REDUCTION OF WARP BREAKS IN WEAVING PREPARATION

THROUGH LEAN TECHNIQUES

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REDUCTION OF WARP BREAKS IN WEAVING PREPARATION THROUGH LEAN TECHNIQUES

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Approval of the Graduate School of Natural and Applied Sciences

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

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We have read the thesis entitled **Reduction of Warp Breaks in Weaving Preparation through Lean Techniques** prepared by **Nurcan GULSUM** under supervision of **Asst. Prof. Dr. Kamil Erkan KABAK** and we here by agree that it is fully adequate, in scope and quality, as a thesis for the degree of **Master of Science** in **Industrial Engineering**.

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ABSTRACT

REDUCTION OF WARP BREAKS IN WEAVING PREPARATION THROUGH LEAN TECHNIQUES

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This thesis studies reducing warp breaks by using actual data in a textile process. Firstly, the major problem is selected by using AHP (analytic hierarchy process) analysis on weaving preparation line. Using the lean Six Sigma DMAIC (define, measure, analyze, improve, control) methodology steps, the causes of root breaks are reduced. This methodology consists of five phases. These phases are: define, measure, analyze, improve and control. Velocity, density and tension values are determined as main factors.

After, using these main factors, a full factorial experimental design is implemented as a part of the improvement phase. The analysis employs a 3^3 full factorial experiment design with two replications. The experimental analysis is conducted to the conical warping machine that has the maximum number of breaks. The experimental results are analyzed with the Minitab 17 software to obtain the minimum number of breaks involving 54 experiments. In addition, the simulation model is designed with the Arena 14 software that includes the data used for the experimental design and it models the textile process analyzed. In this study, the results of experiments are compared with a simulation model, and how to decrease the number of breaks is examined. Finally, monetary savings, cycle time improvements, machine utilization improvements and quality improvements are discussed according to the results obtained from the simulation model, design of experiment and the real system.

Keywords: six sigma, DMAIC, full factorial experimental design, warp breaks, simulation, textile industry

ÖZ

YALIN TEKNİKLERLE DOKUMA HAZIRLIKTA ÇÖZGÜ KOPUŞLARININ AZALTILMASI

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Bu tez, bir tekstil sürecindeki gerçek verilerden yararlanılarak çözgü kopuşlarının azaltılmasını çalışmaktadır. Başlangıçta, AHP (analitik hiyerarşi süreç) analizi kullanılarak dokuma hazırlık hattındaki major problem seçildi. Yalın altı sigma TÖAİK (tanımlama, ölçme, analiz, iyileştirme ve kontrol) methodolojisi basamaklarından yararlanılarak, kopuşa neden olan kök nedenler daraltılmıştır. Bu methodoloji beş farkli aşamadan oluşmaktadır, bunlar: tanımlama, ölçme, analiz, geliştirme ve kontrol.

Hız, sıklık ve tansiyon ana faktörler olarak belirlenmiştir. Sonra, geliştirme aşamasının bir parçası olarak tam faktöryel deney tasarımı uygulanmıştır. Analiz, iki tekrarlı bir 3^3 tam faktöryel deney tasarımı uygulamaktadır. Deney analizi, maximum kopuşa sahip olan konik çözgü makinasına uyarlanmıştır. Deney sonuçları, 54 deney içeren minimum sayıda kopuş bulmak için Minitab17 yazılımı ile analiz edilmiştir. Ayrıca, deney dizaynındaki verileri içeren Arena 14 yazılımı ile benzetim modeli dizayn edilmiştir. Bu model analiz edilen tekstil sürecini modeller. Bu çalışmada, deney sonuçları benzetim modeli ile karşılaştırılmaktadır ve kopuş sayısının nasıl azaltılabileceği değerlendirilmektedir. Son olarak, simülasyon modeli, deney tasarımı ve gerçek sistem sonuçlarına göre parasal tasarruf, çevrim süresi iyileştirmeleri, makine kullanım oranı iyileştirmeleri ve kalite iyileştirmeleri tartışılmaktadır.

Anahtar Kelimeler: altı sigma, DMAIC, tam faktörlü deney tasarımı, çözgü kopuşları, simülasyon, tekstil endüstrisi

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CHAPTER 1: INTRODUCTION

Manufacturing is a complex process for organizing all of inputs like labour, equipment, capital and technology in a proper manner. The products should satisfy certain quality parameters defined by the use of customer requirements. There are several different methodologies in the manufacturing process to optimize manufacturing performance measures and to reduce the defects. For example, Six Sigma, Poke-Yoke, Value Stream Mapping constitute some examples for such methods (Liker, 2010). This thesis applies an experimental design based on lean manufacturing methods.

In this chapter, first research motivation is explained in Section 1.1. Then, a summary of lean production philosophy is described in Section 1.2, and its techniques are presented in Section 1.3. After, research methodology applied in this study is described in Section 1.4. In Section 1.5, thesis chapters are briefly summarized.

1.1 Research Motivation

The principle of this study is based on philosophy of lean production which can be implemented in many sectors nowadays. The competition among the companies to satisfy the customer expectations is urged the companies to lean their manufacturing processes to use less source and more work. In the current production improvements, lean production satisfies the needs of companies and it becomes an important quality approach with increasing popularity (Atmaca and Girenes, 2009).

Lean production can be applied to many areas of textile sector. The research performed by Drohomeretski et al. (2014) indicate that lean applications are affected from the earlier dynamic learning applications of automotive and textile sectors.

The application of lean production methodologies into the textile sector is not conducted broadly. Obeidat et al. (2014) examine the of lean production methodology considering practical issues in sewing industry. Within a former study by Mukhopadhyay and Ray (2007), lean production methodology by investigating the effects on the defects of thread packing is discussed. The positive effects of lean production philosophy help the motivation of this thesis. The motivation of this thesis is originated from the increased benefits of lean manufacturing applications. Several parameters such as materials, man-hour, and energy are saved through the proper implementations. The lean applications also improve the quality of the products. All these results lead to the monetary savings and increase in the customer satisfaction.

1.2 Lean Production

In this section, the focus is on the general outline of lean production philosophy. The definition of lean production is given in Section 1.2.1, pros and cons of lean techniques are summarized in Section 1.2.2, fundamental principles are introduced in Section 1.2.3

1.2.1 Definition of Lean Manufacturing

Lean manufacturing, known as the production system of Toyota, is a fabrication philosophy that is developed and applied while searching for an access of perfection (Liker, 2010). The concept of lean manufacturing is a set of systems and techniques which means to create more value with less resources (Womack and Jones, 2006).

The main principle of the lean manufacturing starts with the understanding of value judgment on the customer's perspective and follows by the elimination of waste in the process (Gupta and Jain, 2013). Furthermore, it involves reasons to have simplified production and steps by removing unnecessary activities during business process (Liker, 2010). It is used for eliminating the amount of waste in each processes, reducing costs and time, increasing production efficiency, cash flow and customer satisfaction (Drohomereski et al. 2013).

1.2.2 Pros and Cons of Lean Manufacturing

This section discusses the lean manufacturing philosophy, the need for lean manufacturing and its targets. Lean manufacturing encompasses all types of wastes and elimination of them related with all activities in the production area (Gupta and Jain, 2013).

•High quality; producing high quality products is one of the most important factors when continuous increase and change in the customer expectations are considered (Drohomereski et al. 2013).

•Low cost; company perspectives are changed, and the expectations of consumers are inserted in the center of the value creation with increased competition. However, “demands of manufacturers were dominant in the past” (Gupta and Jain, 2013). Sustainability is another issue that follows this argument. For this reason, one of the essential parameter is to reduce the costs for sustainability (Drohomereski et al. 2013).

•Fast production; it is necessary to be able to produce goods as quickly as possible upon the customer’s requirements (Drohomereski et al. 2013).

All these objectives are located in the heart of achieving the idea of lean thinking. Following the lean thinking, idea its essential principles are discussed under the following section.

1.2.3 Fundamental Principles of Lean Manufacturing

Lean production principles are analyzed based on the four main concepts: (i) description of wastes, (ii) type of activities, (iii) root causes and (iv) optimal lean solution methods.

Description of Wastes

Every activity or action which does not add a value to the goods directly, does not contribute to the product conversion. Therefore, activities not having a value on the customer's perspective are defined as waste (Obeidat et al. 2014). There are seven basic wastes in the current production system. These wastes are: defects, inventory, overproduction, transportation, waiting time, over-processing and excessive motion. These wastes should be removed from the system (Obeidat et al. 2014).

Types of Activities

There are mainly two types of activities. These are value added activities and non-value added activities (Obeidat et al. 2014). These activities should be determined in order to reach simplified production process (Obeidat et al. 2014).

Root Causes

Output factors of the process and the corresponding input factors are described, and then they are discussed continuously to find out root causes (Obeidat et al. 2014).

Optimal Lean Solution Methods

There are two main lean steps in the lean manufacturing systems, these are “jidoka” and “just-in-time” (Gupta and Jain, 2013).

These lean steps ensure high quality production, possibility to produce best price products and minimization of the waste time spent (Gupta and Jain, 2013).

1.3 Lean techniques

Lean techniques are briefly described in this section. Just in Time (JIT) is discussed in Section 1.3.1. Value Stream Mapping (VSM) is presented in Section 1.3.2. Then, Kanban is explained in Section 1.3.3. Next, Single Minute Exchange Die (SMED) is introduced in Section 1.3.4. This is followed by the descriptions of Jidoka, Poke Yoke, Kaizen, Total Productivity Maintenance and finally Six Sigma in Sections 1.3.5, 1.3.6, 1.3.7, 1.3.8 and 1.3.9 respectively.

1.3.1 Just In Tıme (JIT)

JIT is an approach that provides competitive advantages for the industry as the Japanese style “just in time production” system and it handles the procurement of required materials when needed (Monden, 2012). The main purpose is to decrease waste, and to increase the operation efficiency and quality. This approach can be applied to all operating conditions (Monden, 2012).

1.3.2 Value Stream Mapping (VSM)

VSM is a type of mapping that ensures added value activities, non-value added output, and it realizes the steps that increase costs (Gupta and Jain, 2013). It provides an easy way to understand the communication between process steps during operation (Gupta and Jain, 2013). The VSM in every process has all information, to perceive inputs and outputs, and also to guide action steps needed to perform (Obeidat et al. 2014). It helps to understand resulting alterations and instabilities easily (Hodge et al. 2010). They study the VSM method in non-value adding activities of the processes and wastes by interviews, plant tours and case studies within textile industry to have complete customer satisfaction (Hodge et al. 2010).

1.3.3 Kanban

It is a pull type of manufacturing system in companies based on the understanding the necessary time duration for production planning and inventory supply depending on customer demand (Ramnath et al. 2010). The previous process is not started as long as the following process does not have any requirements (Liker, 2010). In Kanban system, in accordance with customer demands, the needs are pulled to previous process and the required product or service is produced in only desired amount (Gupta and Jain, 2013). Furthermore, Kanban philosophy assumes the control of the logistics flow and organizes the procurement of materials from suppliers (Obeidat et al. 2014).

1.3.4 Single Minute Exchange Die (SMED)

Nowadays, the necessity of manufacturing wide variety of products, sustainability, too many changeovers and setting changes are important issues under consideration (Shingo, 1985). For example, the time spent for setting a changeover in a process for two different types of production is a serious disadvantage for companies. SMED is the lean production methods that aims to reduce machine set up time, die changeover and type of change times (Shingo, 1985).

1.3.5 Jidoka

Jidoka means automation, and it is one of the important principles of Toyota Production Systems (Ohno, 1988). This lean thinking is based on the principle “reveal the problems”, and it gives right to the machine or operators in case of an abnormal situation, to stop or change the mode operation. This lean thinking system increases up production quality and efficiency, also helps to reduce waste (Ohno, 1988).

1.3.6 Poke Yoke

In Japanese, “poke” means mistake and “yoke” means prevent (Shimbun, 1987). The term “poke yoke” which has a meaning of mistake proofing offers low cost solutions to prevent problems arising from carelessness and oversight, and offers improvement opportunities (Shimbun, 1987).

1.3.7 Kaizen

Kaizen is a methodology based on continuous improvement which aims to be applied in all activities (Gupta and Jain, 2013). Improvements are required to be in a systematic manner and should become routine (Gupta and Jain, 2013). Kaizen is a method that promotes the creativity of operating staff, aims to eliminate wastes and increases productivity (Gupta and Jain, 2013).

1.3.8 Total Productivity Maintenance (TPM)

It is a method which aims to prevent sudden stops of machinery, to keep the machinery always maintained and clean (Phusavat, 2013). This approach supports to increase productivity by eliminating losses and also provides to give employees competence and responsibility by creating change in corporate culture (Phusavat, 2013).

1.3.9 Six Sigma

This approach, which has become popular in 1990s, took its name from the letter “sigma (σ)” in Greek alphabet (Drohomeretski et al. 2014). Six Sigma is an approach that aims performance improvement with the difference of current improvements in our days (Tennant, 2001). The target of this methodology is to decrease rates of defects, down to 3.4 ppm level measured over a specified period (Drohomeretski et al. 2014). It is a statistical measurement technique how this period deviates from zero failure position (Drohomeretski et al. 2014). It is a method formed by the incorporation of lean approach and Six Sigma (Drohomeretski et al. 2014).

Lean manufacturing tools and Six Sigma methods of analysis are applied together to the elimination the losses and waste along, they are aimed to demonstrate the improvement and increasing customer satisfaction (Tennant, 2001).

1.4 Research Methodology

In this section, reasons for choosing the research methodology applied in this study are presented.

Several different approaches are considered within lean Six Sigma implementation to increase the effectiveness. These methods are different according to their purposes and solutions suggested to the problem (see Section 1.3). When lean production research in the textile sector is considered, limited number of articles is found. They are briefly explained in the following.

Hodge et al. (2010) apply Value Stream Mapping (VSM) methods to the problems in the textile sector. Obeidat et al. (2014) point Value Stream Mapping (VSM) improvements by determining value and non-value added enhancements for the processes in sewing industry in order to decrease waste production. Mukhopadhyay and Ray (2006) apply Pareto analysis and regression in order to decrease the amount of yarn packing defects in the textile sector. Guner et al. (2009) perform Six Sigma DMAIC methodology aiming a decreasing period during male shirt production.

Considering the above limited research, a full factorial experimental design with DMAIC methodology is not applied in the textile literature. All quality focused textile companies have some lean production applications within their operations, however in the literature only a limited number of these works are published.

A lean manufacturing application in a textile process is studied in this thesis. Design of experiment aims to determine the quality of process. It helps to find the level of these factors (Demir, 2004).

Simulation aims to model and predict the real system outputs (Banks, 2010). Also, AHP (analytic hierarchy process) is used to select important quality problem on weaving preparation line. AHP (analytic hierarchy process) is developed by Satty (1998), it is used to prioritize problems (Ozveri et al. 2012). Applying another research methodology, simulation is modeling of woven fabric process conducted for this research. The simulation technique allows managers and researchers to consider the time factor when modeling real systems. This simulation technique can be interpreted based on the assumptions of operation conditions in a short time (Sariaslan, 1986). Simulation models contribute to the business. In this study, stochastic monthly real system data is used and warp break results are observed. The last study is full factorial experimental design. Factorial designs are the most effective designs to examine the effects of the relevant factors. There are two kinds of effects on the results, these are 2-way interactions and main interaction. The full factorial design examines the effect of these interactions on the results (Demir, 2004).

1.5 Summary

Chapter 2 discusses the production system analyzed. Description of production system and its main steps are briefly explained.

Chapter 3 presents the problem statement for the thesis. It discusses the research questions and the effects of the specified issues.

Chapter 4 covers literature research on the lean applications and research on the textile sector. Literature survey, its summary and a discussion on relevant research are presented in this chapter.

Chapter 5 describes proposed methodology for this thesis study. The steps of followed methodology, data collection and data structure in the system are explained.

Chapter 6 introduces the simulation model built to compare the experimental design results under stochastic conditions.
First, it draws the structure of the analyzed system through conceptual model and assumptions, and then describes the simulation model.

Chapter 7 presents the results of DMAIC methodology and experimental design step by step, and also shows the results obtained from the simulation model.

Finally, chapter 8 includes concluding remarks, discusses the application of lean techniques and presents future research.

CHAPTER 2: WOVEN FABRIC PRODUCTION SYSTEM

In this chapter, a textile production system, woven fabric production is described according to the observations from a real facility. A brief description of the analyzed system is given in Section 2.1. Its main steps are explained in Section 2.2.

2.1 Description of Woven Fabric Production System

The problem that is the subject of this study exists in a company producing woven fabrics as a final product. The cotton taken from the field is processed to get yarn, which is used to produce woven fabrics through weaving. Yarn is made from the cottons, and consists of several number of types. The existing woven fabric production system involves six different operation steps. These steps are: filature process, laboratory tests, dry process, weaving preparation and weaving. Warp break problems are observed during the weaving preparatory phase. In the next section, the main steps of this production system observed from a real production area are briefly summarized (Klein, 2014).

2.2 The Main Steps of Woven Fabric Production System

The operation steps of the woven fabric production system are described here in. The following Figure 1 shows the processing steps of each operation. The warp breaks that occur in the weaving preparation section are considered in this study**.**

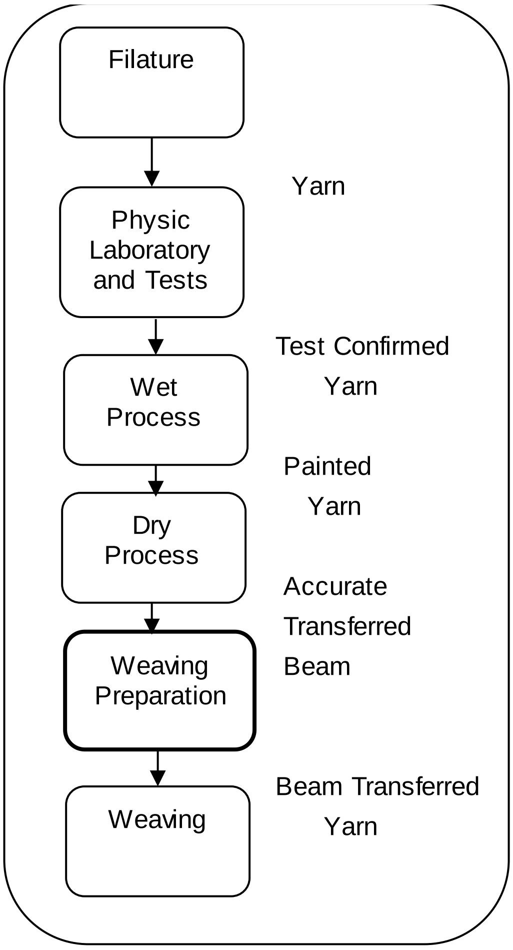


Figure 1 Steps of woven fabric production system.

2.2.1 Filature Process

Filature is the department where the incoming cotton is converted into yarn form (Klein, 2014). Yarn is made from cotton. Various types of yarns are produced in this department. Production of yarns varies depending on the order and trends.

2.2.2 Physics Laboratory and Tests

All quality control and process control procedures are performed in this department. Process controls are in the form of checks, climatic environment, engine speed and cycle checks.

Quality control procedures cover cotton control, yarn number control, twist control, unevenness control, strength control, classmate test (classification of thin and thick places in the yarn), black plate (detection of errors, by wrapping yarn fabric to sheet), sliver data (yield and position control) (Klein, 2014).

2.2.3 Wet Process

Wet process is the part of dying the yarn. Firstly, the yarn is pretreated to remove various chemical substances such as oil, wax, pectin, cellulose, which may prevent dying by using high temperature. After that, the yarn is taken for drying. Then, the dyed yarn is transferred to dry process line (Klein, 2014).

2.2.4 Dry Process

Dry process department is a place where the dyed yarns are quantified in the desired amount by using transfer machines. After this, yarn bobbins are obtained. Color of bobbins and labels are checked and these bobbins are sent to packaging. The packaged products are sent to weaving preparation line (Klein, 2014).

2.2.5 Weaving Preparation

Yarn bobbins are aligned to the creel warping machine according to creel report, and warp beams are formed. The purpose of sizing is to give strength to the yarn, to prevent any breaks that may occur in the loom. After sizing yarns, they are transferred to the weaving draft. Here, it is provided to pass the yarn from dropper, weaving reed and comber. As a result of weaving draft process, warp is ready for weaving. With regard to the beam transferred, yarn quality is expected to be high since minimum number of breaks during weaving is desired (Gandhi, 2012). Table 1 is shows weaving terminology below.

Table 1 Weaving terminology (Gandhi, 2012).

Weaving Terminology	Explanation
Creel	The part where the bobbins are placed on warping machine
Warping machine	The machine in which the warping is made
Loom	Part of a weaving machine
Weaving draft	The process that the order of the warp yarns according to a certain rule
Dropper	The part of weaving draft. Weaving draft consist of dropper and reed
Reed	The part of weaving draft. Weaving draft consists of dropper and reed
Comber	The machine which is used for weaving

2.2.6 Weaving

Preparation procedures are completed after the warp is loaded up to the loom. The warp inlet to weaving machine is fed either in two different forms; team and knot. It is the warp changing process performed in the form of team and knot. Knot means that connecting the previous process to the next one in the weaving machine. Before any application, the weaving machine which provides team warp, frame, comb group is totally emptied with application of machine settings that comply with warp features (Gandhi, 2012). After all these processes, woven fabric is obtained.

CHAPTER 3: PROBLEM STATEMENT

In this chapter, first, main issues in the textile production process of interest are briefly discussed in Section 3.1. Then, the Analytical Hierarchical Process (AHP) methodology is explained to determine the problem in this thesis in Section 3.2. Thereafter, the problem statement is given and discussed in Section 3.3

3.1 Issues in Textile Production Systems

In this thesis, a real textile production process is studied (see Chapter 2). At the textile production system, the products are cotton yarn, raw and finished fabric design. Two types of important issues are discussed in this section. The first type of issue is high yield loss. It is one of the most important parameters which affects production wastes and it is related to defective products (Senol et al. 2009). The yield loss in the products and final goods affect the quality in a negative way. In this thesis, improvements on warp pulling process are studied to decrease yield loss.

The second type of issue is the problems that occur in the weaving preparation. Typically, yarns are prepared in the weaving preparation process. The problems in weaving preparation may cause the weaving machines to stop. For this reason, weaving preparation processes should be flawless for better yield and high quality fabric. Also, the weaving preparatory process enhances the efficiency, quality and speed of the weaving process. For these reasons, minimization of errors in the weaving preparation department is desired.

3.2 Selection of the Problem by AHP Methodology

After specifying main issues as yield loss and problems in weaving department, next step is to find out the issues in more details, and then to determine the main problem for this study. To do this, “Critical-To-Quality” (CTQ) analysis is conducted to find out current issues in the real system. Then, they are prioritized with Analytic Hierarchy Process (AHP) method. The problems that are found from CTQ analysis to decrease yield loss are presented in Table 2.

Table 2 Critical-To-Quality (CTQ) analysis.

CTQ	Current Issues
A	Cross Yarn Defect on Warder’s Beam
B	Blank Jant Defect on Comb in Ready Tool
C	Cross Out Defect
D	Sizing sourced Adherent Yarn
E	Warp Break

Five CTQs are specified, and each of them is represented by a capital letter as given in Table 2. Then, AHP method, improved by Saaty (1998), is used. (See also Bayraktar et al. 1999). The application of AHP methodology is explained in the following.

In this method, four managers and eight operators from the weaving line are chosen, and they are asked to choose one of nine scale parameters in order to do pairwise comparisons of five CTQs (see Appendix A). AHP table of each person is different and they are transformed into one table. The values of pairwise comparison matrix are obtained (see Table 3), and they are subjected to normalization process (Ozveri et al. 2012).

Table 3 Pairwise comparison matrix.

CTQ	A	B	C	D	E	Average
A		1/3	1/7	1/5	1/9	0.035
B	3		1/5	1/3	1/7	0.067
C	7	5		3	1/3	0.260
D	5	3	1/3		1/5	0.134
E	9	7	3	5		0.504

Value of “1/5”, which united with the second line and third Column in Table 3, is less important when it is compared to B-CTQ’ of C-CTQ’. Warp break (E-CTQ’) with a highest average of 0.504 is calculated as the most important factor to be tackled according to normalized values of AHP method. After all, the problems can be ordered from the largest to smallest according to average values in Table 3 as E, C, D, B and A. In the following section, problem statement is given and the reasons why warp end-breaking problem is selected are discussed in more details. AHP survey results and calculation of the values for pairwise comparison matrix are given in Appendix A.

3.3 Problem Statement

After, the warp break problem is decided in Section 3.2, the aim of thesis is decided as follows.

Problem Statement: the objective of this study is to minimize the number of breaks of warp yarn at weaving preparatory machines in the textile production environment.

Material quality, spinning and winding processes are main sources of problems in the weaving preparation processes to cause yarn breaks in the weaving (Meric and Ozkal, 2002). This thesis work focuses on warping, since warp breaks occur in this process. The break of warp yarns occurs due to variety of reasons. Each warp break causes long machine down time. Warps are wound on loom beams in flat or conical machine.

Conical machine data is collected in this work. Loom beam quality affects weaving efficiency significantly.

Loom beam quality determines the amount of warp break (Gandhi, 2012). Warp breaks are expected to be less according to the real system analyzed. Misdelivered beams increase number of yarn breaks during weaving, therefore costs increase and it leads to low quality (Senol et al. 2009). For this reason, determination of a minimum level of warping is required. Further, yarn breaks cause the coarseness, customer dissatisfaction and reproduction. In the following, causes of the warp breaks and its effects are discussed.

3.4 Causes of the Warp Breaks

There are three expected major causes of the breaks of warp yarn. These causes are: yarn, machinery and operator causes.

3.4.1 Yarn

Yarn breaks could be due to different reasons such as yarn unevenness, machine tension, and yarn types.

Yarns that produce a high percentage of break during spinning and winding process lead also increased number of breaks in weaving preparation process. Yarn breaks during the spinning process are a characteristic of textile material due to low quality of the yarn and its products (Prendzova, 2006). The yarn which has high number of breaks during the spinning has also high number of breaks during warping (Gandhi, 2012). Thus, the quality of yarn production is a significant factor to have less number of breaks in warping.

Another factor is the number or types of warps that cause the breaks. Different types of warps are used in the conical warp machines. Warp breaks differ for different yarns. Hence, the types of yarns are important for warp breaks.

3.4.2 Machinery

Types of warping machines are of two kinds; versomat and conical. In this thesis study, data of the warp break is obtained from conical machines. Machine settings are significant factors that cause the breaks. Machine settings affect the number of yarn breaks. Therefore, a set of settings data is needed. Each setting may result in different number of breaks. It is the important principle that optimal settings should be reached for the velocity, density and tension to continue the production smoothly. Also, machine maintenance should be performed periodically. These are the major factors to increase the quality of warp.

3.4.3 Operator

Operator impact is an important factor for the break problem since all data is managed by operators. Operators should be careful about the breaks during the period of the machine uptime, and they should verify the data. Operators should be given the necessary training, since accurate data entry affects the yarn breaks. Different calibrated datasets are suggested to be entered for different yarn break types. The reporting after the break is also important and should be specified properly.

3.5 Effects of the Problem

The quality of product, monetary savings and customer satisfaction are the three significant effects of the breaks of warp as discussed below.

3.5.1 Quality of Product

Woven fabrics consist of warp and weft. Warps are parallel to the edges along the length of the woven fabric, and in this thesis, the problems related to warp break are studied. When a break occurs, after the splicing, the uniformity of the yarn is changed. This may result in another break during weaving phase.

Each stop of the machine causes the decrease in the quality of the fabric produced. Therefore, yarn breaks are one of the most significant factors effecting the efficiency in weaving preparation machinery, since sequential stoppages occur in the production.

Yarn-yarn, yarn-metal friction happens during warp take off process. Because of this reason, the amount of yarn breaks increases, but production quality and speed are affected adversely during manufacturing.

3.5.2 Monetary Savings

Warp breaks have negative effect on product quality during weaving preparation process. Because of warp breaks, weaving and drafting productivity and operating costs affect significantly. Each machine downtime is undesirable in terms of production considerations. The customer satisfaction is also negatively affected.

3.5.3 Customer Satisfaction

Customer satisfaction is a crucial factor for production environment since competition increases in the global world. Each breaks cause a decrease in the fabric quality. The warp breaks are affected adversely caused by the weaving process that lead to increase in reproduction and delays product delivery time.

In this thesis work, DMAIC methodology in line with the targets mentioned above is used. Therefore, breaks are restricted to the number of faults in million meters of production.

Major factors that cause breaks during the production are determined by statistical analysis. Finding an optimal level of breaks is the objective of this study using a real experimental dataset.

When such an optimal level is reached, second quality ratio, high incorrect rate, reproduction, deadline delay could be reduced and consequently, profitability and image of the company could be positively affected.

CHAPTER 4: LITERATURE REVIEW

This section first discusses the relevant literature survey that inspired the thesis and summarizes it in accordance to the textile sector. Then, it presents interpretations and discussions on the textile literature.

4.1 Literature Research

This section first introduces lean production techniques in general, then it surveys the literature in the textile sector. Finally, the studies that apply Six Sigma DMAIC approach are described.

4.1.1 Literature Research on Lean Applications

Lean production methodology is applicable to a variety of systems in the literature such as, textile, automotive, mining, machinery, and the manufacturing sectors (Jasti and Kodali, 2014). Six Sigma methods are mentioned in Chapter 1.

The expectations of customers are met with lowering the prices and shortening the market-to-delivery time for the new innovative products (Jasti and Kodali, 2014). In this research, the lean production is considered as effective use of resources, including the manpower in the factories, production areas, investment tools, engineering time for developing a new product. Six Sigma is one of lean manufacturing tools (Bendell, 2015). It is a business development strategy that eliminates the defects and errors in the process. Most widely used Six Sigma application in practice is DMAIC cycle which consists of five stages (Drohomeretski et al. 2014).

Yang et al. (2014) present an optimal level via mathematical models developed to improve CTQs. They mention DMAIC is the most common Six Sigma method. In this study, the DMAIC cycle is utilized.

4.1.2 Literature Research on Textile Sector

Implementation of Six Sigma in the textile sector is not observed much in the literature. However, most of the companies applies Six Sigma activities within their own production facilities. In a study by Guner et al. (2009), which is performed within a textile company, Six Sigma DMIAC cycle is implemented to the men's shirt production line belt loop and button to decrease the production errors. In their analysis, they improve the time to repair and substitution patterns (Guner et al. 2009). Analytical methods are used in their study in the DMAIC cycle. Pareto analysis and fishbone diagrams guide the analysis. Also, they present improvements based on actual observations against the changes made in the design of current production tools (Guner et al. 2009).

Obeidat et al. (2014) study the case to reduce process wastes in sewing industry. In the study, the lean production of Value Stream Mapping (VSM) method finalizes sewing line wastes. Then, value added and non-value added movements with the help of case studies are identified. After, improvements are achieved on the defects, inventory, overproductions, transportation and waiting time in sewing line (Obeidat et al. 2014).

Hodge et al. (2010) identify lean tools used in companies as a result of their meetings with eleven different textile companies By applying the most preferred two methods of Seiri, Seiton, Seiso, Seiketsu, Shitsuke (5S) and Value Stream Mapping (VSM) methods in three different companies, they develop a lean implementation model on increasing customer’s satisfaction (Hodge et al. 2010). This study is a quite extensive study on this subject.

Mukhopadhyay and Ray (2007) aim through another case study to improve the quality in the textile sector by the reducing yarn defect packing amount with Six Sigma DMAIC cycle. In the define phase, pareto analysis helps to find major error (Mukhopadhyay and Ray, 2007). In the Measure 1 phase, data collection and DPI (defect per million) over the level of sigma are calculated. Identifying starting sigma level is a parameter used to determine to compare whether there is an improvement (Mukhopadhyay and Ray, 2007). In the analysis 1 stage, they are benefited from hypothesis testing for gross weights and the empty reel spool weight (Mukhopadhyay and Ray, 2007). By reducing output gained from the Analysis 1 phase, they work on different numbered two yarns in the stages of Measure 2. In the Analysis 2 stage, for 4/12sp and 2/42sp yarns, they conduct process capability and regression analysis (Mukhopadhyay and Ray, 2007). After, the results of the analysis statistically are carried out in the improve stage. They discuss about the decisions and they calculate the monthly cost gain (Mukhopadhyay and Ray, 2007). This study also utilizes statistical analysis and the DMAIC cycle. The different aspect of this study is that they use two separate phases as the measure and analyze stages.

The above studies are conducted in the textile production field. Each study presents particular information about characteristics of different lean tools. In the next section, the studies of lean manufacturing applied to different sectors are presented.

4.1.3 Literature Research on Six Sigma DMAIC Approach

Ozveri and Cakir (2012) implement Six Sigma DMAIC cycle in a company serving the manufacturing sector. Together with CTQs from customers, they identify problems to be optimized using a binary comparison matrix (Ozveri and Cakir, 2012). They use a tree diagram for the things to be performed to target CTQ (Ozveri and Cakir, 2012). However, SIPOC analysis is used to develop a more detailed work that provides input to the process map (Ozveri and Cakir, 2012).

By the capability analysis test, they investigate whether the product is produced within the limits demanded by the customer range (Ozveri and Cakir, 2012). Similar analyses on pairwise comparisons using a matrix, tree diagram, SIPOC analysis and capability analysis are also applied in this thesis.

Desai and Shrivastava (2008) take advantage of Six Sigma DMAIC methodology for process efficiency in critical operations in welding machines. They consider DMAIC cycle on the efficient use of existing resources and reducing the variation in the final product (Desai and Shrivastava, 2008). In their study, they use Pareto analysis, SIPOC diagram, CTQ tree diagrams, and fishbone diagram. Unlike other studies on machines with low yields, they perform the analysis of Failure Mode and Effect Analysis (FMEA) (Desai and Shrivastava, 2008). The purpose of this analysis is to attempt to hinder the foresight of the errors before they occur (Desai and Shrivastava, 2008).

Srinivasan et al. (2014) conduct DMAIC methodology in a factory producing small sized furnace to improve the quality of them. In this study, they identify the initial sigma level of 1.34 after working sigma level is increased to 2.01 (Srinivasan et al. 2014). That is, it shows the decline in the million production error levels. Also, the sigma level is calculated as the warp break unit in million meter (Srinivasan et al. 2014). Similar identification of the sigma level of quality is applied also in this thesis.

Indrawati and Ridwansyah (2015) apply Six Sigma for increasing the production capacity on iron ores. This study aims to improve the products' quality and to reduce the amount of defect Failure Mode and Effect Analysis (FMEA) study. FMEA study is another Six Sigma method calculating risk priority numbers identifying potential error types.

In another study of DMAIC methodology, Kumar et al. (2011) apply DMAIC method for variation, the reduction of errors and faulty operation for process improvement.

They utilize Taguchi experimental design method unlike other studies and gather data in eight different parameters in the process of casting problems (Kumar et al. 2011). Performance data are subjected to experiments of Taguchi method, and they tabulate the data by observing three times for each test (Kumar et al. 2011). Also, they achieve casting defects that result in three different levels for each performance characteristic (Kumar et al. 2011). The experimental results are interpreted using ANOVA analysis that is a method in interpreting the impact of the results of experiments performed by a number of input factors.

Gologlu and Sarikaya (2007) achieve optimal cutting parameters in the steel milling operations performing the experimental design of Taguchi in the metal industry. To do this, ANOVA is applied, and then the optimal results are obtained from tests performed with different cutting strategies (Gologlu and Sarikaya, 2007).

Srinivasan et al. (2014) examine the defect in the paint line in the shock absorbers. They apply Six Sigma DMAIC methodology. By conducting Pareto analysis, they present two errors that caused the paint defect in define phase. They apply then brainstorming and capability analysis in measure phase (Srinivasan et al. 2014). Fishbone diagram prepared for the analysis phase guides Taguchi design in this study, and the results of the experimental design method are analyzed using ANOVA method (Srinivasan et al. 2014).

Next section discusses the relevant literature and compares the studies, particularly based on the lean techniques and the sector applied.

4.2 Discussion on the Literature

The studies in the Six Sigma literature examined in the previous section are summarized in Table 4.

Table 4 Summary of Six Sigma studies.

Author and Publication Year	Sector	Lean Technique
Jasti and Kodali (2014)	General	Review of lean production
Drohomeretski et al. (2014)	General	Six Sigma, Lean Six Sigma
Gupta and Jain (2014)	General	Review of lean production
Bendell (2015)	General	Six Sigma and choice route
Yang et al. (2014)	General	Mathematical model and Six Sigma methodology
Guner et al. (2009)	Textile	Six Sigma DMAIC methodology
Obeidat et al. (2014)	Textile	VSM method
Hodge et al. (2010)	Textile	5S and VSM methods
Mukhopadhyay and Ray (2007)	Textile	Six Sigma DMAIC cycle implementation
Ozveri and Cakır (2012)	Manufacturing	Six Sigma DMAIC cycle implementation
Desai and Shrivastava (2008)	Machine Industry	Six Sigma FMEA application
Srinivasan et al. (2014)	Manufacturing	Six Sigma DMAIC cycle implementation
Indrawati and Ridwansyah (2015)	Mining Sector	Six Sigma FMEA application
Kumar et al. (2011)	Automobile Industry	Six Sigma Taguchi experimental design and ANOVA implementation
Gologlu and Sarıkaya (2007)	Metal Industry	Six Sigma Taguchi experimental design and ANOVA implementation
Srinivasan et al. (2014)	Manufacturing	Six Sigma Taguchi experimental design and ANOVA implementation

According to Table 4, Six Sigma methodology can be applied in different ways based on the sector and particular production problem.

It is observed that most of the literature is on the implementation of the DMAIC cycle, but studies also exist on Six Sigma without applying its cycle. DMAIC cycle, with specific process steps, provides simpler progress in solving the problems step by step.

Considering above studies, generally VSM, FMEA, design of experiment and solution methods such as 5S are used (see Table 4). Prior to introducing the main method, auxiliary methods such as, brainstorming, Pareto analysis, fishbone diagrams, SIPOC diagrams, CTQ tree diagrams are found. Auxiliary methods are implemented to determine the cause of the problem in early stages. For these reasons, DMAIC methodology is determined to follow for analyzing the number of warp breaks in this study. The methodology is supported with an experimental design, which is performed with a part of improve phase, and a simulation model.

Next chapter describes steps of the methodology applied in this study to reduce the number of warp breaks, collection of data and data structure.

CHAPTER 5: METHODOLOGY

Proposed methodology is described briefly in this part. Accordingly, data collection process and data types are defined in this section. Proposed methodology is presented in Section 5.1, that is followed by description of data collection process and data types in Section 5.2.

5.1 Proposed Methodology

DMAIC methodology, found as the most common methodology in literature survey (see Section 4), is conducted in this thesis to find optimal number of breaks. This methodology includes five main steps. These steps are: define phase, measure phase, anayse phase, improve phase and control phase. The analyses cover filature, dry process and weaving preparation departments of a textile factory (see Section 2). This methodology is known as the process improvement methodology. Steps of proposed DMAIC methodology is presented schematically in Figure 2.

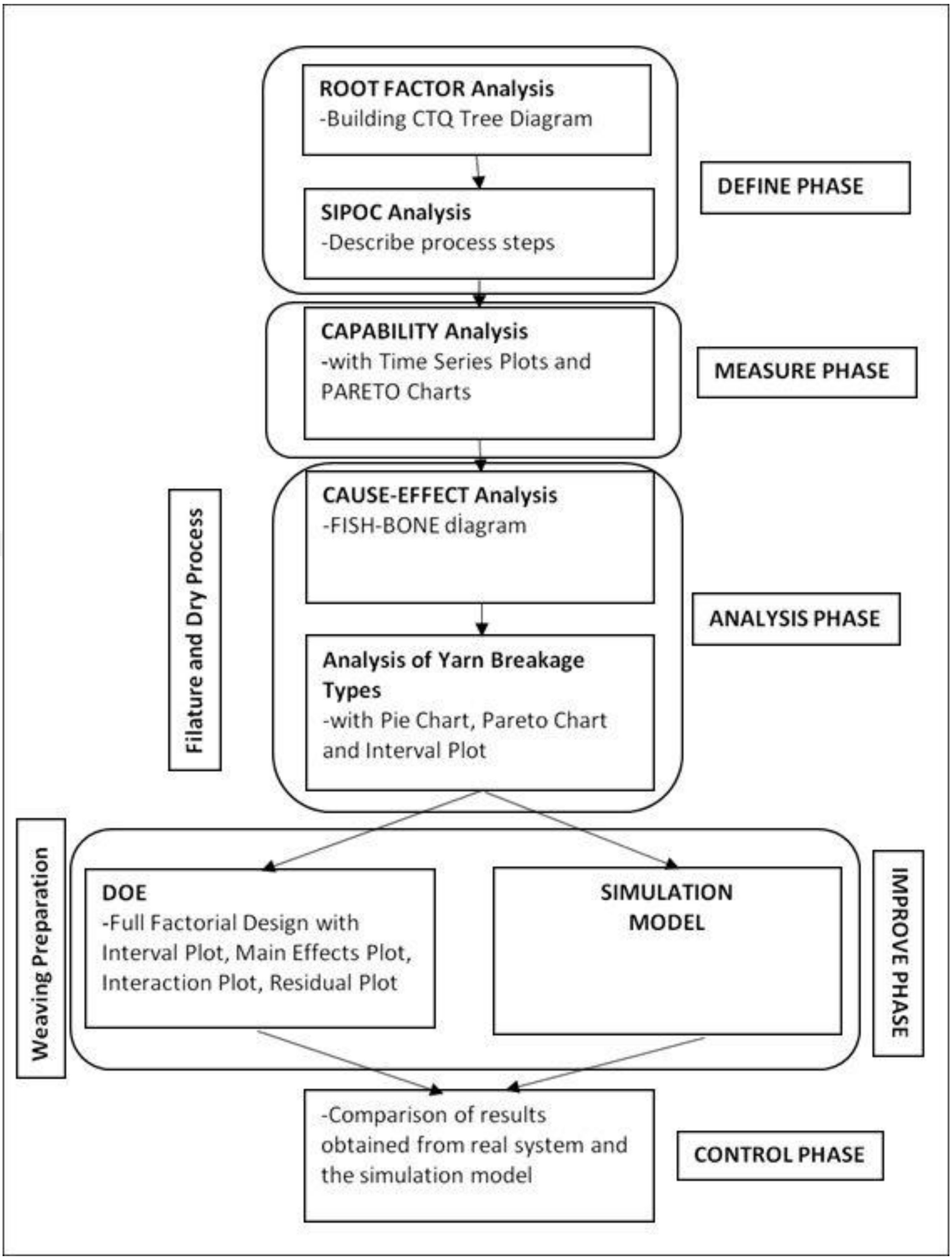


Figure 2 Steps of proposed methodology.

Define phase: It is the first step of the methodology. CTQ tree diagram is created to find major root factors for breaks. Root factors place important information to reach the main problem. With root factor analysis, the need and correspondingly the specifications are identified. The second important step is SIPOC analysis in this part. This analysis shows that inputs and outputs about this problem. To summarize, root factors, process inputs, outputs are determined in this phase.

Measure phase: Capability analysis is used in this part. This analysis is determined whether warp breaks are within the customer specifications. The degree of the problem is evaluated in this way. Time series plot and Pareto chart are used to create the capability analysis. Time series plot shows monthly breaks. Pareto charts lead to find which yarn number is used more and which yarn number has more breaks. Also, breaks per million meter (BPMM) is calculated and given in this part.

Analysis phase: All analyses are implemented for filature and dry process line in this phase. First, a cause and effect diagram is created to find root causes. The main reasons of the warp breaks are determined in four main categories by the help of the cause and effect diagram. As for the studies performed in the filature and dry process line, types of yarn breaks are analysed. As with Pareto chart, the type of the error that causes the most number of breaks is identified. By the help of pie chart, the distributions of these breaks on the machine types are shown. Through the conducted variance analysis, the effects of the yarn knot types on the breaks in the filature and dry process departments are statistically presented and the interval plot graphic is used in this analysis.

Improve phase: design of experiment (DOE) and simulation model are applied by using real production data. First, a full factorial experimental design is applied on conical warp machine to find optimal settings. An Interval plot chart is formed to find having the maximum number of breaks on the machine. Three different essential machine settings are determined to create the experimental design.

Full factorial experimental design is applied by changing such machine settings on each experiment. Main effects and interaction plots are obtained for the graphical analysis. Minimum number of breaks formula is achieved by performing analysis of variance. Also, residual plot and pie chart are another graphical analysis methods used in this phase.

Simulation modelling of the process of interest is another study performed in this phase. Similar machine settings are used as in the experimental design. Stochastic input data is fitted into an empirical distribution through Arena input analyser (Arena, 2017). Verification and validation of the simulation model is conducted according to preliminary simulation results. After that, terminating output analysis is performed to obtain the confidence interval of breaks (Banks et al. 2010).

Control phase: This phase includes the results that are compared with the break values obtained from the simulation model and experimental design.

5.2 Data Collection and Types

The number of warp breaks is determined as a performance measure on this work. Therefore, necessary data is collected for warp breaks in real system. The data is collected from preparation division in order to investigate "warp break" problem and the improvement study, since their outputs of the weaving preparation division has most influencing factors to the breaks. For this purpose, the data is collected with daily charts on “Weaving Preparation Work Order Form” by warp machine operators and they are transferred to electronic environment by department chiefs. Also, using the weaving preparation work order form for each machine operator, information such as types of warp breaks and amount of breaks, work starting and ending hours can be obtained.

Data are collected to analyze and solve the problem from weaving preparation department. Data collection that is obtained from operators covers the time period between February 2015 to February 2016.

Data consists of numerical and categorical data, and it is compiled in MS Excel Software. Table 5 shows data types used in this study.

Table 5 Data types used in this study.

Data	Values
Month	Month in which the yarn is produced.
Machine	One of six machines worked for the yarn.
Number of yarn	One of seven different yarn number
Raw material	The 100% cotton yarn.
Type of raw material	Long staple fibers.
Number of break	Amount of warp break.
Total number of yarn meter	Amount of warp yarn produced according to the order.
BPMM	Break per million meter of warp.
Type of break	Explains break type
Warp density	Number of wires per centimeter
Machine velocity	Velocity value at which yarns are exposed by the machine during spinning.
Yarn tension	Tension that yarns are exposed to by the machine during spinning.

According to Table 5, month represents the date of yarn production. Machine shows the type of machine used for the yarn. Number of yarn shows the type of yarn out of seven types. Type of raw material presents the structure of raw material. Number of break defines the amount of warp breaks occur in the process. Total number of yarn meter describes the amount of warp yarn produced for a particular customer order. BPMM is the abbreviated term to define number of breaks per million meter of warp. Type of break explains how breaks occur and so it defines the type of it. Warp density is related with the velocity value exposed on the machine during spinning operation and yarn tension defines the tension that yarns are exposed during spinning operation.

Next section describes the simulation model built to support experimental analysis.

CHAPTER 6: SIMULATION MODELLING OF WOVEN FABRIC PROCESS

This chapter explains the simulation model that is developed for modelling the woven fabric process. Conceptual model and elements of simulation model are introduced in Section 6.1. Section 6.2 presents the simulation model built Arena software package (Arena, 2017). Finally, verification, validation analyses together with Black-Box representation are described in order to obtain an acceptable base simulation model in Section 6.3.

6.1 Conceptual Model of Simulation Model

Simulation has many meanings conceptually, most common of them is defined as modelling of the real system to the electronic environment (Erge, 2011). The simulation model contains cotton arrivals to the factory in balls, then they become yarns, and they are processed in warp machines. Simulation model is designed by using a monthly dataset when the highest level of breaks occurs. The conceptual model and elements of the system are briefly described in the following.

Entities of the system: Cottons feed into the system by daily arrivals. Thus, cottons are determined as system entities for the simulation model. Deterministic constant daily arrivals are applied to generate cotton arrivals (See Section 6.1.1).

Events and activities of the System: In the model, cottons arrive to the system, then 70% of cottons form the yarn. After, warps feed on the warp machine. Breaks occur during the overthrown phase.

Finally, warps depart the system. Therefore, arrival of cottons, departure of generated yarn, and breaks represent main events in the observed system. Based on them, yam formation and overthrowing the yarn represent main activities in the woven fabric process.

System Boundaries: Woven fabric process including filature and weaving preparation lines are taken as the system boundaries for the simulation model. Next section describes cotton arrivals and determination of machine settings.

6.1.1 Cotton Arrivals and Determination of Machine Settings

Figure 3 and 4 show that cotton arrivals and types of machine settings for the simulation model.

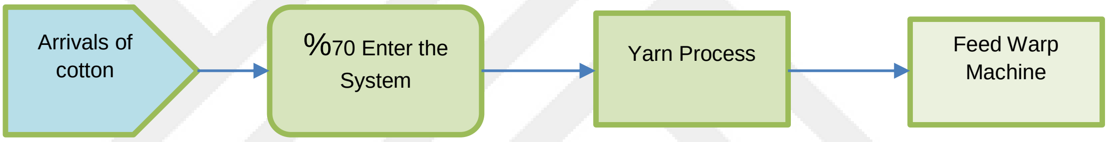


Figure 3 Cotton arrival process.

In Figure 3, 70 percent of cotton arrivals is considered for the yarn process. After yarn process, yarns are fed into the warp machine.

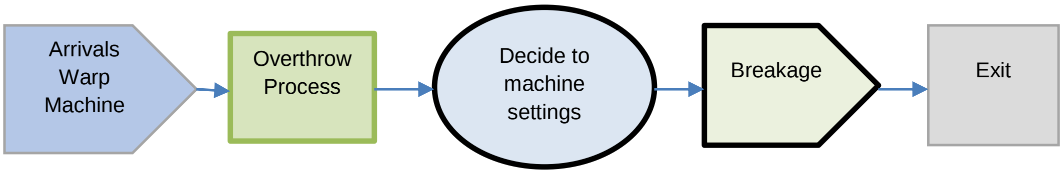


Figure 4 Decision process for the settings of conical warp machine.

In Figure 4, the yarn that exits from warp machine is overthrown on the conical warp machine. After, the remaining steps describe the occurences of breaks according to different machine settings. The parameters of the warp machine provide occurrences of breaks based on the discrete empirical distributions found according to the experimental dataset (see Appendix B). Accordingly, velocity, tension and density are specified as machine parameters.

For each of these parameters, a different discrete empirical distribution is determined (see Appendix B).

6.1.2 Input Analysis

Data collection is considered to be the most essential part of constructing a simulation model. Regarding input data, distribution of cotton arrivals is found by Arena Input analyzer (Arena, 2017). Input Analyzer determines which distribution fits best to cotton kilos for the arrival process. The result is empirical distribution obtained by cumulative probabilities (see Appendix C). Also, this part includes determination of distribution for the parameters of conical warp machine (i.e., velocity, tension and density) using the experimental dataset (See Appendix B).

6.2 Arena Simulation Model

Figure 5 represents Arena Simulation model developed to support experimental design. In the model, cotton arrival kilos are stochastic, a deterministic percentage (i.e., 70%) is defined to convert cotton weights for the yarn machine. Before the model is created, the following arrival the data for cotton bale weight is collected from the database. The arena simulation model for the woven fabric process is developed as follows. First, cotton arrivals is defined by the Create block in the model (see Appendix D). Then continuous empirical distribution for cotton weights and the deterministic percentage for converting cotton weights are inserted into Assign block (see Appendix E). After, the settings of warp machine is given (see Appendix F). Discrete emprica distributions for velocity, tension and density are defined in the Assign block (see Appendix G). In this block, overthrown conversion and calculation for converting the cotton to its length in meters are defined. In the next block, overthrown machine settings are shown (see Appendix H). The decide bock presents the machine settings (see Appendix I).

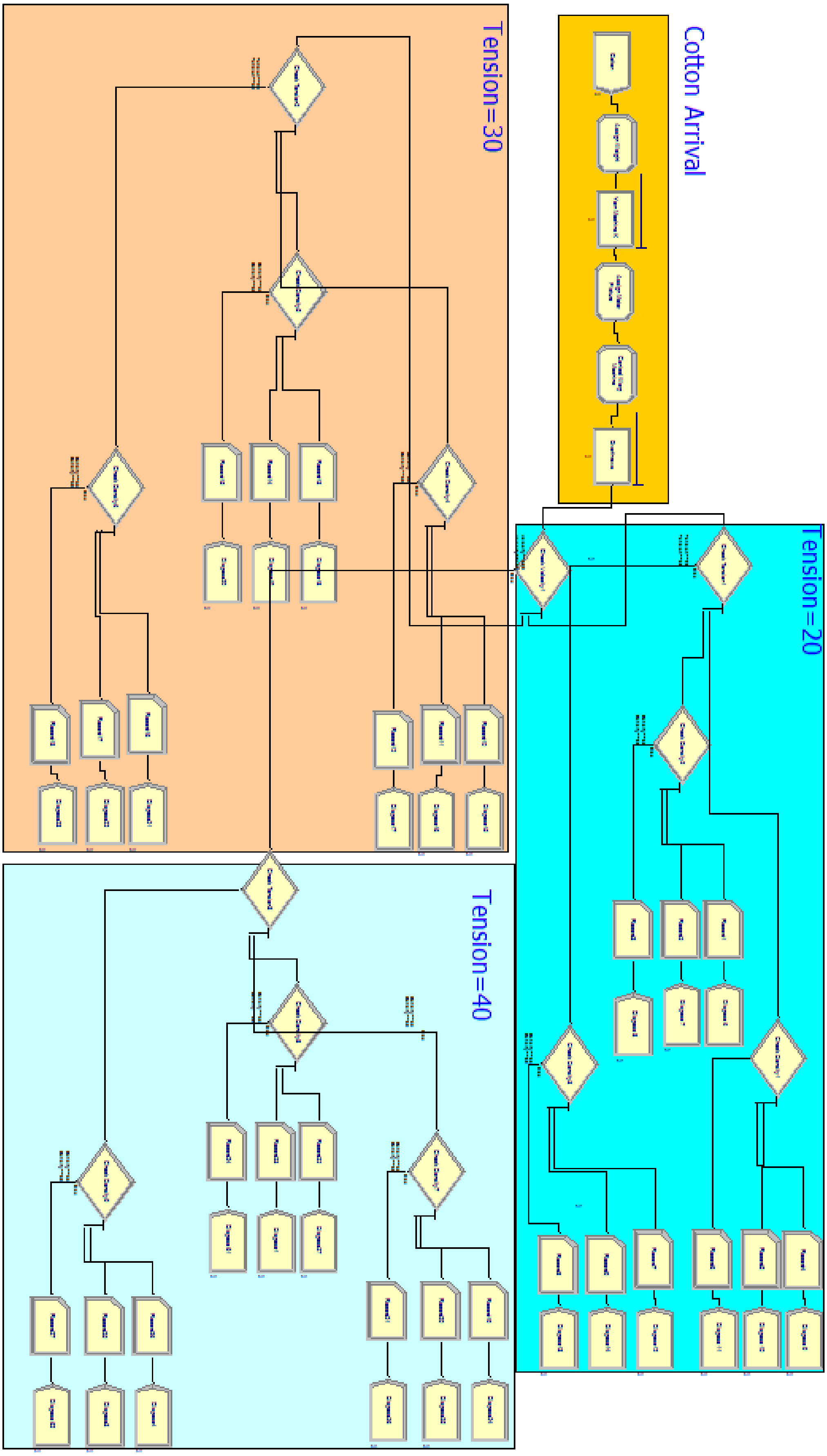


Figure 5 Snapshot from the Arena simulation model.

Stochastic data and values used in the simulation model are given Table 6 below.

Table 6 Data type, distribution and input tables for the simulation model.

Data type	Distribution	Tables in Appendix
Cotton Arrival Kilos	Empirical	(See Appendix J Table J.1)
Conical Warp Machine Parameter (Velocity)	Discrete	(See Appendix J Table J.2)
Conical Warp Machine Parameter (Density)	Discrete	(See Appendix J Table J.3)
Conical Warp Machine Parameter (Tension)	Discrete	(See Appendix J Table J.4)

6.3 Verification, Validation and Black-Box Model

This part describes the verification, validation tools and a black-box model to obtain a base simulation model for modelling warp breaks.

6.3.1 Verification

Verification is concerned with building the model right (Banks et al. 2010). It examines if the conceptual model and the computerized version of the model matches. Following verification tools employed on the model. First tool is someone else checked the model (Banks et al. 2010).To do this, woven chief checks whether the computer model has logical errors in the flow of entities (Banks et al. 2010). Model is also built modularly and each different section is represented by a different color to ease understanding. Second tool is to compare input and output data if unlogical relations and results are obtained. Also, a structural walk-through is conducted through research assistants in the university.

6.3.2 Validation

Confidence interval test is applied in this part. Confidence interval test determines whether the simulation model and real system are close enough (Banks et al. 2010). 676 breaks are observed from the simulation model by using monthly stochastic dataset. (See Appendix K for details of confidence interval test and required accurancy). Confidence interval test is applied and the lower bounis calculated 598 and the upper bound is found 754. Table 7 gives the calculation of minimum number of replications, that is found as 506 for the base simulation model.

Table 7 Table of number of replications

n	500	501	502	503	504	505	506
$\left(t_{\frac{\alpha}{2}}, n-1S_0\right)^2/\varepsilon^2$	505	505	505	505	505	505	505

6.3.3 Black Box Model

Black-Box model defines a function between inputs and outputs in the system. Figure 6 shows inputs and output variables for the simulation model.

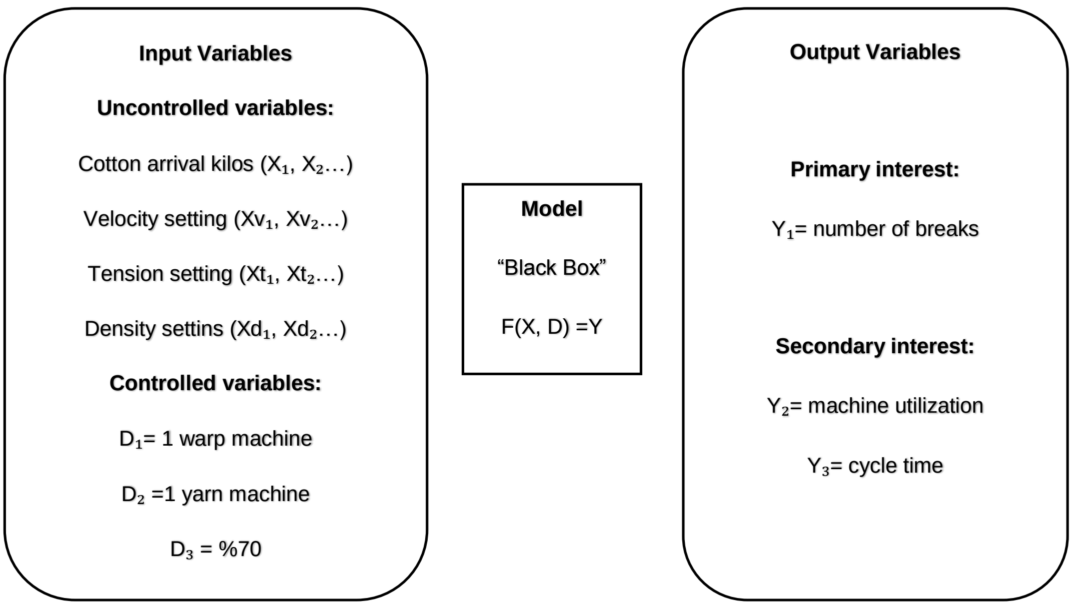


Figure 6 Black-Box model.

Input variables includes uncontrolled and controlled variables. Uncontrolled variables consist of cotton arrival kilos, velocity, density and tension settings. Cotton arrival kilos are entered into the system stochastically by using empirical distribution data. Types of machine settings consist of discrete distributions. Controlled variables are the number of warp and yarn machines and cotton weight convergence percentage. One warp and one yarn machine is used in the simulation model. When cottons are entered the system, 70 percent of cotton feed into yarn machine.

Output variables includes primary and secondary interest performance measures. The major problem is number of warp breaks (Y_1). Also, machine utilization (Y_2) and cycle time (Y_3) can be observed as secondary interest in the system.

CHAPTER 7: RESULTS

This part of the thesis study includes results of the application of Six Sigma DMAIC methodology and the simulation model. In Section 7.1, the results of the define phase are given. In Section 7.2, the results obtained from the measure phase are represented. In Section 7.3, results from the analyze phase are given. In Section 7.4, results from the improve phase are described and in Section 7.5, the results of simulation model are explained. Table 8 shows subsection number and related results for each phase of DMAIC methodology and the simulation model.

Table 8 Subsection number and results related with each subsection.

Subsection Number	Subsection Name
7.1	Results of define phase
7.2	Results of measure phase
7.3	Results of analyze phase
7.4	Results of improve phase
7.5	Results of simulation model

7.1 Results of Define Phase

During the define phase, the root factor analysis using CTQ tree diagram and SIPOC analysis are used. With root factor analysis, the needs and correspondingly the specifications are identified (See Figure 7). The SIPOC analysis introduces suppliers for the problem, inputs, process and customers with a schematic display (See Figure 8).

7.1.1 CTQ Tree Diagram

The CTQ Tree Diagram is applied to get a formal visualization of the "Warp Break" which is the problem that is expected to be improved with the highest average value (See Chapter 3). Figure 7 provides a visual overview of the topics that need improvements in general. In order to reduce the ratio of warp breaks according to the tree diagram below, the yarn production without error and the optimal working of the machines have a crucial role. In this thesis, CTQs are determined in the tree diagram to improve the warp breaks. For this reason, it is planned to reduce the warp break by performing lean studies.

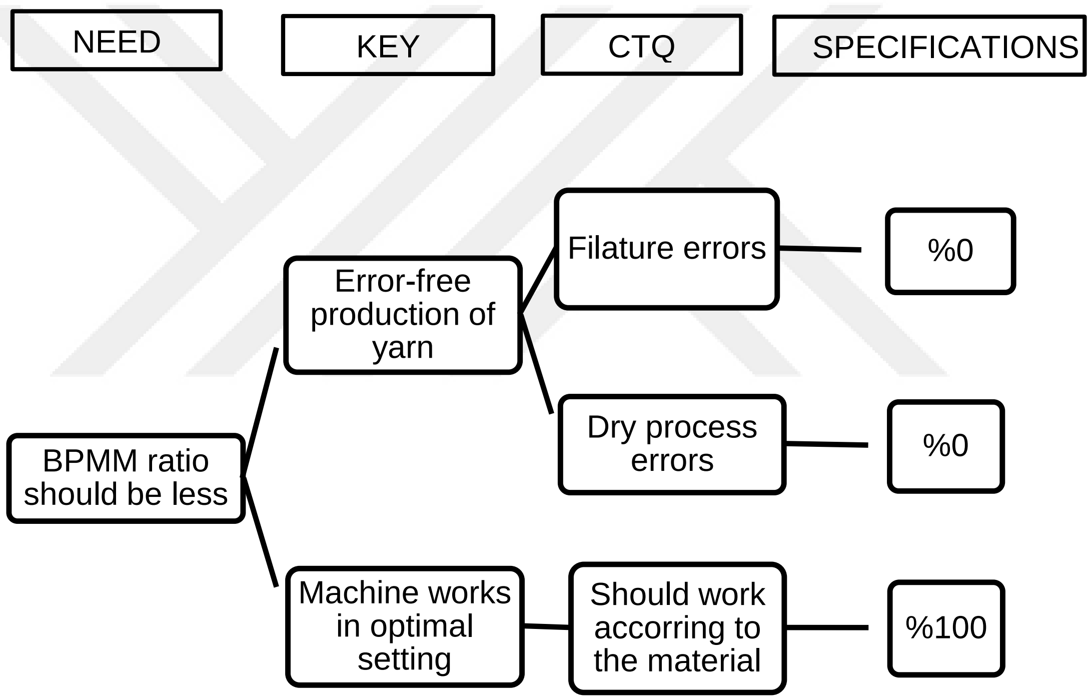


Figure 7 CTQ Tree-Diagram.

7.1.2 SIPOC Analysis

SIPOC analysis is another step in the define phase. With this analysis, suppliers, inputs, processes, outputs and customers are determined for the problem. Weaving and Weaving Draft department uses the output of the process according to the following schematic representation. Since basic process steps can be seen through the SIPOC analysis, it plays a supporting role for the path to be followed for the improvements.

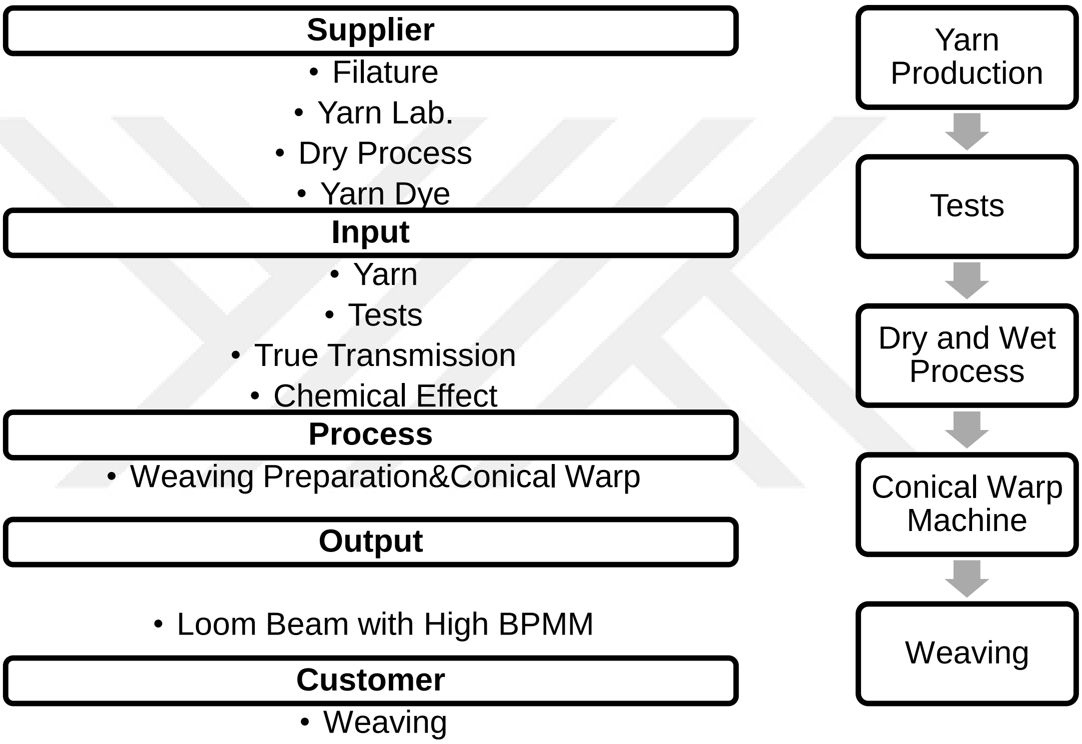


Figure 8 SIPOC Analysis.

7.2 Results of Measure Phase

In the measure phase, analysis of time series for BPMM is performed (See Figure 9). Then, Pareto analysis of BPMM for the particular yarn type is conducted (see Figure 10). Finally, capability analysis is used. With this analysis, whether warps are at the required customer specifications is determined (see Figure 12). In case of not meeting the required specifications, the purpose of orientation to the problem is identified.

7.2.1 Analysis of Time Series for BPMM

In this thesis study, the problem of "warp break" in the weaving preparation machines is investigated through the "break in millions meters" unit. Million-meter break is the number of breaks in a million meters of yarn. For example, there are 1,000,000 meters of yarn on a 100 meters loom beam with 10,000 ends. The break formula for the millions meters is given below (see formula 7).

By using this formula, it is calculated how many times the warp breaks in million meters in the conical warp machine are performed in million meters.

$$BPMM = \frac{\text{Total Yarn Break}*1.000.000}{\text{Total Yarn Meter}} \quad (7)$$

According to BPMM, the analysis of time series plot for the year of 2015 is given in Figure 9. The month in which the highest number of breaks is observed. BPMM difference between the first and second semesters is due to work with finer yarns in the 2^{nd} semester and seasonal trends. In this chart, 7 different yarns are determined for both seasons, and data are collected depending on them.

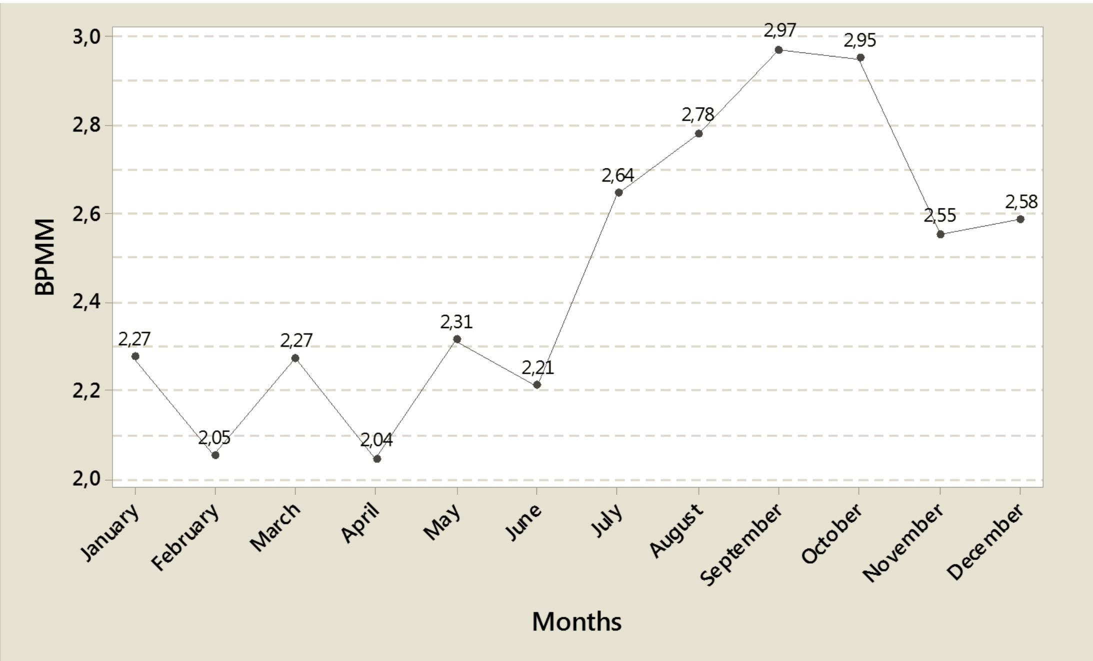


Figure 9 Time Series Plot for BPMM.

7.2.2 Pareto Analysis for BPMM

The Pareto analysis in Figure 10 shows total yarn counts for each yarn number of these seven different yarn numbers addressing both seasons for the year of 2015. According to the chart, the most ordered yarn is the 70/1 UEOOCD (70 number of single fold compact weave), and therefore it is the most used one.

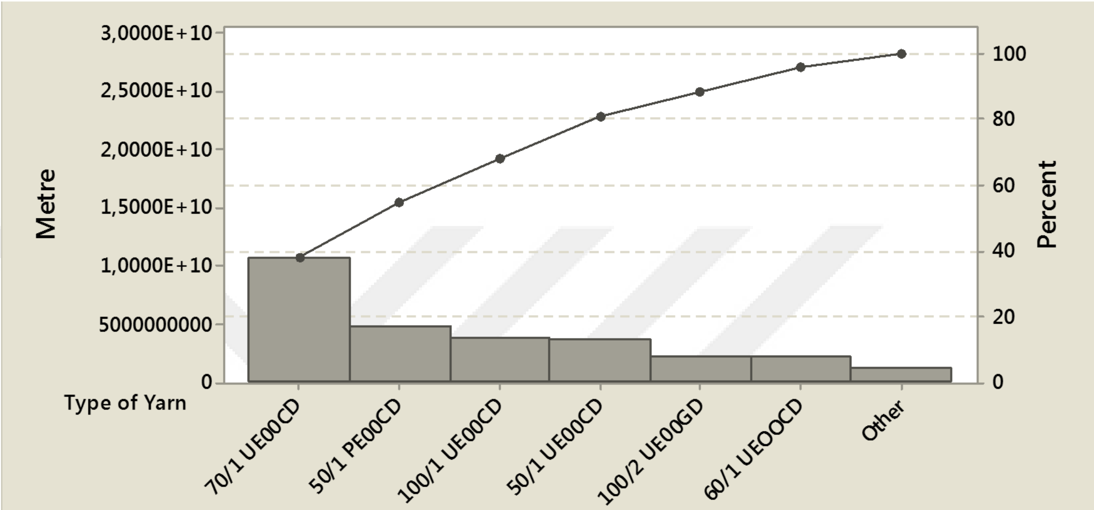


Figure 10 Pareto Chart for yarn type 70/1 (meters).

Figure 11, shows the Pareto analysis for the month of September when the BPMM ratio is highest, it presents the most broken yarn as 70/1. Figures 10 and 11 show that 70/1 is the most used yarn types and the most broken yarn among seven different numbered yarns addressing both seasons.

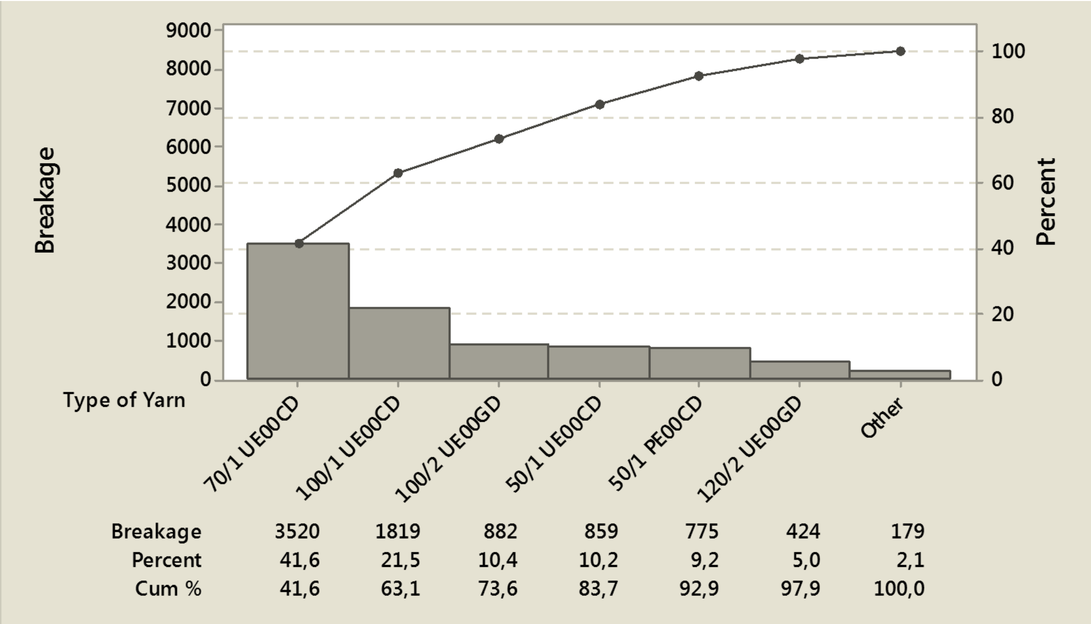


Figure 11 Pareto Chart for yarn type 70/1 (breaks for September).

7.2.3 Capability Analysis

Using Minitab 17 software (Minitab, 2017), process capability analysis for yarn number 70/1 is determined weekly for the year of 2015 in Figure 12. With this analysis, it is determined whether BPMM in the conical warp line is within the customer specification (weaving department). Process capability is calculated by the ratio of customer specification values to the standard deviation of the process (Ozveri and Cakır, 2012).The area outside upper limit area is error area, which refers to non-specification area. Figure 12 has two different values. They are P_{PK} and C_{PK} values. The overall value covers all the values measured over a year, and the considered as the best value is in the short-term process. P_{PK} is the long-term competence of the process and C_{PK} is the short-term competence of the process. (P_{PK}= 0.02, C_{PK}= 0.03). In this process, the long-term competence may rise up to a maximum of 0.03, so there is no great improvement ability in this process. BPMM value is far from the limit requested by the customer.

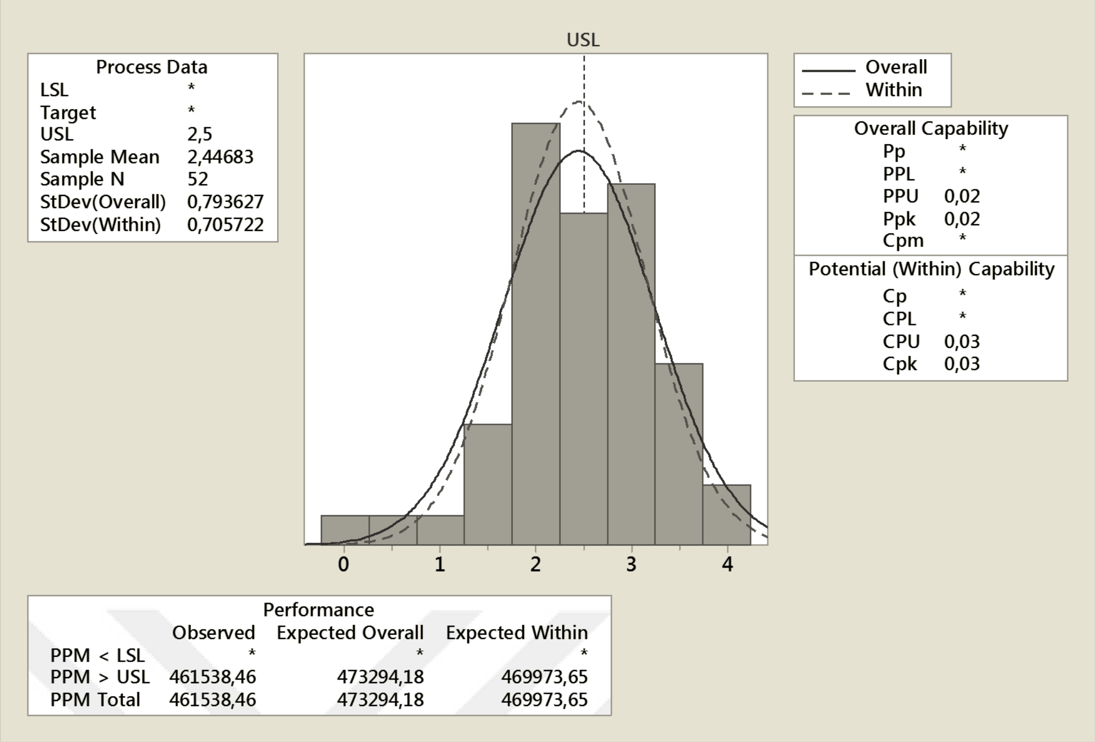


Figure 12 Process capability report for 70/1 UEOOCD.

7.3 Results of Analyze Phase

In the analysis phase, the main reasons of warp breaks are determined in four main categories by the use of cause and effect diagram (See Figure 13). At the studies performed in the filature and dry process line, the yarn break types are analysed. As with the pareto chart (See Figure 16), the type of the error that causes the most break is identified. By the help of pie chart (See Figure 17), distributions of these breaks on the machine types are found. By applying variance analysis (See Section 7.3.3), the effects of the yarn knot types on the breaks in the filature and dry processes are statistically calculated. The interval plot graphic is used during this analysis.

7.3.1 Cause and Effect Diagram

Root causes of BPMM are identified in the cause and effect diagram and the causes of errors are shown. In the cause and effect diagram, Figure 13 shows 4 main factors as the causes.

These factors are: raw material, dry process, filature, conical warping machine. Figure 9 presents underlying causes for each factor. It is considered that each root cause causes BPMM in this area.

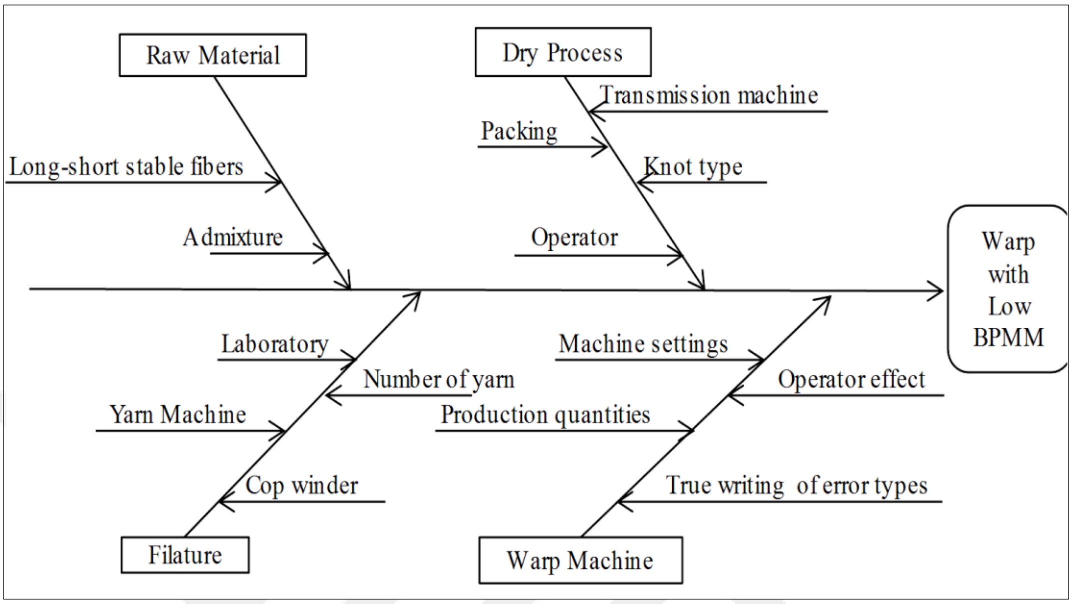


Figure 13 Cause and effect diagram.

7.3.2 Studies on Filature and Dry Processes

According to Figure 9 in the measure phase, September has the highest BPMM ratio. Pareto analysis for the break error types is performed for September. Figure 16, presents Pareto analysis of September. It is observed that the most common types of error breaks are poor insertion and truncation errors.

Poor Insertion Error: It is the type of error that occurs by breaks of knotted part in the previous processes due to the breaks.
Truncation Error: These are breaks due to friction and abrasion in the yarn.

Figure 14 Poor insertion error.

Figure 15 Truncation error.

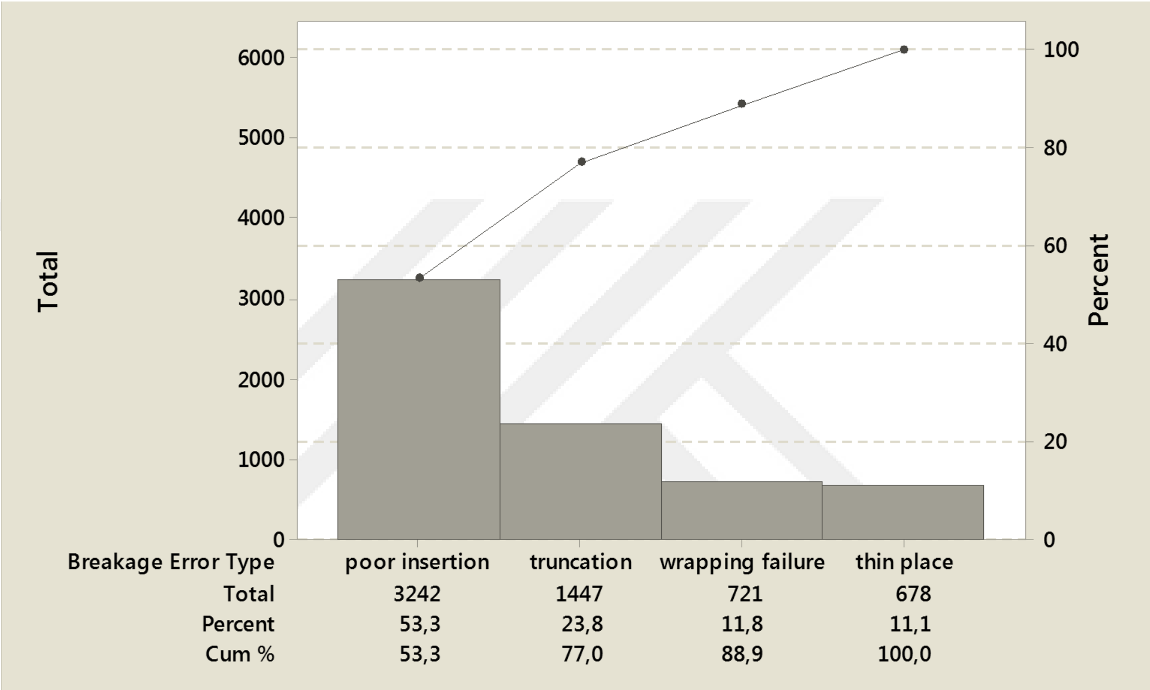


Figure 16 Pareto Chart for break errors in September.

According to the Pie Chart Analysis, that is applied for September, Figure 17 shows that error rates on all machines are similar. For this reason, there is no relation between error types and machine types.

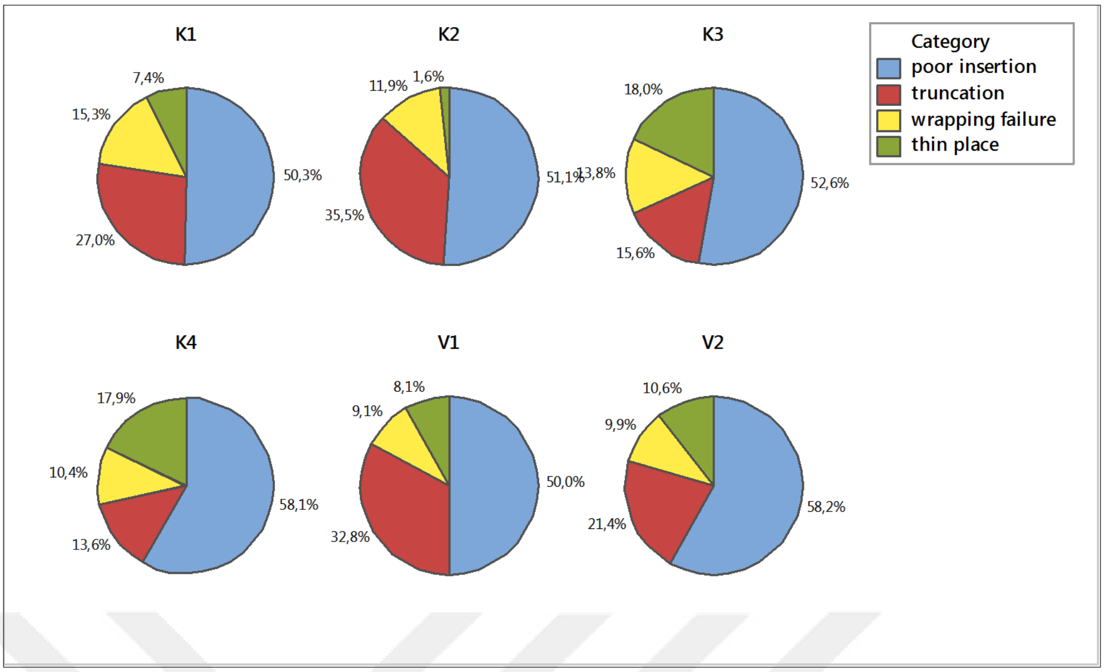


Figure 17 Pie chart for error types.

Figure 10 and 11 show that the yarn number 70/1 is the most commonly used yarn, leading to the most frequent breaks. Split yarns are knotted in two different ways in operation, *Hand knot* and *Splice*.

In order to compare the breaking strength of the yarn, strength test with 10 pieces is carried out for 70/1 single bobbins in hand knot, splice and knotless sections. The average tensile strength values (RKM) are shown in Table 9.

Table 9 Strength test.

Type of Knotting	Average of Tensile Strength Value (RKM)
Hand Knot	20,32 RKM
Splice	16,93 RKM
Knotless Yarn	22,04 RKM

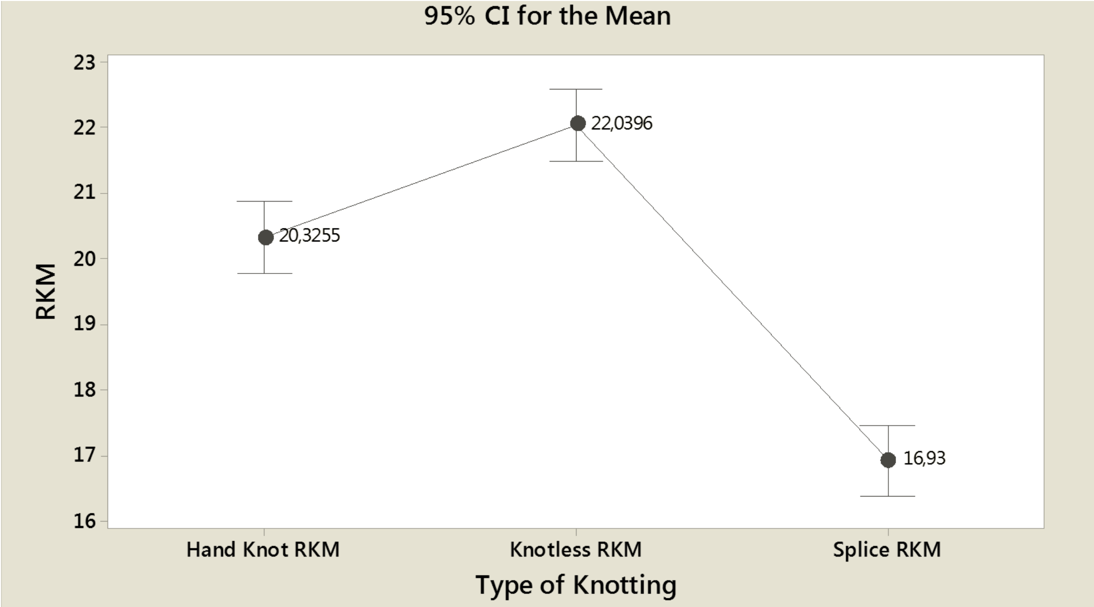


Figure 18 Comparison of interval plot of RKM values to type of knotting.

7.3.3 Analysis of Variance

H_o: There is no difference in the average of strength between the types of knots.
H_a: There is difference.

According to the results of the variance analysis, the hypothesis H_a is accepted because p-value is less than 0.05 in the 95% confidence interval. As a result of the analysis, R-sq. value is increased to 87.83%.of the node types are effective on RKM. Therefore, it is necessary to improve the splice with the lowest RKM value according to Figure 18. Splicing and bonding are performed in filature and dry process sections in the factory.

The number of yarn breaks in an another test on 100,000 meter of yarn on 70/1 is shown in Table 10. It is observed that 93% of the yarns is broken in the filature and 7% is broken in the dry process.

Table 10 Yarn test break values.

Type of Process	Break/100.000 MT
Filature	36.64 breaks
Dry Process	2.8 breaks

7.4 Results of Improve Phase

Another factor affecting the CTQ tree diagram and the BPMM in the identification phase is determined to work at optimal values of the machine settings. In this section, the improvement work on the conical warp machines line is examined.

7.4.1 Studies on Conical Warp Machine Line

There are 7 conical warping machines in the weaving preparation line, and different setting types are available for each machine. In Figure 19, BPMM break averages for September when maximum number of the breaks at the existing machines occurs in the weaving preparation line are observed. During the review, this circumstance happens on yarn numbered 70/1, the greatest break is identified at K1 conical warp machine.

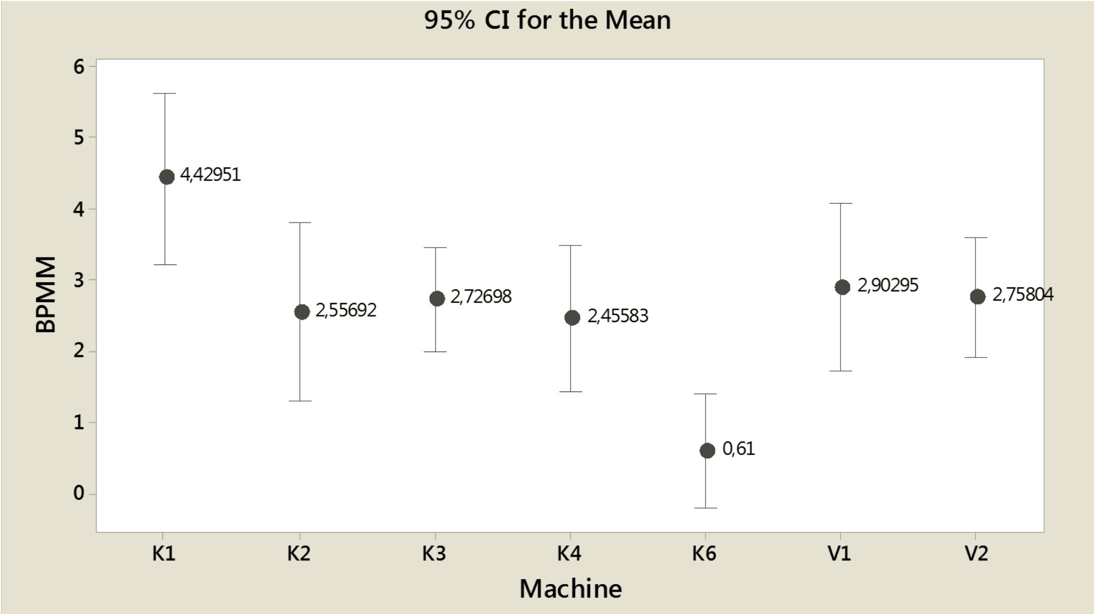


Figure 19 Interval Plot of BPMM.

It is considered that the reason for the high average BPMM in K1 machine is that the machine does not work in optimal settings. For this reason, an experimental design (DOE) in K1 machine is arranged. In the first stage, the factors to be investigated in the experiment, the levels of these factors and the output variable to be measured are determined. In the second stage, the experimental design is determined.

Three different factors are identified for this experimental design, these are:

Warp Density: Number of wires per centimeter is warp density.
Machine Velocity: The velocity value at which the yarns are exposed by the machine during spinning.
Yarn Tension: The tension that the yarns are exposed to by the machine during spinning.

Table 11 Factors of the experimental design and corresponding levels.

Factors	Level 1	Level 2	Level 3
Velocity (m/min)	300	450	600
Tension (CN)	20	30	40
Density (wire/cm)	55	60	65

In this study, there are three factors, each with three levels. Values of these levels are sorted from the smallest to the highest. In other words, while Level 1 has the minimum values, Level 3 has the maximum values. These levels are given in Table 11. In the study, a 3^3 full factorial experiment design is used. In order to evaluate all the existing situations in this design, it is required to realize different 27 test combinations. These combinations are given in Table 12. So as to increase the accuracy of the experiment, two replications are applied for each trial combination and a total of 54 observations are obtained.

Table 12 Different 27 test combinations.

Test Number	Factor			Testing Combination (Level)
	A (Velocity) (m/min)	B (Tension) (CN)	C (Density) (wire/cm)	
1	300	20	55	111
2	300	20	60	112
3	300	20	65	113
4	300	30	55	121
5	300	30	60	122
6	300	30	65	123
7	300	40	55	131
8	300	40	60	132
9	300	40	65	133
10	450	20	55	211
11	450	20	60	212
12	450	20	65	213
13	450	30	55	221
14	450	30	60	222
15	450	30	65	223
16	450	40	55	231
17	450	40	60	232
18	450	40	65	233
19	600	20	55	311
20	600	20	60	312

21	600	20	65	313
22	600	30	55	321
23	600	30	60	322
24	600	30	65	323
25	600	40	55	331
26	600	40	60	332
27	600	40	65	333

Once it is decided to carry out the experiment on the K1 conical warp machine, among the orders given to the enterprise a quality including 70/1 warp yarn is selected to carry out a test. This quality is a quality which has 635 ends, in other words warp yarns. To ensure the accuracy of the experiment, it is decided to wrap 2 bands for each experiment and each band contains 635 warp yarns and 1500 m. yarn is drawn in each experiment. The band is the warp yarn wound on the warp beam. The total yarn meter pulled for each experiment is given in the following. Experiments are performed individually for each testing combination. In order to prevent interaction during the experiments, the sequence of the experiment is performed randomly. This equation shows the used meter of yarn per each experiment (see equation 8).

2 (bands)*635 (ends)*1500 (meters)=1.905.000 meters of yarn per each experiment (8)

7.4.2 Graphical Analysis of the Experiment

In this study, Minitab 17 (Minitab, 2017) software is used and the effects of 3 factors with 3 levels in the experimental model are investigated. The main effect plot table gives the main interactions of the factors independent from each other.

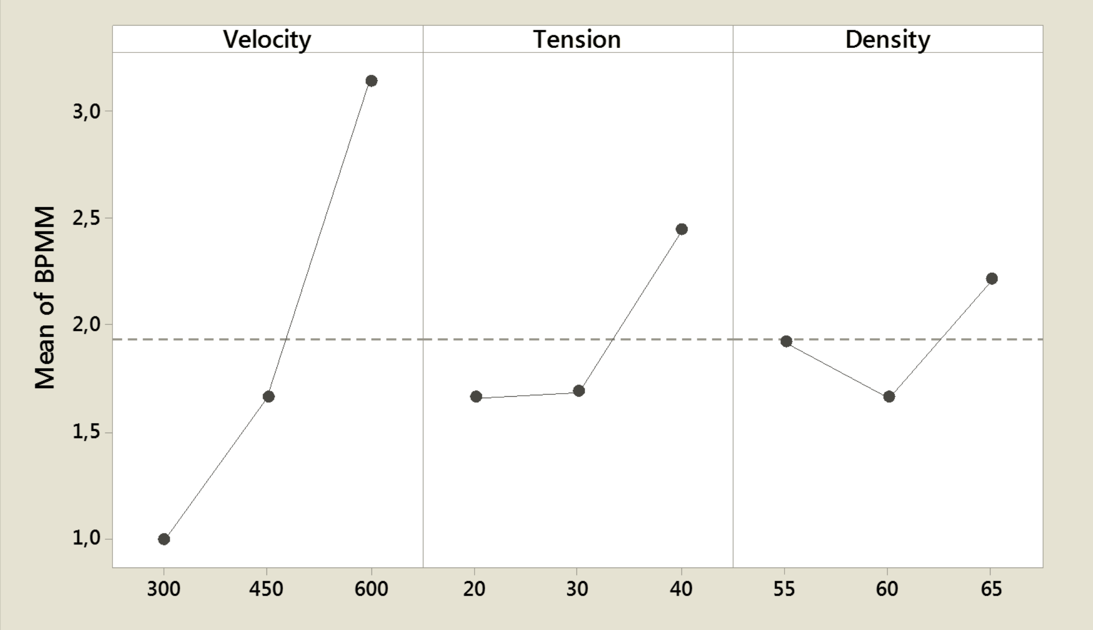


Figure 20 Main effects plot for BPMM

At the main impact graph in Figure 20, the effect of the each input factor on BPMM can be observed.

• The minimum BPMM ratio is observed when the velocity factor is at Level 1.
• The minimum BPMM ratio is observed when the tension factor is at Level 1.
• The minimum BPMM ratio is observed when the density factor is at Level 2.

The interaction plot graph, another analysis method, gives the interactions of the factors. Figure 21 interaction plot shows the interaction between two factors. According to this graph, tension and density are two input factors influenced from each other.

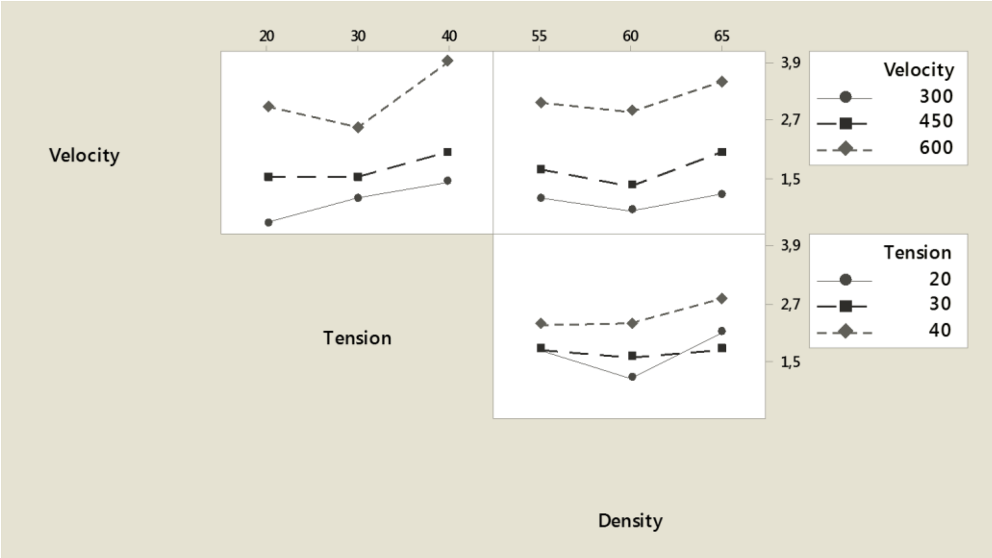


Figure 21 Interaction Plot for BPMM.

7.4.3 Analysis of Full Factorial Experimental Design

The ANOVA table which is acquired in Minitab 17 software (Minitab, 2017) is given in Table 13. The analysis results are interpreted within the 95% confidence interval and the risk level taken is expressed by the p-value.

With regard to the impact of a factor, the risk level corresponding to this factor should be less than the specified risk level. That is, it is interpreted that the F-values are greater than the existing F-values. Here, it is interpreted over p values. The variant analysis of BPMM values at the end of the experiment is given in Appendix L. As p-value is greater than 0.05 within the 95% confidence interval, the 2-way interactions are not effective on the output factor. Each of the input factors which are velocity, density and tension affect on the output variance because p-values are smaller than 0.05. Each input factor is effective on the output factor as the main impact, however they do not impact on the output factor as 2-way interactions. As the 3-way interaction factor is bigger than 0.05 by means of 95% confidence level, it is not effective on the output variance. The ones whose p-value are bigger than 0.05 are not effective on BPMM break. For this reason, the ineffective ones are removed from the model and re-analyzed .

Therefore, as the p-values are bigger than 0.05 and they do not an impact on the output statistically, the 2-way and 3-way are removed from the model and re-analyzed at Minitab. 2-way values are VelocityxTension, VelocityxDensity, TensionxDensity and 3-way value is VelocityxTensionxDensity. In order to perform the variance analysis, firstly, the variabilities are calculated. After that, these variabilities are divided by the degrees of freedom (*) and average variances are obtained (Demir, 2004).

Table 13 Variance Analysis for BPMM

Source	Total of the Squares	Average Squares	F-value	Significance Level (p-value)
Velocity	43.82	2.91	70.48	0.00
Tension	7.14	3.57	11.48	0.00
Density	2.76	1.38	4.45	0.02
VelocityxTension	2.38	0.60	1.92	0.13
VelocityxDensity	0.31	0.08	0.25	0.91
TensionxDensity	1.32	0.33	1.06	0.39
VelocityxTensionxDensity	1.42	0.18	0.57	0.79
Error	8.39	0.31		
Total	67.53			

(*) degrees of freedom

Table 13 shows the variance analysis of the test results. When the p-values of this table are examined, statistically that the 2-way and 3-way interactions above 5% have no effect on BPMM. Starting from this point, it is observed that individual interactions are effective on BPMM. Using thevalues as the estimated experiment values obtained from previous analysis, variance analysis is applied in Minitab software (Minitab, 2017). The difference between experiment results and actual values is called the error which is also named as residual and it is expected to be minimum.

The regression model formula obtained from the result of the first analysis is given in Appendix M. The re-analyzed results obtained after eliminating the factors which are not affecting the model in the equation (9) are given in Table 14.

Table 14 Variance Analysis for BPMM after removing factors.

Source	Total of the Squares	Average Squares	F-value	Significance Level (p-value)
Velocity	43.81	21.91	74.55	0.00
Tension	7.14	3.57	12.14	0.00
Density	2.77	1.38	4.70	0.00
Error	13.81	0.29		
Total	67.53			

Regression Model is given in the below;

BPMM=1, 9311- 0,942 Velocity_300- 0,272 Velocity_450+ 1,214 Velocity_60- 0,272 Tension_20- 0,242 Tension_30+ 0,514 Tension_40- 0,012 Density_55 - 0,271 Density_60+ 0,283 Density_65 (9)

Regression equation defines the minimum number of BPMM value. The value found according to the equation is the estimated value, and the experiment results the actual values. Coefficients give the minimum warp breaks in the formula. In the second analysis, the R-sq. value is obtained as 79.55%, these remaining 3 input factors explain 79.55% of the output factor. The improvements that are performed on the input factors of velocity, tension and density have 79.55% of an improvement potential over BPMM.

Figure 22 shows the distribution of residual values. In order to get an optimum model, it is required to decrease the differences between actual values and estimated values into minimum. This analysis is a graphical analysis which shows the distribution of the residuals and differences between actual values and estimated.

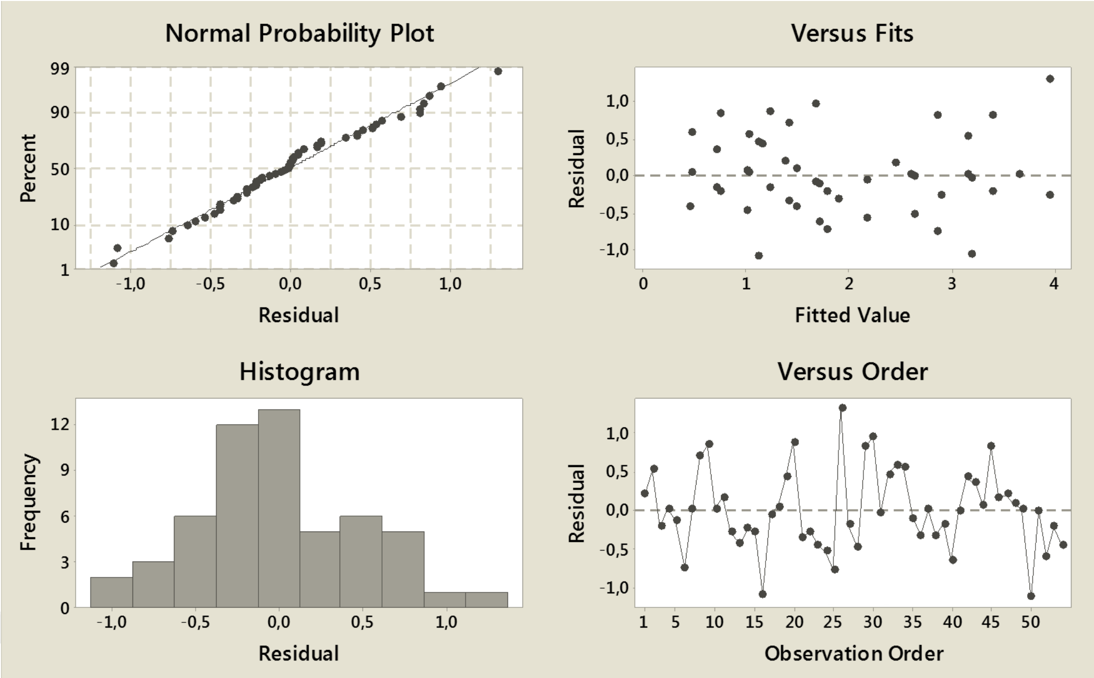


Figure 22 Residual Plot for BPMM.

According to the Normal Probability Plot graphic in Figure 22, the residual values should show normal distribution and these values carry the experiment to the optimal result. Residual values being normal show that the model is accurate and significant.

According to scatter plot for residuals in Figure 22, the points are the estimated values, x-axis is the estimated actual value. As the values on x-axis increase, the range between the residual variance should increase. In other words, it does not show a trend upwardly. In this respect, the testing of the model is correct. Fitted values are the estimated values.

According to the histogram in Figure 22, some of the data takes place at right and some of them are located at the left of the average.

According to residual with observation order in Figure 22 shows the difference between the actual and estimated values according to each observation sequence. The difference between the actual value and estimated value, i.e., the residual, is to be in minimum. This shows the correct modelling of the process.

For the testing of the model, the normal distribution of the residuals presents no wide range occurrences.

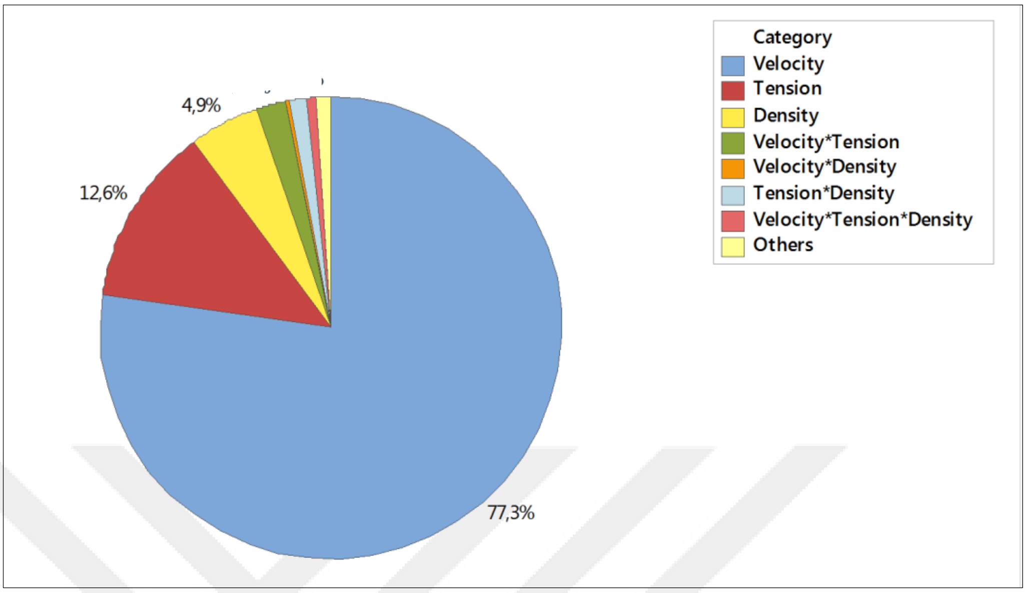


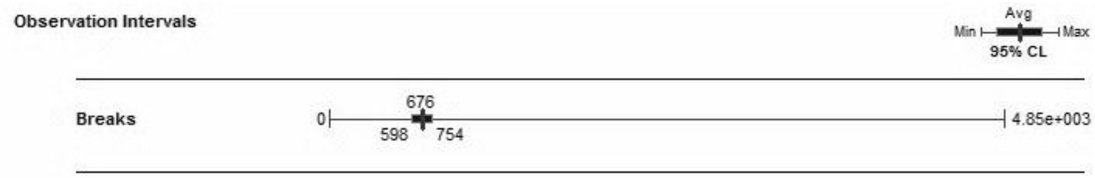
Figure 23 Pie chart

Another graphical analysis is pie chart for one-way, two-way and three-way effects. According to Figure 23, machine velocity is 77.3% effective on BPMM. Density and tension affect 17.5%. So, these three factors have 89.9% significant impact over warp breaks.

7.5 Output Analysis with Simulation

This section, the results of confidence intervals for primary (i.e., warp breaks,Y_1) and secondary performance measures (i.e., utilization, Y_2, and cycle time, Y_3) given in the Black-Boxmode (See Seciton 6) are discussed. The type of the output analysis for the Arena simulation model is terminating output analysis. The reason is that short-term analysis of BPMM is aimed. Performance measure is defined as the number of warp breaks for different density, velocity and tension values. Figure 45 shows confidence interval test that average number of breaks are obtained as 676. Real system breaks are given 680 for one month in machine K1. The lower bound is calculated as 598 and the upper bound is 754 in the confidence interval test.

According to these results, real system breaks are inside the confidence interval. Real data results and simulation results are so close.



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Breaks	676	685	77.9	0	4.85e+003	300

Figure 24 Confidence interval for number of warp breaks.

According to the results of simulation model, average utilization (Y_2) of warp machine is found as 84%. With regard to the confidence of the utilization, the minimum value is 76% and the upper bound utilization value is calculated as %98.

$$680\ breaks * 99\ secs = 67320\ total\ lost\ time \quad (10)$$
$$3600\ secs/67320 = 18.7\ total\ lost\ time\ hourly \quad (11)$$
$$18.7 * 100/672\ hourly\ work/month = 2.78\ utilization\ lost \quad (12)$$
$$100 - 2.78 = 97.22\ warp\ machine\ utilization/month \quad (13)$$

Equation (10) shows total lost time, it is found by multiplying the single break lost time, 99 secs. Equation (11) shows total hourly lost lost time. Equation (12) represents utilization lost for warp machine and the last equation (13) calculates K1 warp machine utilization for one month according to real system data. According to these calculations, real system utilization of 97.22% is inside the confidence interval for the warp machine utilization. When stochastic input data is used, the simulation model captures the real system utilization.

Further, confidence interval for cycle time (Y_3) is calculated. To do this, mean cycle time is found 616 mins, the lower bound of cycle time is calculated as 558 and the upper bound is found as 692 mins. Therefore, this process takes approximately 10-12 hours on the real system.

CHAPTER 8: CONCLUSIONS AND FUTURE WORK

8.1 Introduction

This section summarize main conclusions from the thesis study, and discuss practical and theoretical contributons.In Section 8.2, main concluding remarks are highlighted. This is followed by the discussion on future research in Section 8.3.

8.2 Concluding Remarks

In this study, the data for the yarn type of 70/1 collected for one year in weaving preparation line. The aim of this study is to get high quality warp beam by increasing of the woven fabric yield.

High rate of warp breaks is one of the most important factors that affect the quality. One of the most important quality problems in woven fabrics is the tendency to break in warps during weaving. Therefore, having the smallest break rates is crucial in the textile sector.

The most important quality problem is determined with AHP (Analytic Hierarchy Process) analysis. Firstly, five different CTQs are found in weaving preparation line together with survey results obtained from factory managers. Then, it is decided to improve the warp break problem according to the order of quality importance.

The application area of the Six Sigma in the literature is very wide. However, there is no working area where the actual data is used in the weaving preparation line. When previous studies in the literature are examined, the solution of the Six Sigma method depends on the type of the problem. Factors determined by statistical analysis using Six Sigma DMAIC methodology reduce the number of warp breaks. These factors are: density, velocity and tension. Different levels of these factors are applied as different settings of the conical warping machines in weaving preparation line. The theorical contribution of this study could be the first study that attempts to apply Six Sigma DMAIC methodology and simulation modelling in a textile production process. With regard to practical contributions, practitionars could benefit on the reduction of warp breaks and increase in quality and monetary savings.

Each break is resulted with a 99 secs machine downtime. Therefore, lost time due to the machine interruptions is an another problem in the system. High quality product production is very significant for textile sector. Because of this reason, the first aim is to improve the fabric quality. The second problem is machine down time because if machine velocity increase, the number of warp breaks increase. Therefore, a new warp machine can be added instead of increasing the machine velocity.

In this study, general effects of the warp breaks affecting fabric quality on spinning mill, dry process and weaving preparation lines are examined. This study applies a 3^3 factorial experiment design on warp machines. Another research technique applied in this study is simulation modelling, in which an average break value is obtained in the model using constraints on real data and experiment design. Tables 15 and 16 present the results of experimental design model.

Table 15 Comparison of results based on average breaks.

Machine	Average Machine Downtime (sec/break)	Breaks number/ month	Total downtime (hour/month)	Efficiency Loss (%)
K1 (warp machine)	99	309	8	1.19

1 month = 28 days = 672 hours

Table 16 Comparison of results based on total fabric meters per month.

Machine	Total meters/month	Target meters/month	Lost meters/month
K1 (warp machine)	191.645.756	193.953.806	2.308.050

According to the experimental design results, total breaks are found as 199 for 102,870,000 meters. If the results are assumed for one month, the average breaks is calculated as 371. Real system breaks are given as 680 for September. The difference between the breaks is calculated as 309. The high difference may be due to the raw material of the yarn, the conditions or the production process.

Table 15 and 16 show lost in meter calculations. Monetary savings is calculated as 23,080 TL/month for K1 machine. Equation (14) showshourly breaks, it is found by multiplying the 3600 secs. Equation (15) shows total hourly stoppage. Equation (16) represents efficiency lost for warp machine and the other equation (17) calculates K1 warp machine total meters produce if have any breaks. Last equation (18) shows lost meters per monthly.

$$99 secs/break/3600\ secs = 0.0275\ break/hour \quad (14)$$

$$309\ break * 0.0275\ break/hour = 8\ Total\ stoppage\ (hour/month) \quad (15)$$

$$100\ * 8/672 = 1.19\ Efficiency\ Loss\ (\%) \quad (16)$$

$$100 * 191.645.756/98.81 = 193.953.806\ Total\ m\ /\ month \quad (17)$$

$$193.953.806 - 191.645.756 = 2.308.050\ Lost\ m/month \quad (18)$$

Also, when the same machine settings are used, the average number of breaks is found as 676 in the simulation model. Simulation model provides average number of breaks under stochastic data using experimental data settings. Optimal machine settings giving minimum number of warp breaks is determined by the experimental design.

Average cycle time is found as 616 minutes in simulation model. Each break causes machine down time about 99 minutes for one machine so breaks increase the entity cycle time in the system. Breaks must be decrease to provide fast and quality products. Because of this reason entity cycle time include short time period in the system.

Warp machine utilization is calculated to be between 76%-98% confidence interval obtained from the simulation model. However, in real system it shows that 97%. Machine utilization is an important factor for this research, because %3 loss machine utilization means an average loss of six million meters. Because of that, machine utilization must be at high percent levels.

Other contributions of this study could be on the quality improvements since better fabric quality is obtained when the number of warp breaks is decreased. With the reduction on the warp breaks, customer satisfaction could be increased together with decrease in delivery delay time of the finished products. Better fabric quality is obtained when warp breaks are decreased. Because quality product is most important factor for customer satisfaction, also delivery delay time is decreased and customer satisfaction is gained.

8.3 Future Research

There are many reasons that affect warp breaks such as raw material, fraction, heat and moisture. For this reason, filature department could be considered for future research. Similar simulation and quality studies could be applied on dry process and/or filature department so that reducing the number of warp breaks can be ensured. Further, a more detailed simulation models could be developed with non-terminating analyses. By doing this, long-term analyses could be performed on the number of warp breaks.

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APPENDICES

Appendix A: AHP survey results and calculation of the values for pairwise comparison matrix

This scale is used in Chapter 3, Section 3.2.

The survey questions;

1) How many important issues that effect the fabric quality in the weaving preparation line (See Table 2)?
2) Could you rank of importance these CTQ's?
3) Which CTQ is effect the monetary savings directly?

The value of importance	Value definitions
1	Both factors have equal value
3	The first factor more important than the second factor
5	The first factor much more important than the second factor
7	The first factor more consistent than the second factor
9	The first factor has an absolute superior predication than the second factor
2,4,6,8	intermediate values

CTQ	A	B	C	D	E
A	1	1/3	1/7	1/5	1/9
B	3	1	1/5	1/3	1/7
C	7	5	1	3	1/3
D	5	3	1/3	1	1/5
E	9	7	3	5	1
Totally	25	16.33	4.672	9.53	1.782

CTQ	A	B	C	D	E	Average
A	0.04	0.02	0.03	0.021	0.062	0.035
B	0.12	0.06	0.04	0.03	0.08	0.067
C	0.28	0.306	0.21	0.315	0.185	0.260
D	0.2	0.186	0.07	0.104	0.113	0.134
E	0.36	0.428	0.65	0.53	0.56	0.504

Apeendix B: Emprical distributions for machine settings

This tables are used in Chapter 6, Section 6.6.1.

Table 17 Emprical distribution for velocity.

Cum. Probability	Values
0.33	300
0.66	450
1.00	600

Table 18 Emprical distribution for tension.

Cum. Probability	Values
0.33	20
0.66	30
1.00	40

Table 19 Emprical distribution for density.

Cum. Probability	Values
0.33	55
0.66	60
1.00	65

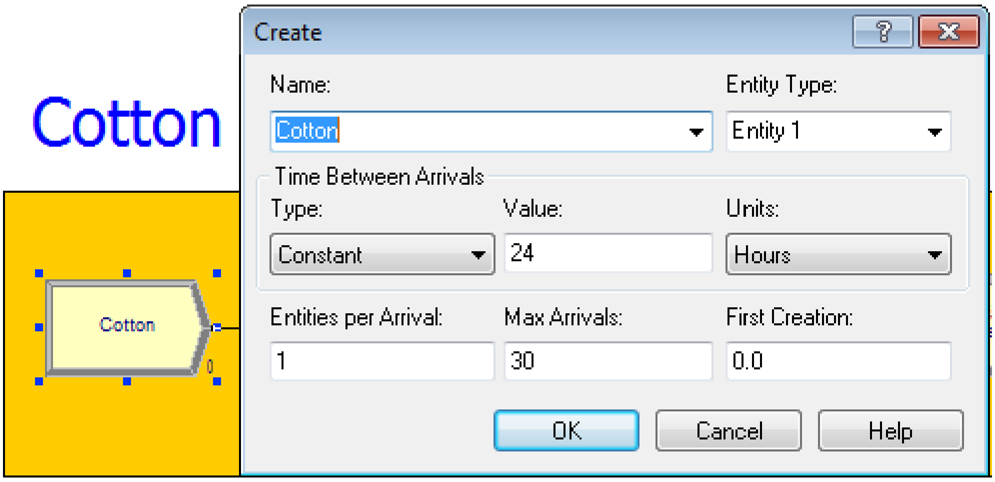
Appendix C: Distribution fits best to cotton kilos for Arena simulation model

Simulation distribution summary is used in Chapter 6, Section 6.1.2.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000,  0.999,
                              0.426, 24.428,
                              0.705, 47.857,
                              0.852, 71.286,
                              0.967, 94.714,
                              0.967, 118.143,
                              0.984, 141.572,
                              0.984, 165.001)


        Data Summary

Number of Data Points   = 61
Min Data Value          = 1
Max Data Value          = 165
Sample Mean             = 38
Sample Std Dev          = 33.3

        Histogram Summary

Histogram Range         = 0.999 to 165
Number of Intervals     = 7
```

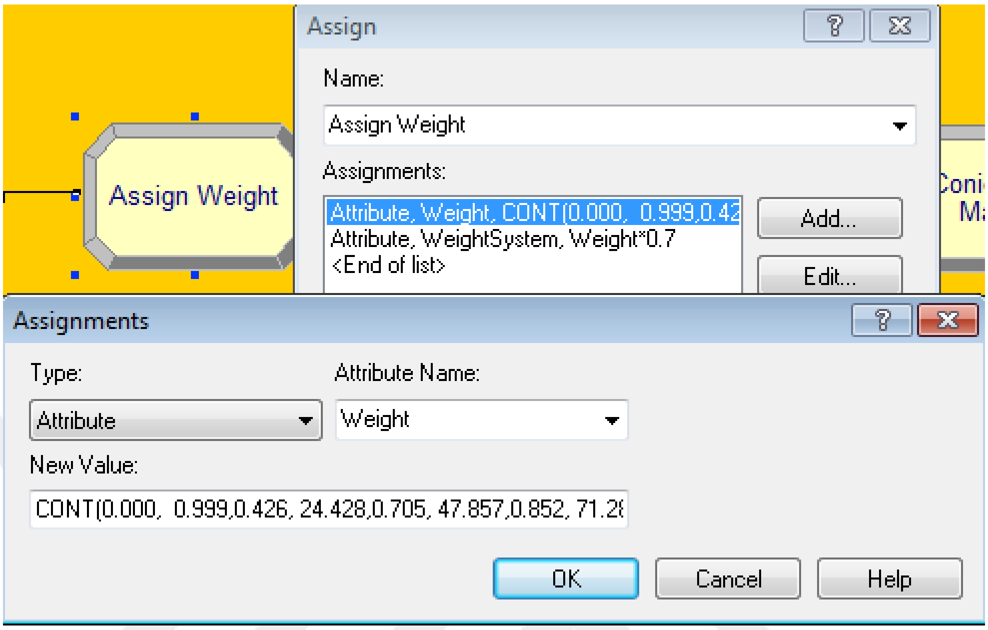
Appendix D: Create module

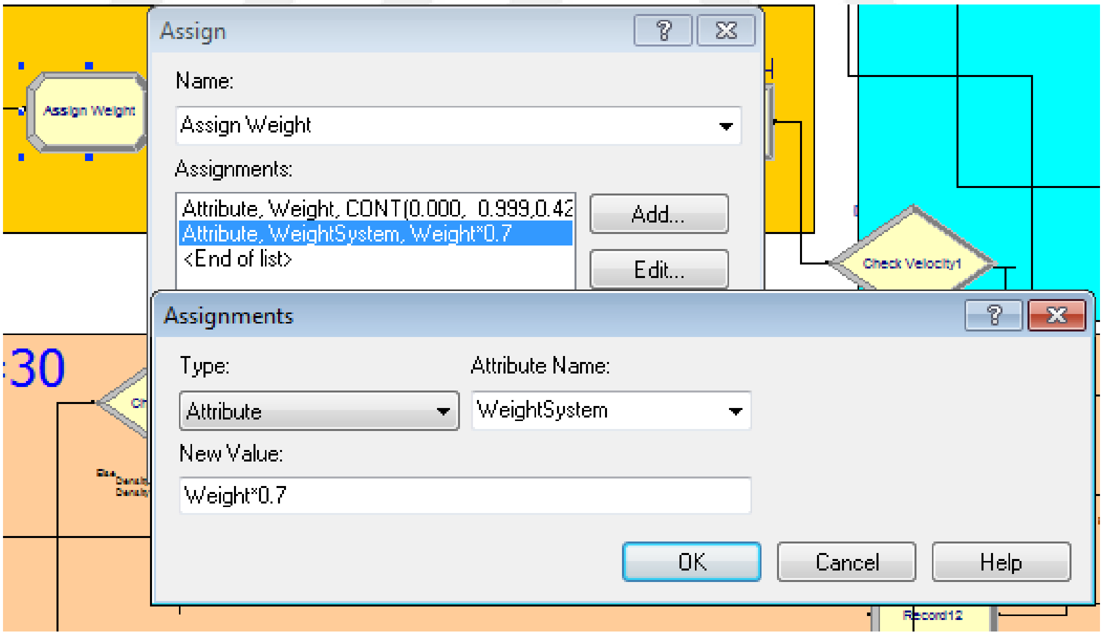
Create module is used in Chapter 6, Section 6.2 arena model.



Appendix E: Assign blocks

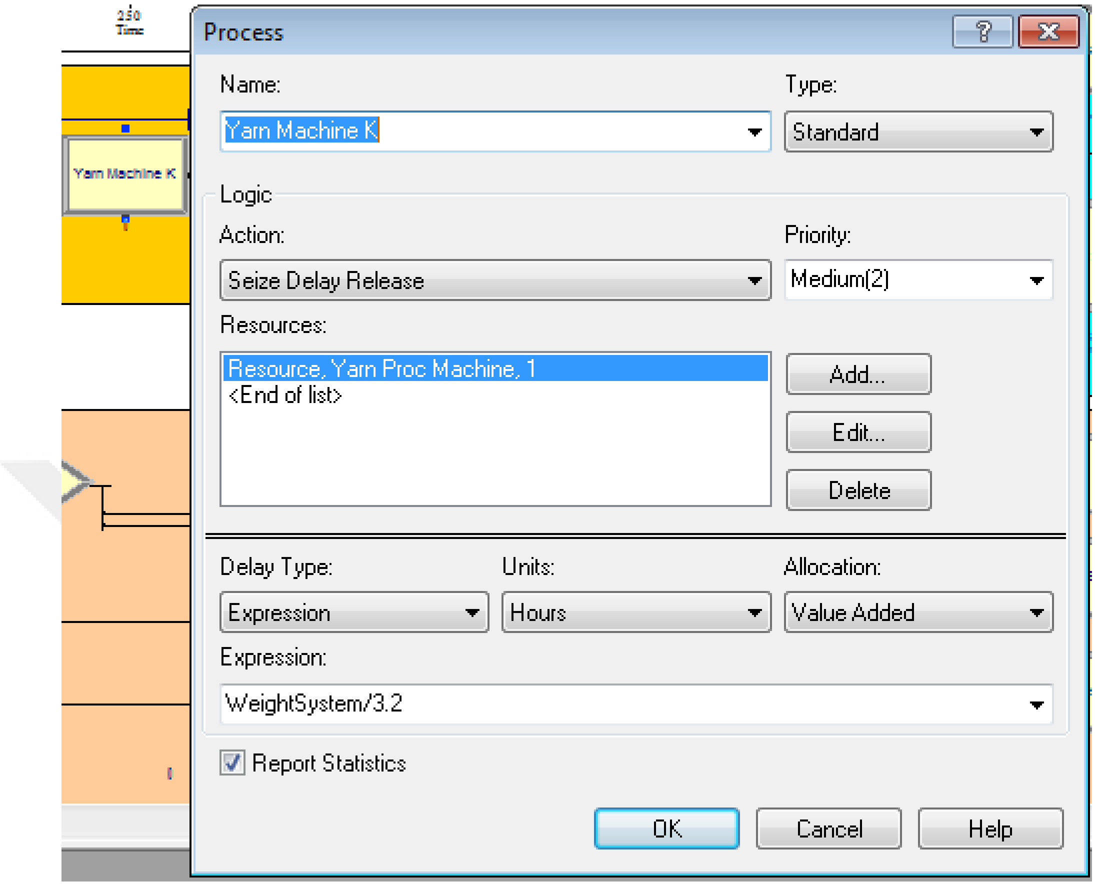
Assign blocks are used in Chapter 6, Section 6.2 arena model.





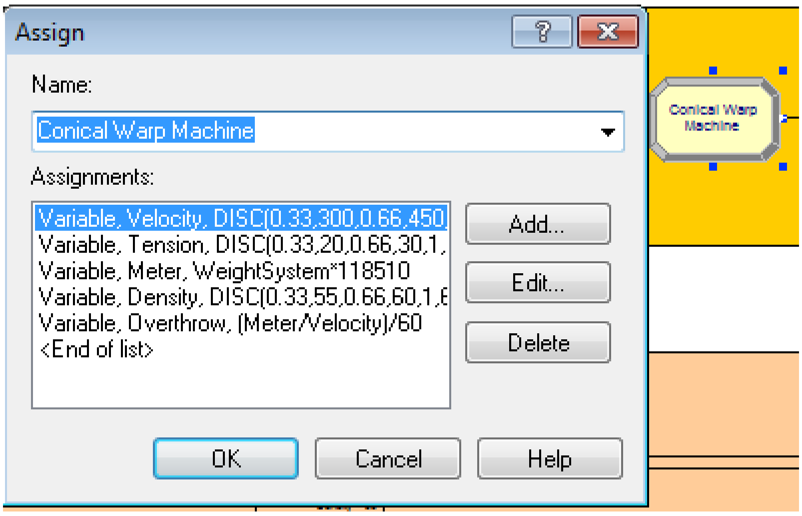
Appendix F: Yarn machine process module

Yarn machine process module is used in Chapter 6, Section 6.2 arena model.



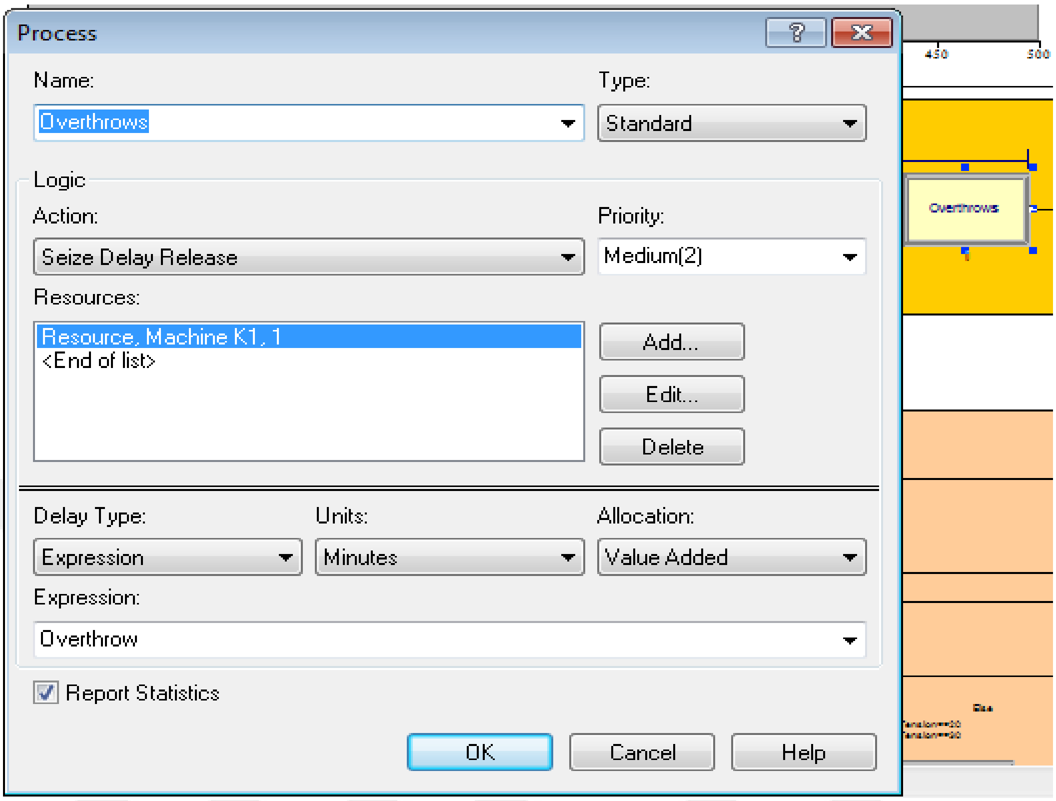
Appendix G: Assign block

Assign block is used in Chapter 6, Section 6.2 arena model.



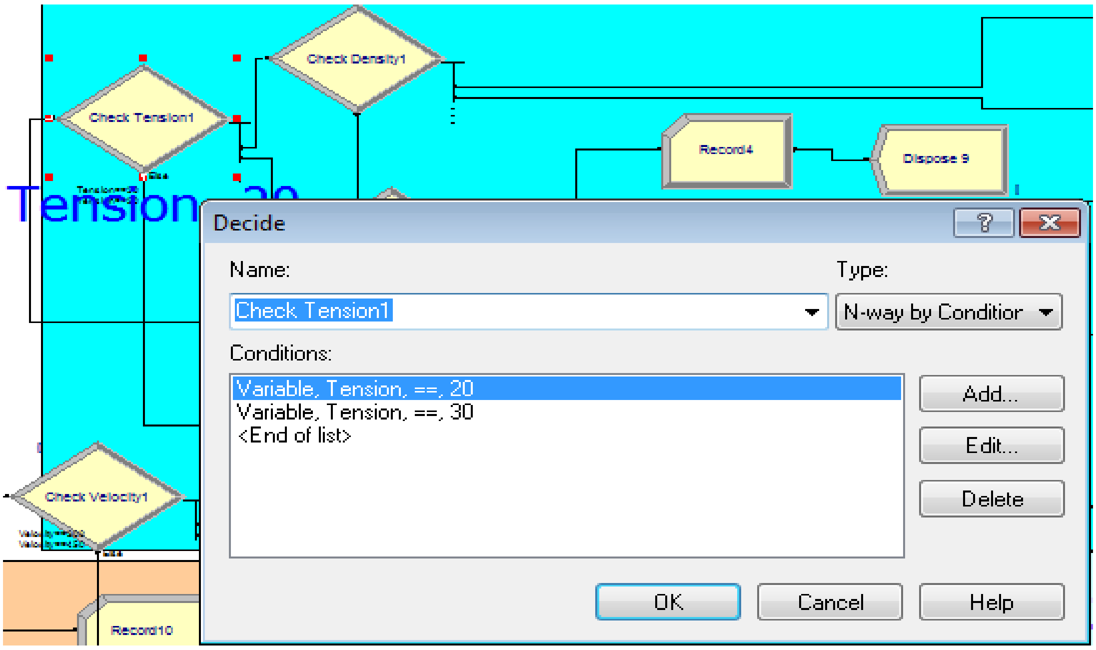
Appendix H: Overthrow process block

Overthrow process block is used in Chapter 6, Section 6.2 arena model.



Appendix I: Decide module for each machine settings

Decide module for each machine settings is used in Chapter 6, Section 6.2 arena model.



Appendix J: Data distribution for simulation model

These tables are used in Chapter 6, Section 6.2.

Table J. 1

Data Type	Distribution	Values
Cotton Arrival Kilos	Emprical	CONT(0.000, 0.999,0.426, 24.428,0.705, 47.857,0.852, 71.286,0.967, 94.714,0.967, 118.143,0.984, 141.572,1.0, 165.001)

Table J. 2

Data Type	Distribution	Values
Conical Warp Machine Parameter(Velocity)	Emprical	DISC(0.33,300,0.66,450,1,600)

Table J. 3

Data Type	Distribution	Values
Conical Warp Machine Parameter(Density)	Emprical	DISC(0.33,55,0.66,60,1,65)

Table J. 4

Data Type	Distribution	Values
Conical Warp Machine Parameter(Tension)	Emprical	DISC(0.33,20,0.66,30,1,40)

Appendix K: Confidence interval and required accurancy

These equations are used in Chapter 6, Section 6.3.2. The following equation shows how many number of replications is needed. The first (1) equation shows that notation simulation output and the second (2) equation shows that general representation of confidence interval equation for simulation model. The third (3) equation illustrates that half-width formula. The acceptable error is given in equation (4). After all these equations given, best-case and worst-case error is calculated in equation (5).

If best-case and worst-case errors are greater than the acceptable error, number of replications should be increased in the system to reach. Equation (6) shows that formula for the determination required number of replications

Y=simulation output and μ= E(Y), (1)

Confidence interval for μ ⟶ $\bar{Y} \pm t_{\alpha/2}, n-1\ S/\sqrt{n}$ (2)

Half-width ⟶ h = $t_{\alpha/2}, n-1\ S/\sqrt{n}$ (3)

The acceptable error, ε = 60 (4)

Best-case |754-676| = 78 and Worst-case |596-676| = 78 (5)

Either the best-case or worst-case error is >ε, we need to increase number of replications to reduce the size of the confidence interval.

R ≥ $(Z_{\alpha/2} S_o)^2 / \varepsilon^2$ (6)

R = 500, 501, 502 … number of replications

Appendix L: BPMM break values

BPMM (breaks per million meter) is used in Chapter 7, Section 7.4.3.

Std Order	Run Order	Factors			BPMM	Break
		Velocity	Tension	Density		
37	1	450	20	55	1,57	3
48	2	600	20	65	3,67	7
36	3	300	40	65	1,57	3
6	4	300	30	65	1,05	2
42	5	450	30	65	1,57	3
9	6	300	40	65	1,05	2
25	7	600	40	55	3,65	7
13	8	450	30	55	2,10	4
4	9	300	30	55	1,57	3
47	10	600	20	60	2,62	5
45	11	450	40	65	2,62	5
27	12	600	40	65	3,67	7

7	13	300	40	55	1,05	2
26	14	600	40	60	3,15	6
22	15	600	30	55	2,62	5
24	16	600	30	65	2,10	4
43	17	450	40	55	2,10	4
5	18	300	30	60	0,52	1
41	19	450	30	60	1,57	3
35	20	300	40	60	2,10	4
40	21	450	30	55	1,05	2
49	22	600	30	55	2,62	5
2	23	300	20	60	0,00	0
23	24	600	30	60	2,10	4
46	25	600	20	55	2,10	4
54	26	600	40	65	5,25	10
28	27	300	20	55	0,52	1
30	28	300	20	65	0,52	1
53	29	600	40	60	4,20	8
39	30	450	20	65	2,62	5
51	31	600	30	65	3,15	6
11	32	450	20	60	1,57	3
32	33	300	30	60	1,05	2
33	34	300	30	65	1,57	3
12	35	450	20	65	1,57	3
17	36	450	40	60	1,57	3
52	37	600	40	55	3,65	7
44	38	450	40	60	1,57	3
8	39	300	40	60	1,05	2
15	40	450	30	65	1,05	2
21	41	600	20	65	3,15	6
14	42	450	30	60	1,57	3
1	43	300	20	55	1,05	2
3	44	300	20	65	1,05	2

19	45	600	20	55	3,67	7
18	46	450	40	65	2,62	5
10	47	450	20	55	1,57	3
34	48	300	40	55	1,57	3
20	49	600	20	60	2,62	5
38	50	450	20	60	0,00	0
50	51	600	30	60	2,62	5
16	52	450	40	55	1,57	3
31	53	300	30	55	0,52	1
29	54	300	20	60	0,00	0

Appendix M: Regression equation formula

The first regression equation formula is calculated by ANOVA analyzing. It is used in Chapter 7, Section 7.4.3.

```
Regression Equation

BPMM = 1,9311 - 0,942 Velocity_300 - 0,272 Velocity_450 + 1,214 Velocity_600
       - 0,272 Tension_20 - 0,242 Tension_30 + 0,514 Tension_40 - 0,012 Density_55
       - 0,271 Density_60 + 0,283 Density_65 - 0,194 Velocity*Tension_300 20
       + 0,299 Velocity*Tension_300 30 - 0,105 Velocity*Tension_300 40
       + 0,096 Velocity*Tension_450 20 + 0,068 Velocity*Tension_450 30
       - 0,164 Velocity*Tension_450 40 + 0,098 Velocity*Tension_600 20
       - 0,368 Velocity*Tension_600 30 + 0,269 Velocity*Tension_600 40
       + 0,069 Velocity*Density_300 55 + 0,068 Velocity*Density_300 60
       - 0,137 Velocity*Density_300 65 + 0,013 Velocity*Density_450 55
       - 0,079 Velocity*Density_450 60 + 0,067 Velocity*Density_450 65
       - 0,082 Velocity*Density_600 55 + 0,011 Velocity*Density_600 60
       + 0,071 Velocity*Density_600 65 + 0,099 Tension*Density_20 55
       - 0,253 Tension*Density_20 60 + 0,154 Tension*Density_20 65 + 0,069 Tension*Density_30
       55 + 0,154 Tension*Density_30 60 - 0,223 Tension*Density_30 65
       - 0,168 Tension*Density_40 55 + 0,099 Tension*Density_40 60 + 0,069 Tension*Density_40
       65 + 0,106 Velocity*Tension*Density_300 20 55 - 0,067 Velocity*Tension*Density_300 20
       60 - 0,038 Velocity*Tension*Density_300 20 65 - 0,128 Velocity*Tension*Density_300 30
       55 - 0,213 Velocity*Tension*Density_300 30 60 + 0,341 Velocity*Tension*Density_300 30
       65 + 0,023 Velocity*Tension*Density_300 40 55 + 0,280 Velocity*Tension*Density_300 40
       60 - 0,303 Velocity*Tension*Density_300 40 65 - 0,013 Velocity*Tension*Density_450 20
       55 - 0,094 Velocity*Tension*Density_450 20 60 + 0,108 Velocity*Tension*Density_450 20
       65 + 0,019 Velocity*Tension*Density_450 30 55 + 0,282 Velocity*Tension*Density_450 30
       60 - 0,301 Velocity*Tension*Density_450 30 65 - 0,006 Velocity*Tension*Density_450 40
       55 - 0,187 Velocity*Tension*Density_450 40 60 + 0,193 Velocity*Tension*Density_450 40
       65 - 0,092 Velocity*Tension*Density_600 20 55 + 0,162 Velocity*Tension*Density_600 20
       60 - 0,069 Velocity*Tension*Density_600 20 65 + 0,109 Velocity*Tension*Density_600 30
       55 - 0,069 Velocity*Tension*Density_600 30 60 - 0,040 Velocity*Tension*Density_600 30
       65 - 0,017 Velocity*Tension*Density_600 40 55 - 0,093 Velocity*Tension*Density_600 40
       60 + 0,109 Velocity*Tension*Density_600 40 65
```