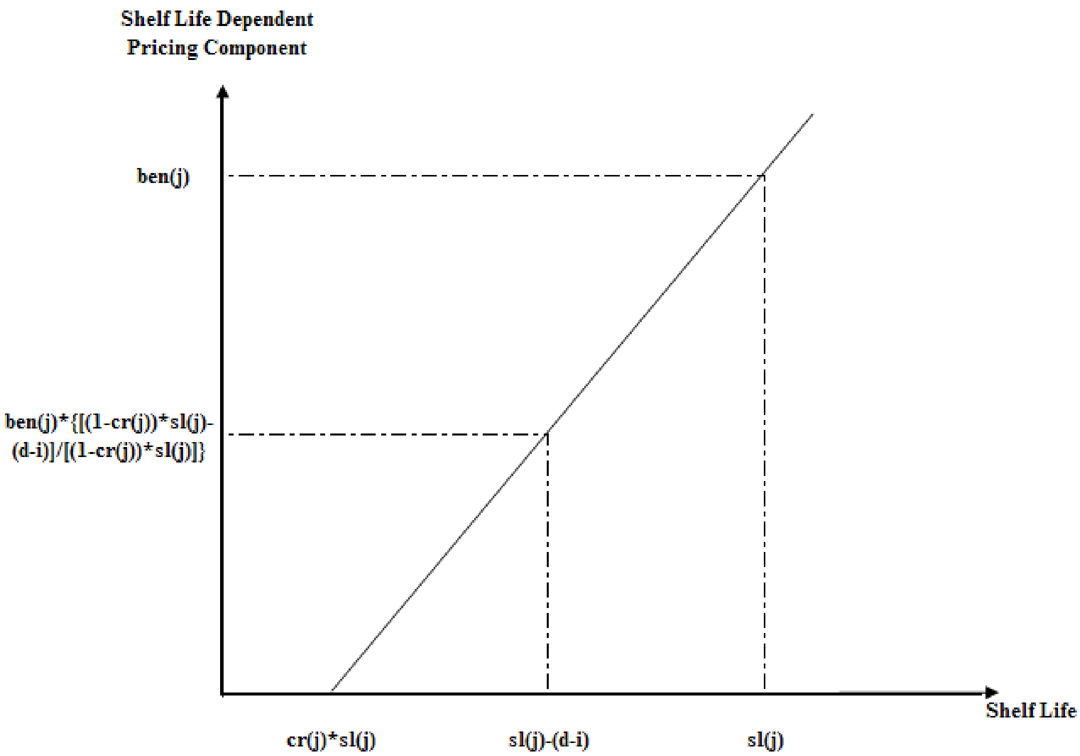


Figure 6.2 Shelf life – Benefit graph

Table 6.8 Benefit for each product

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Benefit (TL/Unit)	400	500	300	250	100	300	350	450	150	375

The objective function aims maximizing the contribution margin by minimizing the variable costs. The costs include the variable cost for products, the overtime cost on production lines, set up cost for changeovers, unmet demand cost, storage cost and transportation cost that are considered to assign demands come from distribution centers to the factories.

Table 6.9 The transportation cost from lines to distribution centers.

Dist. Center / Line (TL/Unit)	L1	L2	L3	L4	L5	L6	L7	L8	L9
DC1	1,2	1,2	1,2	2,2	2,2	2,2	1,2	2,2	2,2
DC2	1,9	1,9	1,9	0,8	0,8	0,8	1,9	0,8	0,8
DC3	1,7	1,7	1,7	0,6	0,6	0,6	1,7	0,6	0,6
DC4	0,2	0,2	0,2	1,5	1,5	1,5	0,2	1,5	1,5
DC5	2,1	2,1	2,1	1,0	1,0	1,0	2,1	1,0	1,0
DC6	1,8	1,8	1,8	2,4	2,4	2,4	1,8	2,4	2,4
DC7	0,4	0,4	0,4	1,3	1,3	1,3	0,4	1,3	1,3

Table 6.10 Operation cost of products

Product / Line (TL/Unit)	L1	L2	L3	L4	L5	L6	L7	L8	L9
P1	8	-	-	8	-	-	-	-	-
P2	-	-	-	12	-	-	-	-	-
P3	15	-	-	-	-	-	-	-	-
P4	-	10	-	-	10	-	-	-	-
P5	-	-	-	-	-	7	-	-	-
P6	-	-	5	-	-	5	-	-	-
P7	-	-	-	-	-	-	9	9	
P8	-	-	-	-	-	-	13	-	-
P9	-	-	-	-	-	-	-	-	11
P10	-	-	-	-	-	-	-	-	16

Table 6.11 Unmet demand cost and storage cost for products

Product/Cost (TL/Unit)	Unmet Demand Cost	Storage Cost
P1	100	50
P2	200	10
P3	70	30
P4	150	70
P5	300	20
P6	250	30
P7	350	25
P8	230	35
P9	400	50
P10	230	45

Unmet demand cost and Storage cost changes with respect to product features such as total cost, profitability, size of order etc. It is stated in Table 6.11. Also overtime cost varies between lines depending on the working operators on that line. The overtime cost for each line is shown in Table 6.12.

Table 6.12 The overtime cost for each line

Line/Cost (TL/Hr)	Overtime Cost
L1	116,5
L2	142,6
L3	100,8
L4	100,8
L5	182,2
L6	182,2
L7	123,4
L8	150,5
L9	135,3

In real systems, the theoretical capacities for machines cannot be used completely because of failures. In this system, there are two types of breakdowns as short and long failures. When a breakdown comes out during production, the production of a product is prevented because of failure.

Table 6.13 shows the probability density of failure and repair times for lines.

Table 6.13 Probability density of failure and repair times

	Short Failure		**Long Failure**	
Lines	**Failure Frequency**	**Repair Time**	**Failure Frequency**	**Repair Time**
1	expo (200)	norm (3, 0.5)	expo (4320)	norm (30, 10)
2	expo (250)	norm (7, 3)	expo (3600)	norm (65, 15)
3	expo (120)	norm (2, 2)	expo (2000)	norm (20, 7)
4	expo (300)	norm (7, 5)	expo (3000)	norm (120, 25)
5	expo (220)	norm (5,4)	expo (2160)	norm (50, 15)
6	expo (175)	norm (5, 2)	expo (1900)	norm (70, 13)
7	expo (80)	norm (3, 1)	expo (1450)	norm (40, 6)
8	expo (300)	norm (2, 0.2)	expo (3600)	norm (170, 20)
9	expo (250)	norm (6.5, 1)	expo (200)	norm (200, 15)

Short failures emerge more often than long failures. But, the repair times for short types are shorter and they do not prevent production as much as long failures.

In this case, the objectives are satisfying the demand of customer and maximizing the revenue by optimizing inventory levels, operating cost, unit utilization, overtime and changeover cost.

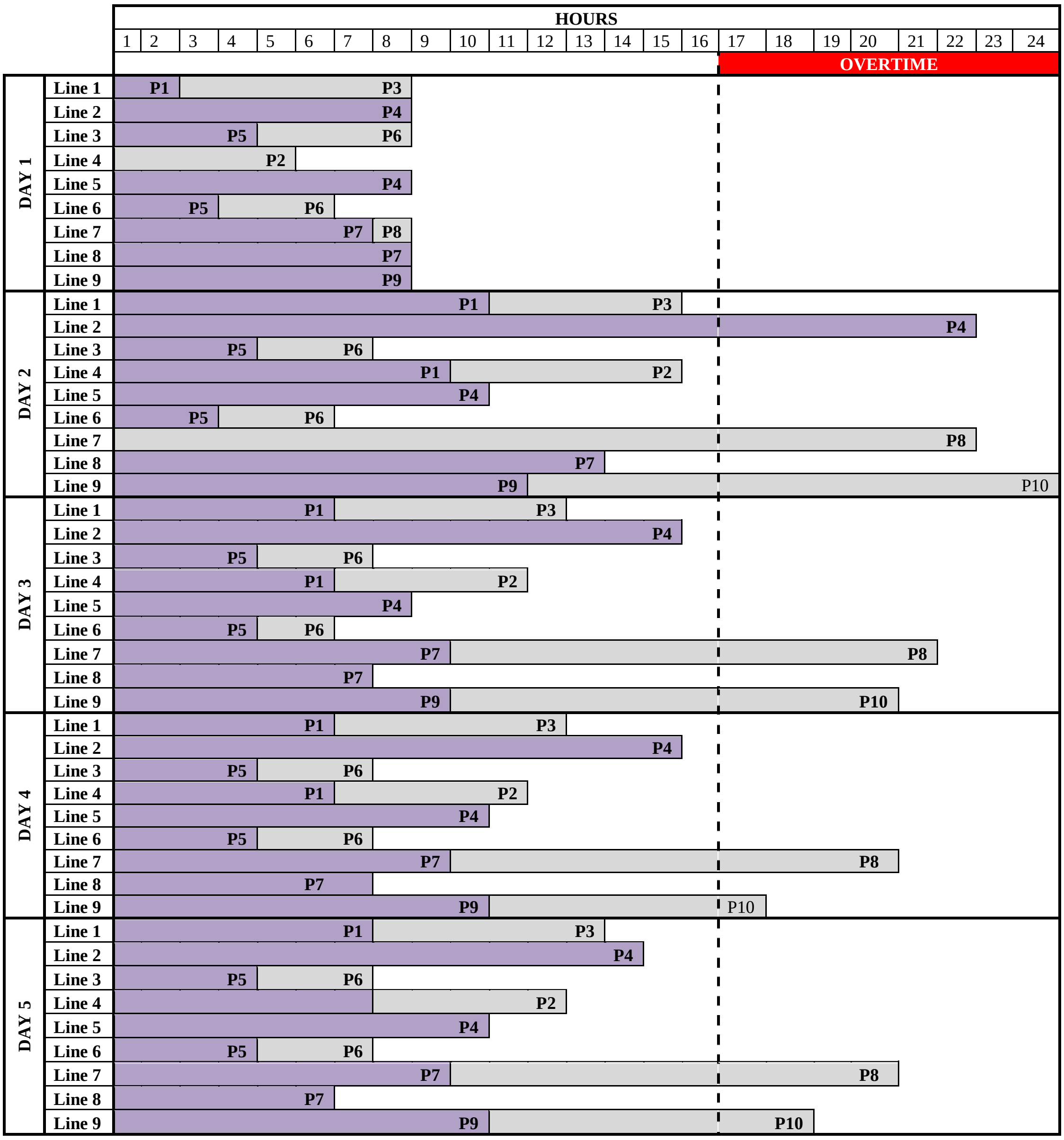
6.2 Computational Results

The hybrid simulation-analytic model approach is applied to a scheduling problem in yoghurt production process for benefit maximization and cost minimization. In order to explain the effectiveness and capability of proposed model, computational results of an example is explained in this chapter. The objective function and the features of the system are explained in Case Study part.

The hybrid method starts with the mathematical model which provides optimal production scheduling program by minimizing the costs such as overtime cost, production cost, setup cost, inventory holding cost etc.

The results of mathematical model are shown in Table 6.14 for initial conditions. Table 6.14 refers the Gantt Chart of lines for each day.

Table 6.14 Gantt Chart of production for initial solution



Secondly, the simulation model that reflects the dynamic situations such as random breakdowns or repair times is applied for obtaining the results of real system behavior. The operation times of products in each machine are obtained by simulation model. More than one replications are needed in order to estimate mean operation times. The independence of replications is accomplished by using different random numbers for each replication. (Safaei et al, 2010). The scheduling program of MILP model is used as input for simulation model.

The results of initial condition for operation times and mean of results are listed in Table 2.

In Table 6.15 pt11 refers the processing time of a unit of Product 1 in Line 1. Similarly, pt45 refers the processing time of Product 4 in Line 5.

Tablo 6.15 The results of simulation model for each replication in initial conditions

	REPLICATIONS					
Operation Time(min)	**1**	**2**	**3**	**4**	**5**	**Mean Time**
pt11	0.030	0.032	0.030	0.030	0.030	0.031
pt31	0.023	0.021	0.020	0.023	0.024	0.022
pt42	0.034	0.034	0.034	0.034	0.034	0.034
pt53	0.013	0.014	0.013	0.014	0.013	0.014
pt63	0.020	0.018	0.019	0.018	0.017	0.018
pt14	0.035	0.031	0.033	0.031	0.040	0.034
pt24	0.035	0.033	0.033	0.033	0.037	0.034
pt45	0.036	0.035	0.034	0.036	0.036	0.035
pt56	0.013	0.013	0.014	0.014	0.014	0.013
pt66	0.019	0.021	0.023	0.019	0.018	0.020
pt77	0.050	0.054	0.052	0.050	0.050	0.051
pt87	0.065	0.059	0.062	0.063	0.064	0.063
pt78	0.053	0.052	0.053	0.052	0.049	0.052
pt99	0.040	0.043	0.039	0.040	0.040	0.040
pt109	0.036	0.033	0.033	0.038	0.033	0.034

Mean operation times obtained from simulation model are used as capacities of lines in MILP model. The results of MILP and simulation models are tabulated in Table 6.16 and Table 6.17.

Table 6.16 Simulation results for each iteration

	SIMULATION RESULTS				
Operation Time(min)	**Initial Solution**	**Iteration 1**	**Iteration 2**	**Iteration 3**	**Iteration 4**
pt11	0.030	0.031	0.030	0.030	0.030
pt31	0.018	0.022	0.021	0.022	0.021
pt42	0.034	0.034	0.034	0.034	0.034
pt53	0.013	0.014	0.014	0.014	0.014
pt63	0.013	0.018	0.019	0.019	0.019
pt14	0.030	0.034	0.032	0.035	0.035
pt24	0.023	0.034	0.034	0.032	0.032
pt45	0.034	0.035	0.035	0.035	0.035
pt56	0.013	0.013	0.014	0.014	0.014
pt66	0.013	0.020	0.018	0.018	0.018
pt77	0.049	0.051	0.052	0.051	0.051
pt87	0.053	0.063	0.064	0.063	0.064
pt78	0.049	0.052	0.052	0.052	0.052
pt99	0.039	0.040	0.040	0.040	0.040
pt109	0.026	0.034	0.034	0.034	0.034

Tablo 6.17 MILP results for each iteration

	MILP RESULTS				
	Initial Solution	**Iteration 1**	**Iteration 2**	**Iteration 3**	**Iteration 4**
OBJECTIVE VALUE(TL)	79.720.150	74.146.450	74.467.570	74.494.210	-

In Table 6.17 and Figure 6.3, we can see the variability of objective function by each iteration.

As it is seen in tables, while simulation solution has 4 iterations, the MILP model ends with the third iteration. The last iteration in simulation model points us to stop iterations. For that reason, there is no need to go on solving MILP model again. The third iteration result of MILP model can be accepted as optimum solution for the problem.

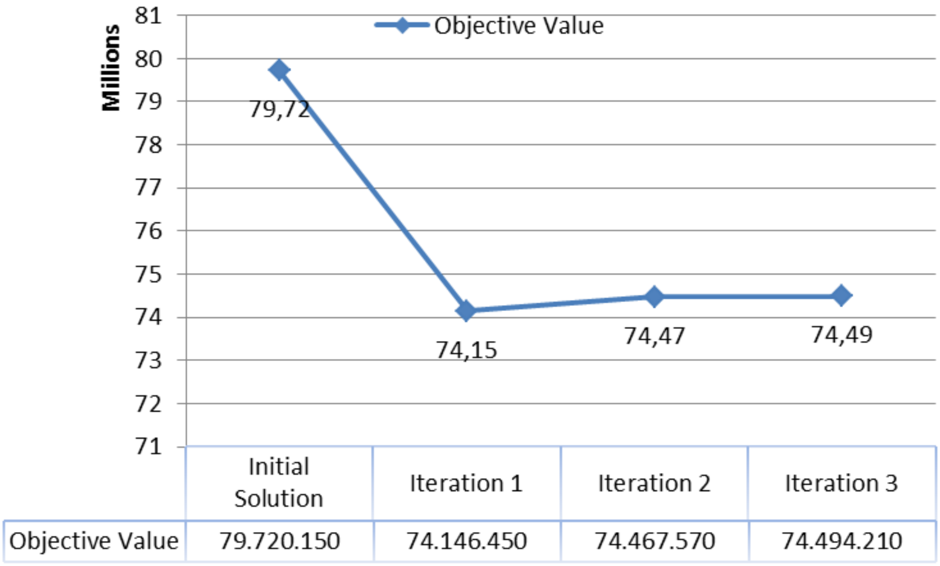


Figure 6.3 The changes of objevtive function

In Table 6.18, the computation of critical rate is shown for hybrid method. The operation times correspond the results of simulation model for Iteration 1-4. For instance, the operation time of Product 5 on Line 3 is 0.013 for initial solution, 0.014 for iteration1, 2, 3, 4 and 5. The critical rate indicates the rate between iterations. Critical Rate 1 refers the analysis of Iteration 1 and Initial solution for operation times. Similarly, Critical Rate 2 refers the analysis of Iteration 2 and Iteration 1 for operation times In order to stop iteration, the critical rate should be less than 0.025 for each operation time.

Tablo 6.18 Computation of Critical Rate for Hybrid Method

Operation Times	Initial Solution	Critical Rate 1	Iteration 1	Critical Rate 2	Iteration 2	Critical Rate 3	Iteration 3	Critical Rate 4	Iteration 4
pt11	0.030	0.024	0.031	0.009	0.030	0.001	0.030	0.007	0.030
pt31	0.018	**0.205**	0.022	**0.040**	0.021	0.013	0.022	0.005	0.021
pt42	0.034	0.000	0.034	0.000	0.034	0.000	0.034	0.000	0.034
pt53	0.013	**0.041**	0.014	0.000	0.014	0.004	0.014	0.013	0.014
pt63	0.013	**0.293**	0.018	0.019	0.019	0.019	0.019	0.008	0.019
pt14	0.030	**0.126**	0.034	**0.052**	0.032	**0.063**	0.035	0.003	0.035
pt24	0.023	**0.337**	0.034	0.011	0.034	**0.067**	0.032	0.021	0.032
pt45	0.034	**0.041**	0.035	0.000	0.035	0.000	0.035	0.000	0.035

Table 6.18 (Cont.)

pt56	0.013	**0.036**	0.013	0.025	0.014	0.002	0.014	0.024	0.014
pt66	0.013	**0.351**	0.020	**0.136**	0.018	0.015	0.018	0.021	0.018
pt77	0.049	**0.049**	0.051	0.008	0.052	0.006	0.051	0.006	0.051
pt87	0.053	**0.163**	0.063	0.013	0.064	0.015	0.063	0.025	0.064
pt78	0.049	**0.057**	0.052	0.007	0.052	0.001	0.052	0.001	0.052
pt99	0.039	**0.041**	0.040	0.000	0.040	0.000	0.040	0.000	0.040
pt109	0.026	**0.247**	0.034	0.011	0.034	0.000	0.034	0.000	0.034

According to the results given in Table 6.18, we have 13 values greater than 0.025 in the first iteration. The number of values greater than 0.025 increases as the iteration number decreases. Finally, in the forth iteration, all critical rates are suitable as required in hybrid method.

The objective value that refers the desired result is 74.494.210 TL as shown in Table 6.17. The reason of decreasing in objective value according to initial solution is considering the failures of machines in last iteration. Despite of decreasing in objective value, the last iteration gives us more realistic and practical solution for the problem.

Table 6.19 The quantity of unmet demand for products in each day

Demand Day	Product	Initial Solution	Iteration 1	Iteration 2	Iteration 3	Grand Total
3	1	13984	0	0	0	13984
	3	0	20145	20145	20145	60435
	4	17267	18329	11957	11957	59510
	7	1000	6607	13925	9722	31254
	8	25168	14084	11335	10215	60802
	9	4400	5480	7480	6480	23840
	10	17465	17465	17465	17465	69860
Total 3		**79284**	**82110**	**82307**	**75984**	**319685**
4	10	7296	19912	17402	17412	62022
Total 4		**7296**	**19912**	**17402**	**17412**	**62022**
5	10	0	8767	11664	11664	32095
Total 5		**0**	**8767**	**11664**	**11664**	**32095**
6	10	0	2142	1330	1330	4802
Total 6		**0**	**2142**	**1330**	**1330**	**4802**
Grand Total		**86580**	**112931**	**112703**	**106390**	**418604**

As well as objective value, the trend of decision variables that affects the objective value is represented in following tables for iterations.

The variations in unmet demand for products are shown in Figure 6.4 and Table 6.19. While the unmet demand quantity of Product 1 decreases in last iteration, increasing for Product 10 is observed for last iteration.

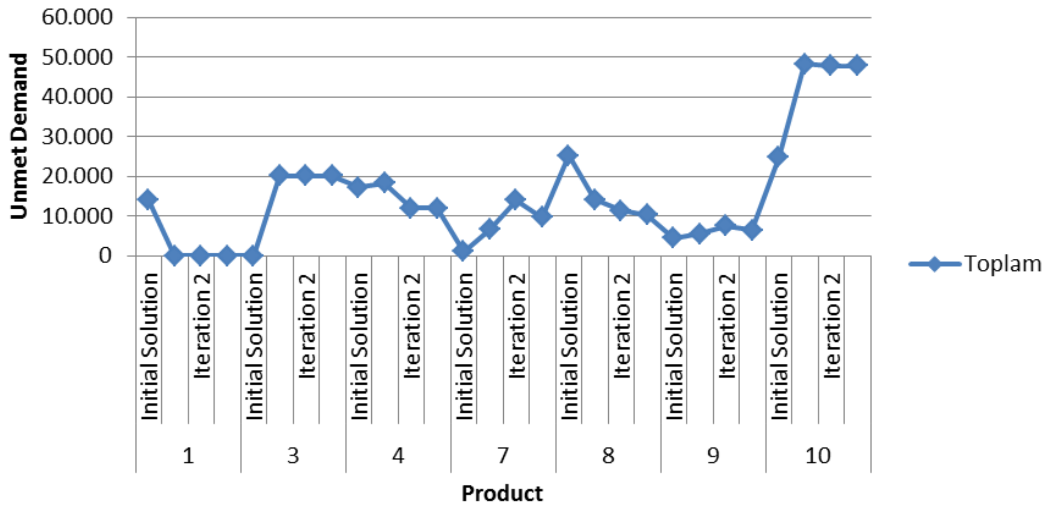


Figure 6.4 The unmet demand quantities of products based on iterations

In Figure 6.5 and Figure 6.6, the trend of inventory is represented. Figure 6.5 shows the variation in stock quantity for lines for each iteration. As it is seen in Figure 6.5, there is no great change between iterations. The inventory levels are balanced in MILP model because of inventory holding cost.

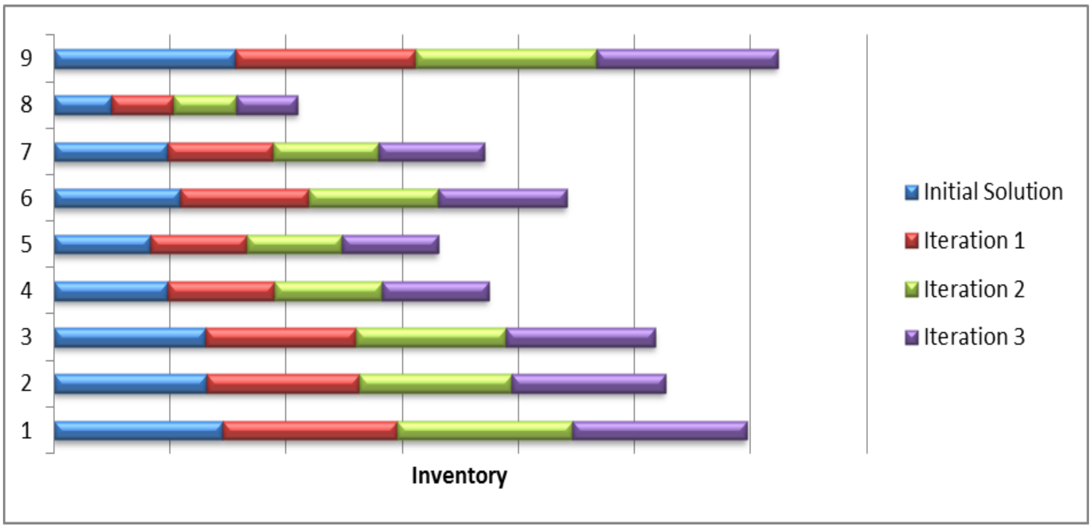


Figure 6.5 Inventory levels for lines

Figure 6.6 shows the total inventory between iterations and initial solution. The decreasing in inventory level after initial solution.

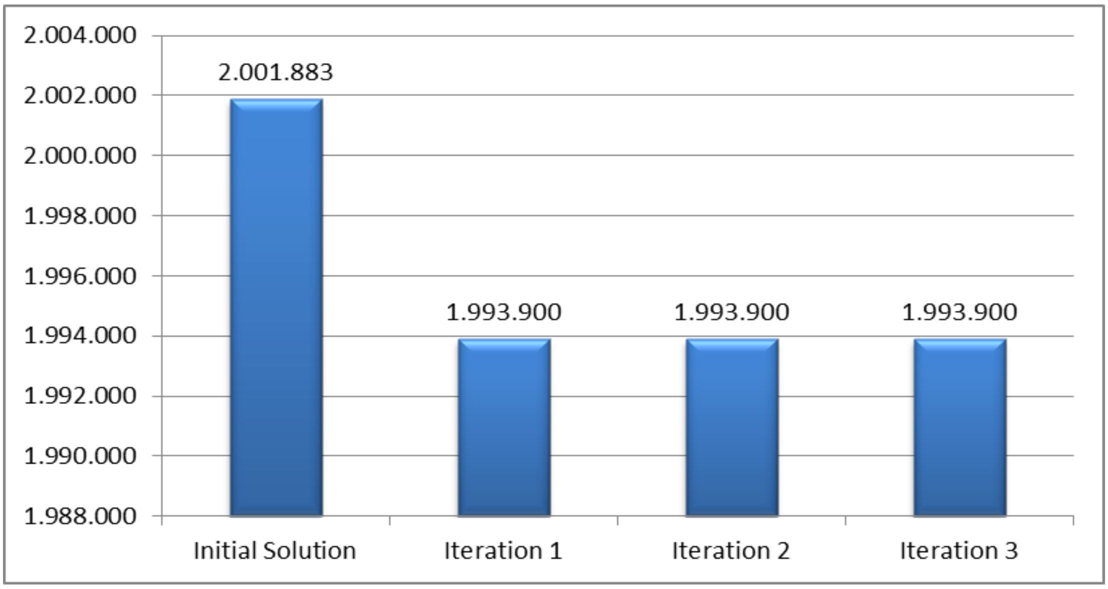


Figure 6.6 Total inventory levels for iterations

Figure 6.7 shows the total and particularly overtime variability for lines between iterations.

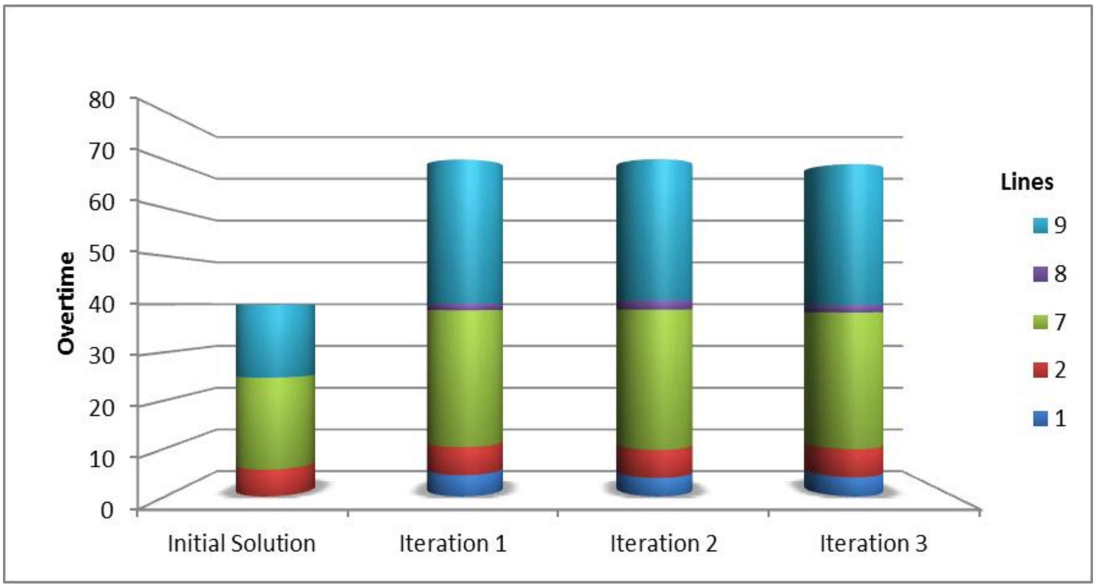


Figure 6.7 Overtime for iterations in each line

As it is seen in Figure 6.7, overtime value increases with iteration 1. However, there is no difference between iterations after initial solution. While there is no need overtime for Line 1 and Line 8 in initial solution, overtime starts with iteration 1 for Line 1 and Line 8. The failures considered in hybrid model causes the decreasing of line capacities. That’s why the lines need overtime for meeting the demands.

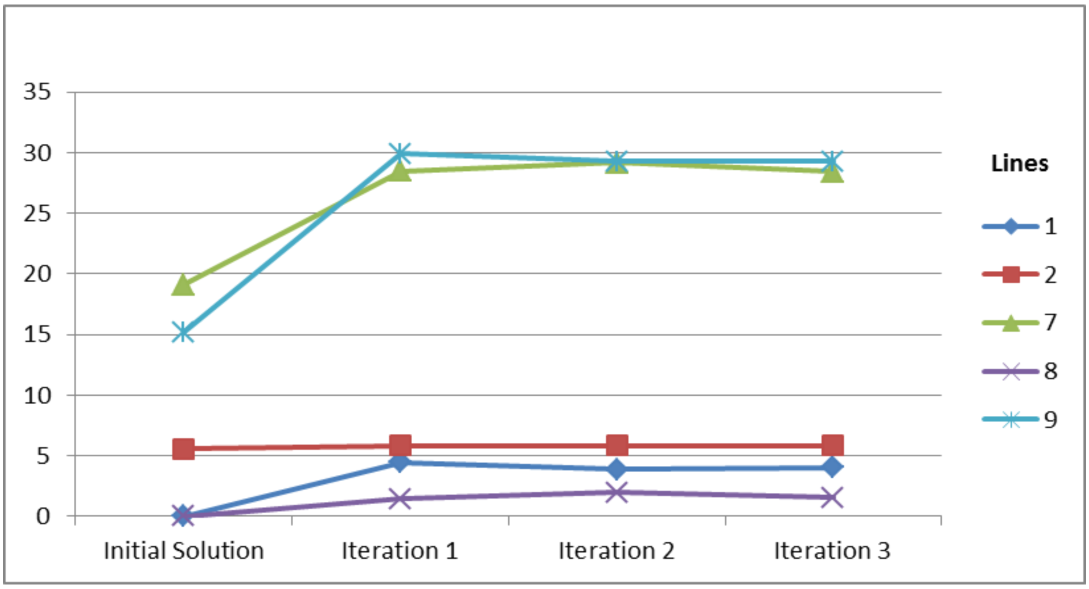


Figure 6.8 Overtime values for lines particularly

In Figure 6.8, we can see the changes of overtime values for lines particularly. Only lines 1, 2, 7, 8 and 9 need overtime for production program.

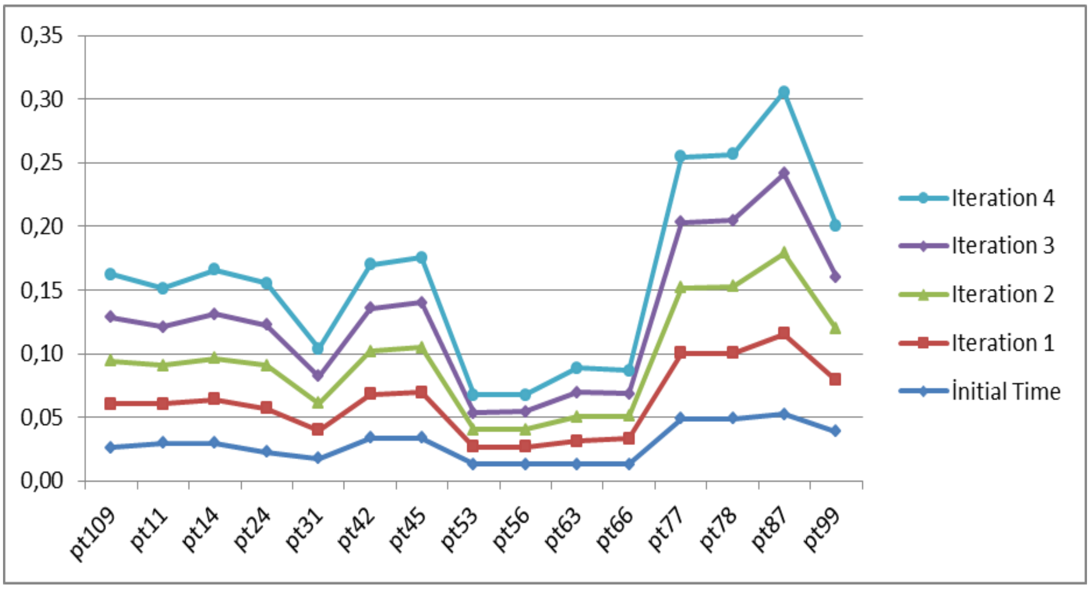


Figure 6.9 Processing times in lines for iterations

In Figure 6.9, the increasing of processing times can be observed between iterations. All of the operation times increase, when failures of machines are taken into account after initial solution.

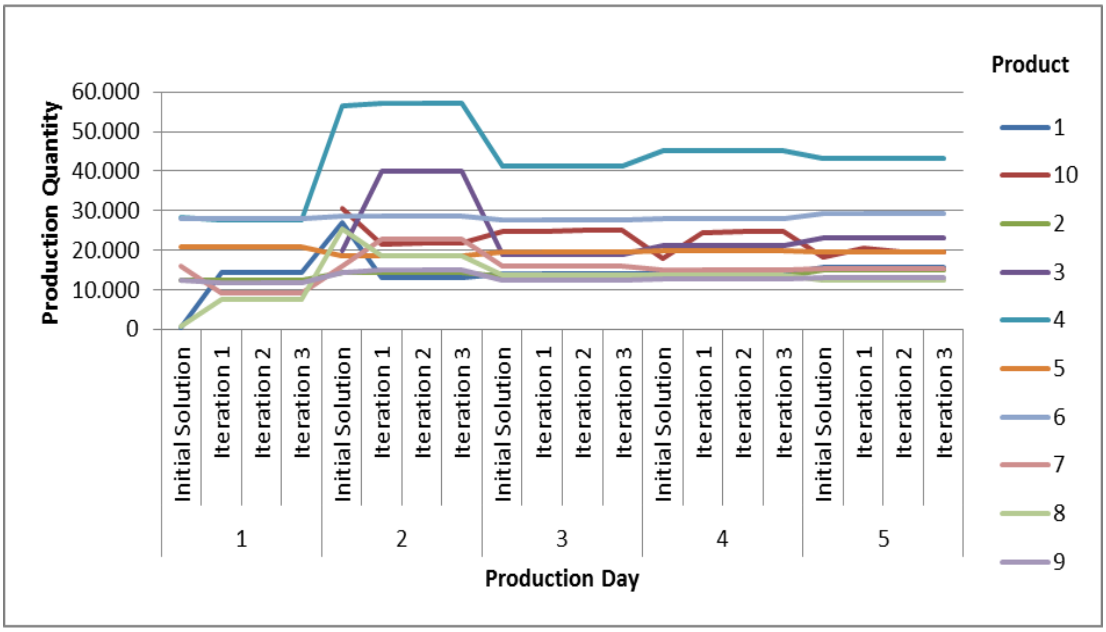
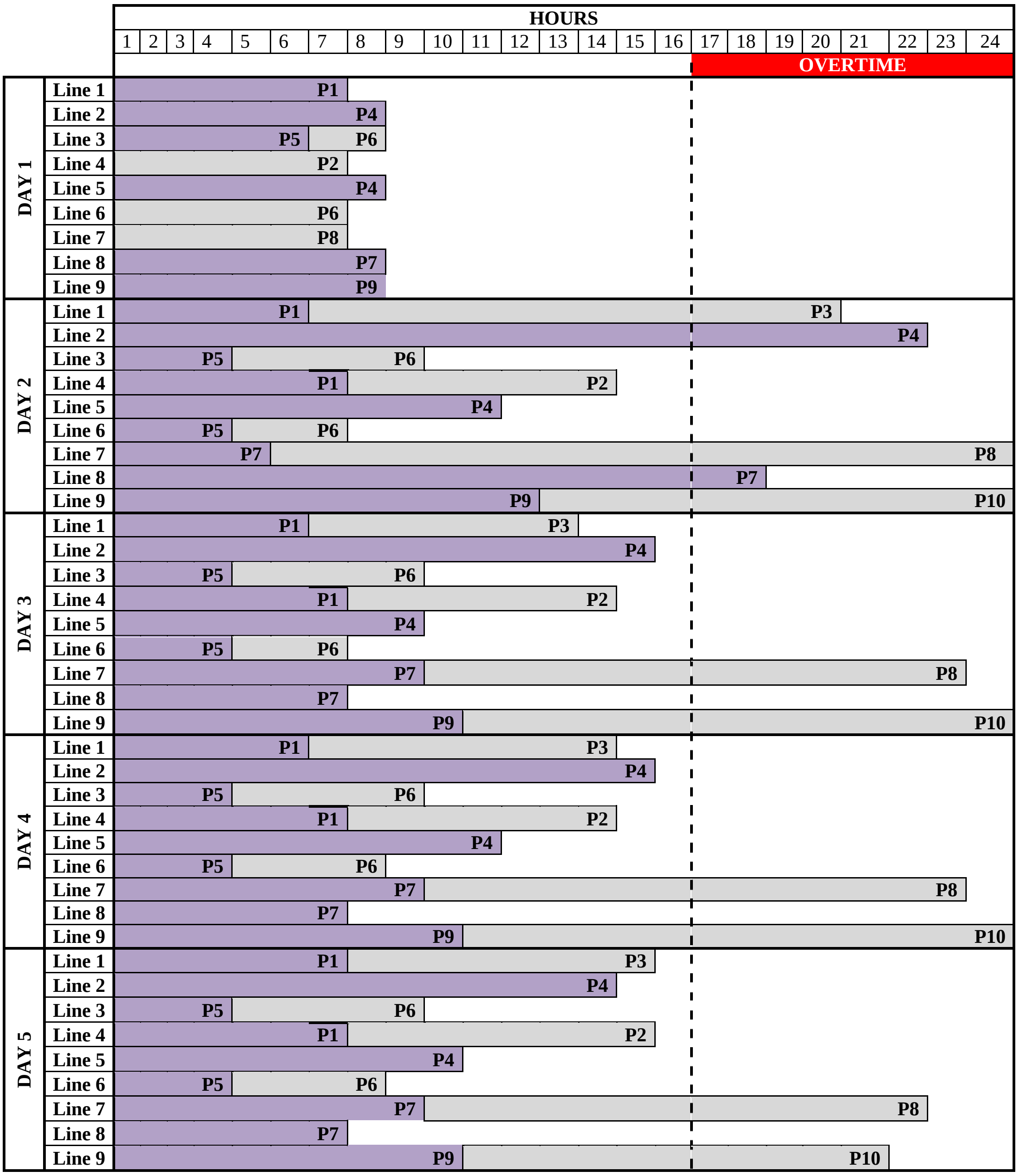


Figure 6.10 Production quantity for products in iteration

The production quantities for products in each iteration are shown in Figure 6.10. In general, after the first iteration, there is a little change in production quantities for each day. The system is balanced with the second iteration.Finally; the optimal production scheduling program obtained through hybrid method is tabulated as Gantt Chart in Table 6.20.

Tablo 6.20 Gantt Chart for optimal production scheduling program



Though the computational experiments, we can conclude the following results:

- The overall benefit decreases in comparison with initial solution. However, the results obtained by considering stochastic factors reflect the real system features.

- The overtime values are redesigned for lines, thus the workforce can be planned more realistic.
- The inventory level of lines start decreasing with iteration 1. That means the inventory holding cost decreases comparing the initial condition.
- Unmet demand values are not affected from failures in the cause of distribution of capacities optimally by MILP model.

CHAPTER SEVEN
CONCLUSION

In this thesis a real life dairy industry producing yoghurt is studied in detail. An efficient hybrid solution methodology based on a MILP formulation and a simulation is presented to address challenging production scheduling and distribution problem in the dairy industry. The needs of dairy companies, their manufacturing plants, and demand of customers motivated this research.

The goal is to minimize total cost while maximizing benefit based on shelf life of products. The shelf life constraints are designed in MILP model to improve product freshness. The shelf-life dependent pricing components are determined based on real data. In order to improve customer satisfaction, freshness is considered in yoghurt production planning. It also provides competitive advantage for manufacturer.

In addition, sequence dependent set up time, demand due dates, different machine capacities for products, overtime planning, and backlogging are included in MILP model formulation. Unlike the previous studies considered only few of them together, in this thesis all important features are evaluated and included in the model. Another option to extend the proposed model is integration of transportation process from plants to distribution centers. The parallel machines located in different plants are scheduled according to distance between plants and distribution centers.

As a result MILP model provides a scheduling program by optimizing the resources. In order to apply scheduling program in practice, the stochastic factors that are ignored in MILP model are added to the problem by the simulation model.

While the attributes of food processing are accepted as fixed values in most of previous studies, operation time is inserted as stochastic for the realistic solution. It is adjusted according to the simulation model results. For determining operation time, probability density of machine failures and repair times are considered as short and long durations in the simulation model.

The hybrid approach is applied by combining MILP and simulation models to solve a production scheduling and distribution problem. This method, commonly applied for production-distribution planning problem is developed for yoghurt production planning and distribution problem. For perishable products, determining inventory levels properly is as important as giving quick response to customer demands.

Hybrid approach provides a great advantage in production planning for fresh products. Therefore, it is clear that this approach is more realistic even compared with traditional planning approaches.

The optimum scheduling program is obtained by hybrid approach. The machines capacities, inventory levels and overtime plans are determined to response the demand of customers. Finally, we obtain a model that can be applied in real life system. It is found that the method has the capability to overcome the variety of manufacturing structures and restrictions for special cases.

There are several future research directions for this important area. This approach can be used for other products of dairy industry. The other stochastic factors can be added to model besides operation time for more realistic solution. It is also applied for determining strategically capacity investments.

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