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M.Sc. in Industrial Engineering

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**UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES**

**DEVELOPMENT OF AN INTEGRATED SOLUTION FOR PRODUCTION
PLANNING IN A YARN PRODUCTION PLANT**

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IN

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BY

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**Development of an Integrated Solution for Production Planning in a
Yarn Production Plant**

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University of Gaziantep

Supervisor

Assoc.Prof.Dr.Zeynep Didem UNUTMAZ DURMUŞOĞLU

by

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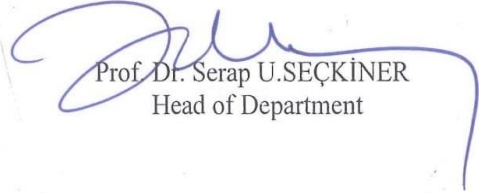
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I declare that all information in this thesis has been prepared in accordance with academic and ethical rules. I also declare that, I have referenced all material that not original to this thesis.

Muhammed İdris AKTAŞ

ABSTRACT

DEVELOPMENT OF AN INTEGRATED SOLUTION FOR PRODUCTION PLANNING IN A YARN PRODUCTION PLANT

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Nowadays, satisfying customer demand at an optimal cost is one of the most important subjects for the textile market. In the developing world of technology, companies are working on how to handle effective solutions to increase customer expectations and product diversity. Therefore, the firms have been researching for cost effective solutions for their operational tasks, with the increasing competition and the rapid change in technologies. Production planning supported by computer systems and software has become part of these solution strategies. In this thesis, model was set up firstly, then a production planning software was designed for a real yarn production company. Firstly, the demand forecasts are produced by using historical data with several forecasting methods and the method that produces the minimum error is selected. Subsequently, a mathematical model is established to maximize the total profit (minimize the total cost) under certain constraints. An interface was also developed to manage all of the operations required to run the system. Java programming language was used to design the interface. The developed software is capable of retrieving the related data from the ERP system of the company and capable of exporting the mathematical model to Gurobi Optimization solver and importing the results. The obtained results were evaluated by considering sensitivity analysis report. Results indicated that, the annual profit for selected products increased by proposed production planning.

Key Words: Production planning optimization, Demand forecasting, Software design, Interface design, Time study, and Sensitivity analysis.

ÖZET

BİR İPLİK ÜRETİM TESİSİNDE ÜRETİM PLANLAMASI İÇİN ENTEGRE BİR ÇÖZÜM GELİŞTİRİLMESİ

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Günümüzde tekstil firmalarında müşteri talebini en düşük maliyetle karşılamak, yöneticilerin en önemli konulardan biridir. Gelişmekte olan teknoloji dünyasında, organizasyonlar müşteri beklentilerini ve ürün çeşitliliğini artırmak için etkin çözümlerin nasıl ele alınacağı üzerine çalışmaktadırlar. Bu nedenle firmalar, artan rekabet ve teknolojideki hızlı değişimler ile işlevsel görevler için uygun maliyetli çözümler araştırmaktadır. Bilgisayar sistemleri ve yazılımları tarafından desteklenen üretim planlaması bu çözüm stratejilerinin bir parçası haline gelmiştir. Bu çalışmada reel bir iplik üretim şirketi için üretim planlama yazılımı hazırlanmıştır. Öncelikle, birkaç tahmin yöntemiyle geçmiş veriler kullanılarak talep tahminleri geliştirilmiş ve minimum hata üreten yöntem seçilmiştir. Ardından, belirli kısıtlar ile toplam karı (toplam maliyeti en aza indirmek) maksimize etmek için matematiksel bir model oluşturulmuştur. Sistemi çalıştırmak için gereken tüm işlemleri yönetmek için bir ara yüz geliştirilmiştir. Ara yüz tasarımı için Java programlama dili kullanılmıştır. Geliştirilen yazılım, ilgili verilerin ERP sisteminden alınabilmesi ve matematiksel modelin Gurobi Optimizasyon programına aktarılma işlemini kolaylıkla sağlamaktadır. Elde edilen sonuçlar, duyarlılık analiz raporuna göre değerlendirilmiştir. Sonuçlar, seçilen ürünler için önerilen üretim planlamasının yıllık kârı artırdığını göstermiştir.

Anahtar Kelimeler: İplik, Maliyet, Yazılım, Arayüz tasarımı, Optimizasyon, Talep, Tahmin, Zaman Etüdü ve Duyarlılık analizi.



To my dear Mother and Father ...

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ABBREVIATIONS

LP	Linear Programming
ERP	Enterprise Resource Planning
GAMS	General Algebraic Modeling System
PAN	Poly acrylonitrile
LTS	Long Term Support
GUI	Graphical user interface
SQL	Structured Query Language
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol Secure
IDE	Integrated Development Environment
JDK	Java Development Kit
MAPE	Minimum Mean Absolute Percent Error
MAD	Mean Absolute Deviation
MSE	Mean Squared Error
Nm	Kilometer of Yarn per Kilogram
FCFS	First Come First Served
OC	Coefficient of the Objective Function
RC	Reduced Cost
SP	Shadow Price
UB	Upper Bound
LB	Lower Bound
SL	Slack
FV	Final Value

CHAPTER 1

INTRODUCTION

The textile and clothing sector plays an important role in the Turkish manufacturing industry and the demands are increasing day by day. Textile technologies enable the development and application of modern cost accounting methods where main scope is to evaluate required information to management about the effectiveness of certain products. To cope with the orders having short lead time, textile manufacturers strive to improve their production processes in order to deliver finished products within the expected time frame at the lowest production cost. Production planning is therefore gaining importance in contemporary apparel manufacturing. Production planning systems supported by computers have been a part of these solution strategies. The main purpose of production planning systems is to organize resources to build the products time with minimum cost.

Production of yarn, like many other production systems, are generally confronted with the problem of the most efficient use of limited resources, regardless of the type of production. The aim of production planning is to ensure that resources such as raw materials, machinery, and labor required for production are used at the right time, in the right place, and in sufficient quantity, thus maximizing productivity.

The highest point of productivity [1] is to produce the product on time and in the cheapest quality. Optimization techniques can be utilized in production planning, Linear Programming (LP) method is the most common method used in operation research. In this thesis, a production planning software was developed for five selected products (X1, X2, X3, X4 and X5) which are the best seller products in a typical real yarn production company.

The developed software has 4 modules and these modules are used namely to perform the demand analysis, cost analysis, LP modelling and sensitivity analysis, respectively. Monthly demand, average sale prices and raw material types, which are obtained from the ERP program, are first entered into the software. Then demand and cost analysis are performed in the first and second module, respectively. In the third module, pre-determined parameters are used to construct the corresponding LP model. Finally, sensitivity analysis of the model is performed in the Module 4. An overview of the flow chart is as given in Figure 1.1.

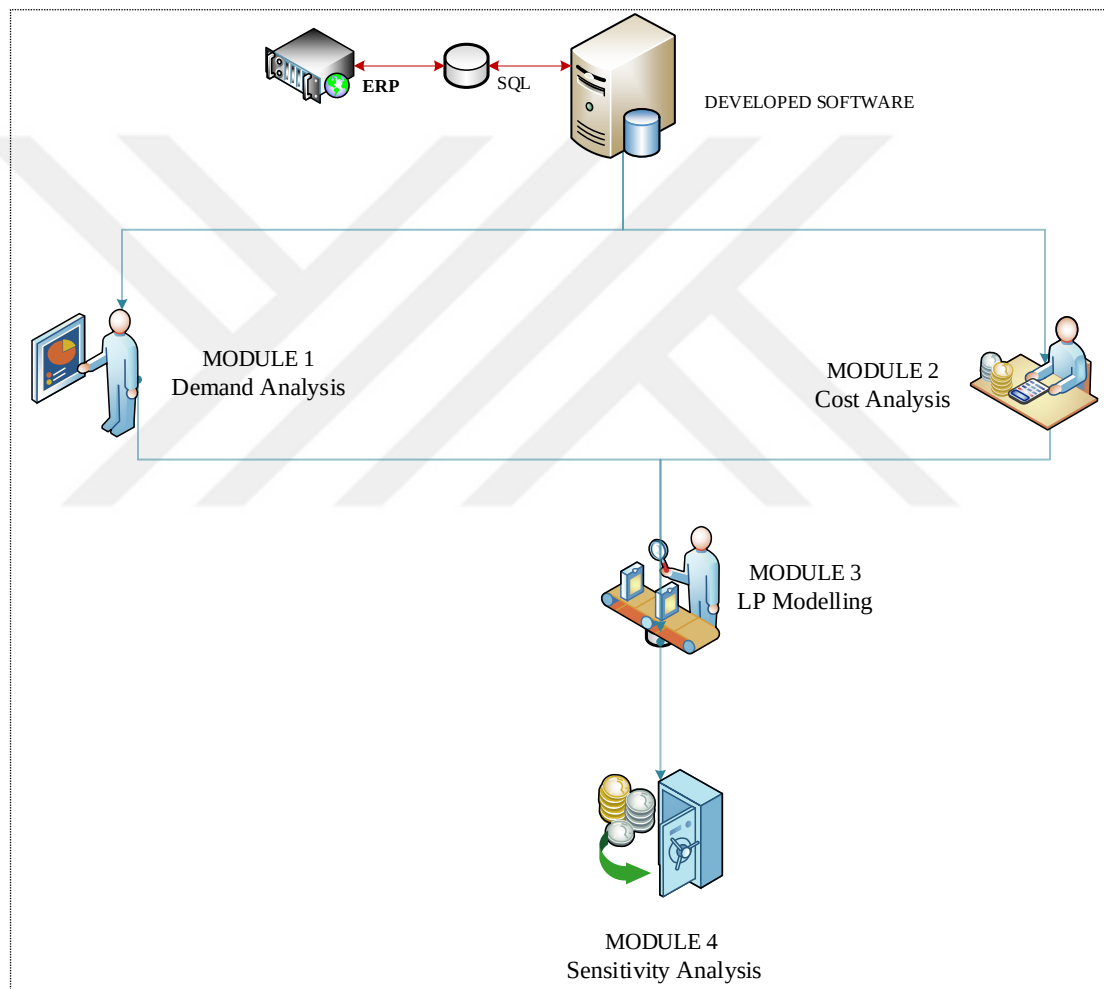


Figure 1.1 Control system of breaker machine

1.1 Contribution of thesis

The integration of production planning and order acceptance decisions has been an important issue for textile manufacturing firms. Production companies mostly try to tend to accept orders which provide much more profit in a competitive environment. There are various decisions made by experts to raise the profit rate to the upper levels. This research aims to use the linear programming technique to determine the optimum production quantities with maximum profit. The interface, which consists of several integrated applications, provides easy updating and data entry using predetermined estimation methods. The developed software can estimate demand by using data from ERP systems.

1.2 Purpose of the thesis

Nowadays, one of the main problem in Turkish textile yarn manufacturing industry is the minimization of production cost. Manufacturing managers face increasing pressure to reduce inventories and cost of production according to the market demand. The main purpose of this thesis is to develop a computer aided resource planning system by maximizing the profit. To be able to maximize the total profit and meet market demand, companies and company wants to determine the optimum yarn production quantities by using LP model.

1.3 Organization of thesis

This thesis is structured as follows. Introduction and purpose of the thesis have been described in chapter 1. Chapter 2 consists literature survey about Production planning and Optimization production planning. In chapter 3 we have discussed about material and method. Chapter 4 consists acrylic fiber, acrylic yarn production system and their production planning. Expenses types and costing systems have been described in chapter 5. In chapter 6 provides information about system definition, demand analysis, unit cost calculation, time study and linear programming (LP) model.

Additionally, in chapter 7 consist some experimental studies results with time study method, forecasting methods, LP model and sensitivity analysis. Finally chapter 8 included conclusion and further studies.

CHAPTER 2

LITERATURE SURVEY

Scientific papers related with the optimization techniques employed in production planning area have been investigated. Since the production planning problem is considered as a cost-based optimization problem in this study, the studies that focus on the same problem are summarized in this section.

2.1 Production planning

One of the earliest applications of optimization techniques in production planning is the study of Jaaskelainen's [2]. He introduced a simple goal programming model to deal with an aggregate planning. After two years Lee and Jaaskelainen [3] developed more advanced goal programming model. The developed model was established according to management objectives. Some of these objectives are inefficient production capacity and the overtime production.

In the study of Goodmans [4] another goal formulation in a production planning process was proposed. In this study he tried to estimate and reformulate of a quadratic cost model for production planning. In Goodman's model goal programming was used as a linearization of objective functions of the quadratic cost model.

Laurent [5] developed an extension of Goodman's model. The name of model was specified as "Range programming". In this model a satisfying range has been achieved instead of an optimal point. The model structure included multiple objectives, such as minimizing regular payroll, hiring and firing, overtime and idle time, and inventory holding.

Fisk [6] developed a goal programming model that related with minimizing inefficient capacity for production planning. Later Hindelang and Hill [7] also presented the goal programming model that includes objectives about worker productivity and motivation, inventory investment, and subcontracting costs. Both works include more detailed goals for production planning was compared to the earlier models.

A multiple objective formulation of the multi-product and multi-period production planning problem studied by Masud and Hwang [8]. Three methods were applied in their study with a numerical example in order to obtain the optimum levels of production, inventory, and the regular and overtime workforces. Goal programming, step method and sequential multiple objective problem solving method were used. Labor force balance, production balance, production capacity and regular and/or overtime labor constrains where included the model. The main objectives of the study were maximizing profit, minimizing backorders, and minimizing changes in workforce levels.

Lawrence and Burbridge [9] developed a model for aggregating a company's production and logistic planning. The objectives of the study were to maximize total sales revenue for specific location and customer, minimizing the total production and distribution cost, maximizing the production of a particular item. There are also some another constraints except objective constraints, such as total demand for each item at each customer location, available production capacity at each production location.

Zanakis and Smith [10] used goal programming, and developed a mathematical model for the production plans of intermediate and final chemical product quantities. The model functions determine the production levels for each product to maximize management's goal. There were two production units and four chemical reactors in the factory. There were also nine management objectives in the model also. Some of these goals are related with profit maximization, sales maximization, maintenance cost minimization, sale limits, and underutilization minimization of production capacities.

Sun, Ui and Nakayasu [11] developed a production planning system for solving semi-large size multi-criterion planning problems by using goal programming method. Two-step modeling method for building the goal programming model were presented. Researchers examined how to develop a goal programming system to easy use even for the users who do not understand the details of goal programming. Consequently, in order to, illustrate the developed model, a production planning case was used.

Karpic, Mornar and Baranovic [12] developed a production planning model that included calculating the optimum production and achieving the capacity, while maximizing the contribution and minimizing the duration of the longest resource engagement. The model contained time scheduling problem as well.

A model presented by Weng [13] about manufacturing lead time planning problem where lead time sensitive and insensitive customers had been. The goal of the study was increasing the utilization rate of the system where manufacturing flow times were stochastic. The model created as a queuing system, so lead time sensitive customers had a priority and first come first served (FCFS) discipline based for each order group. For time sensitive customers the penalty cost were considered.

Nagarur, Vrat, and Duongsuwan [14] introduced a production planning and scheduling model for injection molding of PVC pipe fitting in a factory. The objectives of the model were minimize the total costs of production, inventory and shortages. The problem was divided into three sub problems, such as a single-machine, multi-product and capacity lot sizing problem. A zero-one goal programming approach is used to obtain the solution.

To maximize the revenue, Palaka et al. [15] studied capacity utilization, lead time setting and pricing decisions for make-to-order production system. Some customers which had lead time dependent demand were served on a first come first served principle and assumed that customers arrived by Poisson process and processing times of the orders were exponentially distributed. Also, lateness penalty cost, production cost and work-in-process inventory cost were considered in this study. Moodie [16] researched on the similar subjects. The research considers the problem of demand management in a firm where the firm's historical delivery service level reputation influences the number of quotation requests from its potential customers. Customers have a maximum and the firm has a minimum net price to due date tradeoff curve for each job. In the study of Moodie & Bobrowski [17], the purpose of the firm's was maximizing its long term net revenue and bidding process defines the firm's demand management negotiation strategy. They considered only price and due production planning, quality was not considered in this study. They considered demand management in a job shop where the number of potential customers were affected from previous delivery service level. According to this strategy the firm could make a negotiation with customers about the over price and given dispatch date. Penalty costs and inventory

holding costs were ignored for early or tardy jobs. Furthermore, they assumed that the future potential orders would not be affected from rejecting the customers' order.

Lorena Predenas and Fernando Penailillo [18] proposed a mathematical model and a heuristic procedure based on Tabu Search for the problem of aggregate production planning at sawmill to determine the production rates. In the same year Silva et al. [19] introduced a multiple criteria mixed integer linear programming to solve aggregate production planning problems. The model has been structured to optimize three performance parameters for a set of workforce, production and inventory related constraints. Furthermore, a decision support system has been included in order to extend its application in practice.

Akhil Jain and Udatta S. Palekar [20] were presented a configuration-based formulation for one such manufacturing environment, where production may involve dissimilar machines performing similar operations at different rates and equipment could be connected together to form different production lines. The production process was continuous and no in-process inventory can be kept.

2.2 Optimization for production planning

A mathematical model of production planning in yarn enterprises created by using Lindo Optimization in the thesis of Sabır [1]. Mixed integer programming method was used for yarn operation of all sizes, as well as the number of processes, number of machines, yarn types, number of raw material types and variables in normal and/or overtime work. Production planning in the model has been taken into consideration factors such as sales price, costs, raw material usage and employee machine capacities. As a result, production costs were reduced by the developed mixed integer programming method. In thesis of Timur [21], a mathematical model established to maximize the total profit. He investigated possible cost variability in a cotton production mill. A production plan consists of a yarn production quantity that should maximize the total profit by considering the availability of resources such as raw material, machinery and labor. In the study of the Timur [21] a linear mathematical programming model was developed to solve the production planning problem faced in spinning mills, considering the relevant production costs. The developed model wasn't used for mixed yarns due to the limitation of some cost analysis. The developed model was applied on a spinning mill for one type of yarn and maximum profit was obtained.

Bayazit, Arıkan and Taner [22] developed a software in a fabric manufacturing company which was similar with the one used in yarn spinning companies. Developed software coded in Quick Basic 4.5 computer programming language. The optimum production amount determined by using the actual unit cost with constantly updating some variable parameters with based model constraints. All the factors affecting cost in the production of T-shirt fabric were considered. The results of the program were used for determining the optimum amount of production. Sakallı [23] preferred the casting industry in his study. It is an important process to obtain the raw material by blending the required metal ratios in the brass casting industry. Therefore, the blending process requires the determination of the cheapest way of available raw materials meeting the specified metal ratios. In this study, single and multi-blending models have been formulated and LINGO package program was used to solve the linear programming problem. As a result of study production cost of raw material reduced and determined the various raw-material purchasing policy.

Cetinbag [24] developed a computer program for preparing the daily production program planning using LP, with constraints of costs, daily demands and capacity of machines for maximizing the income of a textile company. The model was setup with Solver add-in of Microsoft Excel. The application was carried out for 8 products. As a consequence, maximum profit was determined with developed mathematical model. The main limitation of this study was to employ Microsoft Excel which has some boundaries while coding LP. Tamer [25] also developed a software which has more complex than Cetinbag [24]. In this study a mathematical model is established to maximize the total profit under certain constraints. GAMS software package was used to solve the relevant problem. Further, the cost of different production alternatives was calculated by using sensitivity analysis. In the study, a cost-effective production program was developed and minimum material cost obtained with constructed linear mathematical programming model.

Schonung, Bay and Clement [26] studied the concept of economy in dynamic and linear models, considering all the factors that can affect the unit cost in yarn spinning machine. Parameters such as yarn quality, production characteristics and unit yarn costs were examined and optimum quality values and machine cycle determined. As a result of model, machine speeds should have been reduced in spinning machine. Increasing the speed increases cost and decreases yarn quality. Therefore, they suggested

that the machines should be run in determined optimum speed to decrease cost of spinning machine. Rusch, [27] also proposed to reduce the cost in spinning mills with changing some parts of machines and software. With technological possibilities optimum production quantity determined and efficiency of the spinning machine also increased. The unit cost of product has been reduced in this study.

An article published about optimizing production scheduling by Zhou [28]. Textile dyeing industries need huge quantity of freshwater for textile dyeing, and discharges a huge amount of wastewater. Genetic algorithm was used in this paper for the optimization of dyeing production schedule, and it aimed to reduce the freshwater consumption by optimization of scheduling based on dyeing color. Then a scheduling model including a database developed by using dynamic genetic algorithm. Proposed model developed by using MATLAB program. The system was implemented in a typical textile dyeing enterprise which rescheduled about 50-70 orders with unexpected orders insert as a case study. The results showed that compared to traditional production scheduling, the proposed production scheduling could reduce freshwater consumption about 18.4-21%.

The study of the Ramezani [29]'s related with aggregate production planning, it was a medium-term capacity planning to determine the quantity of production. In this study, a mixed integer linear programming model for general two-phase aggregate production planning systems was developed. The goal was to minimize costs and instabilities in the work force and inventory levels. This paper is concentrated on multi-period, multi-product and multi-machine systems with setup decisions. In order to solve the problem, a genetic algorithm and tabu search were used. The computational results showed that proposed algorithms obtain good quality solutions for aggregate production planning and could be efficient for large scale problems. Also an aggregate production planning published in 2015 by Gansterer [30]. Different forecasting techniques used in this study. The planning problem was formulated as a linear mathematical model and solved by a standard optimization engine. A discrete-event simulation model issued to perform lower level planning steps. The performance of the model was evaluated based on service-and inventory levels. Real world data coming from the automotive supplier industry was used to define four demand scenarios. Their experiments results show, that in a setting of low capacity utilization, aggregate plans were rather unprofitable. Moreover researchers indicated that, using time series forecasting techniques seems to be a good strategy if demand is highly.

Büyükkelik [31] emphasized in his thesis that there was too much idle capacity in an enterprise that makes production with a heuristic method. It has been pointed out that the large number of parameters in operation cause difficulties in the application of linear programming. It has been stated that the amount of this idle capacity can be reduced to minimum by the production plan realized by linear programming method. In another study, linear programming method used by Bircan and Kartal [32] in a construction firm to maximize profits. It was stated that there are 6 different types of cement production in operation. The CPLEX program was used to solve the linear model. One of the results obtained in the study is to indicate that there is idle capacity in the units where production was performed. It is stated that this study is based on production and that alternative models can be obtained with sensitivity analyzes. This shows that planning could be used not only in the period of production planning, also in the future, in order to reach useful information in terms of operation. In the thesis of Yılmaz [33], he emphasized that enterprises need to build production areas in order to realize production within a certain plan and they were aiming to utilize their resources more efficiently in this way. The WINQSB packet program was used to solve the problem expressed linearly in the study.

CHAPTER 3

MATERIAL AND METHOD

Calculating the minimum production cost for yarn producers and optimizing the quantity of stock is one of the most important problems. The goal of production planning is to ensure that resources such as raw materials, machinery and labor are used at the right time, in the right place, and in sufficient quantity, thus maximizing productivity. The production planning system tries to determine the optimum yarn production quantities which increase the total profit by using minimum quantity of raw material, machine and work force.

The primary objective of this thesis is to develop an optimization algorithm to obtain minimum production and inventory cost. The demand can be estimated with the pre-determined estimation methods using the data taken from the ERP. To increase profits, firms aim to determine optimum yarn production quantities that maximize total profits with LP modeling. In this thesis, a production planning application is designed for five selected products (X1, X2, X3, X4 and X5), which are the most seller products in the real yarn production company.

3.1 Material

A real yarn production manufacturing company, Gurobi optimization software to solve mathematical model, Java programming language to design interface of the software and MySQL database used as material in this thesis. Details will be explained in the next sections.

3.1.1 Description of company

In this thesis it is assumed that the manufacturing company consists of dye house, textile, controlling and production planning, purchasing, inventory and packaging departments. The production is a continuous process for 24 hours with tree shift. The company produces the following products: acrylic, viscose cotton, wool, cotton/acrylic yarns.

The company is manufacturer of acrylic based yarns made from long staple fiber. Production is in Gaziantep, and the head office is in Istanbul. Around 700 labors are working in production area. It has a very wide range of qualities from Nm 1 to Nm 40 (count of yarn). Company product range are acrylic, acrylic wool, acrylic mohair, acrylic viscose polyamide and many different type and blends even fancy yarn. Capacity of machines is 550 tons/month for industrial yarns, 60 tons/month for fancy yarns and 450 tons/month for dyeing.

3.1.2 Software

In this thesis, production planning of an acrylic yarn production company is employed. In order to retrieve data MYSQL workbench (database) is used. Interface of the program is developed by using NetBeans IDE (JAVA). LP model is solved by using Gurobi Optimization.

Gurobi optimization¹: Gurobi [34] features provide data attachments to mathematical models that give information about the timing and production processes to the producers. The features of these models influence strategic planning decisions and are useful for increasing productivity and reducing costs. Optimization will help managers to unify their development processes with relevant supply chain and distribution systems. Production planning optimization, Inventory optimization, supply chain, detailed planning, shipment planning, factory estimates and maintenance planning are some examples of business problems that can be solved by Gurobi solvers.

¹ <http://www.gurobi.com/index>

MySQL workbench²: MySQL Workbench [35] combines database design and maintenance, improves fault tolerant tasks and facilitates communication between developer teams and DBA. It enables data architects to visualize requirements, communicate with stakeholders, and solve design problems before investing a great deal of time and resources.

It allows model-based database design to build well-performing databases while providing the flexibility to respond to business needs. Model and Scheme Validation programs implement application standards for data modeling as well as physical design standards specific to MySQL so that no mistakes are made while creating new ER diagrams or creating physical MySQL databases.

NetBeans IDE³: NetBeans [36] provides a ready to use code analyzer and editor for working with Java technologies. It also has some tools for HTML5/JavaScript. NetBeans packages require the installation of the Java Runtime Environment. To use Java features JDK 8 must be installed.

3.2 Methods

Predetermined forecasting methods, linear programming method and time study were used to develop integrated system.

3.2.1 Time Study

A work measurement technique for recording the times and rates of working for the elements of a specified job carried out under specified conditions and for analyzing the data so as to determine the time necessary for carrying out the job at the defined level of performance [37]. In other words measuring the time through stop watch is called time study. Time study is also called work measurement.

Time study is absolutely essential for both the planning and control of operations. Without measurement data, we cannot determine the capacity of facilities or it is not possible to quote delivery dates or costs [38].

Stop watch time is the basic technique for determining accurate time standards. They are economical for repetitive type of work. Steps in taking the time study are [39]:

² <https://www.mysql.com/products/workbench/>

³ <https://netbeans.org/>

- 1) Select the work to be studied.
- 2) Obtain and record all the information available about the job, the operator and the working conditions likely to affect the time study work.
- 3) Breakdown the operation into elements. An element is a distinct part of a specified activity composed of one or more fundamental motions selected for convenience of observation and timing.
- 4) Measure the time by means of a stop watch taken by the operator to perform each element of the operation. Either continuous method or snap back method of timing could be used.
- 5) At the same time, assess the operator effective speed of work relative to the observer's concept of 'normal' speed. This is called performance rating.
- 6) Adjust the observed time by rating factor to obtain normal time for each element in equation (3.1)

$$Normal = \frac{Observed\ time \times rating}{100} \quad (3.1)$$

- 7) Add the suitable allowances to compensate for fatigue, personal needs and contingencies. To give standard time for each element.
- 8) Compute allowed time for the entire job by adding elemental standard times considering frequency of occurrence of each element.
- 9) Make a detailed job description describing the method for which the standard time is established.
- 10) Test and review standards wherever necessary.

Standard time is the time allowed to an operator to carry out the specified task under specified conditions and defined level of performance. Standard time may be defined as the, quantity of time required to complete a unit of work. Under existing working conditions, using the specified method and machinery, by an operator, able to the work in a proper manner, and at a standard pace.

Thus basic constituents of standard time are [39]:

- 1) Elemental (observed time).
- 2) Performance rating to compensate for difference in pace of working.
- 3) Relaxation allowance.
- 4) Interference and contingency allowance.
- 5) Policy allowance.

3.2.2 Forecasting Methods

Forecasting is defined as the art or science of predicting future events [40]. The method of forecasting generally focuses on time and future; that is, a prediction must be made at a specific time point, and the change of this point generally affects what is predicted. It should contain decisions and provide information on which to base estimates [41]. This information is generally collected from historical data. The methods employed in this study are; Regression Analysis, Single Exponential Smoothing, Time Series.

Demand forecasting is the activity of predicting the product or the quantity of service that consumers will purchase. Demand forecasting can be used to evaluate pricing and capacity requirements, or to decide whether to enter a new market [42]. From our raw data, we used developed integrated system software to analyze the 3 methods. Developed software is using 3 methods to forecast next 12 months and compare the 3 method results to select which has minimum which has minimum mean absolute percent error (MAPE). Mostly Time Series Method was selected and followed by Single Exponential Smoothing.

3.2.2.1 Regression analysis

In this method it is tried to develop a mathematical relationship between two or more than two variables. If dependent and independent variables occur at the same time, we cannot predict the future values of the dependent value unless we use the estimate of the independent variable [42].

If we know that something caused demand to behave in a certain way in the past, we would like to identify that relationship so if the same thing happens again in the future, we can predict what demand will be.

Linear regression that associates a dependent variable as an independent variable with an equation for a straight line is the simplest form of regression. The general form is given in linear equation (3.2) as follows [44]:

$$Y=A + B_x \quad (3.2)$$

Y: Dependent variable

A: the intercept

B: the slope of the line

X: the independent variable

3.2.2.2 Time series analysis

Time series stands out as one of the most common statistical forecasting methods. The decomposition procedure that underlying data is broken down into sub patterns to identify the component factors that influence each of the values in series [45]. This model assumes that the data has the forms as given in equations (3.3), (3.3), and (3.3) [44]:

$$Data = Pattern + Error \quad (3.3)$$

$$Data = f(trend - cycle, seasonality, error) \quad (3.4)$$

$$Y_t = f(S_t, T_t, E_t) \quad (3.5)$$

Y_t : Time series value at period t .

S_t : Seasonal component at period t

T_t : Trend cycle component at period t

E_t : irregular component at period t

To estimate a discrete time series, we separately estimate the seasonal component S_t and the seasonally removed component at. It is generally assumed that the seasonal component has not changed or changed too slowly and is therefore estimated by taking the last year of the estimated component.

3.2.2.3 Single exponential smoothing

Exponential smoothing is an average method that strongly evaluates current data. It is useful if the recent changes in the data are significant and unpredictable instead of just random fluctuations (for which a simple moving average forecast will suffice). Exponential smoothing is one of the more popular and frequently used forecasting techniques due to require minimal data and give more significance to recent observations. Only the forecast for the current period, the actual demand for the current period, and a weighted factor called a smoothing constant are necessary. The mathematics of the technique is easy to understand by management that is given in equation (3.6) [46].

$$F_{t+1} = aD_t + (1 - a) F_t \quad (3.6)$$

F_{t+1} : the forecast for the next period

D_t : actual demand in the present period

F_t : the previously determined forecast for the present period

a : a weighting factor referred to as the smoothing constant

Using exponential smoothing, the forecast for the next period is equal to the forecast of the current period, plus a proportion of the forecast error in the current period.

3.2.2.4 Forecast accuracy

The difference between forecasts and actual demand is considered a forecast error. It is necessary to minimize the errors. If the error rate is large, either the estimation method is wrong or the parameters need to be adjusted [44].

In this thesis the estimation error E_t is the difference between the demand and the estimated value for the corresponding period. It is represented mathematically in equation (3.6) [44]:

$$E_t = D_t - F_t \quad (3.7)$$

3.2.2.5 Measuring forecast errors

Mean Absolute Deviation (MAD), Mean Squared Error (MSE) and Mean Absolute Percent Error (MAPE) are the most common forecast errors measuring methods [44]:

- a) Mean absolute deviation (MAD): MAD is an important criterion of the estimation errors of a model. It is calculated by dividing the sum of the absolute value of forecast errors with the number of periods of data (n) that given in equation (3.8).

$$MAD = (\sum |D_t - F_t|) / n \quad (3.8)$$

t : period number

D_t : Demand in period t

F_t : forecast for period t

n : total number of periods

- b) Mean squared error (MSE): MSE is another method used in measuring entire forecast errors. MSE is the average of the squared differences between the observed and predicted values. Its formula is given in equation (3.9):

$$MSE = (\sum \text{Forecast errors}^2) / n \quad (3.9)$$

The drawback of using the MSE is that it tends to accentuate large deviations due to the squared term. Using of MSE as the measure of forecast error typically indicates that we prefer to have several smaller deviations rather than even one large deviation.

- c) Mean absolute percentage error (MAPE): A problem with both MAD and MSE is that their values depend on the magnitude of the item being forecast. If the forecast item is measured in thousands, its MAD and MSE values can be very large. To avoid this problem, we can use MAPE, which is the average of the absolute difference between the observed and predicted values, expressed as a percentage of the actual values.

3.2.3 Linear Programming Model

Linear programming is a method to achieve the best outcome in a mathematical model whose requirements are represented by linear relationships. This section aims to clarify the linear programming (LP) model in the process of allocating a number of limited resources among a number of products, and in determining the best mix of products which leads to maximize profits and/or minimize costs in the presence of a number of restrictions [47]. This method includes steps to define and manage constraints that control the production processes. These steps can be defined as follows [48]:

- a) Identify the constraints that control the system, and determine the most profitable product mix under specific constraints [49].
- b) Identify the constraints that control the system: A constraint is anything can limit an organization's ability to generate more outputs. The process of determining constraints requires the performance of a number of tasks such as making a diagram of production lines clarifying the sequence of production processes and the required time for each process, as well as determining how often machines are to be re- configured to work per day, and the time required for each configuration process, thus determining the daily available time for each line of production. This is one of the constraints that must be taken into account when designing a linear programming model [50].

3.2.3.1 LP concept

Linear programming is as a mathematical method for allocating limited resources to achieve a specific objective. Linear programming can be used in the following cases [51]:

- 1) Address the situations that allocate limited resources among multiple competing uses.

- 2) The situations in which the different relations among the factors related to the phenomena can be represented by straight lines; in other words, the relations in such situations are linear.
- 3) Achieving a goal such as minimizing costs or maximizing profits for a company.

3.2.3.2 Assumptions of using LP

Employing LP requires on a number of assumptions. When linear programming is used in business management, it is viewed as a mathematical method by which a limited number of resources are allocated to a number of alternative uses such that it achieves the best possible use of those resources in a specific form [52]. It can be summarized under two categories: *activity* and *alternatives*. [48] The idea of activity in business is the way in which production can be carried out, while the idea of alternatives in this regard refers to those different means, each of which can lead to the goal set. In this case, linear programming in its theoretical basis is based on five main assumptions. These five assumptions are: certainty, proportionality, additivity, divisibility or functionality, and non-negativity [51].

3.2.3.3 Conditions of LP

In order to use linear programming, there are conditions that must exist in the problem to be solved. The conditions are as following [51]:

- 1) Linear programming must be used in the case of scarcity of resources because if all resources are available, no problem exists. This scarcity is one of the most important constraints that administration faces in achieving an objective.
- 2) There must be a specific objective expressed in form of a mathematical equation. The goal is usually to maximize profits.
- 3) There must be different alternatives to achieve the objective. Additionally, there must be scientific methods used to mix resources to reach the objective, where each alternative has expected revenue.
- 4) The relationships between variables must be linear. Linear means proportional relationship between two 'or more variable, the degree of variables should be maximum one.
- 5) The value of variables must be zero or positive and not negative.

3.2.3.4 Formulation of the general form of LP

Linear programming technique is used to find the best allocation of limited resources for different uses in order to achieve a specific objective, such as maximizing profit or minimizing costs under fixed constraints and factors where the economic problem is formulated and written in the form of linear mathematical relations, that is, equations of the first degree [53].

3.2.3.5 Elements of LP model

The linear programming model consists of the following basic elements: variables, objective function, constraints, and non-negativity state.

3.2.3.6 Variables

Variables are an essential element of a linear programming model they are called the decision variables. By determining their values, we reach the desired objective of largest profit or least cost of the studied issue. The variables should not be negative. These variables are subject to a particular type of measurement, that is, they are expressed in quantitative terms and symbolized thus:

$X_1, X_2, X_3, \dots, X_n$

Where n: represents the number of variables in the problem [54].

These variables may reflect one of the following concepts: [55]

- Production quantities for specific products
- Working hours available in certain sections of the organization
- Quantity of money allocated for activities or certain efficacies
- The quantity of foreign exchange allocated for the import of goods
- Quantities of materials transported on a particular road, or by certain means of transport.

3.2.3.7 Objective function

It is a mathematical function that represents the objective we want to reach and achieve, such as implementing the greatest profit or the lowest possible cost. The general form of this function is given in (3.10) [56].

$$Z = C_1X_1 + C_2X_2 + \dots + C_nX_n \quad (3.10)$$

The abbreviated form is given in equation (3.11).

$$Z = \sum_{j=1}^n C_j X_j \rightarrow \text{MAX} \quad i = 1, 2, \dots, m. \quad (3.11)$$

X_j represents decision variables, and C_j units show the profit margin per unit of X_j units. The other group contains the minimization state of the objective function as if we are attempting to reduce costs to the minimum, or minimize losses as much as possible. The objective function is written as is equation (3.12).

$$Z = C_1 X_1 + C_2 X_2 + \dots + C_n X_n \rightarrow \text{MIN} \quad (3.12)$$

The abbreviated form is given in equation (3.13).

$$Z = \sum_{j=1}^n C_j X_j \rightarrow \text{MIN} \quad i = 1, 2, \dots, m. \quad (3.13)$$

Where X_j are decision variables and C_j are the costs of each X_j unit.

The objective function therefore consists of variables that, for example, refer to the different products that can be produced on condition that the coefficient for each variable is the profit of one unit of product in the case of a profit maximization function, or the cost per unit in the case of a cost reduction function [55].

3.2.3.8 Constraints

There are constraints limiting an organization's ability to achieve a desired objective. Such constraints may be indicative of limited resources available to the organization. They may also be constraints related to the nature of the activity and the surrounding environment. That is, the decision-maker is not free in his choice of the values of decision variables which achieve the desired objective.

These constraints can be represented in four forms of linear programming as following equations [57]:

$$\sum_{j=1}^n a_{ij} x_j \leq b_i \quad i = 1, 2, \dots, m. \quad (3.14)$$

When the objective function is maximization type as given in equation (3.14).

$$\sum_{j=1}^n a_{ij} x_j \geq b_i \quad i = 1, 2, \dots, m. \quad (3.15)$$

When the objective function is minimization type as given in equation (3.15).

The first and second forms are called the Canonic Form of the linear planning or programming model, when the objective function is of the maximization type MAX or of the minimization type MIN.

$$\sum_{j=1}^n a_{ij}x_j = b_i \quad i = 1, 2, \dots, m. \quad (3.16)$$

The third form is called the Standard Form given as equation (3.16).

$$\sum_{j=1}^n a_{ij}x_j (\geq, =, \leq) b_i \quad i = 1, 2, \dots, m. \quad (3.17)$$

When the objective function is maximization type or the minimization type given as equation (3.17).

The last form is called the Mixed Form of the linear programming. In all these forms:

- n : the number of variables in the linear model.
- m : the number of problem constraints (number of linear conditions).
- a_{ij} : the real numbers (factors).
- b_i : the real numbers which reflect the available resources or requirements for each constraint of the problem, which must be positive.

Non-negativity condition: Variables should not be negative. ($x_j \geq 0$)

This is what must be imposed on all models as they all express production quantities, and it is impossible for quantities to be negative.

3.2.3.9 Methods of solving LP models

Linear programming methods can be classified into three main groups, General methods, Special methods and approximate methods.

The general methods can solve all linear programming problems. The simplified method (simplex) is the most widely used method, while the special methods are used to solve specific types of linear programming problems, and the transfer method is considered to be the best of these methods. The approximate methods are a set of methods that are described as not being able to reach the optimal solution accurately but rather approximately. The most important methods that can be applied to solve

problems of linear programming are Graphical solution method, Simplified method or Simplex, Transport method, Customization method (assignment) [58].

Linear programming is used to solve problems of the optimal distribution of limited resources to different uses. This mathematical method is one of the most widely used methods in academic studies and scientific practice. It has been proven to be useful to address the majority of problems faced by business organizations. Examples of these problems include [59]:

- 1) Distribution of productive resources (raw material, machinery, labor, etc.) into different products to determine the optimum production quantities.
- 2) Making an overall plan in which different types of energy are distributed onto the expected demand in the following planning periods.
- 3) Making an optimal distribution plan in which the quantities of production or raw materials to be transferred from different sources to different uses are determined, that is known as a transport problem.

3.2.4 Sensitivity Analysis

The subject of sensitivity analysis is a very important factor for managers because of the dynamics of the surrounding environment where the prices of raw materials are continuously changing, the level of demand for a product changes in addition to the rapid changes in technology. It has been assumed that in order to find the optimal solution in linear programming, prices must be fixed, whether for raw materials or produced goods, and a full knowledge of available resources must also be present. However, if goods are produced and offered, there are various conditions, including technological developments and economic situation.

In such cases, the question emerge as to whether the optimal solution will change or remain as it is. Moreover, if it changes, a point remains as to whether the entire problem has to be solved again with new values to reach a new solution. Furthermore, we may ask whether there is any way to determine the new solution without solving the problem again. The answer lies in the sensitivity analysis, which, measures the degree of sensitivity of the current optimal solution to the change in the values contained in the original problem. Therefore, a sensitivity analysis is the study of the change in the value of the optimal solution in the case of changing the problem coefficients, and it is used to determine the effect of any changes in the objective function parameters,

problem constraints parameters, number of available resources (right side) in the problem constraints. Some parameters of sensitivity analysis are defined as follows:

- *The shadow price* refers how much the optimal solution can be increased or decreased if we change the right hand side values (resources available) with one unit.
- *The reduced costs* tell us how much the objective coefficients (unit profits) can be increased or decreased before the optimal solution changes. If we increase the unit profit of Child Seats with 20 or more units, the optimal solution changes.
- The term *slack* applies to less than or equal constraints, and the term *surplus* applies to greater than or equal constraints. If a constraint is binding, then the corresponding slack or surplus value will equal zero.



CHAPTER 4

ACRYLIC MANUFACTURING SYSTEM AND PRODUCTION PLANNING

In this chapter, we will define the acrylic fiber and type of production processes which are used in a typical real yarn production company. Also, definition of production planning will be briefly mentioned.

4.1 Acrylic Fiber

Acrylonitrile can be obtained easily and cheaply from petroleum distillation products. Polyacrylonitrile (PAN) polymers that used in acrylic fiber production are obtained by radical chain polymerization of acrylonitrile monomers. At present, 100% PAN cannot be used in the production of polyacrylonitrile fiber. Instead, acrylonitrile copolymers containing up to 1% of synthesized monomer are used, to improve their properties and dyeability. Fibers made of polyacrylonitrile that containing up to 15% co-monomer as seen in Figure 4.1 are called acrylic fibers. Fiber made from synthetic copolymers which containing 35-85% polyacrylonitrile in its composition is called "modacrylic fiber".

4.1.1 Types of acrylic fiber

Acrylic fibers are grouped according to their usage feature as; acrylic fiber with high tensile properties, acrylic fiber with water-absorbing properties and acrylic fibers with different dyeing properties.

- **Acrylic Fibers with High Tensile Properties:** compared to normal acrylic fibers the draw ratio (40%) is increased by making an extra stretch. Such fibers are used in making high-bulk yarns.

- **Water Absorbing Acrylic Fibers:** It consists porous core like sponge so its water absorption ability is high and absorbers up to 38% humidity. Lightweight garments are produced from these fibers because their specific gravity is low.
- **Acrylic Fibers with Different Dyeing Properties:** Orlon Acrylic, Acrylic Fibers, Creslan Fibers and Zefran Fibers are some example of this type fiber.

4.1.2 Usage area of acrylic fibers

Acrylic fibers are produced in various grades and in length depending on their usage area. These products are used for all woven or knitted fabrics where high light and weather resistance is required. Acrylic fibers are very similar to wool, so they are used in making knitting wool, blanket, carpet and rug. In addition, acrylic fibers are suitable for making male and female stockings, flag fabrics, pile fabrics, plush fur.

4.2 Acrylic Yarn Production

In the following, acrylic yarn production stages will be explained.

4.2.1 Breaker

Breakers operation converts the filament produced from artificial and synthetic polymer into yarn, allows the fibers to be stabilized at desired intervals and weight. Also helps to make Bulk yarn in the iron and steam zone and it performs the breakage process for desired fiber gap as shown in Figure 4.2. Additionally, it folds the fibers to simulate natural fibers as wool fibers.

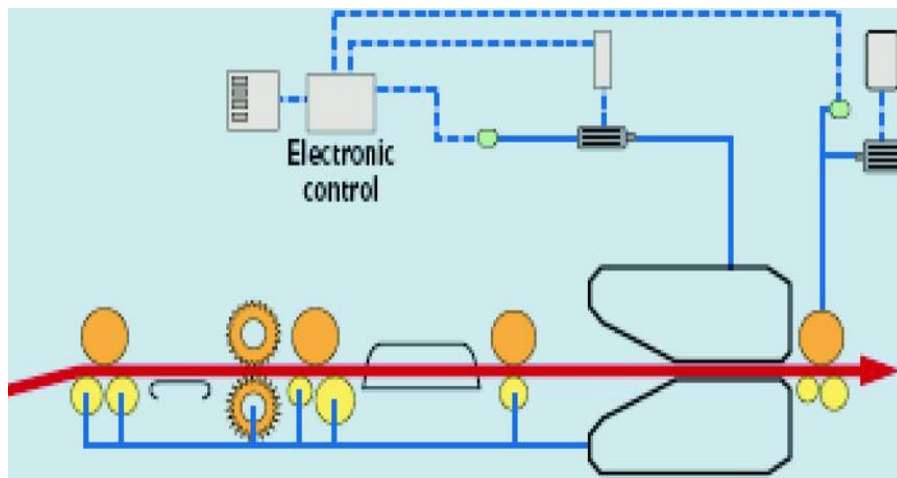


Figure 4.1 Control system of breaker machine

4.2.2 Re-Breaker

Re-Breaker is the second process of the fiber preparation. This process is used to make fiber combination which has different composition. For example, acrylic/polyamide blends fibers are combined in this process. Increasing the homogeneity of fiber, making a color blend, lubricant to prevent static electricity, making parallelization, smoothing and obtaining the desired weight band are some important tasks of the re-breaker process.

4.2.3 Drawing frame

This process is used to increase evenness of the fiber to reduce weight of fiber. Additionally, it increases homogeneity of fiber by thinning hairs of fiber. The ribbons are first dubbed to form a homogeneous structure and then drawn and thinned.

There are three parts in this process. Parts are named as, drawing-1, drawing-2 and drawing-3 respectively. Draw [60] frame play very important role in spinning regarding to quality point of view. The role of this machine is important for the quality of yarn, because it is final process in the preparation of the fiber. This process takes place in the Drafting arrangement center which has the ability to produce high quality fibers and has high yarn control. The effects of the drawing process can be summarized as follows:

- Decreasing the number of fibers in the cross section
- Decreasing thickness, thinning
- Decreasing fiber hooks
- Increasing length of material for unit weight

4.2.4 Finisor

In this process, roving yarn obtained from roving frames, which is the last machine of the preparation room, becomes ready for use in the spinning machine. The roving machines have two different technologies Flayer roving frame and Finisher roving frame. The most basic difference of these machines is that the bending is used to give the fleshy strength in the film machine; rubbing technique is used to give strength to the finishing machine.

4.2.5 Ring spinning

Ring Spinning is the oldest of the present day spinning processes. The ring spinning machine is used to twist staple fibers into yarn and then wind it onto bobbins for storage. The fiber material is supplied to the ring-spinning machine in the form of roving. The fiber mass of the roving is reduced by a drafting unit. The twist inserted moves backwards and reaches the fibers leaving the drafting unit.

4.2.6 Winder spinning

Winding is the process of transferring yarn or thread from one type of package to another to facilitate subsequent processing. This process is also referred to as coil transfer. In this process [60] there are heads in machines use to wound the yarn to paper cone yarn. After the yarns are produced, they are wrapped in bobbins or in the open-end bending system. Winding machine causes direct effect on quality of yarn. It will either be presented to the market as the final product, or it will be treated as an intermediate product within the enterprise and shipped to the weaving or knitting unit.

4.2.7 Folding

Folding means that more than one single layer yarn is brought together without giving twist. In some cases, the yarns are wet-folded by immersing them in water containing pure or suitable chemical substances. The winding speed of the folding machines is less than the winding machines. The breaks are individually controlled by the yarn breakers for each yarn and stop winding when breaks occur.

4.2.8 Twisting

Twisting machines are used to fold single filament yarn into two or more single filament yarns. These machines are folding and twisting machines with more than one yarn and they are similar to folding machines. The most significant difference between twisting machines and folding machines is the presence of twisting devices in the twisting machines. The bending process is performed to increase the strength of yarns, to reduce irregularities or to provide different effects. For this purpose, ring bending system and double bending system, which are used in plain bending, are widely preferred today.

4.2.9 Volufil

Heat shrinkage of acrylic yarns and acrylic blended yarns gives high volume to the yarns. It is performed by breakout process and using the ability to revert back to its original length with the effect of heat. The machines used for inflating acrylic fibers contain the same features as the general working principle. According to this, the inflating machines are classified under 2 main groups as steam blowing machines and electric blowing machines.

4.2.10 Fiber pressing

Fiber pressing is the process before dying. Before dying process, fiber should enter to pressing machine to better absorb chemical substance. Also the pressing process giving shapes to the fiber to be easily enter in dyeing machine.

4.2.11 Fiber dyeing

Dyeing is a method for coloring a textile material in which a dye is applied to the substrate in a uniform manner to obtain an even shade with a performance and fastness appropriate to its final use. Acrylic fiber is easily softened by the effect of heat in dyeing baths. Properties also change depending on the softness of the fiber. The temperature of the dyeing bottle should be kept under control in order to be able to smoothly dye and make wrinkles on the fiber. The temperature should neither rise fast nor fall fast.

4.3 Production Planning

Although acrylic production facilities have a complex and flexible structure, time is a very important factor in these facilities, therefore production planning plays an important role. The production planning unit [48] is one of the most important units of production management. The job of planning is to define the final objectives as well as the partial objectives that the organization seeks to achieve followed by identifying any needed capacities, resources and work plans, and finally to determine the time required to track processes and end the work, thus achieving the set objectives.

Decision of a production plan is one of the most important strategic decisions of management. The production planning divided into three groups according to the planning period.

Long-term production plan is developed to determine the level of production in the future for a period of one year or more than one year up to five year. Medium-term production plan is a plan that is prepared for a period of one year and it has detailed plans for each month of the year. The purpose of this plan is to compromise between production capacity and demand volume. The short-term production plan refers to a detailed description of production activities in less than a month.

4.3.1 Aggregate (medium-term) planning

As mentioned earlier, the aggregate production planning or medium-term planning refers to the production plan, which covers a period of time based on the total estimates of output from production, labor, and inventory levels. The aim of this plan is to identify the best spot for expected demand levels, to ensure efficiency and optimum resource utilization, and to define the scope and limitations of relevant decisions. The aggregate planning is a system with inputs, outputs and planning methods. The inputs of the production planning process come from expected demand of products, production capacities and costs involved in selecting a particular strategic production. The production planning process as a system has outputs as inventory, and employment for each period of the plan, information about the estimated costs that result from the implementation of the aggregate plan at the end of the plan period. The methods of aggregate [48] production planning vary according to the relationships that govern the variables of a problem as following:

- 1) Methods that are based on a linear relationship between the variables; examples for these methods include:
 - a) Methods of experimentation and error by using Tables.
 - b) Linear programming such as the simplex method, transportation method, and graphical method.
- 2) Methods that based on a non-linear relationship between the variables; examples for these methods include:
 - a) Models of systematic diligence and models of searching using a computer.
 - b) Methods of linear rules such as dynamic programming.

CHAPTER 5

COST ACCOUNTING SYSTEMS

Costing is an important process for manufacturer corporations to keeping track of where the money is spent in the production and distribution processes. In this chapter, we will give the definition and types of cost accounting systems. In addition, types of expenses will be explained.

5.1 Cost Accounting System

A cost accounting system (also called product costing system or costing system) is a framework used by companies to forecast the cost of their products for profitability analysis, inventory evaluation and cost control [61]. There are several different cost accounting methods for various purposes, having different calculation methods. The method to be selected should be appropriate to the type of products, the size of the enterprise, the production technique and the general organization of the business. An effective cost system can only be realized through the joint efforts of staff working in accounting service, technical service and cooperation between them.

The most important factors that affecting costs as follows [62]:

- Management's efficiency and management's abilities
- Status of board captain utilization
- Energy costs and savings in these costs
- Efficiency and technology
- Prices of inputs
- The amount of equity and operating capital
- Capacity and size of business
- Raw material supply and stock status
- The quantity of equity and operating capital

5.2 Cost Accounting Types

In general, product price analysis and cost determination in companies are made in three groups as order costing, standard costing and process costing system.

5.2.1 Order costing system

The product costing system [63] is used for unique or different products such as buildings, customized furniture, large boats, special dresses and others. The costs of materials, labor, and overhead of each job are summarized in the job order cost sheet.

The order cost method is not a good solution for a plant that produces the same type of material, this method is used more often in industries where various orders can be separated from each other. Generally it is used by companies with limited quantities of product. Order Costing System is widely applied in industries producing various parts, in apparel workshops, repair shops, furniture workshops. It may be used in a large number of mass production plants but the standard cost method is more useful in such industries.

5.2.2 Standard costing system

In this case [63], estimated costs based on pre-determined values are used, even if actual costs are not yet available. Estimated costs are then adjusted to reflect the impact of actual costs occurring. It is used in conjunction with other cost accounting systems such as process costing and work order costing.

5.2.3 Process costing

Process costing is a cost accounting system that accumulates production costs separately for each process. It is convenient for products whose production is a process involving different departments and costs flow from one department to another.

The system is basically to distribute the costs of manufacturing at each stage of production. The costs of each process are collected separately and divided by the quantity of goods produced in that process to evaluate the average cost.

Process costing is suitable for industries that produce homogeneous products with continuous flow of production. In order to be able to apply process costing system, the costs of the goods produced must be known separately for each good. Examples for

sequential product flow and parallel product flow are shown in Figure 5.1 and Figure 5.2 respectively.

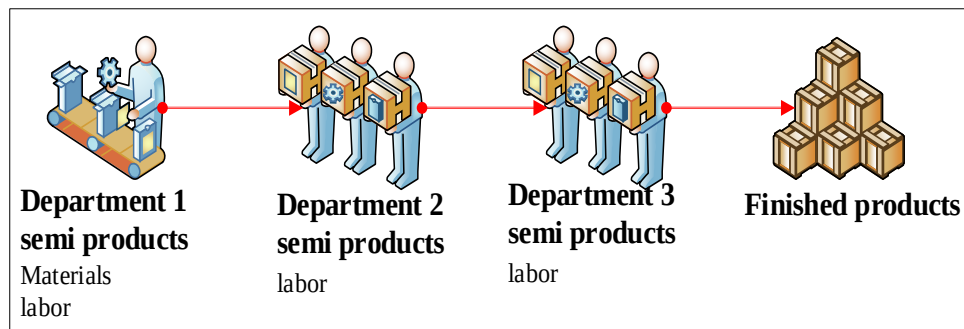


Figure 5.1 Sequential product flow

To use this method, industries must have the following characteristics:

- There must be one or several kinds of goods for goods that produced in every process
- Produced goods should be standard, not different from one unit to another,
- The production operation must be the same for the goods produced,
- Production must be serial and continuous,
- The entity should be able to separate the departments responsible for a specific mode of production.

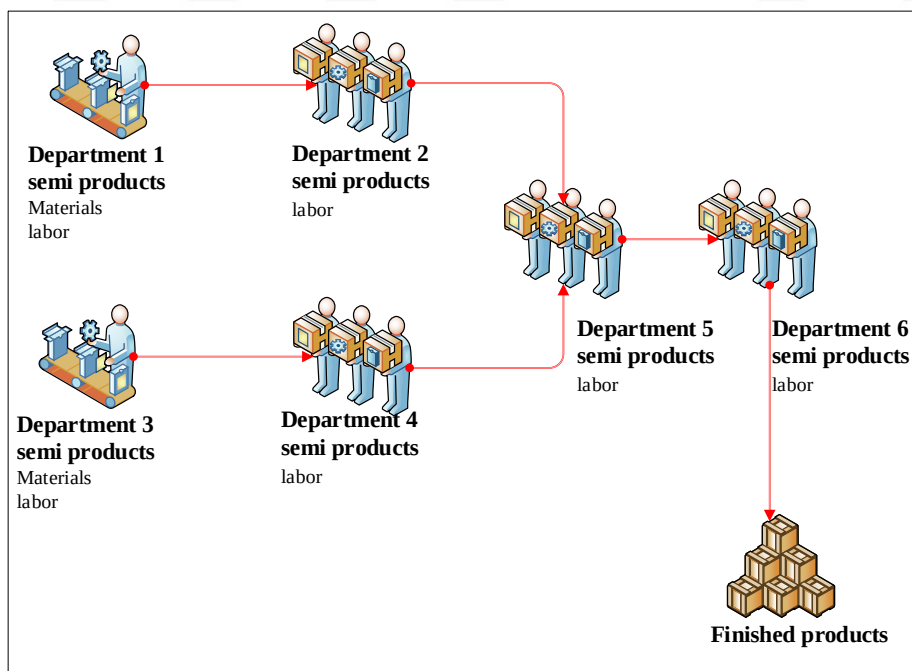


Figure 5.2 Parallel product flow

It is suitable for manufacturers that produce a continuous unit of mass throughout a series of processes. This process can be used when a standardization of the process and product applied and an order does not affect the production process. This cost system will not provide reliable information, when there are clear differences between the costs of several products. Examples of such industries are textile, iron, oil, chemical, cement, sugar, gas, flour, beer and glass. As an example flow chart of selected product is shown in Figure 5.3.

The steps for calculating the cost of units are as follow:

- 1) The costs associated with each phase, the identification of the direct materials, the labor costs of general labor and general production,
- 2) Determination of the production quantity carried out in each phase;
 - Stock quantity at the beginning of the accounting period
 - The quantity of finished goods produced during the accounting period
 - Quantity of unfinished semi-finished products in the accounting period
 - The quantity of Wastage
- 3) Determination of the equivalent quantities of production by multiplying the quantity indicated in the second step by the completion grades.
- 4) The calculation of the equivalent unit costs by dividing the direct materials, direct labor and general production costs calculated in the first step by the equivalent units in the third step.
- 5) The equivalent unit costs in the fourth article are multiplied by the quantity of products and semi-finished products in equivalent units and the costs of finished and semi-finished goods are found.

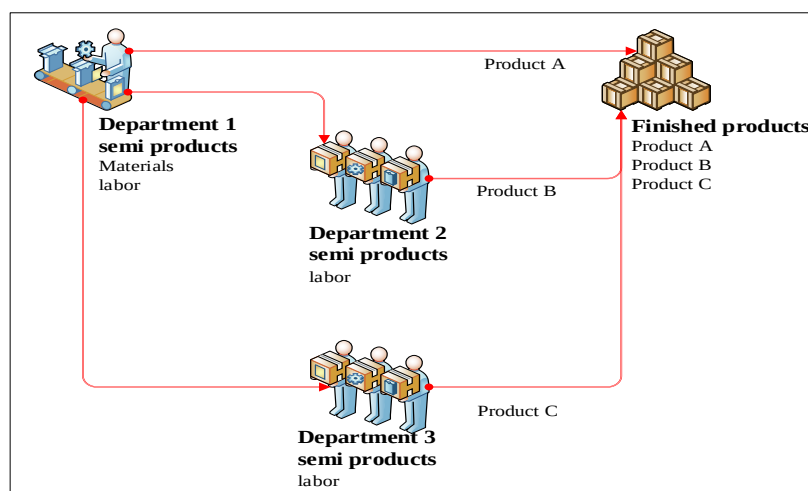


Figure 5.3 Selected product flow

5.3 Expenses

Expense is an accounting [64] and budgeting term used in every-day speech to refer to anything that causes spending. Accountants, however, define expense more broadly and more precisely as follows:

In accounting, an "expense" is a decrease in owners' equity caused by using up assets in producing revenue or in other activities that are part of entity operations. Spending on employee wages, for instance, is an expense because it uses up cash assets. The broader definition also covers non-cash expenses, such as depreciation or bad debt expenses. However, every expense event—cash or non-cash calls for an impact on an expense category account. The types of expenses, as operating expenses, financial expenses and other nonoperation expenses will be explained in the next sections.

5.3.1 Operating expenses

Operating expenses [65] are the costs associated with a company's main operating activities and which are reported on its income statement. For example, payroll is a common operating expense, as you must pay your employees to help you make or sell your product. Other common examples include advertising, computer expenses, packaging materials, maintenance costs, utility expenses and the cost of your accountant or attorney. On an expense report, operating expenses are often subdivided into categories such as fixed and variable expenses, or into selling, general and administrative expenses. The operating expenses are often subdivided into categories such as direct and indirect labor expenses.

5.3.1.1 Direct and indirect labor

The direct labor costs [66] are expenditures that directly involve the conversion of raw materials into a finished product. Meal fee, social insurance premium, unemployment insurance, employer's premium, educational expenses, service fee, health expenditures are some examples of direct labor costs for the cotton yarn sector. Contrarily, indirect labor costs are all other labor costs outside of the production process. Workers who are not directly involved in the produced yarn are known as indirect labor. Assisted labor and administrative labor are two groups of indirect labor.

Assisted labor is the labor that is used without interruption in the production process, and for the cotton spinning sector. Maintenance-repair workers, cleaning workers, security officers, are some example of assisted labor. The labor of personnel who manage production actions is known as administrative labor. The expenses paid to people such as foreman, engineer and workshop chief are examples of administrative cost.

5.3.2 Taxes and other financial expenses

Taxes have their [65] own accounting category, and depending on the type and locations of your business, it can be an extensive one. Tax expenses are calculated by multiplying the appropriate tax rate of an individual or business by the income received before taxes. If the company sells a product, it may have sales and tax debts that must be collected from customers and also payroll taxes are added if employees are present. The property taxes paid are also entered into this expenses, if the business has property.

5.3.3 Other nonoperating expenses

It is known as non-operating [65] expenses that does not enter any other clearly defined category. Capital used to buy office buildings, expenditures made on corporate loans are considered non-operating expenses. The losses arising from the sale of the property to the enterprise and litigation costs are also considered as non-operating expenses.

5.3.3.1 Amortization expense

The amortization expense [67] is the portion of the fixed asset that is consumed in the current period. This quantity is then charged as expense and is a non-cash expense. The purpose of this fee is to gradually reduce the value of fixed assets. The balance in the amortization expense account increases during the fiscal year of a business and is cleared and reset at the end of the year. The account is then used again to record depreciation expenses in the next fiscal year.

CHAPTER 6

CASE STUDY

In this chapter we will firstly define the developed Modules. Description of selected products and time studies are presented secondly. The daily capacity of selected products are calculated in the next section. Lastly, LP model formulation and definitions are given.

6.1 System definition

In this thesis, a production planning software was developed with selected products named X1, X2, X3, X4 and X5. The developed software has 4 modules and these modules are used for demand analysis, cost analysis, LP model and sensitivity analysis respectively. Some necessary inputs like demand quantities, sale prices and raw material types, are obtained from the ERP program. These parameters can also be entered from the database, from Microsoft Excel, or manually. Then demand forecasts is performed with three methods as regression, exponential and time series in the Module 1. After entering the required parameters, the software automatically selects the best method with minimum MAPE value.

In the second, module cost analysis are performed in two parts. In the first part, software is run for calculation of unit cost of selected products including labor cost, warehouse cost, maintenance cost and production costs. Time study calculations are made in the second part. In the module 3, predetermined parameters from Module 1 and Module 2 are used to construct the corresponding LP model. Solutions and results can be stored in the software database. In last Module 4, it is tried to determine how the change of input parameters would affect the change of the output. Information flow and interaction of modules of the developed software is given in Figure 6.1.

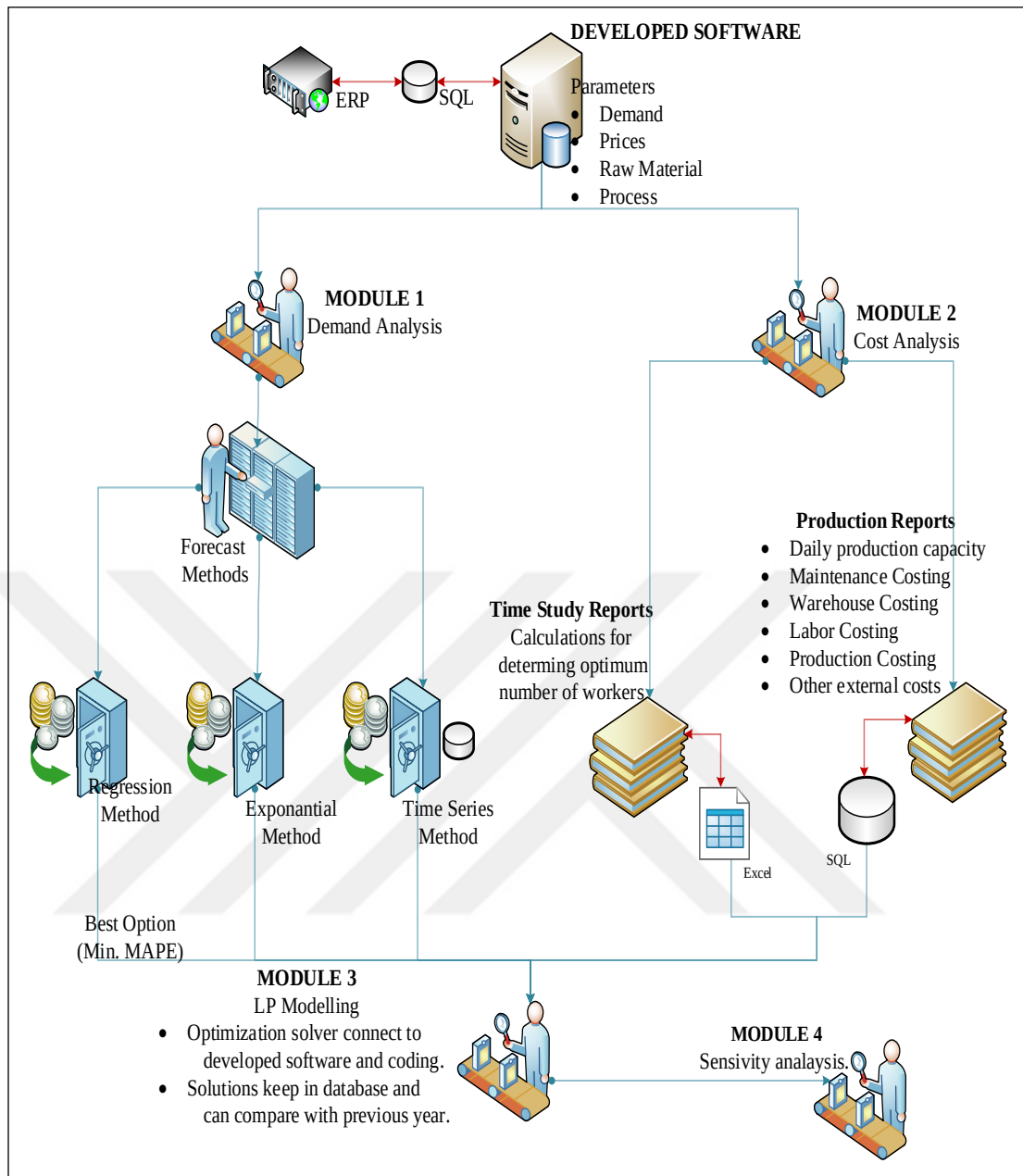


Figure 6.1 System definition scheme

6.1.1 Database design

A database [35] is a collection of information that is organized so that it can be easily accessed, managed and updated. Databases process workloads to create and update themselves, querying the data they contain and running applications against with relational tables. A relational database is a set of described tables from which data can be accessed or reformed in many different ways without having to reorganize the database tables. In developed system, relational database was used to provide a flexible structure to meet changing requirements and increasing amounts of data. With developed database, results can be filtered based on the content of any column, and on any number of columns, allowing users to easily retrieve meaningful results and we can choose which columns to include in the results so that only relevant data are displayed.

6.1.2 Description of selected products

The company which we studied produces acrylic, acrylic wool, acrylic mohair, acrylic viscose polyamide and many different types and blends even fancy yarn. It has a very wide range of qualities from Nm 1 to Nm 40. Capacity of production machines is 550 tons/month for industrial yarns, 60 tons/month for fancy yarns and 450 tons/month for dyeing. More than 50 different types of products are produced each year in order to meet the demands of different customers. X1, X2, X3, X4 and X5 products, selected for production planning software, cover almost 55% of market share.

The product X1 is a knitted yarn made of acrylic fibers used for women and children's sweaters and winter products. It gives a soft and slippery feel when you touch a sweater. It is a yarn obtained by giving a special chemical to gain softer touchiness. Production capacity for X1 is lower than others. The thread is running at low speeds to avoid losing its soft touch.

The product X2 is a carpet yarn produced from acrylic fibers. It is generally used in long-lasting and high-wash fastness. A special chemical is given to give the yarn low peeling properties. This yarn has fewer wash and finish results than others. Production capacity of X2 is the same as plain acrylic yarn and there is no loss of production.

The product X3 is a knitwear yarn made of acrylic fiber used for sweaters and winter products. It is a flat acrylic yarn with no characteristics compared to others. It is used in three low-cost colors, which are usually preferred by traders.

The product X4 is a knit and weft thread. It is usually used for winter products such as sweaters, gloves, scarves, hats. It is produced from acrylic and polyamide blended fibers. It looks hairy because it is polyamide compared to plain acrylic.

The product X5 is a knitwear yarn produced from acrylic and polyamide blended fibers used for sweaters and winter products. The most preferred reason is that it has a blurred and bulky appearance. In addition, these yarns can be used in multi colors. The polyester yarn is used to provide flexibility for yarn and extend the life of knitwear. It is usually used in women's and men's knitwear.

X1, X2, X3 and X4 have common process flow scheme. The differences can be observed just in raw material type and chemical operations. In order to complete the production of the product, it is necessary to complete the 17 processes given in Figure 6.3.

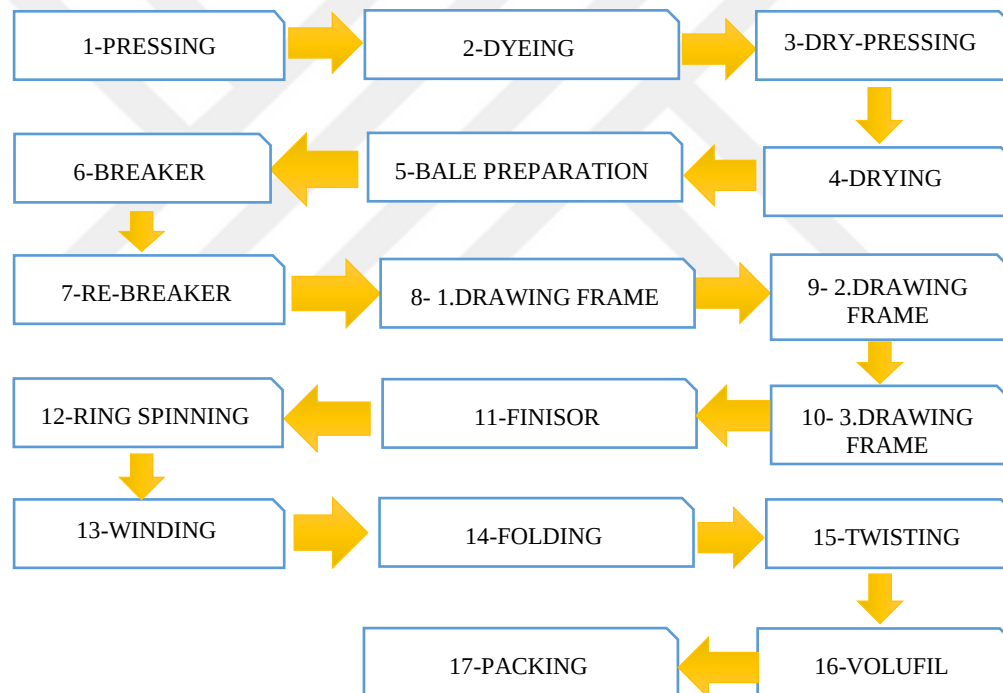


Figure 6.2 Production process for X1, X2, X3 and X4

X5 has different production process flow chart. Differences in raw materials and chemical processes can be seen in the production process. As shown in Figure 6.4 in order to complete the production, a total of 22 processes must be completed. All operations except bale preparation are done by machines. Bale preparation is manually performed by the blue collar.

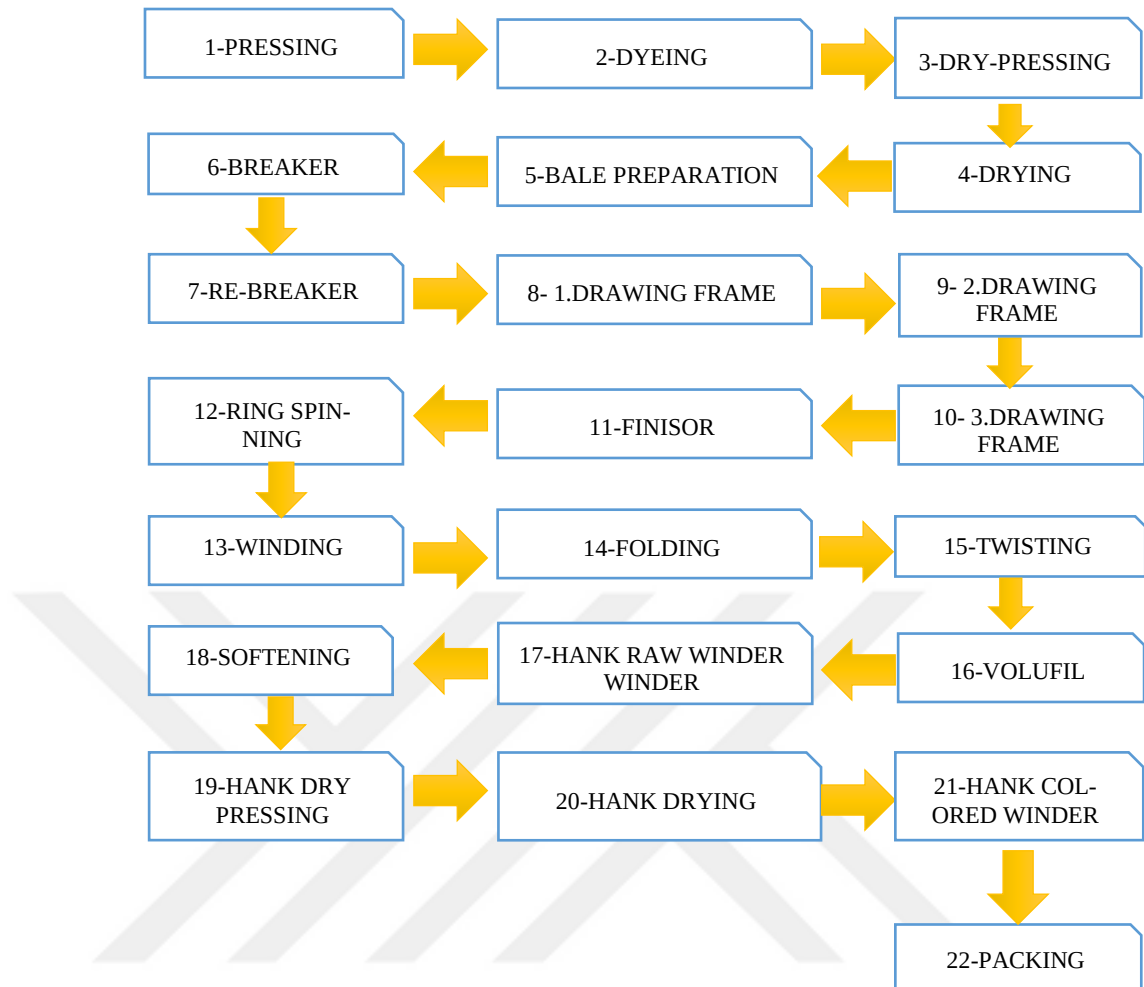


Figure 6.3 Production process for X5

6.1.3 Annual demand of selected products

Demand is the quantity of production that is requested by a customer of a product in a production system. Demand forecasts are performed by fitting a curve according to the data previous years. Textile sector is affected by seasonal changes. In addition, seasonal yarn production depends on climatic conditions.

Accordingly, sales budgets for the upcoming periods are determined. The sales forecasts specified are converted to product codes.

Annual analysis for these products is based on production capacity. The constraints on which periods need to be stocked are analyzed. Short, medium and long cycle planning is done and a material requirement plan is prepared according to this plan.

Table 6.1 shows comparison of demand quantity for selected 5 products in 3 years. X axis shows demand quantity of products and Y axis shows months. As it can be seen on the graph in Figure 6.5, the least demanded product is X1 and demand reached the

highest point in the last three months of the years. For X2, demand reached the highest point in the last June and July months as can be seen in Figure 6.5. Since the X2 product is winter, manufacturers strive to supply raw material during the summer months to prepare winter products. Also for X3, it has reached the highest points in various months of the year because the X3 is used in knitwear and carpet production. However, demanded quantity of X4 reached the highest level only in the March and April months. Also demanded quantity of X4 is very close to X3. The most demanded product is X5 and it reached the highest level in various months of the year.



Table 6.1 Annual demand of selected 5 products

Year	Month	X1 Quantity (kg)	X2 Quantity (kg)	X3 Quantity (kg)	X4 Quantity (kg)	X5 Quantity (kg)
2015	1	38380	48222	11530	12071	176512
	2	20254	51860	19589	21003	155000
	3	16953	48193	15000	43429	137124
	4	55000	71701	17723	35000	143783
	5	28846	84095	25409	20336	135000
	6	20856	62334	30742	37213	115012
	7	22510	87671	52414	10991	90000
	8	40000	117992	30407	12368	115000
	9	25000	75453	28073	15000	90202
	10	67665	60531	41000	15079	122624
	11	60478	57805	35000	10408	113512
	12	56577	53950	35000	25470	80000
2016	1	28000	41000	8000	19882	169810
	2	16216	49000	15000	25705	145000
	3	13176	45000	20000	49624	130000
	4	50000	76236	25000	45031	150000
	5	24000	78000	21007	31045	150000
	6	20423	60000	25000	30310	125292
	7	19494	85000	47015	17054	95000
	8	30000	104780	18441	19962	120000
	9	20129	72000	18476	13583	97000
	10	58054	53035	51413	19000	130000
	11	55000	55000	42178	7159	105000
	12	32386	55000	42835	12016	95000
2017	1	29000	40000	15078	11702	155078
	2	12000	45000	11953	18787	114793
	3	25000	50000	29000	40209	142230
	4	48815	64033	32057	36150	160043
	5	18283	75000	22203	18000	155000
	6	19677	65000	20000	20000	135000
	7	15634	80000	49000	13544	105000
	8	35000	85746	26210	14967	135000
	9	30000	70000	13000	19330	110000
	10	50000	50000	59618	11406	137000
	11	45000	48389	35745	8411	110740
	12	25000	52000	31181	6848	130740

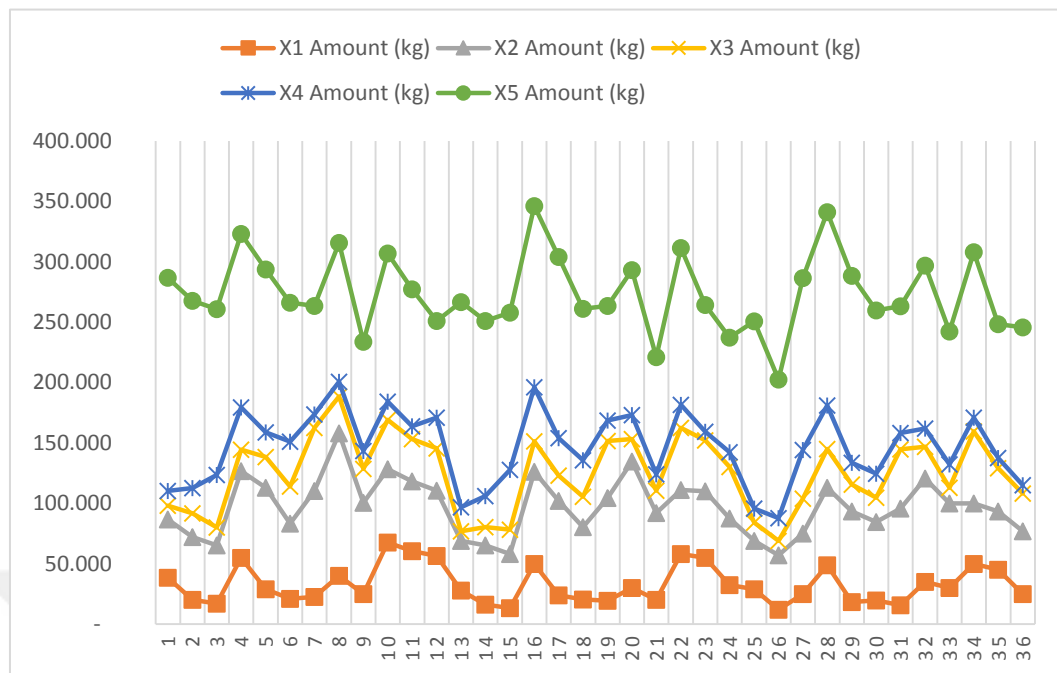


Figure 6.4 Comparison of demand quantity for X1, X2, X3, X4 and X5.

As seen at the Table 6.2, the total demands of the products are compared on a yearly basis. There is a certain increment in total annual demand from 2015 to 2017. For example, the demand for X5 product increased by 38,334 kg in 2016 compared to 2015.

Table 6.2 Distribution of demand for selected products by years

Year	Total Demand Quantity (kg)	X1 Quantity (kg)	X2 Quantity (kg)	X3 Quantity (kg)	X4 Quantity (kg)	X5 Quantity (kg)
2015	5484228	452520	819808	341887	258367	1473768
2016	5852789	366878	774051	334365	290369	1512102
2017	5937640	353407	725168	345045	219353	1590624
Average	5758219	390935	773009	340432	256030	1525498

6.1.4 Daily capacity of selected products

The production quantity that can be produced within a certain period is known as capacity. The capacity of the production shows the competition limits of the company and it has a key role in the client's eyes. When capacity is insufficient, it cannot meet consumer demands and the company will lose its power after a certain time.

There are some external and internal factors that influence capacity. External factors include labor power, security and government decisions on environmental pollution.

Internal factors are product design, staff training, motivation, learning, business methods, plant layout, workflow, look, materials management, quality control systems and management policies.

The production capacity of the machines used in the textile industry for yarn processing varies according to the yarn type. For the capacity calculations X1, X2, X3 and X4 are calculated jointly. However, X5 is calculated separately, because it is thicker yarn and the production takes longer time than the other types. The capacity calculations vary according to the type of yarn and machines. Generally, the criteria to be taken into consideration in the production calculations of the machines are determined and these criteria are evaluated according to the operation. Machine production capacity formulas can be developed for each production. The production capacity (kg/h) is specified for each type of operation. Production speed of machines is very important for determining production capacity. The speed of the machines is not fixed, it can be changed according to the type of yarns. Furthermore, it can be increased at a certain level according to the demanded quantity, for example the speed of the machine can be increased, if customer wants a quick lead time. Therefore, the average running speed of the machines is measured for each type of yarns.

6.1.4.1 Daily capacity for X1, X2, X3 and X4 products

Daily production capacities of X1, X2, X3 and X4 products are calculated totally for 16 processes. There are two machines for the pressing process and production efficiency was measured as 80%, as seen in Table 6.3. The fiber weight was taken as 120 grams. The machines produce 450 kg in every 40 minutes. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.8 = 1,152 \text{ minutes/day}$$

$$1,152/40 = 28.8 \text{ period/day (number of period should be integer, so it is taken 28)}$$

$$28 * 450 = 12,600 \text{ kg/day.}$$

Table 6.3 Daily capacity of pressing process for X1, X2, X3 and X4 products

PRESSING							
Process No	Machine No	Capacity	Efficiency	Fiber Quantity (gr.)	Period	Total Shift Hour	Quantity
1	1	450	80%	120	40 min.	24	12.600,00
	2	450	80%	120	40 min.	24	12.600,00
Total Quantity:							25.200,00

As shown in Table 6.4, four machines are available for dying process. The average daily capacities of machine 1 and machine 2 are calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224/6 * 60 = 3.4 \text{ period/day (number of period can be taken as decimal number)}$$

$$3.4 * 1350 = 4,590 \text{ kg/day for machine 1}$$

$$3.4 * 1900 = 6,080 \text{ kg/day for machine 2.}$$

Table 6.4 Daily capacity of dying process for X1, X2, X3 and X4 products

DYEING							
Process No	Machine No	Capacity	Efficiency	Fiber Quantity (gr.)	Period	Total Shift Hour	Quantity
2	1	1350	85%	120	6 hours	24	4590
	2	1900	85%	120	6 hours	24	6080
	3	1900	85%	120	6 hours	24	6080
	4	1350	85%	120	6 hours	24	4590
Total Quantity:							21340

One machine is available for dry-pressing as seen in Table 6.5. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224/30 = 40.8 \text{ period/day (number of period can be taken as decimal number)}$$

$$40.8 * 450 = 18,360 \text{ kg/day.}$$

Table 6.5 Daily capacity of dry-pressing for X1, X2, X3 and X4 products

DRY-PRESSING							
Process No	Machine No	Capacity	Efficiency	Fiber Quantity (gr.)	Period	Total Shift Hour	Quantity
3	1	450	85%	120	30 min	24	18,360.00
Total Quantity:							18,360.00

One machine is available for drying and production efficiency was measured as 85%. The fiber weight was taken 120 grams as seen in Table 6.6. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.83 = 1,195.2 \text{ minutes/day}$$

$$1,195.2 * 102 * 120 = 14,629,248 \text{ gr/day}$$

$$14,629,248 / 1000 = 14,629.248 \text{ kg/day.}$$

Table 6.6 Daily capacity of drying process for X1, X2, X3 and X4 products

DRYING							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
4	1	102	83%	120	1	24	14,629.248
Total Quantity:							14,629.248

As shown in Table 6.7, four machines are available for breaker process. Production efficiency was measured as 80% and fiber weight was taken as 27 grams. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.8 = 1,152 \text{ minutes/day}$$

$$1,152 * 210 * 27 = 6,531,840 \text{ gr/day}$$

$$6,531,840 / 1000 = 6,531.84 \text{ kg/day.}$$

Table 6.7 Daily capacity of breaker process for X1, X2, X3 and X4 products

BREAKER							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
5	1	210	80%	27	1	24	6531.84
	2	230	80%	27	1	24	7153.92
	3	230	80%	27	1	24	7153.92
	4	240	80%	27	1	24	7464.96
Total Quantity:							28304.64

Four machines are available for re-breaker process and production efficiency was measured as 65%. As shown in Table 6.8, fiber weight was taken as 25 grams and number of spindles for each machine is one. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 290 * 25 = 6,786,000 \text{ gr/day}$$

$$6,786,000 / 1000 = 6,786 \text{ kg/day.}$$

Table 6.8 Daily capacity of re-breaker process for X1, X2, X3 and X4 products

RE-BREAKER								
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Hour	Shift	Quantity
6	1	290	65%	25	1	24		6786.00
	2	300	65%	25	1	24		7020.00
	3	264	65%	25	1	24		6177.60
	4	290	65%	25	1	24		6786.00
Total Quantity:								26769.60

There are four machines are available for 1.drawing frame and fiber weight was taken as 25 grams. As shown in Table 6.9, production efficiency was measured as 65% and the number of spindles of each machine is 1. The average daily capacity of machine 2 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 300 * 25 = 6,786,000 \text{ gr/day}$$

$$6,786,000 / 1000 = 7,581.6 \text{ kg/day.}$$

Table 6.9 Daily capacity of 1.drawing frame for X1, X2, X3 and X4 products

1.DRAWING FRAME								
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Hour	Shift	Quantity
7	1	290	65%	25	1	24		6786.00
	2	300	65%	27	1	24		7581.60
	3	262	65%	25	1	24		6130.80
	4	250	65%	25	1	24		5850.00
Total Quantity:								26348.40

As seen in Table 6.10, four machines are available and production efficiency was measured as 65% for the 2.drafting frame process. The numbers of spindles vary according to machine type. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 250 * 15 = 3,510,000 \text{ gr/day}$$

$$3,510,000 / 1000 = 3,510 \text{ kg/day.}$$

Table 6.10 Daily capacity of 2.Drawing Frame for X1, X2, X3 and X4 products

2.DRAWING FRAME							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
8	1	250	65%	15	1	24	3,510.00
	2	260	65%	15	2	24	7,300.80
	3	227	65%	14	2	24	5,949.22
	4	200	65%	15	2	24	5,616.00
Total Quantity:							22,376.02

There are four machines for the 3.Drawing Frame process as seen in Table 6.11 and production efficiency was measured as 65%. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 220 * 9 * 2 \text{ spindles} = 3,706,560 \text{ gr/day}$$

$$3,706,560 / 1000 = 3,706.56 \text{ kg/day.}$$

Table 6.11 Daily capacity for press operation of X1, X2, X3 and X4 products

3.DRAWING FRAME							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
9	1	220	65%	9	2	24	3,706.56
	2	240	65%	9	4	24	8,087.04
	3	216	65%	9	4	24	7,278.34
	4	200	65%	9	4	24	6,739.20
Total Quantity:							25,811.14

There are four machines for the finisor process as seen in Table 6.12 and the numbers of spindles vary according to machine type. Production efficiency was measured as 65%. Fiber weight was taken as 1.8 grams. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 200 * 1.8 * 16 \text{ spindles} = 5,391,360 \text{ gr/day}$$

$$5,391,360 / 1000 = 5,391.36 \text{ kg/day.}$$

Table 6.12 Daily capacity of finisor process for X1, X2, X3 and X4 products

FINISOR							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
10	1	200	65%	1.8	16	24	5,391.36
	2	204	65%	1.8	20	24	6,873.98
	3	216	65%	1.8	16	24	5,822.67
	4	200	65%	1.8	16	24	5,391.36
Total Quantity:							23,479.37

As seen in Table 6.13, production efficiency of ring spinning was measured as 85% and the sample yarn quantity was taken 0.0286 grams. The average daily capacity of machine 5 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ min/day}$$

$$1,224 * 29.50 * 0.0286 * 1104 \text{ spindles} = 1,140,088.43 \text{ gr/day}$$

$$1,140,088.43 / 1000 = 1,140.09 \text{ kg/day.}$$

Table 6.13 Daily capacity of ring spinning for X1, X2, X3 and X4 products

RING SPINNING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
11	1	29.5	85%	0.0286	1056	24	1,090.52
	2	29.5	85%	0.0286	1056	24	1,090.52
	3	29.5	85%	0.0286	1056	24	1,090.52
	4	29.5	85%	0.0286	1056	24	1,090.52
	5	29.5	85%	0.0286	1104	24	1,140.09
	6	29.5	85%	0.0286	1104	24	1,140.09
	7	29.5	85%	0.0286	1104	24	1,140.09
	8	29.5	85%	0.0286	1104	24	1,140.09
	9	29.5	85%	0.0286	1104	24	1,140.09
	10	29.5	85%	0.0286	1104	24	1,140.09
	11	29.5	85%	0.0286	1104	24	1,140.09
	12	29.5	85%	0.0286	1104	24	1,140.09
	13	28	85%	0.0286	748	24	733.17
	14	28	85%	0.0286	748	24	733.17
	15	28	85%	0.0286	748	24	733.17
	16	28	85%	0.0286	748	24	733.17
	17	28	85%	0.0286	748	24	733.17
Total Quantity:							17,148.66

There are 9 machines for winding process as seen in Table 6.14. Production efficiency was measured as 70% and fiber weight was taken as 24 grams. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.70 = 1,008 \text{ minutes/day}$$

$$1,008 * 60 * 0.0285 * 1200 \text{ spindles} = 2,068,416 \text{ gr/day}$$

$$2,068,416 / 1000 = 2,068.41 \text{ kg/day.}$$

Table 6.14 Daily capacity of winding process for X1, X2, X3 and X4 products

WINDING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
12	1	60	70%	0.0285	1200	24	2,068.42
	2	60	70%	0.0285	1200	24	2,068.42
	3	60	70%	0.0285	1200	24	2,068.42
	4	60	70%	0.0285	1000	24	1,723.68
	5	60	70%	0.0285	1000	24	1,723.68
	6	60	70%	0.0285	1200	24	2,068.42
	7	60	70%	0.0285	1200	24	2,068.42
	8	60	70%	0.0285	1200	24	2,068.42
	9	60	70%	0.0285	1200	24	2,068.42
Total Quantity:							17,926.27

7 machines are available for folding process and the production efficiency was measured as 75%. The yarn weights was taken 5.71 grams. As shown in the given Table 6.15, the number of spindles. The average daily capacity of machine 1 calculated as follows:

$$24 * 60 * 0.75 = 1,080 \text{ minutes/day}$$

$$1,080 * 640 * 0.0571 * 72 \text{ spindles} = 2,841,661.44 \text{ gr/day}$$

$$2,841,661.44 / 1000 = 2,841.66 \text{ kg/day.}$$

Table 6.15 Daily capacity of folding process for X1, X2, X3 and X4 products

FOLDING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
13	1	640	75%	0.0571	72	24	2,841.66
	2	618	75%	0.0571	60	24	2,286.65
	3	441	75%	0.0571	84	24	2,284.43
	4	640	75%	0.0571	60	24	2,368.05
	5	550	75%	0.0571	30	24	1,017.52
	6	650	75%	0.0571	72	24	2,886.06
	7	650	75%	0.0571	60	24	2,405.05
Total Quantity:							16,089.43

There are 17 machines for twisting process and production efficiency was measured 85% as seen in Table 6.16. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224 * 54 * 0.0571 * 208 \text{ spindles} = 785,008.973 \text{ gr/day}$$

$$785,008.973 / 1000 = 785.01 \text{ kg/day.}$$

Table 6.16 Daily capacity of twisting process for X1, X2, X3 and X4 products

TWISTING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
14	1	54	85%	0.0571	208	24	785.01
	2	54	85%	0.0571	208	24	785.01
	3	54	85%	0.0571	208	24	785.01
	4	54	85%	0.0571	208	24	785.01
	5	54	85%	0.0571	208	24	785.01
	6	54	85%	0.0571	208	24	785.01
	7	54	85%	0.0571	208	24	785.01
	8	54	85%	0.0571	208	24	785.01
	9	54	85%	0.0571	208	24	785.01
	10	54	85%	0.0571	160	24	603.85
	11	54	85%	0.0571	160	24	603.85
	12	54	85%	0.0571	290	24	1,095.31
	13	54	85%	0.0571	290	24	1,095.31
	14	54	85%	0.0571	290	24	1,095.31
	15	54	85%	0.0571	290	24	1,095.31
	16	54	85%	0.0571	208	24	785.01
	17	54	85%	0.0571	208	24	785.01
Total Quantity:							14,224.03

There are 7 machines available for the volufil process as shown in Table 6.17. Production efficiency was measured as 85% and fiber weights was taken as 7.14 grams. The number of spindles are 18 and 36. The average daily capacity of a machine 4 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224 * 550 * 0.0714 * 36 = 1,730,394 \text{ gr/day}$$

$$1,730,394 / 1000 = 1,730.40 \text{ kg/day.}$$

Table 6.17 Daily capacity of volufil process for X1, X2, X3 and X4 products

VOLUFIL							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
15	1	850	85%	0.0714	18	24	1337
	2	850	85%	0.0714	18	24	1337
	3	850	85%	0.0714	18	24	1337
	4	550	85%	0.0714	36	24	1730
	5	550	85%	0.0714	36	24	1730
	6	550	85%	0.0714	36	24	1730
	7	550	85%	0.0714	36	24	1730
Total Quantity:							10,933

There are 2 machines available for the packing process. Production efficiency was measured as 90% as seen in Table 6.18. The average daily capacity of a machine 1 is calculated as follows:

$$9 * 60 * 0.90 = 486 \text{ minutes/day}$$

$$486 * 16 * 1100 = 8,553,600 \text{ gr/day}$$

$$8,553,600 / 1000 = 8,553.6 \text{ kg/day.}$$

Table 6.18 Daily capacity of packing process for X1, X2, X3 and X4 products

PACKING							
Process No	Machine No	# of cone/min	Efficiency	Yarn Quantity (gr/cone)	# of spindle	Total Shift Hour	Quantity
16	1	16	90%	1100	1	9	8,553.60
	2	16	90%	1100	1	9	8,553.60
Total Quantity:							17,107.20

6.4.1.2 Daily Capacity for X5 product

Daily production capacities of X5 are calculated totally for 22 processes. There are two machines for the pressing process and production efficiency was measured as 80%, as seen in Table 6.19. The fiber weight was taken as 120 grams. The machines produce 450 kg in every 30 minutes. The average daily capacities of machine 1 is calculated as follows:

$$24 * 60 * 0.8 = 1,152 \text{ minutes/day}$$

$$1,152/30 = 38.4 \text{ period/day (number of period should be integer, so it is taken 38)}$$

$$38 * 450 = 17,100 \text{ kg / day.}$$

Table 6.19 Daily capacity of pressing process for product X5

PRESSING							
Process No	Machine No	Capacity	Efficiency	Fiber Quantity (gr.)	Period	Total Shift Hour	Quantity
1	1	450	80%	120	30 min.	24	17,100.00
	2	450	80%	120	30 min.	24	17,100.00
						Total:	34,200.00

As shown in Table 6.20, four machines are available for dying process. The average daily capacities of machine 1 and machine 2 are calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224/6 / 60 = 3.4 \text{ period/day}$$

$$3.4 * 1,350 = 4,590 \text{ kg/day for machine 1}$$

$$3.4 * 1,900 = 6,460 \text{ kg/day for machine 2.}$$

Table 6.20 Daily capacity of dyeing process for X5

DYEING							
Process No	Machine No	Capacity	Efficiency	Fiber Quantity (gr.)	Period	Total Shift Hour	Quantity
2	1	1350	85%	120	6 hours	24	4,590.00
	2	1900	85%	120	6 hours	24	6,460.00
	3	1900	85%	120	6 hours	24	6,460.00
	4	1350	85%	120	6 hours	24	4,590.00
Total Quantity:							22,100.00

One machine is available for dry-pressing as seen in Table 6.21. The efficiency of drying process was measured as 85%. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224/30 = 40.8 \text{ period/day}$$

$$40.8 * 450 = 18,360 \text{ kg/day.}$$

Table 6.21 Daily capacity of dry-pressing for product X5

DRY-PRESSING							
Process No	Machine No	Capacity	Efficiency	Fiber Quantity (gr.)	Period	Total Shift Hour	Quantity
3	1	450	85%	120	30 min	24	18,360.00
Total Quantity:							18,360.00

There is one machine is available for dry-pressing. Production efficiency was measured as 83% as seen in Table 6.22. The fiber weight was taken as 120 grams. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.83 = 1,195.2 \text{ minutes/day}$$

$$1,195.2 * 102 * 120 = 14,629,248 \text{ gr/day}$$

$$14,629,248 / 1000 = 14,629.248 \text{ kg/day.}$$

Table 6.22 Daily capacity of drying process for X5

DRYING							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
4	1	102	83%	120	1	24	14,629,25
Total Quantity:							14,629,25

As shown in Table 6.23, four machines are available for breaker process. Production efficiency was measured as 80% and fiber weight was taken as 27 grams. The average daily capacity of machine1 is calculated as follows:

$$24 * 60 * 0.8 = 1,152 \text{ minutes/day}$$

$$1,152 * 210 * 27 = 6,531,840 \text{ gr/day}$$

$$6,531,840/1000 = 6,531.84 \text{ kg/day.}$$

Table 6.23 Daily capacity of breaker process for X5

BREAKER							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
5	1	210	80%	27	1	24	6,531.84
	2	230	80%	27	1	24	7,153.92
	3	230	80%	27	1	24	7,153.92
	4	240	80%	27	1	24	7,464.96
Total Quantity:							28,304.64

Four machines are available for re-breaker process and production efficiency was measured as 65%. As shown in Table 6.24, fiber weight was taken as 25 grams and number of spindles for each machine is one. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 290 * 25 = 6,786,000 \text{ gr/day}$$

$$6,786,000/1000 = 6,786 \text{ kg/day.}$$

Table 6.24 Daily capacity of re-breaker process for X5

RE-BREAKER							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
6	1	290	65%	25	1	24	6,786.00
	2	300	65%	25	1	24	7,020.00
	3	264	65%	25	1	24	6,177.60
	4	290	65%	25	1	24	6,786.00
Total Quantity:							26,769.60

There are four machines are available for 1.drawing frame. As shown in Table 6.25, production efficiency was measured as 65% and the number of spindles of each machine is 1. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 290 * 25 = 6,786,000 \text{ gr/day}$$

$$6,786,000 / 1000 = 6,786 \text{ kg/day.}$$

Table 6.25 Daily capacity of 1.drawing frame process for X5

1.DRAWING FRAME							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
7	1	290	65%	25	1	24	6,786.00
	2	300	65%	27	1	24	7,581.60
	3	262	65%	25	1	24	6,130.80
	4	250	65%	25	1	24	5,850.00
Total Quantity:							26,348.40

As seen in Table 6.26, there are 4 machines for the 2.drawing frame process with efficiency 65%. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 250 * 15 = 3,510,000 \text{ gr/day}$$

$$3,510,000 / 1000 = 3,510 \text{ kg/day.}$$

Table 6.26 Daily capacity of 2.drawing frame process for X5

2.DRAWING FRAME							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
8	1	250	65%	15	1	24	3,510.00
	2	260	65%	15	2	24	7,300.80
	3	227	65%	14	2	24	5,949.22
	4	200	65%	15	2	24	5,616.00
Total Quantity:							22,376.02

There are four machines for the 3.drawing frame process as seen in Table 6.27 and production efficiency was measured as 65%. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 220 * 9 * 2 \text{ spindles} = 3,706,560 \text{ gr/day}$$

$$3,706,560 / 1000 = 3,706.56 \text{ kg/day.}$$

Table 6.27 Daily capacity of 3.drawing frame process for X5

3.DRAWING FRAME							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
9	1	220	65%	9	2	24	3,706.56
	2	240	65%	9	4	24	8,087.04
	3	216	65%	9	4	24	7,278.34
	4	200	65%	9	4	24	6,739.20
Total Quantity:							25,811.14

As seen in Table 6.28, there are 4 machines for the finisor process with efficiency 65% and numbers of spindles vary according to machine type. Fiber weight was taken as 1.8 grams. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.65 = 936 \text{ minutes/day}$$

$$936 * 200 * 1.8 * 16 \text{ spindles} = 5,391,360 \text{ gr/day}$$

$$5,391,360 / 1000 = 5,391.36 \text{ kg/day.}$$

Table 6.28 Daily capacity of finisor process for X5

FINISOR							
Process No	Machine No	RPM (m/min)	Efficiency	Fiber Quantity (gr.)	# of spindle	Total Shift Hour	Quantity
10	1	200	65%	1.8	16	24	5,391.36
	2	204	65%	1.8	20	24	6,873.98
	3	216	65%	1.8	16	24	5,822.67
	4	200	65%	1.8	16	24	5,391.36
Total Quantity:							23,479.37

As seen in Table 6.29, there are 17 machines for the ring spinning process. The production efficiency of ring spinning was measured as 85% and numbers of spindles vary according to machine type. The average daily capacity of machine 5 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224 * 29.50 * 0.0416 * 1104 \text{ spindles} = 1,658,310.45 \text{ gr/day}$$

$$1,658,310.45 / 1000 = 1,658.31 \text{ kg/day.}$$

Table 6.29 Daily capacity of ring spinning process for X5

RING SPINNING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
11	1	29.5	85%	0.0416	1056	24	1,586.21
	2	29.5	85%	0.0416	1056	24	1,586.21
	3	29.5	85%	0.0416	1056	24	1,586.21
	4	29.5	85%	0.0416	1056	24	1,586.21
	5	29.5	85%	0.0416	1104	24	1,658.31
	6	29.5	85%	0.0416	1104	24	1,658.31
	7	29.5	85%	0.0416	1104	24	1,658.31
	8	29.5	85%	0.0416	1104	24	1,658.31
	9	29.5	85%	0.0416	1104	24	1,658.31
	10	29.5	85%	0.0416	1104	24	1,658.31
	11	29.5	85%	0.0416	1104	24	1,658.31
	12	29.5	85%	0.0416	1104	24	1,658.31
	13	28	85%	0.0416	748	24	1,066.43
	14	28	85%	0.0416	748	24	1,066.43
	15	28	85%	0.0416	748	24	1,066.43
	16	28	85%	0.0416	748	24	1,066.43
	17	28	85%	0.0416	748	24	1,066.43
Total Quantity:							24,943.50

There are 9 machines available for the winding process as seen in Table 6.30. Production efficiency was measured as 70% on average. There are type spindles as 1000 and 1200. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.70 = 1,008 \text{ minutes / day}$$

$$1,008 * 60 * 0.0416 * 1200 \text{ spindles} = 3,019,161.6 \text{ gr/day}$$

$$3,019,161.6 / 1000 = 3,019.16 \text{ kg/day.}$$

Table 6.30 Daily capacity of winding process for X5

WINDING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
12	1	60	70%	0.0416	1200	24	3,019.16
	2	60	70%	0.0416	1200	24	3,019.16
	3	60	70%	0.0416	1200	24	3,019.16
	4	60	70%	0.0416	1000	24	2,515.97
	5	60	70%	0.0416	1000	24	2,515.97
	6	60	70%	0.0416	1200	24	3,019.16
	7	60	70%	0.0416	1200	24	3,019.16
	8	60	70%	0.0416	1200	24	3,019.16
	9	60	70%	0.0416	1200	24	3,019.16
Total Quantity:							26,166.07

As seen in Table 6.31 there are 7 machines for the folding process. The production efficiency was measured as 75%. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.75 = 1,080 \text{ minutes/day}$$

$$1080 * 640 * 0.0832 * 72 \text{ spindles} = 4,140,564.48 \text{ gr/day}$$

$$4,140,564.48 / 1000 = 4,140.56 \text{ kg/day.}$$

Table 6.31 Daily capacity of folding process for X5

FOLDING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
13	1	640	75%	0.0832	72	24	4,140.56
	2	618	75%	0.0832	60	24	3,331.86
	3	441	75%	0.0832	84	24	3,328.63
	4	640	75%	0.0832	60	24	3,450.47
	5	550	75%	0.0832	30	24	1,482.62
	6	650	75%	0.0832	72	24	4,205.26
	7	650	75%	0.0832	60	24	3,504.38
Total Quantity:							23,443.79

There are 17 machines for twisting process and production efficiency was measured 85% as seen in Table 6.32. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224 * 54 * 0.0832 * 208 \text{ spindles} = 1,143,830.94 \text{ gr/day}$$

$$1,143,830.94 / 1000 = 1,143.83 \text{ kg/day.}$$

Table 6.32 Daily capacity of twisting process for X5

TWISTING							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
14	1	54	85%	0.0832	208	24	1,143.83
	2	54	85%	0.0832	208	24	1,143.83
	3	54	85%	0.0832	208	24	1,143.83
	4	54	85%	0.0832	208	24	1,143.83
	5	54	85%	0.0832	208	24	1,143.83
	6	54	85%	0.0832	208	24	1,143.83
	7	54	85%	0.0832	208	24	1,143.83
	8	54	85%	0.0832	208	24	1,143.83
	9	54	85%	0.0832	208	24	1,143.83
	10	54	85%	0.0832	160	24	879.87
	11	54	85%	0.0832	160	24	879.87
	12	54	85%	0.0832	290	24	1,594.76
	13	54	85%	0.0832	290	24	1,594.76
	14	54	85%	0.0832	290	24	1,594.76
	15	54	85%	0.0832	290	24	1,594.76
	16	54	85%	0.0832	208	24	1,143.83
	17	54	85%	0.0832	208	24	1,143.83
Total Quantity:							20,720.94

There are 7 machines available for the volufil process as shown in Table 6.33. Production efficiency was measured as 85%. The number of spindles are 18 and 36. The average daily capacity of a machine 4 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224 * 550 * 0,104 * 36 \text{ spindles} = 2,520,460.8 \text{ gr/day}$$

$$2,520,460.8 / 1000 = 2,520.46 \text{ kg/day.}$$

Table 6.33 Daily capacity of volufil process for X5

VOLUFIL							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Amount (gr/m)	# of spindle	Total Shift Hour	Quantity
15	1	850	85%	0.104	18	24	1.947,63
	2	850	85%	0.104	18	24	1.947,63
	3	850	85%	0.104	18	24	1.947,63
	4	550	85%	0.104	36	24	2.520,46
	5	550	85%	0.104	36	24	2.520,46
	6	550	85%	0.104	36	24	2.520,46
	7	550	85%	0.104	36	24	2.520,46
Total Quantity:							15.924,73

As seen in Table 6.34, there are 7 machines available for the hank raw winder process.

The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes/day}$$

$$1,224 * 750 * 0.104 * 19 \text{ spindles} = 1,813,968 \text{ gr/day}$$

$$1,813,968 / 1000 = 1,813.97 \text{ kg/day.}$$

Table 6.34 Daily capacity of hank raw winder process for X5

HANK RAW WINDER							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
16	1	750	85%	0.104	19	24	1,813.97
	2	750	85%	0.104	19	24	1,813.97
	3	750	85%	0.104	19	24	1,813.97
	4	750	85%	0.104	19	24	1,813.97
	5	750	85%	0.104	19	24	1,813.97
	6	750	85%	0.104	19	24	1,813.97
	7	750	85%	0.104	19	24	1,813.97
Total Quantity:							12,697.78

As shown in Table 6.35, there are two machines for the softening process. The production efficiency was measured as 85%. Softening process works with the periodic system, which means it produces 240 kg for every 40 minutes. The average daily capacity of a machine 1 is calculated as follows:

$$24 * 60 * 0.85 = 1,224 \text{ minutes / day}$$

$$1,224/40 = 30.6 \text{ period/day (number of period should be integer, so it is taken 30)}$$

$$30 * 240 = 7,200 \text{ kg/day.}$$

Table 6.35 Daily capacity of softening process for X5

SOFTENING							
Process No	Machine No	Capacity	Efficiency	Yarn Quantity (gr/m)	Period	Total Shift Hour	Quantity
17	1	240	85%	0.104	40 min	24	7,200.00
	2	240	85%	0.104	40 min	24	7,200.00
	3	240	85%	0.104	40 min	24	7,200.00
Total Quantity:							21,600.00

As seen in Table 6.36, two hank dry pressing machine are available. The hank dry-pressing produce 240 kg for every 30 minutes. The average daily capacity of machine 1 is calculated as follows:

$$24 * 60 * 0.90 = 1,296 \text{ minutes/day}$$

$$1,296/30 = 43.2 \text{ period/day (number of period should be integer, so it is taken 43)}$$

$$43 * 240 = 10,320 \text{ kg/day.}$$

Table 6.36 Daily capacity of hank dry-pressing for X5

HANK DRY-PRESSING							
Process No	Machine No	Capacity	Efficiency	Yarn Quantity (gr/m)	Period	Total Shift Hour	Quantity
18	1	240	90%	0.104	30 min	24	10,320.00
	2	240	90%	0.104	30 min	24	10,320.00
Total Quantity:							20,640.00

As seen in Table 6.37, there are two machines are available for the hank drying process. The efficiency of production was measured as 90%. It produces 240 kg for every 25 minutes. The average daily capacity of a machine 1 is calculated as follows:

$$24 * 60 * 0.90 = 1,296 \text{ minutes/day}$$

$$1,296/25 = 51.84 \text{ period/day (number of period should be integer, so it is taken 51)}$$

$$51 * 240 = 12,240 \text{ kg/day.}$$

Table 6.37 Daily capacity of hank drying process for X5

HANK DRYING							
Process No	Machine No	Quantity	Efficiency	Yarn Quantity (gr/m)	Period	Total Shift Hour	Quantity
19	1	240	90%	0.104	25 min	24	12,240.00
Total Quantity:							12,240.00

There are two machines for hank colored winder process as shown in Table 6.38, and production efficiency change between 75-88%. The average daily capacity of machine 7 is calculated as follows:

$$24 * 60 * 0.88 = 1,267.2 \text{ minutes/day}$$

$$1,267.2 * 0,104 * 450 * 24 \text{ spindles} = 14,540.50 \text{ gr/day}$$

$$14,540.50/1000 = 1,423.32 \text{ kg/day}$$

Table 6.38 Daily capacity of hank colored winder process for X5

HANK COLORED WINDER							
Process No	Machine No	RPM (m/min)	Efficiency	Yarn Quantity (gr/m)	# of spindle	Total Shift Hour	Quantity
20	1	600	75%	0.104	30	24	2,021.76
	2	600	85%	0.104	30	24	2,291.33
	3	450	85%	0.104	26	24	1,489.36
	4	450	85%	0.104	26	24	1,489.36
	5	450	85%	0.104	26	24	1,489.36
	6	450	85%	0.104	26	24	1,489.36
	7	450	88%	0.104	24	24	1,423.32
	8	450	88%	0.104	24	24	1,423.32
	9	450	88%	0.104	24	24	1,423.32
Total Quantity:							14,540.50

As seen in Table 6.39 there are 2 machines for the packing process, with production efficiency 90%. The average daily capacity of machine 1 is calculated as follows:

$$9 * 60 * 0.90 = 486 \text{ minutes/day}$$

$$486 * 16 * 1200 = 9,331,200 \text{ gr/day}$$

$$9,331,200 / 1000 = 9,331.2 \text{ kg/day.}$$

Table 6.39 Daily capacity of packing process for X5

PACKING							
Process No	Machine No	# of cone/min	Efficiency	Yarn Quantity (gr/cone)	# of spindle	Total Shift Hour	Quantity
21	1	16	90%	1200	1	9	9,331.20
	2	16	90%	1200	1	9	9,331.20
Total Quantity:							18,662.40

6.1.5 Price forecasting

Price forecasting plays key role, when establish a production planning with maximum profit. The prices may be variable or may differ from the actual values in the estimation for the future. In this study, the prices of yarns were taken on the basis of foreign exchange rate and an average value was calculated considering that the price fluctuation would be at the minimum level. The weighted average method was used in the price estimates of yarns and forecasted prices are determined as seen in Table 6.40. The price list of yarn produced in last 3 years is given in Table 6.41. As it can be seen, price changes within 3 years are not constant per kilogram yarn. Therefore, it has been decided to use the average price of the yarn as the selling price. Yarn prices are given in dollar per kg. For example, as given Table 6.41, 38.380,00 kg of product X1 was sold at \$4.70 in 2015.

Table 6.40 The weighted average price of yarns produced in company

	X1	X2	X3	X4	X5
Price:	\$4.94	\$4.89	\$4.77	\$5.35	\$5.89

The weighted [68] average is equal to the sum of the product of the weight W_i times the value of X_i divided by the sum of the weights that given in equation (6.1).

$$\bar{x} = \frac{\sum_{i=1}^n w_i \cdot x_i}{\sum_{i=1}^n w_i} = \frac{w_1x_1 + w_2x_2 + \dots + w_nx_n}{w_1 + w_2 + \dots + w_n} \quad (6.1)$$

The weighted average formula is used to calculate the average value of a set of numbers at different levels. The relevance of each number is called its weight. The weights should be represented as a percentage of the total relevancy. Therefore, sum of weights should be equal to 100%, or 1.

Table 6.41 Sales prices for last three years

Year	Month	X1		X2		X3		X4		X5	
		kg	\$	kg	\$	kg	\$	kg	\$	kg	\$
2015	1	38380	4.7	48221.6	4.65	11530	4.5	12071	5.2	176512	5.65
	2	20254	4.7	51860.1	4.65	19589	4.5	21003	5.2	155000	5.65
	3	16953	4.7	48193	4.65	15000	4.5	43429	5.2	137124	5.65
	4	55000	4.7	71700.7	4.65	17723	4.5	35000	5.2	143783	5.65
	5	28846	4.7	84095.4	4.65	25409	4.5	20336	5.2	135000	5.65
	6	20856	4.75	62334.4	4.7	30742	4.6	37213	5.2	115012	5.7
	7	22510	4.75	87671.3	4.7	52414	4.6	10991	5.2	90000	5.7
	8	40000	4.75	117992	4.7	30407	4.6	12368	5.2	115000	5.7
	9	25000	4.75	75453.3	4.7	28073	4.6	15000	5.2	90202	5.7
	10	67665	4.75	60530.9	4.7	41000	4.6	15079	5.2	122624	5.7
	11	60478	4.75	57804.5	4.7	35000	4.6	10408	5.2	113512	5.7
	12	56577	4.75	53950.4	4.7	35000	4.6	25470	5.2	80000	5.7
2016	1	28000	4.8	41000	4.75	8000	4.6	19882	5.3	169810	5.75
	2	16216	4.8	49000	4.75	15000	4.6	25705	5.3	145000	5.75
	3	13176	4.8	45000	4.75	20000	4.6	49624	5.3	130000	5.75
	4	50000	4.8	76235.6	4.75	25000	4.6	45031	5.3	150000	5.75
	5	24000	4.8	78000	4.75	21007	4.6	31045	5.3	150000	5.75
	6	20423	4.9	60000	4.85	25000	4.7	30310	5.4	125292	5.85
	7	19494	4.9	85000	4.85	47015	4.7	17054	5.4	95000	5.85
	8	30000	4.9	104780	4.85	18441	4.7	19962	5.4	120000	5.85
	9	20129	4.9	72000	4.85	18476	4.7	13583	5.4	97000	5.85
	10	58054	4.9	53034.9	4.85	51413	4.7	19000	5.4	130000	5.85
	11	55000	4.9	55000	4.85	42178	4.7	7159.3	5.4	105000	5.85
	12	32386	4.9	55000	4.85	42835	4.7	12016	5.4	95000	5.85
2017	1	29000	5.05	40000	5	15078	4.9	11702	5.5	155078	6
	2	12000	5.05	45000	5	11953	4.9	18787	5.5	114793	6
	3	25000	5.05	50000	5	29000	4.9	40209	5.5	142230	6
	4	48815	5.05	64033.1	5	32057	4.9	36150	5.5	160043	6
	5	18283	5.2	75000	5.15	22203	5	18000	5.7	155000	6.15
	6	19677	5.2	65000	5.15	20000	5	20000	5.7	135000	6.15
	7	15634	5.2	80000	5.15	49000	5	13544	5.7	105000	6.15
	8	35000	5.2	85746	5.15	26210	5	14967	5.7	135000	6.15
	9	30000	5.5	70000	5.45	13000	5.3	19330	6	110000	6.45
	10	50000	5.5	50000	5.45	59618	5.3	11406	6	137000	6.45
	11	45000	5.5	48388.9	5.45	35745	5.3	8410.9	6	110740	6.45
	12	25000	5.5	52000	5.45	31181	5.3	6847.6	6	130740	6.45

6.2 Time study

Time study is a structured process of directly observing and measuring human work using a timing device to estimate the time required for completion of the work by a qualified worker when working at a defined level of performance. The enterprise needs the number of the staff to determine the net human power need. To calculate the number of required staff, we need the time that a person will spend to complete a job in one period and the total time required for all the work of a job in one period. In addition, the relevant formula is given equation (6.2) [69].

$$\text{number of worker} = \frac{\sum_{i=1}^n F_i * Z_i}{\text{Working Time per shift}} \quad (6.2)$$

F_i : number of repetitions of related process

Z_i : time required for one process

i : precedence of job

n : total number of job

The observed operation times for X1, X2, X3, X4 and X5 are given in Table 6.42 and Table 6.43 respectively. The times were observed separately by 3 observers and average of the data were considered. There are two types of observation time, working time and stopping time. Working time is time that operations carried out while the machine is running. In contrast, stopping time is time that operations carried out while the machine is stopping.

To complete production processes of X1, X2, X3 and X4 require 320.78 minutes and the most time-consuming process is Finisor as seen in Table 6.42. Operator spent 132 minutes when machines are working and also 8.31 minute when machines are stopping for finisor process.

Table 6.42 Observed operation times for X1, X2, X3 and X4

No	Process Type	Stopping Time (min)	Working Time (min)
1	Wet Pressing	33.75	-
2	Dyeing	26.5	33
3	Dry Pressing	8.6	-
4	Drying	9.4	2
5	Bale Preparation	6.91	21
6	Breaker	45.9	19
7	Re-breaker	6.1	99
8	1.Drawing Frame	18.16	0.42
9	2.Drawing Frame	18.16	0.42
10	3.Drawing Frame	18.16	0.42
11	Finisor	8.31	132
12	Ring Spinning	10.32	6.32
13	Winding	1.54	0.75
14	Folding	2.2	0.65
15	Twisting	20.51	2.2
16	Volufil	11.71	1.55
17	Packing	0.5	2.05
Total:		246.73	320.78

To complete production process of X5 360.73 minutes is required and the most time-consuming process is Finisor as seen in Table 6.43. Operator spent 127 minute when machines are working and also 8.31 minutes when machines are stopping for finisor process.

Table 6.43 Observed operation times for X5

No	Process Type	Stopping Time (Min)	Working Time (Min)
1	Wet Pressing	33.75	-
2	Dyeing	26.5	33
3	Dry Pressing	8.6	-
4	Drying	9.4	-
5	Bale Preparation	6.91	17
6	Breaker	45.31	28
7	Re-Breaker	6.1	111
8	1.Drawing Frame	18.16	0.42
9	2.Drawing Frame	18.16	0.42
10	3.Drawing Frame	18.16	0.42
11	Finisor	8.31	127
12	Ring Spinning	10.32	6.32
13	Winding	1.43	0.75
14	Folding	1.4	0.85
15	Twisting	20.51	2.2
16	Volufil	11.71	1.55
17	Hank Raw Winder	17.1	-
18	Softening	34	-
19	Hank Dry Pressing	17	-
20	Hank Drying	0.5	30
21	Hank Colored Winder	4.4	-
22	Packing	0.5	1.8
Total:		318.23	360.73

6.3 Linear Programming (LP) model

In a spinning business, production planning should be considered mathematically according to the improvements in the field of optimization techniques. Successful results in application areas and results obtained from the solution should be technically evaluated.

Optimization techniques have an important role in the solution of problems in production planning in the world of technology. The linear programming (LP) approach among these techniques is commonly used to solve problems in production planning.

Here, a mathematical model has been created to determine optimum production and stock levels that will minimize costs in accordance with the structure of a yarn operation.

Integration of production planning with order acceptance decisions is an important issue for textile production. Production companies often endeavor to obtain very profitable orders in a competitive environment. The company's expert staff explores ways to increase the rate of profit. The LP model is an important tool for increasing the rate of profit.

There are 5 assumptions in developed LP model. These assumptions of the LP model are given as following:

- 1) *Public holidays during the year*: There are public holidays during the year like feast holiday, labor day and etc. These holidays are eliminated from total annual working time.
- 2) *Repetition process of products*: There is a repetition process for selected products however it is assumed, when the calculating the production capacity.
- 3) *The variation of raw material price during the year*: The raw material price can change especially in the winter seasons. It's depending on the price of oil. The variation of raw material price eliminated from cost of products.
- 4) *Idle time in manufacturing*: Idle time is unproductive time on the part of employees or machines caused by management. Therefore, there are breaking times such as smoking break or dressing time, which is eliminated from daily working time.
- 5) *Maintenance scheduling of machines*: In generally, maintenance of machines is done twice in textile yarn manufacturing mill during a year. It's eliminated from the total annual time.

Sets:

- N : set of products ($i = 1, 2, 3 \dots n$)
- T : time interval ($j = 1, 2, 3 \dots t$)

Parameters:

- D_{it} : The demand of product i in period t $\forall i \in N, \forall t \in T$
- B_i : The unit production cost of product i $\forall i \in N$
- R_i : Unit stock cost of product i $\forall i \in N$
- C_i : The average daily production capacity of product i $\forall i \in N$
- A_i : The number of working days of product i $\forall i \in N$
- P_i : Price of product i $\forall i \in N$
- W : Warehouse Capacity

Decision Variables:

- S_{it} : Stock quantity of product i in period t $\forall i \in N, \forall t \in T$
- K_{it} : The quantity of sales of product i in period t $\forall i \in N, \forall t \in T$
- X_{it} : Production quantity of product i in period t $\forall i \in N, \forall t \in T$

6.3.1 Mathematical Formulas**Objective function:**

$$Max Pro = \sum_{i=1}^n \sum_{t=1}^T P_i * K_{it} - \left[\sum_{i=1}^n \sum_{t=1}^T B_i * X_{it} + \sum_{i=1}^n \sum_{t=1}^T R_i * S_{it} \right] \quad (6.3)$$

Constraints:

$$\frac{\sum_{i=1}^n \sum_{t=1}^T X_{it}}{\sum_{i=1}^n C_i} \leq A_i \quad (6.4)$$

$$\sum_{i=1}^n \sum_{t=1}^T X_{it} + \sum_{i=1}^n \sum_{t=1}^T K_{i(t-1)} = \sum_{i=1}^n \sum_{t=1}^T K_{it} + \sum_{i=1}^n \sum_{t=1}^T S_{it} \quad (6.5)$$

$$\sum_{i=1}^n \sum_{t=1}^T S_{it} \leq W \quad (6.6)$$

Bounds:

$$\sum_{i=1}^n \sum_{t=1}^T K_{it} \leq \sum_{i=1}^n \sum_{t=1}^T D_{it} \quad (6.7)$$

6.3.2 Definition of Formulas

Objective Function:

Maximum profit is obtained by dropping total Production Cost from total Revenue as given in equation (6.8).

$$\text{Max. Profit} = \text{Total Revenue} - \text{Total Cost} \quad (6.8)$$

The Total Revenue is obtained as the product of the total sales quantity multiplied by the Sales price as given in equation (6.9).

$$\text{Total Revenue} = \sum \text{Sales Quantity} * \text{Sales Price} \quad (6.9)$$

Total Cost Value is obtained by summing Total Production Cost and Total Inventory Cost as given in equation (6.10).

$$\text{Total Cost} = \sum \text{Production Cost} + \sum \text{Stock Cost} \quad (6.10)$$

Total Production Cost is obtained by multiplying Total Unit Cost by Total Production Quantity as given in equation (6.11) and (6.12).

$$\text{Total Production Cost} = \sum \text{Production Cost} * \sum \text{Production Quantity} \quad (6.11)$$

$$\text{Total Stock Cost} = \sum \text{Stock Cost} * \sum \text{Stock Quantity} \quad (6.12)$$

Constraints:

The production quantity divided by capacity should not exceed the working time as given in equation (6.13).

$$\sum \text{Production Quantity} / \text{capacity} \leq \text{Working Time} \quad (6.13)$$

The total quantity of yarn produced and entering stock should be equal to the sum of the quantity of yarn to be sold and the staple remaining. In other words, inventory level is aimed at minimum level as given in equation (6.14).

$$\sum \text{Production Quantity} + \text{Current Inventory Quantity} = \sum \text{Sales Quantity} + \text{Expected Inventory Quantity} \quad (6.14)$$

Here, the condition of the total stock quantity does not exceed the capacity of the warehouse as given in equation (6.15).

$$\sum \text{Stock Quantity} \leq \text{Warehouse Capacity} \quad (6.15)$$

Bounds:

The total sales quantity can be equal or less than the total demanded quantity as given in equation (6.16). With this bound, the demanded quantity is defined to the model for each product. Therefore, the maximum quantity of sales can be as demanded quantity.

$$\Sigma \text{ Sales Quantity} \leq \Sigma \text{ Demand Quantity} \quad (6.16)$$

The Figure 6.6 includes incoming demand data for module 2. For convenience, data can also be transferred from Excel. The screen shot shows the 12-month data for 5 sample products.

Month	Ocak	Subat	Mart	Nisan	Mayıs	Hazir...	Tem...	Ağus...	Eylul	Ekim	Kasım	Aralık
# of prod...												

Figure 6.5 A snapshot for demand Table

The parameters used in the model are located in the Second tab, as shown in Figure 6.7. The required parameters for the LP model are entered in this section.

PRICE					
	X1	X2	X3	X4	X5
	4.50	4.65	4.70	5.00	6.00

COST					
	X1	X2	X3	X4	X5
	4.00	4.10	4.15	4.40	5.25

CAPACITY					
	X1	X2	X3	X4	X5
	9000	8500	8000	6500	6000

WORKING DAY					
	X1	X2	X3	X4	X5
	30	30	30	30	30

WAREHOUSE COST					
	X1	X2	X3	X4	X5
	0.12	0.12	0.12	0.15	0.15

Figure 6.6 A snapshot for model parameters

CHAPTER 7

EXPERIMENTAL RESULTS

7.1 Findings of forecasting methods

To find estimated order quantity of selected products for next 12 months, three forecasting methods are used and the results are compared according to the forecasted quantity and MAPE values. The obtained results are calculated by formulas given in Chapter 2.

7.1.1 The Demand for X1

The Figure 6.1 shows comparison of the actual demand and forecasted quantity. “Quantity” in the graph refers to the demand quantity of the last 3 years. Time Series method is the closest method to the realized demand quantity as seen in Figure 7.1. Considerable results are also achieved when using exponential smoothing ($\alpha = 0.2$). However, in some months, forecasted demand is far from the realized demand quantity due to the seasonal variations. When we take α value as 0.5 in Exponential Smoothing method, Figure 7.1 changes completely, which means that the estimated quantity is deviating. The forecasted quantity for this method appears to be a straight line as seen in the Figure 7.1. Lastly, the trend line is far from the realized demand quantity in the regression method. So it is not a suitable method to forecast for this product.

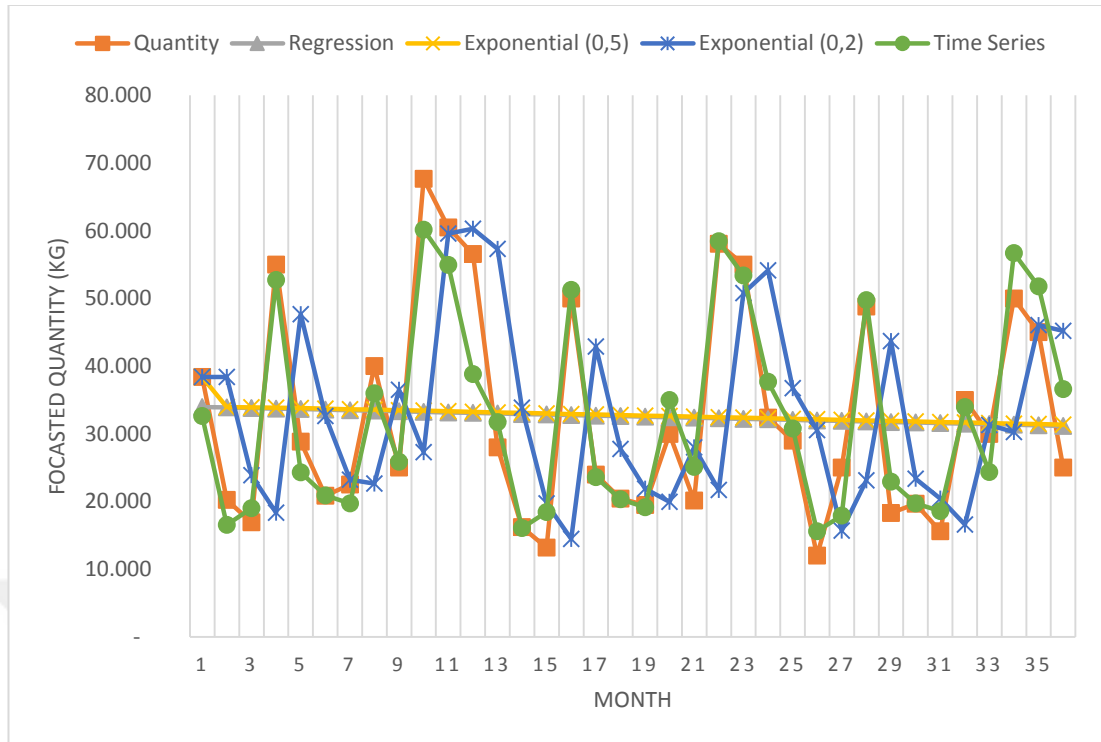


Figure 7.1 Comparison of the actual demand versus forecasted demand for X1

In all methods, forecasted demands are shown separately for 36 months with Exponential Smoothing α value as 0.5 and 0.2 as given in Table 7.1.

Table 7.1 Forecasted quantity for product X1

Year	Month	Demanded Quantity	Regression	Exponential (0,5)	Exponential (0,2)	Time Series
2015	1	38,380	33,968	38,380	38,380	32,638
	2	20,254	33,889	33,968	38,380	16,551
	3	16,953	33,809	33,928	23,879	19,002
	4	55,000	33,730	33,869	18,338	52,731
	5	28,846	33,650	33,799	47,668	24,309
	6	20,856	33,571	33,725	32,611	20,912
	7	22,510	33,491	33,648	23,207	19,718
	8	40,000	33,412	33,570	22,649	36,000
	9	25,000	33,333	33,491	36,530	25,847
	10	67,665	33,253	33,412	27,306	60,158
	11	60,478	33,174	33,332	59,593	54,950
	12	56,577	33,094	33,253	60,301	38,817
2016	13	28,000	33,015	33,174	57,322	31,722
	14	16,216	32,935	33,094	33,864	16,086
	15	13,176	32,856	33,015	19,746	18,466
	16	50,000	32,777	32,935	14,490	51,241
	17	24,000	32,697	32,856	42,898	23,620
	18	20,423	32,618	32,777	27,780	20,319
	19	19,494	32,538	32,697	21,894	19,156
	20	30,000	32,459	32,618	19,974	34,973
	21	20,129	32,379	32,538	27,995	25,108
	22	58,054	32,300	32,459	21,702	58,433
	23	55,000	32,220	32,379	50,784	53,371
	24	32,386	32,141	32,300	54,157	37,699
2017	25	29,000	32,062	32,220	36,740	30,806
	26	12,000	31,982	32,141	30,548	15,620
	27	25,000	31,903	32,062	15,710	17,930
	28	48,815	31,823	31,982	23,142	49,751
	29	18,283	31,744	31,903	43,680	22,932
	30	19,677	31,664	31,823	23,362	19,725
	31	15,634	31,585	31,744	20,414	18,595
	32	35,000	31,506	31,664	16,590	33,946
	33	30,000	31,426	31,585	31,318	24,369
	34	50,000	31,347	31,506	30,264	56,709
	35	45,000	31,267	31,426	46,053	51,792
	36	25,000	31,188	31,347	45,211	36,581

7.1.2 The Demand for X2

The data in Table 7.2 was obtained for the X2 product using all estimation methods and forecasted demands are shown for 36 months.

Table 7.2 Forecasted quantity for X2

Year	Month	Quantity	Regression	Exponential (0,5)	Exponential (0,2)	Time Series
2015	1	48,222	67,423	48,222	48,222	44,373
	2	51,860	67,252	48,222	48,222	50,116
	3	48,193	67,080	50,041	51,132	49,298
	4	71,701	66,908	49,117	48,781	72,866
	5	84,095	66,736	60,409	67,117	81,507
	6	62,334	66,565	72,252	80,700	64,514
	7	87,671	66,393	67,293	66,007	86,897
	8	117,992	66,221	77,482	83,339	105,859
	9	75,453	66,049	97,737	111,061	74,811
	10	60,531	65,877	86,595	82,575	56,206
	11	57,805	65,706	73,563	64,940	55,405
	12	53,950	65,534	65,684	59,232	55,409
2016	13	41,000	65,362	59,817	55,007	43,017
	14	49,000	65,190	50,409	43,801	48,580
	15	45,000	65,019	49,704	47,960	47,783
	16	76,236	64,847	47,352	45,592	70,621
	17	78,000	64,675	61,794	70,107	78,989
	18	60,000	64,503	69,897	76,421	62,517
	19	85,000	64,332	64,948	63,284	84,199
	20	104,780	64,160	74,974	80,657	102,564
	21	72,000	63,988	89,877	99,955	72,476
	22	53,035	63,816	80,939	77,591	54,447
	23	55,000	63,644	66,987	57,946	53,667
	24	55,000	63,473	60,993	55,589	53,666
2017	25	40,000	63,301	57,997	55,118	41,660
	26	45,000	63,129	48,998	43,024	47,044
	27	50,000	62,957	46,999	44,605	46,268
	28	64,033	62,786	48,500	48,921	68,376
	29	75,000	62,614	56,266	61,011	76,471
	30	65,000	62,442	65,633	72,202	60,519
	31	80,000	62,270	65,317	66,440	81,501
	32	85,746	62,098	72,658	77,288	99,269
	33	70,000	61,927	79,202	84,054	70,141
	34	50,000	61,755	74,601	72,811	52,688
	35	48,389	61,583	62,301	54,562	51,928
	36	52,000	61,411	55,345	49,624	51,923

Figure 7.2 is a comparison of actual demand and forecasted demand. The "Quantity" in the graph shows the demand quantity of the product X2 for the last 3 years. Time Series forecasting method is the best option among the forecasting methods to determine forecasted quantity of product X2. As seen in Figure 6.2 it is very close to realized demand quantity. Exponential Smoothing method for both α is also close to demand quantity. But it is not close as much as Time Series method. The regression method is far from the realized demand. So it is not the suitable method to forecast for this product.

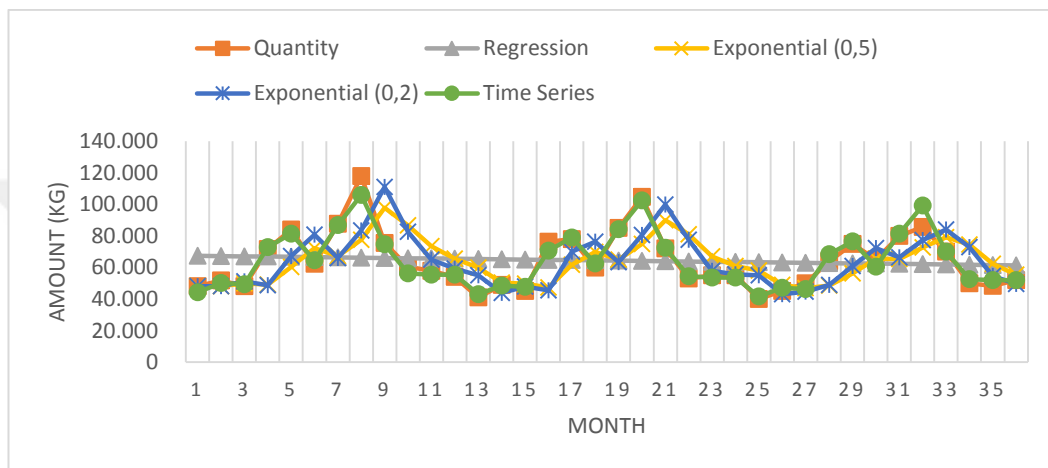


Figure 7.2 Comparison of the actual demand versus forecasted demand for X2

7.1.3 The Demand for X3

Figure 7.3 compares the actual demand and the expected demand. The "Quantity" in the chart refers to the quantity of demand for the last 3 years for the X3 product. Time Series forecasting method is the best option among forecasting methods to determine forecasted quantity of X3. It is very close to realized demand quantity. Exponential Smoothing method in $\alpha=0.2$ is better than when $\alpha=0.5$. It means that error increases as α value increases. The regression method is not suitable option for this product, as seen Figure 7.3.

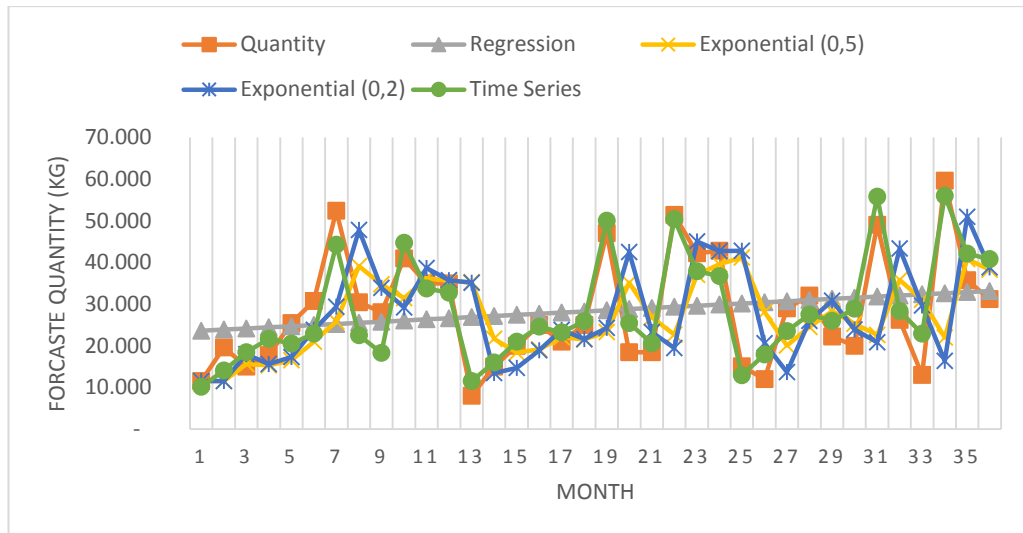


Figure 7.3 Comparison of the actual demand versus forecasted demand for X3

The data in Table 7.3 are obtained for the X3 product with all employed methods, forecasted demands were calculated separately for 36 months on this Table.

Table 7.3 Forecasted quantity for X3

Year	Month	Quantity	Regression	Exponential (0,5)	Exponential (0,2)	Time Series
2015	1	11,530	23,586	11,530	11,530	10,117
	2	19,589	23,859	11,530	11,530	14,051
	3	15,000	24,133	15,560	17,978	18,470
	4	17,723	24,406	15,280	15,596	21,676
	5	25,409	24,679	16,502	17,298	20,497
	6	30,742	24,953	20,955	23,786	22,891
	7	52,414	25,226	25,848	29,351	44,302
	8	30,407	25,499	39,131	47,801	22,531
	9	28,073	25,773	34,769	33,886	18,275
	10	41,000	26,046	31,421	29,236	44,762
	11	35,000	26,319	36,211	38,647	33,706
	12	35,000	26,593	35,605	35,729	32,714
2016	13	8,000	26,866	35,303	35,146	11,524
	14	15,000	27,139	21,651	13,429	15,982
	15	20,000	27,413	18,326	14,686	20,980
	16	25,000	27,686	19,163	18,937	24,589
	17	21,007	27,959	22,081	23,787	23,221
	18	25,000	28,233	21,544	21,563	25,900
	19	47,015	28,506	23,272	24,313	50,062
	20	18,441	28,779	35,144	42,475	25,429
	21	18,476	29,053	26,792	23,248	20,601
	22	51,413	29,326	22,634	19,430	50,399
	23	42,178	29,599	37,023	45,016	37,906
	24	42,835	29,873	39,601	42,746	36,749
2017	25	15,078	30,146	41,218	42,817	12,931
	26	11,953	30,419	28,148	20,626	17,914
	27	29,000	30,693	20,051	13,688	23,490
	28	32,057	30,966	24,525	25,938	27,502
	29	22,203	31,239	28,291	30,833	25,946
	30	20,000	31,513	25,247	23,929	28,909
	31	49,000	31,786	22,624	20,786	55,823
	32	26,210	32,059	35,812	43,357	28,327
	33	13,000	32,333	31,011	29,639	22,927
	34	59,618	32,606	22,005	16,328	56,036
	35	35,745	32,879	40,812	50,960	42,107
	36	31,181	33,153	38,278	38,788	40,784

7.1.4 The Demand for X4

In Figure 7.4, a comparison of actual demand and estimated demand has been shown. The "Quantity" in the graph expresses the quantity of demand for the last 3 years. The closest forecasted quantity to the realized demand quantity is the Time Series method as seen in Figure 7.4. It also returns an appropriate result when using exponential smoothing it is taken α value as 0.2. However, when we take α value as 0.5, the graph changes completely, which means that the estimated quantity is deviating from the demand quantity. Lastly, the trend line is far from the realized demand quantity in the regression method. As a result, the best method for X4 is Time series method.

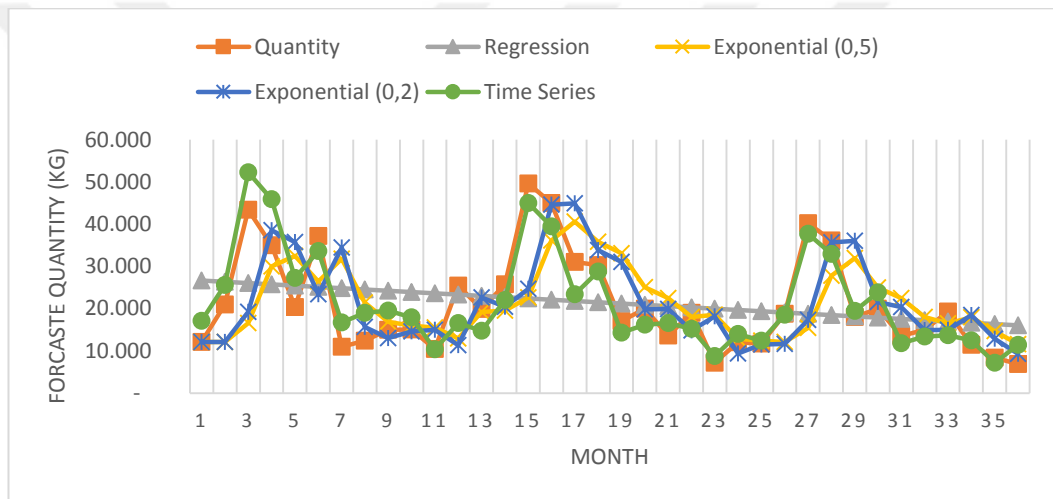


Figure 7.4 Comparison of the actual demand versus forecasted demand for X4

The forecasted quantity of demands for selected methods for the X4 product was presented in Table 7.4. The forecasted demands were given separately for 36 months in Table 7.4.

Table 7.4 Forecasted quantity for X4

Year	Month	Quantity	Regression	Exponential (0,5)	Exponential (0,2)	Time Series
2015	1	12,071	26,634	12,071	12,071	17,062
	2	21,003	26,331	12,071	12,071	25,590
	3	43,429	26,029	16,537	19,216	52,295
	4	35,000	25,726	29,983	38,586	45,939
	5	20,336	25,423	32,491	35,717	27,254
	6	37,213	25,120	26,414	23,412	33,596
	7	10,991	24,818	31,813	34,453	16,707
	8	12,368	24,515	21,402	15,684	19,025
	9	15,000	24,212	16,885	13,031	19,533
	10	15,079	23,909	15,943	14,606	17,956
	11	10,408	23,607	15,511	14,984	10,340
	12	25,470	23,304	12,959	11,323	16,552
2016	13	19,882	23,001	19,214	22,640	14,734
	14	25,705	22,698	19,548	20,433	22,059
	15	49,624	22,395	22,627	24,651	44,995
	16	45,031	22,093	36,125	44,629	39,451
	17	31,045	21,790	40,578	44,950	23,359
	18	30,310	21,487	35,811	33,826	28,737
	19	17,054	21,184	33,061	31,013	14,261
	20	19,962	20,882	25,057	19,846	16,205
	21	13,583	20,579	22,509	19,938	16,602
	22	19,000	20,276	18,046	14,854	15,228
	23	7,159	19,973	18,523	18,171	8,749
	24	12,016	19,671	12,841	9,362	13,971
2017	25	11,702	19,368	12,429	11,485	12,407
	26	18,787	19,065	12,065	11,659	18,528
	27	40,209	18,762	15,426	17,361	37,696
	28	36,150	18,460	27,817	35,639	32,963
	29	18,000	18,157	31,984	36,048	19,464
	30	20,000	17,854	24,992	21,610	23,878
	31	13,544	17,551	22,496	20,322	11,815
	32	14,967	17,248	18,020	14,900	13,386
	33	19,330	16,946	16,493	14,953	13,671
	34	11,406	16,643	17,912	18,455	12,499
	35	8,411	16,340	14,659	12,816	7,157
	36	6,848	16,037	11,535	9,292	11,391

7.1.5 The Demand for X5

Comparison of the actual demand and forecasted demand are given in Figure 7.5 “Quantity” in the graph refers to the demand quantity of the last 3 years for X5. Time Series forecasting method is the best option among the forecasting methods to determine forecasted quantity of X5. It is very close to realized demand quantity. Exponential Smoothing method for $\alpha=0.2$ is close to demand quantity. However, this method is not suitable for seasonal changes. Exponential Smoothing method for $\alpha=0.5$ and the regression method are far from the realized demand as seen in below Figure 7.5 Both method are not the appropriate method for X5.

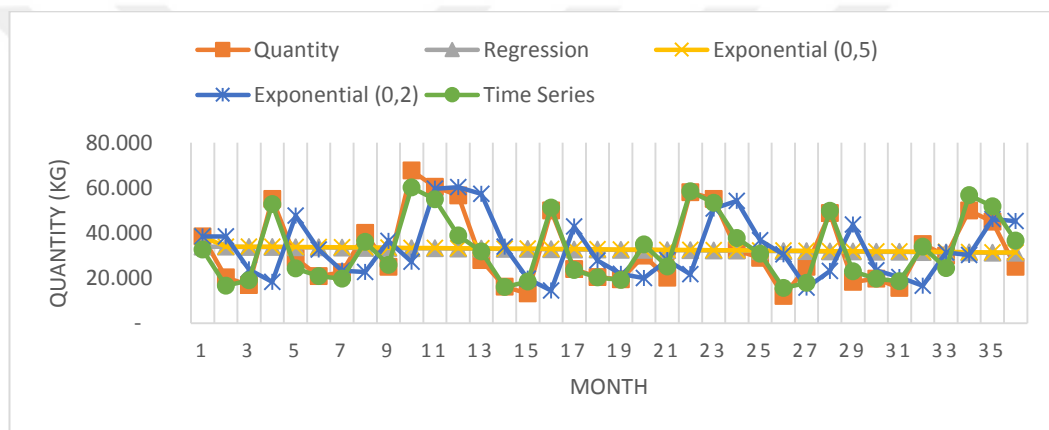


Figure 7.5 Comparison of the actual demand versus forecasted demand for X5

The data in Table 7.5 are obtained for X5 product for selected methods. Forecasted demands was presented separately for 36 months in that Table 7.5.

Table 7.5 Forecasted quantity for X5

Year	Month	Quantity	Regression	Exponential (0,5)	Exponential (0,2)	Time Series
2015	1	38,380	33,968	38,380	38,380	32,638
	2	20,254	33,889	33,968	38,380	16,551
		16,953	33,809	33,928	23,879	19,002
	4	55,000	33,730	33,869	18,338	52,731
	5	28,846	33,650	33,799	47,668	24,309
	6	20,856	33,571	33,725	32,611	20,912
	7	22,510	33,491	33,648	23,207	19,718
	8	40,000	33,412	33,570	22,649	36,000
	9	25,000	33,333	33,491	36,530	25,847
	10	67,665	33,253	33,412	27,306	60,158
	11	60,478	33,174	33,332	59,593	54,950
	12	56,577	33,094	33,253	60,301	38,817
2016	13	28,000	33,015	33,174	57,322	31,722
	14	16,216	32,935	33,094	33,864	16,086
	15	13,176	32,856	33,015	19,746	18,466
	16	50,000	32,777	32,935	14,490	51,241
	17	24,000	32,697	32,856	42,898	23,620
	18	20,423	32,618	32,777	27,780	20,319
	19	19,494	32,538	32,697	21,894	19,156
	20	30,000	32,459	32,618	19,974	34,973
	21	20,129	32,379	32,538	27,995	25,108
	22	58,054	32,300	32,459	21,702	58,433
	23	55,000	32,220	32,379	50,784	53,371
	24	32,386	32,141	32,300	54,157	37,699
2017	25	29,000	32,062	32,220	36,740	30,806
	26	12,000	31,982	32,141	30,548	15,620
	27	25,000	31,903	32,062	15,710	17,930
	28	48,815	31,823	31,982	23,142	49,751
	29	18,283	31,744	31,903	43,680	22,932
	30	19,677	31,664	31,823	23,362	19,725
	31	15,634	31,585	31,744	20,414	18,595
	32	35,000	31,506	31,664	16,590	33,946
	33	30,000	31,426	31,585	31,318	24,369
	34	50,000	31,347	31,506	30,264	56,709
	35	45,000	31,267	31,426	46,053	51,792
	36	25,000	31,188	31,347	45,211	36,581

7.1.6 Comparison of the MAPE values

In textile market, especially for yarn manufacturer, demands are variable according to the seasons. It is also seen in results Figure 7.6. Time series method which has minimum MAPE method is the best option for the selected products. MAPE values are also shown for selected products in Table 7.6.

Table 7.6 MAPE results for X1, X2, X3, X4 and X5

	Regression		
	MAD	MSE	MAPE %
X1	13130	235449759	48
X2	14681	313328231	24
X3	10404	158218362	47
X4	8658	118359932	50
X5	19845	556405610	17
	Exponential Smoothing ($\alpha=0,5$)		
	MAD	MSE	MAPE %
X1	14592	304902000	52
X2	14741	310240468	22
X3	10805	209260303	47
X4	8521	122371957	45
X5	20257	616319934	17
	Exponential Smoothing ($\alpha=0,2$)		
	MAD	MSE	MAPE %
X1	14461	336931159	50
X2	13791	288337995	21
X3	11719	247790038	49
X4	7733	116105976	41
X5	21841	705833661	18
	Time Series		
	MAD	MSE	MAPE %
X1	3837	27316046	13
X2	2652	14881263	4
X3	4501	28052197	19
X4	3936	21975611	21
X5	8726	118887594	7

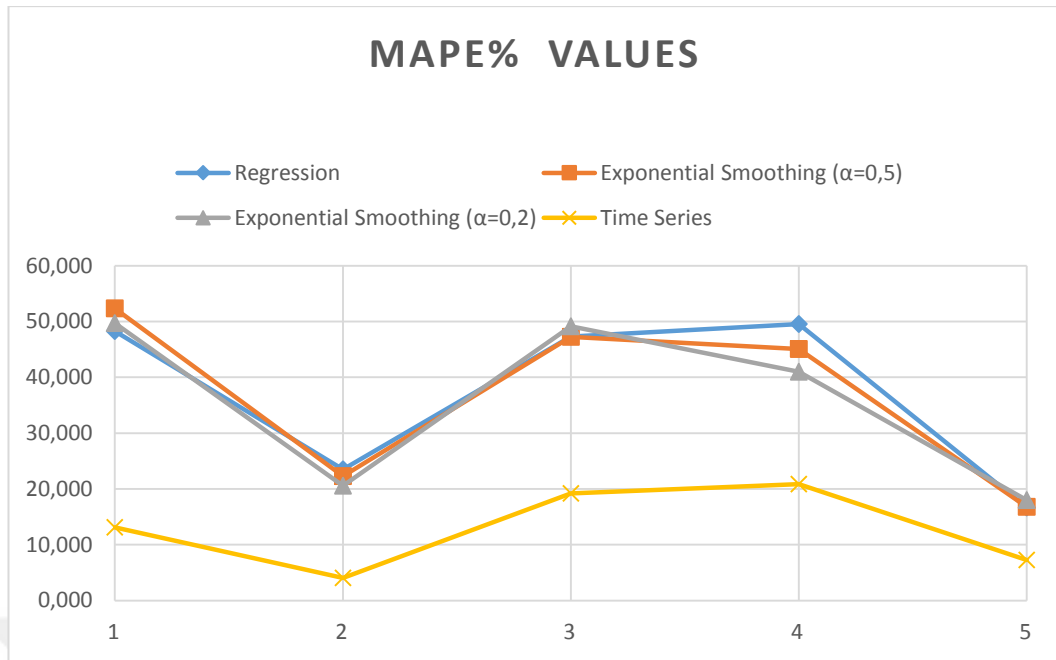


Figure 7.6 Graphical view of MAPE results for X1, X2, X3, X4 and X5

According to the results obtained, Time Series is the most appropriate method. For the next 12 months estimation, the time series method was used and the data are shown in Table 7.7.

Table 7.7 Forecasted quantity for next 12 months

	1	2	3	4	5	6	7	8	9	10	11	12
X1	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
X2	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
X3	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
X4	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
X5	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870

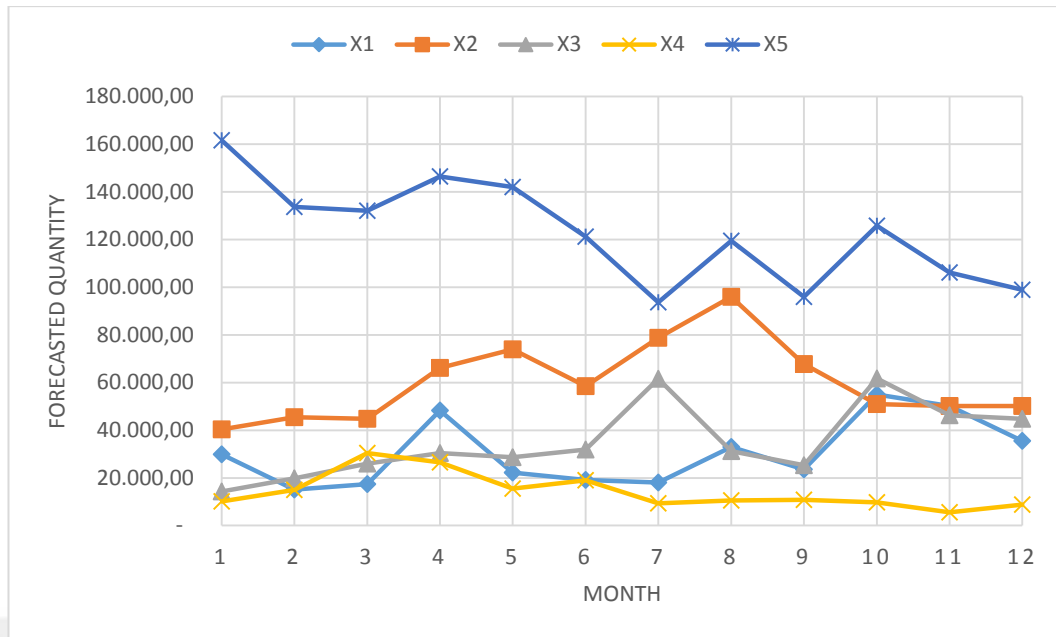


Figure 7.7 Graphical view of forecasted quantity for best option method

As presented in Figure 7.7, the demand for X5 product is increased, but the demand for X4 product is reduced. Five snapshots from the software of the demand analysis module are given in Figure 7.8-712. Separate screens were designed for each method and used the database features to compare the results. The developed system also automatically compares the MAPE values and selects the smallest of the MAPE values among the 3 methods. For example, the time series method for the products X1, X2, X3 and X5 was chosen as shown in Figure 7.8.

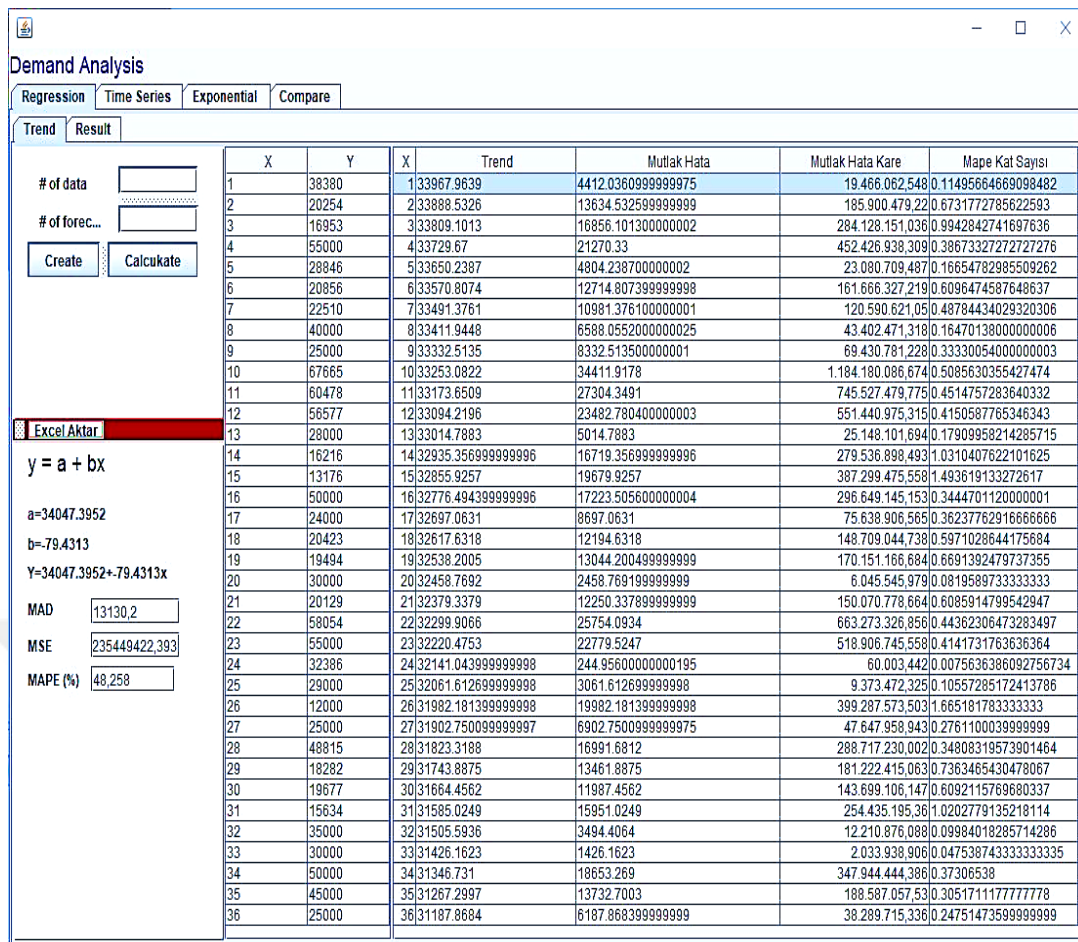


Figure 7.8 A snapshot from the interface for regression analysis

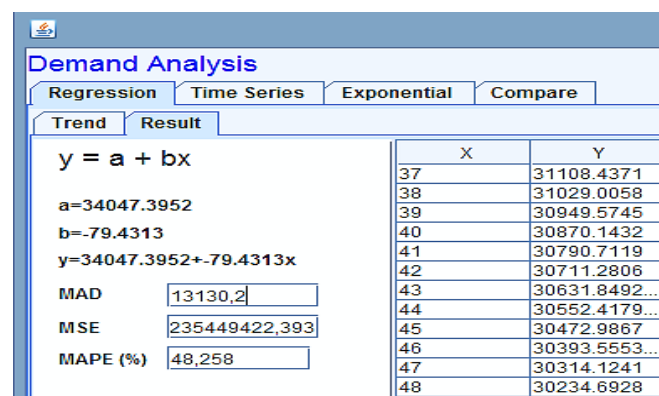


Figure 7.9 A snapshot for results of regression analysis

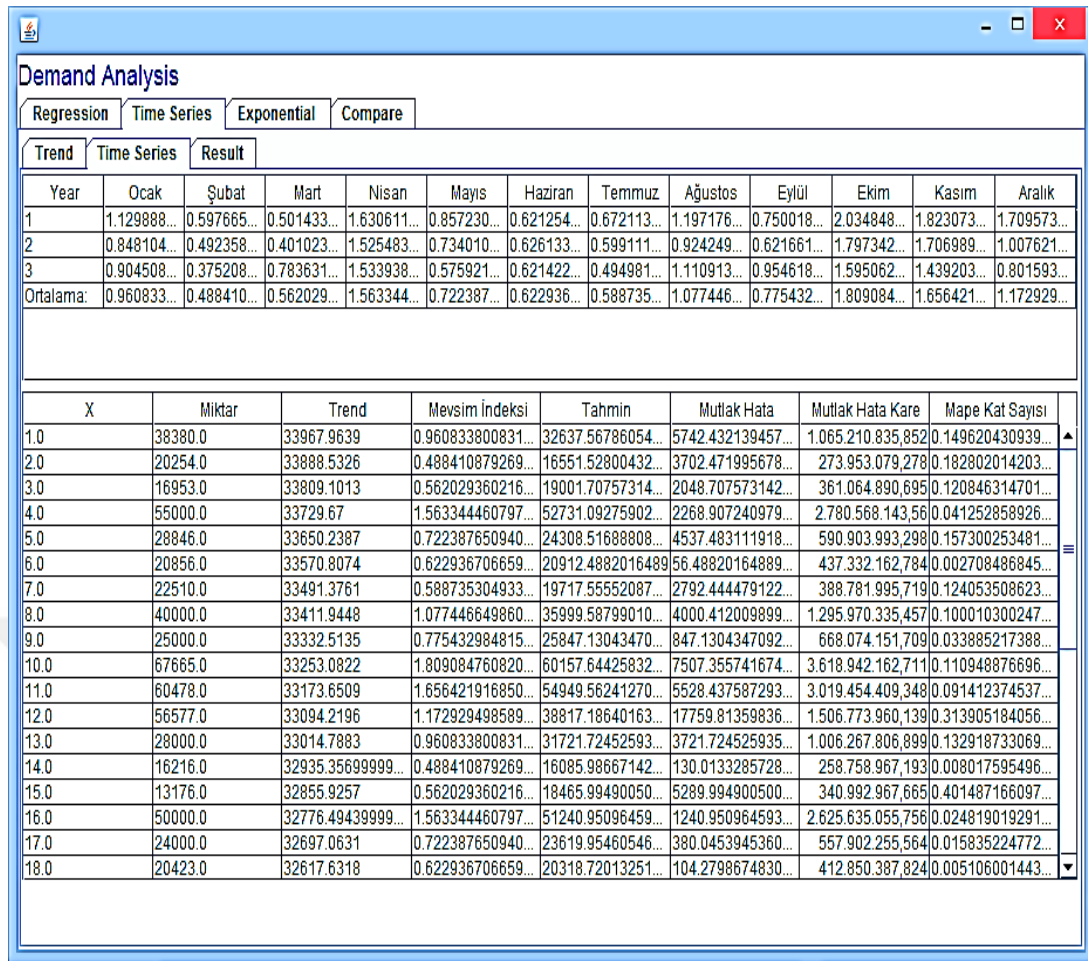


Figure 7.10 A snapshot from the interface for time series analysis

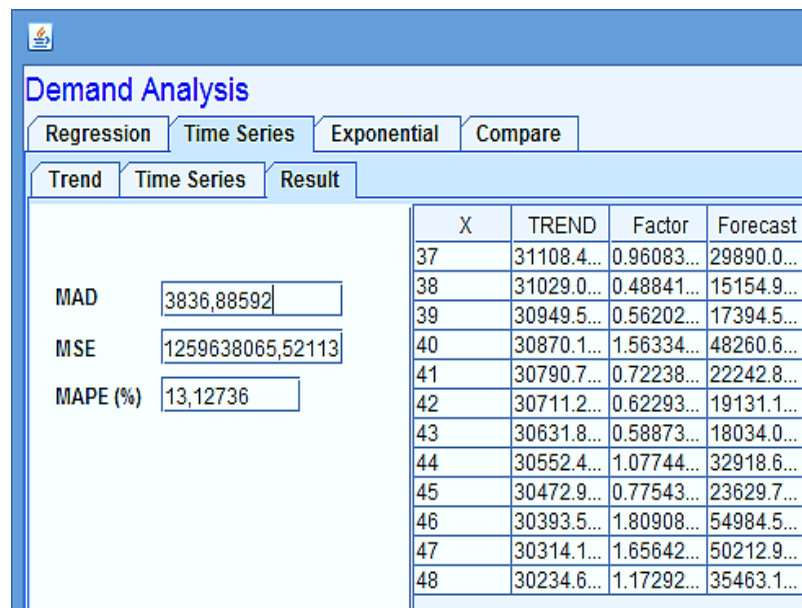


Figure 7.11 A snapshot for results of time series analysis

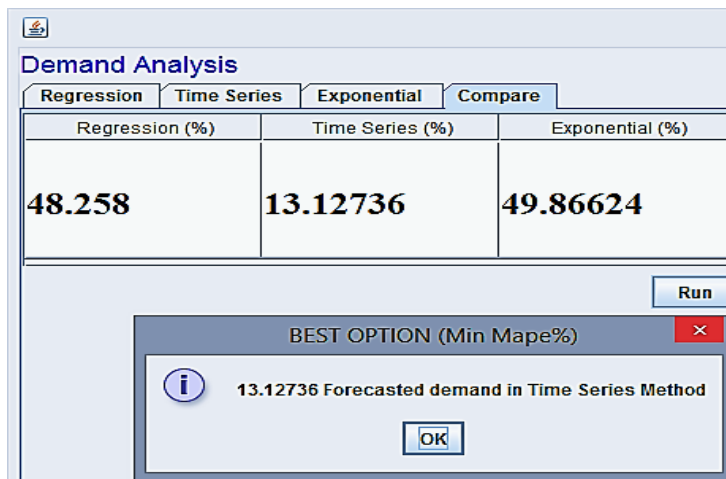


Figure 7.12 A snapshot from the interface for comparisons of MAPE values

7.2 Time Study Results

The time study results are calculated by formulas which are given in Chapter 3. In the shift of a worker, the total duration of the shift is 480 minutes. In this duration, 410 minutes were observed for operations, 40 minutes for breaking time and 30 minutes for meals.

X1, X2, X3 and X4 have common process and results are summarized in Table 7.8. In order to complete production processes for X1, X2, X3 and X4, 5136.17 minutes and 24 workers/shift are needed.

X5 has different production flow chart diagram and results are summarized in Table 7.9. To complete production process for X5 products, 7760.85 minutes and 32 workers/shift are needed.

For each process number of workers were calculated separately. For example, number of workers were calculated as $168.75 \text{ min} / 410 \text{ min} = 0.41$ for Wet Pressing process in Table 7.8. The number of workers needs to be rounded up because it must be an integer. Therefore we need 1 worker to be completed Wet Pressing process and there should be 3 workers in 3 shifts.

Table 7.8 Results of time study for X1,X2,X3 and X4

Process Type	Process Time per shift	# of Shift	Daily Process Time (min)	Total Labor	Labor per shift
WET PRESSING	168,75	3	506,25	3	1
DYEING	71,5		214,5	3	1
DRY PRESSING	86		258	3	1
DRYING	112,8		338,4	3	1
BALE PREPARATION	16,46		49,38	3	1
BREAKER	112,8		338,4	3	1
RE-BREAKER	72		216	3	1
1.DRAWING FRAME	77,5		232,5	3	1
2.DRAWING FRAME	84,7		254,1	3	1
3.DRAWING FRAME	83,86		251,58	3	1
FINISOR	100,5		301,5	3	1
RING SPINNING	502,22		1506,66	6	2
WINDING	347,2		1041,6	3	1
FOLDING	545		1635	6	2
TWISTING	230,08		690,24	3	1
VOLUFIL	1.340,80		4022,4	12	4
PACKING	1184		3552	9	3
Total	5136,17		15408,51	72	24

Table 7.9 Results of time study for X5

Process Type	Process Time per shift	# of Shift	Daily Process Time (min)	Total Labor	Labor per shift
WET PRESSING	168,75	3	506,25	3	1
DYEING	71,5		214,5	3	1
DRY PRESSING	86		258	3	1
DRYING	112,8		338,4	3	1
BALE PREPARATION	12,64		37,92	3	1
BREAKER	108,68		326,04	3	1
RE-BREAKER	72		216	3	1
1.DRAWING FRAME	77,5		232,5	3	1
2.DRAWING FRAME	84,7		254,1	3	1
3.DRAWING FRAME	83,86		251,58	3	1
FINISOR	100,5		301,5	3	1
RING SPINNING	739,66		2218,98	6	2
WINDING	520,8		1562,4	6	2
FOLDING	347,4		1042,2	3	1
TWISTING	314,16		942,48	3	1
VOLUFIL	1.725,00		5175	15	5
HANK RAW WINDER	446,4		1339,2	6	2
SOFTENING	340		1020	3	1
HANK DRY PRESSING	170		510	3	1
HANK DRYING	366		1098	3	1
HANK COLORED WINDER	675		2025	6	2
PACKING	1.137,50		3412,5	9	3
Total	7760,85		23282,55	96	32

7.3 Solving LP model

In this thesis, Gurobi optimization Solver program was used to solve the mathematical production planning model developed by using linear programming method. The program can run over Windows operating system which's designed with Java programming language. Taking advantage of the linear programming technique, the annual production schedule was calculated with the Gurobi optimization program.

Developed software was tested in the acrylic production mill and an optimal production plan was created for the selected 5 products and optimum solution is given in next sections.

7.3.1 Optimum solution

The optimal solution of the model is \$4,928,725.00 according to the parameters given in Table 7.10. If the obtained plan is applied, the company will have the same quantity of profit at the end of one year. The total cost is \$12,050,719.00 in one year, while the total income is \$16,979,445.00. Cost, revenue and profit are also given as follows:

- Total Cost = \$12,050,719.00
- Total Revenue = \$16,979,445.00
- Total Profit = \$4,928,725.00.

Table 7.10 Parameters of selected 5 products

PARAMETERS					
	Price	Cost	Warehouse Cost	Working Day	Daily Capacity
X1	4.94	3.61	0.05	30	10,933.00
X2	4.89	3.48	0.05	30	10,933.00
X3	4.77	3.35	0.05	30	10,933.00
X4	5.35	3.71	0.05	30	10,933.00
X5	5.89	4.17	0.04	30	12,240.00

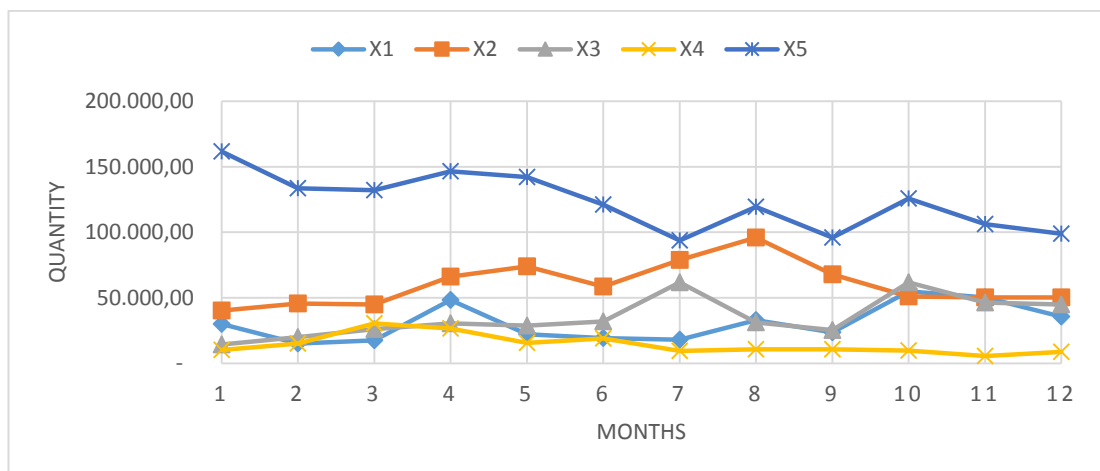
The demanded quantity, production quantity and sales quantity are shown respectively in Tables 7.11, 7.12, 7.13. The results of each decision variable are examined separately and the graphs are shown in Figure 7.13.

Table 7.11 Demand quantity of selected 5 products

Demand Quantity												
	1	2	3	4	5	6	7	8	9	10	11	12
X1	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
X2	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
X3	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
X4	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
X5	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870

Table 7.12 Production quantity of selected 5 products for optimum solution

Production Quantity												
	1	2	3	4	5	6	7	8	9	10	11	12
X1	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
X2	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
X3	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
X4	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
X5	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870

**Figure 7.13** Annual production plan chart for selected 5 products

As shown in figure 7.13, all of the selected products should be produced. Since profit rates are very close for 5 products, the production quantity is determined by the amount of demand. 3,160,726.00 kg products were produced annually.

The monetary value of the produced product is \$ 12,050,719.00. As shown in the chart, the maximum share of this production is 1,476,950.00 kg with X5 products per year and this corresponds to 47% of the total production. The total cost of the X5 product is \$ 6, 158,881.50.

Table 7.13 Annual sales quantity of selected 5 products for optimum solution

Sales Quantity												
	1	2	3	4	5	6	7	8	9	10	11	12
X1	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
X2	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
X3	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
X4	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
X5	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870

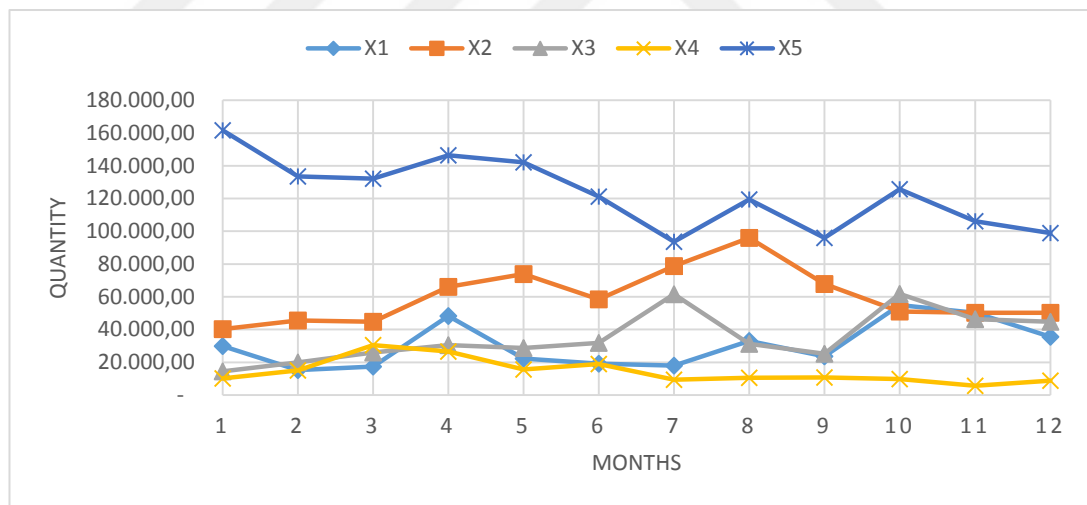


Figure 7.14 Annual sales plan for the selected 5 products for optimum solution

When the solution is examined, it is seen that the production quantity are equal to sales quantity. It is seen in Figure 7.14, that the sales quantity is equal to the demand quantity and accordingly it is equal to the production quantity. In total, sales quantity is 3,160,726.00 kg in one year. The revenue generated from this sale is \$ 16,979,445.00.

As seen in Table 7.14, the production model for stock is calculated as zero. Because the stock cost is high, the decision variables takes zero value and it shows that stocking is not good option.

Table 7.14 Annual stock quantity of selected 5 products for optimum solution

Stock Quantity												
	1	2	3	4	5	6	7	8	9	10	11	12
X1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
X2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
X3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
X4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
X5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 7.15 A snapshot for interface of results in LP module

7.3.1 Sensitivity analysis

Sensitivity analysis is used to explain two cases. The first one, is about how the changes in unit profit effect the optimal solution. The unit profit and the unit cost are represented by the coefficient of the objective function (OC). The second case is about how the changes in available production capacity and working time effect the optimal solution. The available production capacity and working time are represented by right hand side (RHS) of the constraints.

Table 7.15, 7.16 and 7.17 presents the model sensitivity report for decision variables and the top section of given Tables represents the months. The optimal solution is represented by the final value (FV), so the optimal objective function value can be calculated by multiplying decision variable with the coefficients in objective function to obtain the optimal net return.

The upper bound (UB) and lower bound (LB) values indicate the limits of the coefficients without changing the optimal solution.

These values allow the company to analyze how much variation in the coefficients of the variables will change the structure of the optimal solution. For example, the upper bound (UB) of X_{12} is $1E+30$. Therefore, if the objective coefficient of X_{12} is increased from 3.61 to any value up to the upper limit to be at the maximum ($3.61+1E+30$) the optimal solution will not change. On the other hand, the lower bound of X_{12} is 0.00. Therefore, if we decrease objective coefficient of X_{12} as between upper and lower limit the optimal solution will not change.

The Table 7.15, 7.16 and 7.17 shows the reduced cost (RC). For example, the reduced cost of the K_{11} is \$1.33. It means that if 1 more kilogram of product sold, the optimal objective function value would increase by the value of the reduced cost (\$1.33). Another example, the reduced cost of the S_{11} is \$-0.05. If we increase the profit of S_{11} by less 0.05, the existing solution stays optimal. To change solution, S_{11} should be increased by more than 0.05, then the solution will change. In this case, S_{11} will be positive in the new optimal solution. When the optimal value of a variable is zero and the reduced cost corresponding to the variable is also zero and the value of this variable will be positive.

Table 7.15 Sensitivity analysis for decision variable X_{it} (production quantity)

Sensitivity Analysis (X_{it})												
	1	2	3	4	5	6	7	8	9	10	11	12
X1												
FV	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
OC	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61
RC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30
X2												
FV	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
OC	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48
RC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30
X3												
FV	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
OC	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35
RC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30
X4												
FV	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
OC	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71
RC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30
X5												
FV	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870
OC	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
RC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30	1E+30

Table 7.16 Sensitivity analysis for decision variable K_{it} (sales quantity)

Sensitivity Analysis (Kit)												
	1	2	3	4	5	6	7	8	9	10	11	12
X1												
FV	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
OC	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94	4.94
RC	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	29890	15155	17395	48260	22243	19131	18034	32919	23630	54984	50213	35463
X2												
FV	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
OC	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89
RC	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	40303	45508	44753	66131	73954	58521	78803	95974	67807	50930	50190	50181
X3												
FV	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
OC	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77	4.77
RC	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	14337	19845	26000	30415	28670	31918	61583	31226	25253	61672	46307	44819
X4												
FV	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
OC	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35	5.35
RC	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	10080	14997	30396	26475	15569	19019	9370	10566	10740	9771	5566	8810
X5												
FV	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870
OC	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89
RC	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	161672	133623	132099	146498	142051	121174	93626	119453	95966	125742	106176	98870

Table 7.17 Sensitivity analysis for decision variable S_{it} (stock quantity)

Sensitivity Analysis (S_{it})												
	1	2	3	4	5	6	7	8	9	10	11	12
X1												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OC	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RC	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-3.66
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000
X2												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OC	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RC	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-3.53
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000
X3												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OC	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RC	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-3.40
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000
X4												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OC	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RC	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-3.76
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000
X5												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OC	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
RC	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-4.21
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000

Table 7.18, 7.19 and 7.20 presents the model sensitivity report for constraints and the top section of given Tables represents the months. Final value (FV), shadow price (SP), slack (SL), upper bound (UB), lower bound (LB) are included. Final value refers to optimal solution and the shadow price which refers to the amount of change in the optimal objective value for a unit increase or decrease in RHS of constraints. The slack value is the amount of the resource, as represented by the less-than-or-equal constraint that is not being used. The upper bound and the lower bound values indicate the limits that the RHS of constraints can be changed before the solution structure will change. These values allow the firm to analyze how much the variation in the available resources will change the value of the optimal solution.

For example, the shadow price of the first product (X1) is \$-3.61. This represents the actual worth of 1 unit (1 Kg) of the first product. That is, if 1 more kilogram of product produced, the optimal objective function value would decrease by the value of the shadow price. When a constraint is non-binding, the shadow price takes zero. Therefore, changing the value of the X1 constraint has no binding effect on the optimal solution structure. The upper bound of the product X1 is 30 day. This represents the maximum value of the X1.

Therefore, if the value of the first constraint is increased from 27.68 to the maximum value (30 day) the solution will not change. It means that increasing the number of working day of the X1 will not change the optimal solution results. Furthermore, we can obtain the slack value of X1 as 2.32 (UB - FV). This value means that we have free working days as 2.32.

Table 7.18 Sensitivity analysis for constraint of working time (equation 6.13)

Sensitivity Analysis (Constraint 1)												
	1	2	3	4	5	6	7	8	9	10	11	12
FV	27.68	21.34	23.81	23.28	28.52	21.90	19.21	26.30	21.91	28.53	18.15	22.24
SL	2.318	8.654	6.184	6.718	1.479	8.091	10.782	3.697	8.083	1.465	11.844	7.753
SP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30
UB	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00

Table 7.19 Sensitivity analysis for balance constraint (equation 6.14)

Constraint 2												
	1	2	3	4	5	6	7	8	9	10	11	12
X1												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61	-3.61
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X2												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48	-3.48
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X3												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35	-3.35
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X4												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
X5												
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SP	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17	-4.17
LB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7.20 Sensitivity analysis for constraint of stock capacity (equation 6.15)

Constraint 3												
	1	2	3	4	5	6	7	8	9	10	11	12
FV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000
SP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LB	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30	-1E+30
UB	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000	300000

CHAPTER 8

CONCLUSION AND FUTURE STUDIES

Production planning is defined as determining the quantity to be produced from each product for the next periods. The firms have been searching for cost effective solutions for their operational tasks, with the increasing competition and the rapid change in technologies. To determine production planning with maximum profit, linear programming technique can be used to allocate a number of limited resources among a number of products, and to determine the best mix of products which leads to increase profits and/or decrease costs in the presence of a number of restrictions.

In this thesis, production planning software is developed for a real yarn production company. The software automatically searches for a demand curve that fits the real values obtained in the past. Subsequently, a mathematical model is established to minimize the total cost under certain constraints. The developed software is capable of retrieving the related data from the ERP system of the company and capable of exporting the mathematical model to Gurobi Optimization solver and importing the results. It has been seen that linear programming techniques can be useful tool to provide optimum short or long term production plans.

When using the linear programming technique in determining and managing the constraints which control the production process with a view to improve, two main steps are essential. The first step is identifying the constraints that control the system, and the second step is determining the most profitable product range under specific constraints. These steps were followed for the preparation of the mathematical model at a yarn manufacturer company. The problem was discussed several times with company's managers to understand the problem very well. After many observations, about the stages of production of the acrylic/acrylic blend yarns and the time, raw materials, other production requirements of each stage, demand for each type of product, and other data necessary for the formulation of the mathematical model was gathered.

After the mathematical model is formulated, a production planning software was designed and coded in Java programming language. Developed mathematical model was solved in Gurobi Optimization solver to maximize total profit. Lastly, the obtained results evaluated with the sensitivity analysis.

To ensure the effectiveness of the proposed model and its ability to improve production planning, this model compared with the current production model, which has been used by the planning department. In this thesis, to compare between two models, we focused profitability factor and production quantities.

In the current production model, stock production of X5 was done for the summer months and because of this stock production, the demands for X1, X2 and X3 could not met. The annual stock quantity was 100,000 kg for X5. However, in the proposed model, there is no stock in any period of year for X5 as seen in Table 7.10. Proposed model produced lower profitable products (X1, X2 and X3) to avoid inventory cost of X5, rather than the stock production of X5. With developed model, the obtained profit is \$4,928,725 however in current model annual profit was \$4,815,234. Therefore, total annual production of proposed model more profitable than the current model.

The obtained production planning can be changed according to the sensitivity analysis report. The sensitivity analysis represents the shadow price which refers to the amount of change in the optimal objective value for a unit increase or decrease in RHS of constraints. The obtained upper and lower limit values allow the company to analyze how much variation in the coefficients of fourteen variables will change the structure of the optimal solution. Within the minimum and maximum limits, the firm can increase the optimal objective function value by the previously stated rates upon expanding the constraints. By reviewing its pre-determined lower and upper bounds from this perspective, the firm should evaluate whether any modification can be performed.

With the developing technology, the textile machines were fully automated. In this case, most or all of the operations are done with robots or other automation systems. Labor is minimized in this case. It turns out that modern acrylic yarn enterprises should find the optimum number of workers to reach minimum cost of production. Therefore, in addition to production planning, the optimum number of workers required for each operation of the yarn production process was determined by the time study method.

The model in this thesis is limited with production planning methods, a linear programming technique, and the ability of this technique to find the optimal solution. For further studies, same problem can be solved with nonlinear programming technique if the assumptions are reduced. Furthermore, developed software can be enriched with mixed integer linear programming to determine production schedule. The model can be installed accurately, if production and sales quantities with actual costs can be obtained. Furthermore, additional constraints can be included in mathematical model to find optimum number of worker, instead of using time study method.



REFERENCES

- [1] Sabir, E. C. (2000). Linear programming approach of production planning for ring and open-end spinning systems and industrial application, PhD Thesis, Department of Industrial Engineering, Çukurova University.
- [2] Jaaskelainen, V. (1969). A goal programming model of aggregate production planning. *Swedish Journal of Economics*, **71**, 14-29.
- [3] Lee, S.M., Jaaskelainen, V. (1971). Goal programming: management's math model. *Industrial Engineering*, **1**, 30-35.
- [4] Goodman, D.A. (1974). A goal programming approach to aggregate planning and work force. *Management Science*, **20**, 1569-1575.
- [5] Laurent, G. (1976). A note on range programming: Introducing a satisfying range in a LP. *Management Science*, **22**, 713-716.
- [6] Fisk, J.C. (1974). A goal programming model for output planning. *Decision Sciences*, **10**, 593-603.
- [7] Hindelang, T.J. and Hill, J.L. (1978). A new model for aggregate output planning. *Omega*, **6**, 267-272.
- [8] Masud, A.S.M. and Hwang, C.L. (1980). An aggregate production planning model and application of three multiple objective decision methods. *International Journal of Production Research*, **6 (18)**, 741-752.
- [9] Lawrence, K.D. and Burbidge, J.J. (1976). A multiple goal linear programming model for production and logistics planning. *International Journal of Production Research*, **1**, 14-15.
- [10] Zanakis, S.H. and Smith, J.S. (1980). Chemical production planning via goal programming. *International Journal of Production Research*, **1**, 18.
- [11] Sun, G., Ui, T. and Nakayasu, H. (1995). Development of a practical goal programming system for solving semi-large size multi-criterion planning problems. *International Journal of Production Economics*, **39**, 227-242.

- [12] Kalpic, D., Mornar, V., Baranovic, M. (1995). Case study based on a multi-period multi-criteria production planning model. *European Journal of Operation Research*, **87**, 658-669.
- [13] Weng, Z. K. (1996). Manufacturing lead times, system utilization rates and lead-time-related demand. *European Journal of Operational Research*, **89**, 259-268.
- [14] Nagarur, N., Vart, P., Duongsuwan, W. (1997). Production planning and scheduling for injection moulding of pipe fitting: a case study. *International Journal of Production Economics*, **53**, 157-170.
- [15] Palaka, K., Erlebacher, S., Kropp, D. H. (1998). Lead-time setting, capacity utilization, and pricing decisions under lead-time dependent demand. *IIE Transactions*, **30 (2)**, 151-163.
- [16] Moodie, D. R. (1999). Demand management: The evaluation of price and due date negotiation strategies using simulation. *International Journal of Production Research*, **8(2)**, 151-162.
- [17] Moodie, D. R. and Bobrowski, P. M. (1999). Due date demand management: Negotiating the trade-off between price and delivery. *International Journal of Production Research*, **37 (5)**, 997-1021.
- [18] Pradenas, L. and Penailillo, F. (2004). Aggregate production planning problem: a new algorithm. *Electronic notes in Discrete Mathematics*, **18**, 193-199.
- [19] Silva, C. G., Figueira, J., Lisboa, J., & Barman, S. (2006). An interactive decision support system for an aggregate production planning model based on multiple criteria mixed integer linear programming. *Omega*, **34**, 167-177.
- [20] Jain, A. and Palekar, U.S. (2005). Aggregate production planning for a continuous reconfigurable manufacturing process. *Computers and Operations Research*, **32**, 1213-1236.
- [21] Sulaymanov, T. (2002). Cost and production optimization in a short fiber spinning process, Master Thesis, Department of Textile Engineering, Çukurova University.
- [22] Bayazit, Y., Arikan, A., Taner, C. (2011). A software developed to calculation of cost for T-Shirt production in a knitted factory. *Textiles & Technical Journal*, **132**, 46-52.
- [23] Sakallı, Ü. S., (2005). A spreadsheet-based linear programming application to blending problem in brass casting industry, Master Thesis, Department of Industrial Engineering, Kırıkkale University.

- [24] Cetinbag, M., BARACLI H. (2005). Using linear optimization model in companies for preparing daily production programming and a study about model, Master Thesis, Department of Business Administration, University of Yıldız Technical.
- [25] Eren, T., Atak, T., (2000). Determining material cost by using linear programming method in PIRINCSAN A.S, Master Thesis, Department of Industrial Engineering, Gazi University.
- [26] Schonung, B., Bay, E., Clement, M., (1994). Economic analysis of each spindle in ring spinning machine, *Textile Marathon*, **4**, 19-29.
- [27] Rusch, B. (1998). Determining of optimum raw material for ring spinning machine, *Melliand International*, **1**, 8-9.
- [28] Zhou L., Xu K., Cheng X., Xu Y., Jia Q. (2017). Study on optimizing production scheduling for water-saving in textile dyeing industry. *Journal of Cleaner Production*, **141**, 721-727.
- [29] Ramezani, R. (2012). An aggregate production planning model for two phase production systems: Solving with genetic algorithm and tabu search. *Expert Systems with Applications*, **39(1)**, 1256–1263.
- [30] Gansterer M. (2015). Aggregate planning and forecasting in make-to-order production systems. *Int. J. Production Economics*, **170**, 521-528.
- [31] Buyukkeklik, M. (2007). Using linear programming models in production planning problems: application in a manufacturing company, Master Thesis, Department of Business Administration, Nigde University.
- [32] Bircan, H., Kartal, Z. (2004). Capacity planning approach with linear programming technique and application in cement production firm. *CU Journal of Economic and Science*, **5**, 11-13.
- [33] Yılmaz, H. (2010). Application of production planning with linear programming in furniture sector, Master Thesis, Department of Business Administration, Süleyman Demirel University.
- [34] Gurobi Optimization, <http://www.gurobi.com/index>.
- [35] MySQL Workbench, <https://www.mysql.com/products/workbench/>, 20.08.2018.
- [36] NetBeans IDE, <https://netbeans.org/>, 20.08.2018.
- [37] Mikell P. Groover. (2007). Work systems: The methods, measurement management of work. New Jersey: Pearson Prentice Hall.

- [38]Freivalds A. and Niebel B. (2012). Niebel's methods, standards, & work design. Eleventh edition. New Jersey: McGraw-Hill Publishing Co.
- [39]Merrick K. Singhal. (2009). Production and operations management. 2nd edition. Delhi: New Age International Pvt Ltd Publishers.
- [40]Heizer, J., Barry R. (2001). Operation management. Sixth Edition. New Jersey: Prentice Hall.
- [41]Bails, D., G., Peppers, L., C. (1993). Business fluctuations forecasting techniques and applications. London: Prentice Hall International.
- [42]Russell, R. S., Taylor, B.W. (2011). Operations management. 7th edition. Asia: John Wiley.
- [43]Chambers, J. C., Satinder, K., M. Smith, D. (1971). How to choose the right forecasting technique. *Harvard Business Review*, 45-74.
- [44]Hassan, A. I., Tasgetiren, F., (2014). Forecasting and inventory control in a company in Izmir, Master Thesis, Department of Industrial Engineering, Yasar University.
- [45]Box, G.E.P., Jenkins, G., M. (1976). Time series analysis: Forecasting and control. 2nd edition. Oakland: Holden-Day.
- [46]Gardner, E. S., Dannenbring, D., G. (1980). Forecasting with exponential smoothing: Some guidelines for model selection. *Decision Sciences*, **11 (2)**, 370-383.
- [47]Hamdy A. Taha, Operations Research an Introduction (6th Edition), University of Arkansas, New Jersey.
- [48]Aboudhier, A. (2017). A linear programming model for production planning, Master Thesis, Department Of Business Administration, Atilim University.
- [49]Gupta, M., Boyd, L. (2006). Theory of constraints: a theory for operations management. *International Journal of Operations Management*, **28(10)**, 991-1012.
- [50]Umran, Q. (1997). Reducing shipping costs by using linear programming, Master Thesis, Process Engineering, Algeria University.
- [51]Lieberman, H. F. (2001). Introduction to operations research. 7th Edition, New York: McGraw-Hill Science.
- [52]Duloy, J. H., Norton, R. D. (1975). Price and incomes in linear programming models. *American Journal of Agricultural Economic*, **57(4)**, 591-611.
- [53]Mazi, M. T. (1999). Operations and production management. Egypt: Aljameya for printing and distribution.

- [54] Bousahmin. (2008). Quantitative methods and their role in administrative decision making. International conference on the effectiveness of using linear programming in business organizations in Algeria, University of Skikda, 112-115.
- [55] Zadeh, L. A. (1975). The concept of a linguistic variable and its application to approximate reasoning. *Information Sciences*, **8(3)**, 199-249.
- [56] Pohlheim, H. (1997). Advanced techniques for the visualization of evolutionary algorithms. *International Scientific Colloquium Ilmenau*, **3**, 60-68.
- [57] Marey, R. R., and Hamadan, Kh. (1996). Introduction to operations research, 1st edition. Amman, Jordan: Almeseera for printing and distribution.
- [58] Al-Shamarti. H. S., and Al-Zubaidi. A. K. (2007). Product Planning by Goal Programming. *Technical Magazine*, **20(2)**, 15-25.
- [59] Alalawana, A., Ubaidat, M. and Awad, A. (2000). Operations research in business science. 1st edition. Amman, Jordan: Almostakbel for printing and distribution.
- [60] Gupta N. (2013). Analysis on the defects in yarn manufacturing process and its prevention in textile industry. Master Thesis, Integral University.
- [61] Özak Ö. (1990). Cost analysis in cotton textile industry. Master Thesis, Istanbul Technical University.
- [62] Wikipedia. https://en.wikipedia.org/wiki/Process_costing, 20.08.2018.
- [63] Accounting. <https://www.accountingverse.com/managerial-accounting/cost-concepts/product-costing-systems.html>, 20.08.2018.
- [64] Building the Business Case. <https://www.business-case-analysis.com/expense.html>, 20.08.2018.
- [65] Chron. <http://smallbusiness.chron.com/accounting-basics-types-expense-accounts-40284.html>.
- [66] Kasapoglu, Ö. (2007). Organic cotton and organic cotton yarn cost calculations, Master thesis, Istanbul Technical University.
- [67] Investopedia. <https://www.investopedia.com/terms/d/depreciation.asp>, 20.08.2018.
- [68] Rapid Tables. <https://www.rapidTables.com/calc/math/weighted-average-calculator.htm>