Optimization of the Critical Production Process in a Textile Factory using AHP

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Certificate of Approval

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DEDICATION

This thesis is dedicated to my beloved parents and family.

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First and foremost, I thank Almighty Allah (SWT) for my life and for giving me wisdom, health, and passion to complete all courses as well as the thesis of a postgraduate thesis.

I wish to extend my heartiest gratitude to all my course supervisor for their help and guidance without which I would not have been able to complete all the courses. I am also extremely grateful to my supervisor Associate Professor Dr. Abu Raihan Md. Harunur Rashid for his extended guidance, inspiration, and ideas to make this thesis successful.

And I believe that full credit for my effort must be given to my parents. From behind the curtain, they make every good thing possible in my life.

Md. Tajul Islam

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Abstract

The process of converting raw materials, components, or parts into finished goods that meet customer's expectations or specifications is called the production process. Manufacturing commonly uses a man-machine set up with division of labor in a large scale production. It includes a design to raw material collection to manufacturing to distribution towards its end of life, including disposal. The textile industry has prominence globally and locally. Also, it has a vast relation with RMG (Ready Made Garments) production in Bangladesh and other countries, which is earning a lot of foreign remittance for the economic development for the country. There are many segments and factors involve in the entire production process. Therefore, it will be effective and economical if key segments and factors could be identified for optimization. A standard textile production process comprises spinning, weaving, dyeing, printing, and finishing. In this study, to find out the most prominent segment of the textiles industry production process initially Ishikawa diagram, 5 why the method was used for brainstorming purpose. Then a questionnaire was developed based on the idea received from the brainstorming part. The questionnaire was sent to the experts. Data received from them were used to perform analysis using Analytical Hierarchy Process (AHP). The AHP analysis shows that yarns manufacturing is the most critical segment in the textiles production process. Later, 5s and statistical process control charts were used to improve selected parameters of the production process. Data collected shows that productivity increased by 0.88%, maintenance frequency decreased by 20%, the defective number decreased by 20%, and decreased injured number by 16.66 %.

Chapter 1 Introduction

1.1 Background of the Study

In the textile industry, the understanding of the production quality, productivity, maintenance frequency, defective number, occupational health, and safety are major issues for financial stability and growth. In a developing country like Bangladesh, there are many textile industries. They support a substantial portion of the economy of those countries. To stay in the market and further expansion of the business, the textile industry needs to improve productivity and quality, at the same time reducing maintenance costs. However, due to a shortage of financial ability, they could not work in this area. Therefore, if a prominent segment could be identified, then resources could be concentrated to the improvement of these parameters. It would be economically viable for these textile industries located in developing countries. Textiles Industries in Bangladesh, particularly the RMG sector has endeavored to implement this, however, a little research work has been done concerning its appropriateness.

In a broader sense, optimization means reducing cost and time, increase revenue, quality, productivity, and health safety management. Finding an alternative with the cost-effective or highest achievable performance under the constraints, by maximizing the desired segment and minimizing undesired once.

Accordingly, AHP may be used to identify prominent factors that will help to cost minimization. A statistical control chart may be used to improve quality and that would be termed as quality optimization. 5S may be used to organize effectively which may impact overall maintenance equipment.

1.2 Statement of the problem

There were quality and productivity issues in the textile factory. Because of this, there was a need to improve from this situation. So this improvement needed to be done economically and effectively.

1.3 Objectives:

Objectives of this research are:

1. Finding the critical segment of the textile production process using AHP.

2. Optimization of the critical textiles production process through the improvement of relevant industrial engineering parameters by implementing selected tools and methods using 5s and a control chart.

1.4 Significance of the study

The textile production process is not only an art but also a lengthy process that demands a series of engagement/decisions, trial & error, simulation with not only size, shape, and aesthetics but also other variables like productivity, manufacturability, environment, durability, market feedback, and ergonomics. Emphasis on each variable defines the nature or method of the production process from the very beginning. Thus the production process is distinguished with a good explanation in this research work.

Besides, emphasis on the above-mentioned variables varies from production engineers and finish product to product, which ultimately affects the product's sales, marketing, pricing, cost-saving, etc. Thus, the Production process has different effects on the product's sales, marketing, pricing, cost-saving, etc. So, there may be some criteria to judge a production process which are to be clarified. Therefore, a comparative study of the production process based on different criteria may improve the production system to the next level. AHP could be a useful tool for this purpose, as it can express qualitative judgments into quantitative judgments. Thus, production system strategies on prominent segment as suggested by AHP may be reviewed and optimized economically and effectively

1.5 Assumptions

The researcher also assumes that the scope of the study remains within the present circumstances of Bangladesh for finding out the best-suited production process for textiles manufacturing.

1.6 Limitation of the study

Many organizations in Bangladesh are involved in the textiles business. Some engineers are working on textiles on the research and development side. The other engineers are serving there in the production process. And the experts who previously served in the production process are transferred or promoted to other functions or joined with some other organizations. Furthermore, industries usually do not allow experts to take part in such research studies due to their confidentiality policy. So, a few experts are available to carryout AHP related surveys.

1.7 Contribution to the study

Based on the findings, optimization were done in the yarn manufacturing segment using the relevant method like 5s and statistical process control chart. Significant improvement was found as measured by different metrics like productivity, maintenance frequency, defective number, occupational safety & health record.

Chapter 2 Literature Review

This chapter comprises the production process of the textiles industry, relevant textiles production machinery and its process, productivity, optimization, Ishikawa Diagram, 5 why method, statistical control chart, and 5S method.

2.1 Production of the textiles industry

The production process is the creation of a plan or convention for the construction of different segment selection. In some cases, the direct construction of an object production engineering, operations management is also considered. At present, the textile industry encompasses a significant number and variety of processes that are adding value to fiber. These processes may range over the yarn making through the garment stitching, fabric embossing, and composite production [1,2]. However, considering the textile fiber as the basic building unit of any textile product, textile manufacturing may be identified as conventional and technical textiles. The conventional textile manufacturing process has a long history of converting natural fiber into useful products including fabric, home textiles, and apparel, and more recently into a technical textile through the utilization of special finishing effects. The synthetic and semisynthetic fiber manufacturing is diversified with the utilization of monomer, chemical agent, precursor, catalyst, and a variety of auxiliary fibers are perceived as a separate specialized subject and beyond the scope of this book. Therefore, man-made fiber manufacturing is not discussed. The innovation in textile manufacturing introduced a variation in raw materials and manufacturing processes. Therefore, process control to ensure product quality is desired. Monitoring and controlling process parameters may introduce a reduction in waste, costs, and environmental impact [3]. All the processing stages in textile manufacturing from fiber production to finished fabric are experiencing enhancement in process control and evaluation. It includes textile fiber production and processing through blow room, carding, drawing, and combing; and fabric production including knitted, woven, nonwoven, and subsequent coloration and finishing and apparel manufacturing. The global textile industry, in yarn and fabric production, has a strong presence and experiencing growth. In 2016, the yarn and fabric market was valued at USD 748.1 billion, where the fabric product was more in consumption and contributed 83.7% and the yarn product was at 16.3%. The market consumption is forecasted for growth at a CAGR of 5.1% between

2016 and 2021, reaching a market value of USD 961.0 billion in 2021. Apparel production is another important area in textile manufacturing around the textile industry chain. Probably the apparel is what individuals wear for body coverage, beautification, or comfort. Apparel and garment terms are used interchangeably. However, the two terms may be differentiated as apparel is outerwear clothing and garment is any piece of clothing. The study of yarns manufacturing market includes all the clothing articles except leather, footwear, knitted product, and technical, household, and made-up items. The worldwide apparel manufacturing market was valued at USD 785.0 billion in 2016 and estimated to reach the level of USD 992 billion in 2021. The market enhancement is forecasted to move from 2016 to 2021 at a CAGR of 4.8% [4,5].

Traditionally, yarn manufacturing comprises a series of processes involved in converting the fiber into yarn. It was rooted in natural fibers obtained from natural plant or animal sources. Natural fibers are produced with natural impurities that are removed from the yarn in subsequent pretreatment processes. Possibly, cotton is the fiber that has rooted the yarn manufacturing from fiber bale opening, followed by the series of continuous operations of blending, mixing, cleaning, carding, drawing, roving, and spinning. Yarn manufacturing using cotton fibers through a sequence of processing stages may be shown by the process flow diagram in Figure 2.2 All these operations are mechanical and do not require a chemical application. Each processing stage in yarn manufacturing used a machine of specialized nature and provided quality effects in yarn production. The advancement in fiber processing and machine technology for yarn manufacturing is continuous. The manual picking of cotton fiber is now replaced with machine picking. However, conventional systems of blending, carding, drawing, roving, and spinning are indicated important in the future [6]. Yarn diameter, hairiness, linear density, permeability, strength properties, etc. depend upon the end-use requirement of fabric to be produced for woven or knitted end products (e.g., apparel or industrial fabrics), sewing thread, or cordage. Several interesting works on the production of yarn are available that provide details of the material processing and technological control. Introductory spinning technology is described by Lawrence [7]. It covers the rudiments of staple-yarn technology, the manufacturing process, the raw materials, and the production processes for short-staple, worsted, semi-worsted, woolen spinning, doubling, and specialty yarn. Some of the useful advanced topics discussed are staple-yarn technology, including new development in fiber preparation technology, carding technology, roller drafting, ring spinning, open-end rotor spinning, and air-jet spinning. Tobler-

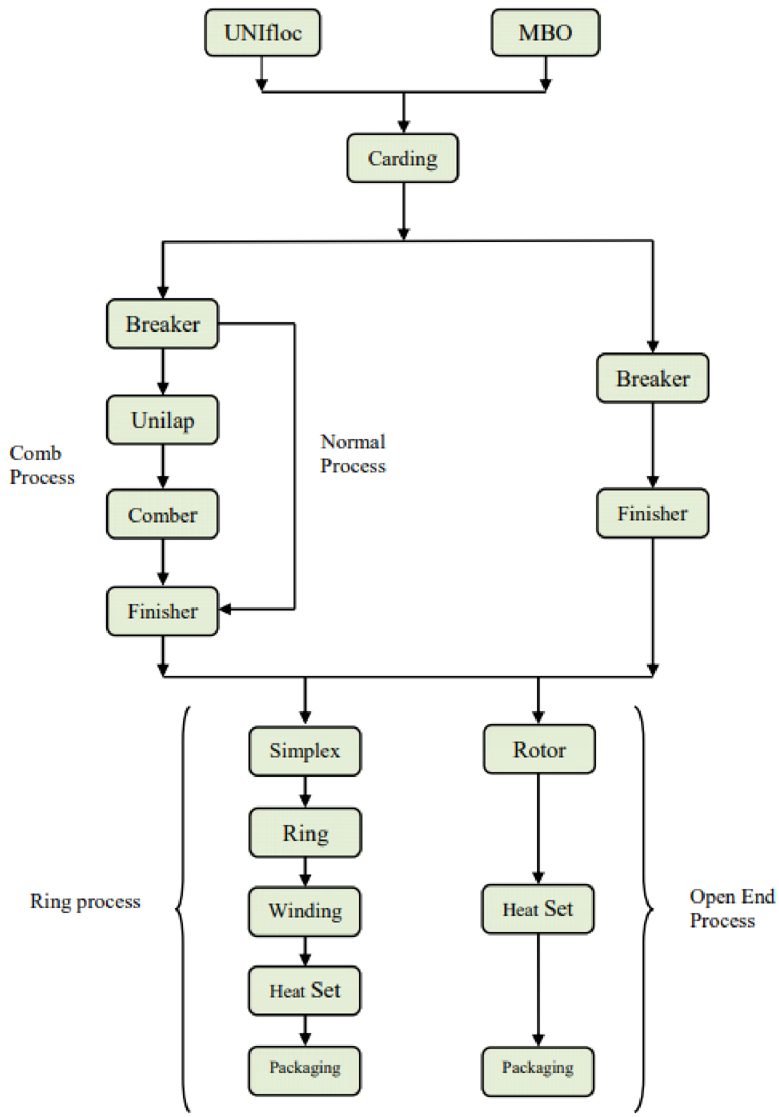
Rohr MI [9] described the yarn production technology in combination with economics. The study is useful for yarn manufacturing and its development in the textile industry. Important aspects of yarn manufacturing are filament yarn production, carding, and prior processes for short-staple fibers, sliver preparation, short-staple spinning, long-staple spinning, post-spinning processes, quality control, and economics of staple-yarn production [8,9,10].

2.2.1 Counting systems of yarn

The following are important parameters for counting system of yarn: Yarn Count: It is the relationship between the mass and length of the yarn. It describes the linear density of the yarn. In simpler words is the measure of the thickness of the yarn.
The two numbering systems counts are;
Direct count system
Indirect count system
Mathematical expression = length/Weight
Two systems of numbering indirect system;
Cotton system (Ne) is defined as the number of hanks per pound. (hk/pd)
1 hank = 840 yards.
Metric system (Nm) is defined as the number of hanks per kilogram. (hk/kg).

2.1 Process Flow diagram of textiles production

Different types of machinery are used for the conversion of fibers into yarn, and their functions are different. A brief functions of the major types of machinery used in the textiles factory are described in this section.



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igure 2.1: Process flow chart of textiles production

2.1 Description of textile production process

Blow Room

Blow room is the starting of the operation of the textile. It is the section where supplied compressed bale is turned into a uniform lap of a particular length. The basic functions of the blow room are opening, cleaning, and dust removal, blending, and evenly feeding the material on the card. The machinery required to carry out these functions are:

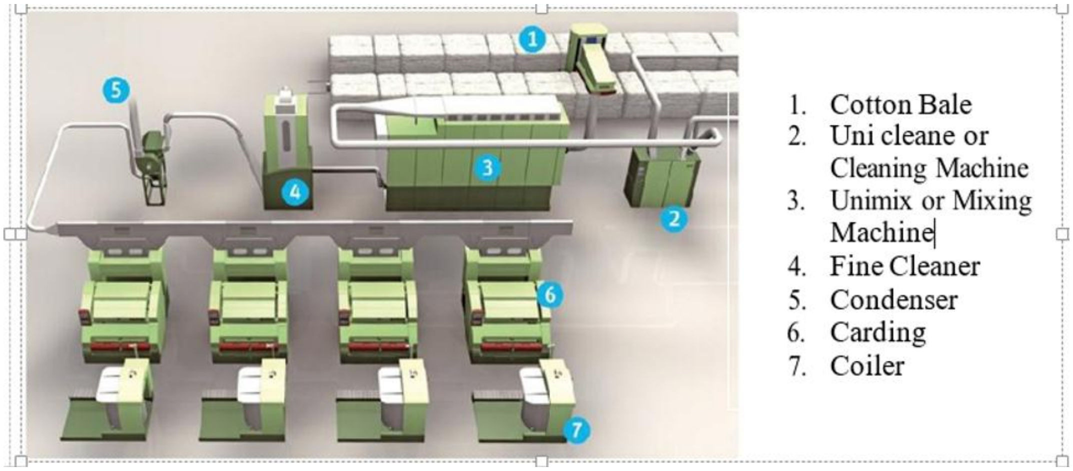

Figure 2.2: Work flow diagram of Blow room

Bale Opener Machine is the first major machine in the Blow Room. It could be automatic or manual. The functions of a bale opener machine are open the tuft of cotton, mix & blend the fiber, remove a considerable amount of trash from fiber which is taken out by fan to FDP and act as a reservoir for the next machine. Unifloc is an automatic bale opener machine that plucks raw cotton in lump form and sends these to clean through air transportation for coarse cleaning.

Function: To open the bales into smaller and lighter tuffs or floc

Figure 2.3: Unifloc A11 machine

Cleaner machine is an important machine in spinning for opening and cleaning impurities from cotton. This machine is set normally after Bale Opener machine. It main functions are to open & clean the cotton by combinations of opposite spike & the beating action. It also removes the impurities such as leaves, stalk, motes & sand without damaging the fiber.

Function: To remove dust, trash, foreign matters, seed contents etc. from fiber flock.

Figure 2.4: Uniclean B11 machine

This is a process of mixing the same or different category of fibers to get desired properties and cost effectiveness. Mixing is done after the study of the essential properties of fiber like staple length, tensile strength, fineness, uniformity etc. Fibers actually stored in six chambers and mixed up by beating.

Object : Homogeneous & Effective mixing of fibers

Figure 2.5: Unimix B70 machine

Traditional methods use more number of machines to open and clean natural fibers. In this section fine cleaning is done through beating and waste products are separated. Mechanical action on fibers causes some deterioration on yarn quality, particularly in terms of neaps.

Function: to optimize waste extraction to suit ~~his~~ the requirements without any mechanical intervention (VARIO set)

Figure 2.6: Uniflex B60 machine

In every steps of blow room, the main function is cleaning. The most effective protection here consists of two stages: one of separation of metal heavy parts and burning materials at the start of cleaner line and one for the specific separation of foreign parts (foreign fiber) at the end of cleaning line. The wide range of special contamination separator machines makes it possible .here to find the ideal configuration for each line.

Function: To sort out the Poly propylene (PP) contaminants from fiber using optical method

Figure 2.7: SP-FPU machine

The condenser are de-dusting duct remove from chute material by suction air. This chute material sends to the carding machine for further processing via chute line.

Function: To control the width of the fiber strand move to upper line.

Figure 2.8: Condenser A21 machine

Carding Section

The carding machine mainly removes the naps, short fibers and remaining impurities in the cotton fiber and forms carded sliver. Mainly impurities are removed at the intake and the naps and short fibers are removed by action between the cylinder and flat. It is called the heart of cotton spinning because the quality of a yarn is greatly dependent upon the carding machine. In carding machine, cotton converted into sliver, which is deposited in sliver can.

Function: To individualize, parallelize, cleaning, reduction of neps, aligning, blending & elimination of short fibers

Figure 2.9 : Carding C60 machine

Drawing Section

Carded sliver are fed into the draw frame. Here silver are stretched and made into a single silver. Also fiber blending can be done at this stage. Some other task of draw frame, drafting, parallelizing, blending, dust removal etc. Usually it take 12 silver can as input and give one sliver can as output.

Function: To stretch or straighten the fed card sliver to one single sliber, blending of different slivers.

Figure 2.10: Breaker Draw frame machine

Function: To arrange the fibers in parallel fashion, to reduce irregularity of silvers by auto levelling device

Figure 2.11: Finisher Draw frame machine

Lap Formers: Forming the interfacing or lap, which is employed to feed the combing machine, lighter draft is provided here (1.5-2)

Figure 2.12: Unilap E5/3 machine

Combers Section

The process of straightening and parallelizing of fibers and the removal of short fibers by using combs and this combs assisted by brushes. This processes carried out in order to improve the quality of the sliver coming out of the card. It also removes naps and residue impurities. It takes 8 laps from lap former and make a single sliver can.

Function: To produce smoother, softer sliver by eliminating short fibers

Figure 2.13: Comber machine

Simplex Section

In yarn manufacturing system, simplex frame is situated after the drawing frame. The sliver which is produced from the draw frame that is thicker and it is not suitable to feed into the ring frame directly to produce yarn. For this reason, drawn sliver is treated before entering into the ring frame. There are three basic steps in the operation of the roving frame — drafting, twisting and winding. In this process drawn sliver is input and fine Roving is output. The roving is feed into ring frame for yarn production. It is noted that, simplex is essential for the production of cotton yarn in case of ring spinning system.

Function: To convert the drawn sliver into much fine sliver called roving by drafting and slight twist insertion

Figure 2.14: Simplex Electrojet machine

Ring Frame

Roving produced in roving frame used in ring frame to obtain the desired yarn. Main function of ring frame is to draft the roving until the required fineness is achieved, then twist the drafted yarn to form yarn of required count and strength. Finally, wind the twisted yarn on the bobbin for further processing. In ring frame, any type of fiber can be spun and wide range of count can be processed. Higher yarn strength can also be achieved through ring frame.

Function: To convert the roving into yarn of definite/respective count by creeling, drafting, blending, twisting, winding and doffing operation

Figure 2.15: Ring frame machine

Rotor Frame Section

When a spun yarn end emerges from the draw-off nozzle into the rotor groove, it receives twist from the rotation of the rotor outside the nozzle, which then continues in the yarn into the interior of the rotor. The yarn end rotates around its axis and continuously twists-in the fibers deposited in the rotor groove, assisted by the nozzle, which acts as a twist-retaining element.

Function: To produce yarn from the low quality fibers by the process of open end spinning

Figure 2.16: Rotor frame machine

Winding Section

Winding is one of the most important operation, which is mainly occurred in spinning section. The ring-spinning operation produces a ring bobbin containing just a few grams of yarn, which is unsuitable for the further processing. This necessitates the preparation of a dense and uniform yarn package of sufficiently large size. The packages prepared in winding are normally cross-wound, containing several kilograms of yarns. Clearer device is also installed in each spindle of winding machine. The clearer for winding machines is a sophisticated sensor which is able to eliminate disturbing thick places, thin places, foreign fibers and separate bobbins which do not fulfill the conditions with respect to evenness, imperfections, hairiness, count deviations, etc.

Function : To rewound the yarn from ring bobbin into suitable package

Figure 2.17: Winding machine

Heat Setting Section and Finished product

After winding process, the yarn cones are sent to heat setting section. In this chamber, yarn packages are heated by steam generated from boiler for several hours. This process reduces the hairiness of the yarn, will give the yarn better shape and will increase the strength of the yarn. During heat setting, yarn packages can gain weight up to 2%. After heat settings yarn packages are sent for packaging.

Function: To increase yarns moisture content

Figure 2.18: Finished product or yarns

2. 3 Productivity

Productivity is the quantitative relation between what we produce and what we use as a resource to produce them, *i.e.*, the arithmetic ratio of the amount produced (output) to the number of resources (input). Productivity can be expressed as:

Productivity =Output /Input

Depending upon the individual input partial productivity measures are expressed as:

Partial productivity =Total output/ Individual input

Labor productivity =Total output/ Labor input (in terms of man-hours)

Capital productivity =Total output/ Capital input

Material productivity =Total output/ Material input

Energy productivity =Total output/Energy input

Total productivity =Total output/ Total input

One of the major disadvantages of partial productivity measures is that there is an over emphasis on one input factor to the extent that other input are underestimated or even ignored [9].

2.4 Optimization

Optimization is the art of making good decisions. It is the process of finding an alternative with the cost-effective or highest achievable performance under the constraints, by maximizing the desired segment and minimizing undesired once. In comparison, maximization means trying to attain the top or maximum result or outcome without this cost or expenditure. The good practice of optimization is restricted by the lack of complete information or data, and the lack of time to evaluate what data or in is available[10].

Objectives of the optimization are to reduce cost and time, increase revenue, quality, productivity, and health safety management. Accordingly, AHP may be used to identify prominent factors that will help to cost minimization. A statistical control chart may be used to improve quality and that would be termed as quality optimization. 5S may be used to organize effectively which may impact overall maintenance scenario of the equipment.

2.5 Ishikawa Diagram

Dr. Kaoru Ishikawa, a Japanese quality control expert, is credited with inventing the fishbone diagram also known as Ishikawa diagram or cause and effect diagram, to help employees avoid solutions that merely address the symptoms of a much larger problem. Ishikawa diagrams are considered one of the seven basic quality tools and are used in the "analyze" phase of Six Sigma's DMAIC (define, measure, analyze, improve, control) approach to problem-solving [12].

Ishikawa diagram also called a cause and effect diagram or a fishbone diagram is a visualization tool for categorizing the potential causes of a problem to identify its root causes. Typically used for root cause analysis, a fishbone diagram combines the practice of brainstorming with a type of mind map template. Ishikawa diagram is useful in product development
and troubleshooting processes that focuses the conversation. After the group has brainstormed all the possible causes for a problem, the facilitator helps the group to rate the potential causes according to their level of importance. The design of the diagram looks much like a skeleton of a fish. Fishbone diagrams are typically worked right to left, with each large "bone" of the fish branching out to include smaller bones containing more detail [13,14,15].

2.6 5 whys method

The technique was originally developed by Sakichi Toyoda and was used within the Toyota Motor Corporation during the evolution of its manufacturing methodologies. It is a critical component of problem-solving training, delivered as part of the induction into the Toyota Production System. The architect of the Toyota Production System, Taiichi Ohno, described the five whys method as "the basis of Toyota's scientific approach by repeating why five times the nature of the problem, as well as its solution, becomes clear." The tool has seen widespread use beyond Toyota and is now used within Kaizen, lean manufacturing, and Six Sigma.

In other companies, it appears in other forms. Under Ricardo Semler, Semco practices "three whys" and broadens the practice to cover goal setting and decision making [16,17].

2.7 Analytical Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then[16,17].It has particular application in group decision making and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education.

Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, representing and quantifying its elements, relating those elements to overall goals, and evaluating alternative solutions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well- or poorly-understood—anything at all that applies to the decision at hand[18].

Once the hierarchy is built, the decision-makers systematically evaluate its various elements by comparing them to one another two at a time, concerning their impact on an element above them in the hierarchy. In making the comparisons, the decision-makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations [19].

The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another rationally and consistently. This capability distinguishes AHP from other decision-making techniques [20,21].

In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

AHP has got the following steps:

a) **Model the problem as a hierarchy:** The first step in the analytic hierarchy process is to model the problem as a hierarchy. In doing this, participants explore the aspects of the problem at levels from general to detailed, then express it in the multileveled way that the AHP requires. As they work to build the hierarchy, they increase their understanding of the problem, of its context, and each other's thoughts and feelings about both.

b) **Evaluate the hierarchy:** Once the hierarchy has been constructed, the participants analyze it through a series of pair-wise comparisons that derive numerical scales of measurement for the nodes. The criteria are pair-wise compared to the goal for importance. The alternatives are pair-wise compared against each of the criteria for preference. The comparisons are processed mathematically, and priorities are derived for each node.

c) **Establish priorities:** At last, priorities are established by calculating the values of each node, which will see in our next chapter.

2.8 5S method

Takashi Osada in 1991 coined the original concept of 5S. 5S is the acronym for five Japanese words Seiri (organization), Seiton (neatness), Seiso (cleanliness), Seiketsu (standardization) and Shitsuke (discipline) respectively. 5S has been introduced in Japan mainly in the manufacturing and service industries. Toyota, the major car manufacturer is one of the pioneering firms who adopted the 5S principles. Japanese believe that 5S Principles are not only valuable at their workplaces but also improves their cognitive sense. Osada refers to the 5S as the five pillars to establish and maintain total quality environment in an organization [23,24].
5S Principles focuses on effective workplace organization, simplification of the work environment, and minimization of waste while improving quality and safety. The success of 5S depends upon total employee involvement, its continuous monitoring, and everyone should work in a team.

5S is regarding make the workplace is an organized one, as problems are really difficult to define in an unorganized organization.

5S effects on performance in similar organizations, review requirements of the implementation and deployment of 5S practice, and review of the key success factors for organizations that have been successful in implementing of 5S and other quality management systems. [26]

The 5S methodology relies on the creation and keeping of a well-organized, clean, highly effective, and high-quality workplace. 5S could only improve the result in the working environment, but it proved also to help the company to gain better efficiency.

***2.8.1* 5s Principle**

Implementing the 5S rules should begin with training of productive workers in the range of the 5S's elements and advantages from their usage. All participants of the training must understand the need of using the 5S rules in their work and will agree on the changes. During training, it is essential to train the usage of all rules on the clear example so that every participant can understand the methodology of realization of the 5S's elements. A very important fact is that these rules do not refer only to the productive positions, but also refer to the warehouse, office positions, and others.
The 5S implementation requires commitment both from the top management and everyone in the organization.

5S can be used in any environment to support work-place issues including process, delivery, safety, quality, stock, and equipment control and improvement targets. [27,28]. 5S term is shown the folowing Table 2.1.

2.8.2 Benefits of 5S Implementation

Improving organization performance is an ongoing challenge and organizations benefit best from a holistic approach, and here is an extremely useful roadmap to 5S implementation [29].

It provides an excellent framework for establishing

- ❑ The fundamental process for Productivity and Quality Improvements
- ❑ A firm foundation for Continual Improvement
- ❑ Best Practices
- ❑ Key Performance Results

Removing wastes

5S removes instances of the seven wastes within the working environment:

- ❑ Transport
- ❑ Inventory
- ❑ Motion
- ❑ Waiting
- ❑ Overproduction
- ❑ Over Processing
- ❑ Defects

Reduction in delays

5S will reduce delays in process.

- ❑ Visual management shows when products and tools are missing.
- ❑ Problems highlighted
- ❑ Materials out of place.
- ❑ Leaks and other machine problems.

Reduced setups

Setup times reduced through the same process as increasing production efficiency.

- ❑ Ergonomic workplace
- ❑ All tools to hand
- ❑ Standardized process

Improved quality

- ❑ The right tools and equipment available
- ❑ Standardized processes
- ❑ Improved handling so less damage
- ❑ Improved reliability of equipment

Safety and Ergonomics

- ❑ No clutter to create obstacles and hazards
- ❑ Ergonomic stress-free workplace
- ❑ No stretching or reaching
- ❑ No lifting heavy objects
- ❑ Standardized ways of working

Marketing

A highly visual and tidy workplace can give a great impression to a current or potential customer.

Morale and motivation

- Less stress for operators
- Safer work environment
- Involvement in making own improvements
- Empowerment to make changes

Continuous improvement and problem-solving

- Implemented correctly 5S will drive continuous improvement of products and processes.
- Abnormalities are immediately visible allowing action to be taken

2.9 Statistical Process Control Chart

Statistics is a science which deals with the collection, summarization, analysis, and drawing of information from the data. Process: It converts input resources into the desired output (goods or services) with a combination of people, materials, methods, machines, and measurements. Control means system, policies, and procedures are in place so that the overall output meets the requirement [30].

Today's companies are facing increasing competition and also operational costs, including raw materials continuously increasing. So for the organizations, it is beneficial if they have control over their operation [32.]

Organizations must make an effort for continuous improvement in quality, efficiency, and cost reduction. Many organizations still follow inspection after the production for quality-related issues.

SPC helps companies to move towards prevention-based quality control instead of detection based quality controls. By monitoring SPC graphs, organizations can easily predict the behavior of the process. The visual representation makes it clearer that there are likely subgroups within the data. The control chart appears to be out of control with a lot of special cause variation but there is likely a good explanation [32,33].

SPC charts measure the output on a continuous scale. It is possible to measure the quality characteristics of a product by using SPC. There are two widely used SPC charts namely X bar and R Charts when data is readily available. X bar and R chart are used to monitor the process performance of continuous data and the data are to be collected in sub groups at a set time. It has two plots to monitor the process mean and the process variation over time.

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Statistical Process Control Benefits

The benefits of SPC charts may be summarized as follows:

- Increase productivity
- Reduce scrap and rework
- Improve overall quality
- Match process capability to product requirement
- Continuously monitor the process of maintaining control
- Provide data to support decision making
- Streamline the process
- Increase in product reliability
- Opportunity for company-wide improvements

SPC focuses on optimizing continuous improvement by using statistical tools to analyze data, make inferences about process behavior, and then make appropriate decisions.

The basic assumption of SPC is that all processes are subject to variation. Variation measures how data are spread around the central tendency. Moreover, variation may be classified as one of two types, random or chance cause variation and assignable cause variation[34,35].

Common Cause: A cause of variation in the process is due to chance, but not assignable to any factor. It is the variation that is inherent in the process. A process under the influence of a common cause will always be stable and predictable.

Assignable Cause: It is also known as "special cause". The variation in a process that is not due to chance therefore can be identified and eliminated. The process under influence of special cause will not be stable and predictable.

2.10 Review of Related Research works

Relevant papers for the last ten years were reviewed. Key points from this paper review are presented in Table 2.1

Table 2.1: Key points from the review papers.

Author	Objective	Methodology	Result & Findings
Majid Dekamin, Morteza Barmaki, Amin kanooni [10]	Selecting the best environmental friendly oilseed crop by using Life Cycle Assessment, water footprint and analytic hierarchy process methods	Using analytic hierarchy process, Life Cycle Assessment, water footprint methods.	The AHP criteria were selected based on the two aspects of sustainable development: environment aspect and economic aspect. The results indicated that the integration of WF and LCA methods into AHP for comparing the agro-environmental efficiency of oilseed crops can be applied as the starting point for the assessments of different crop production systems aiming at cost management, WF and environmental burden reductions, and optimization of the oilseed crop production sector.

Author with publication year	Objective	Methodology	Result & Findings
Cebeci,U. [12]	Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard	Using Fuzzy AHP method with balanced scorecard for selecting appropriate ERP	In this study, the fuzzy analytic hierarchy process, a fuzzy extension of the multi-criteria decision-making technique AHP, was used to compare these ERP system solutions. The methodology was applied for a textile manufacturing company.
S.M. Aqil Burney, Syed Mubashir Ali[15]	Fuzzy Multi-Criteria Based Decision Support System for Supplier Selection in Textile Industry	This research applied F-AHP methodology in a XYZ textile manufacturing company in Pakistan which produces denim fabric and cotton yarn.	This research has done three novel contributions. First, AHP has been applied in textile industry in Pakistan for supplier selection which will gives confidence to the decision makers and procurement managers within this industry to perform decision making with confidence. Second, by incorporating fuzzy soft computing technique in AHP analysis enabled the decision maker to deal with vagueness, imprecision and linguistic chaos while performing pair-wise comparison. Lastly, this research can become a simple decision making tool and a starting point for other.

Author with publication year	Objective	Methodology	Result & Findings
Selim Zaim et.al [20]	The purpose of this paper is to demonstrate the use of two general purpose decision-making techniques in selecting the most appropriate maintenance strategy for organizations with critical production requirements.	The Analytical Hierarchical Process (AHP) and the Analytical Network Process (ANP) are used for the selection of the most appropriate maintenance strategy in a local newspaper printing facility in Turkey.	The two methods were shown to be effective in choosing a strategy for maintaining the printing machines. The two methods resulted in almost the same results. Both methods take into account the specific requirements of the organization through its own available expertise.
Punyasloka Pattnaik et.al [22] 24 February 2019	Sustainability of Textile wastewater management by using Fuzzy AHP method	Using FAHP	As FAHP is one of the potential multi-criteria decisions making method benefit the textile manufacturing sectors by minimizing waste utilization.

Author with publication year	Objective	Methodology	Result & Findings
Ruchi Mishra et.al [26] 23 May 2017	Evaluation and prioritization of manufacturing flexibility alternatives using integrated AHP and TOPSIS method: evidence from a fashion apparel firm	This paper develops an integrated AHP and TOPSIS approach to ascertain the importance of each type of manufacturing flexibility with regard to the environmental uncertainty criterion and sub criterion.	Therefore, the proposed framework offers a new valid and reliable approach to evaluate and prioritize the manufacturing flexibility with respect to uncertainties present in the environment. Like all modelling method, the proposed modelling approach also has certain limitations.

Author with publication year	Objective	Methodology	Result & Findings
S.R. Dulange et.al [28] 06 August 2014	Prioritization of factors impacting on performance of power looms using AHP	Using AHP	The paper gives an idea of factors which influences on performance of power loom textiles which gives guidelines to the owners/managers about the potential area of improvement. The priority for the human resource is 37.66 %. The labor absenteeism is observed as 23.97 %, which highly impact the performance. The absenteeism of workforce means loss of production. Training facility for the employee and management is also important; the effect of this is 20.01 %. To achieve high performance, a motivated workforce is an important factor which is 20.02 %. A second important factor is a product.

Author with publication year	Objective	Methodology	Result & Findings
Raghu Natha reddy et.al [30]	A comprehensive study in finding the risk assessment using a fuzzy analytical hierarchal model in textile industry.	Using FAHP	The proposed approach is valuable for evaluating improvement, which can prompt enhancing profitability and manage the upper hands. In this case study, the sub-criteria of manufacturing with technical capability has more risk prioritized. So the organization has to develop the technical capability workers as well as supervisors by continuous improvement.
Ernesto Mastrocinque et.al [32] 2016	Manufacturing Technology Selection in the Supply Chain Context by Means Of Fuzzy-Ahp: A Case In The High Performance Textile Industry	Using FAHP	Full lamination/solvent type turned out to be the suggested technology option for high performance textile manufacturing. Finally, Fuzzy AHP proven to be a fast, simple and valid decision-making support tool for technology selection.

2.11 Research Gap

In the review of past research works, it has been found that optimization things were done in other industries except for textiles industries in developing countries. AHP and similar tools have been used to find out the most prominent factor. So, AHP may be used to find out the prominent segment of Textile Industry to carry out optimization effectively and economically. Therefore, the current research works mentioned in this study are expected to fill this research gap.

Chapter 3 Research Methodology

This chapter describes the research methodology that includes Ishikawa Diagram, 5 whys method, AHP analysis, statistical control chart, and 5s method.

3.1 Ishikawa Diagram

An Ishikawa diagram is a diagram that shows the causes of an event and is often used in yarns manufacturing and finished product development to outline the different steps in a process, implemented where quality control issues might arise and determine which resources are required at specific times. The diagram shown in Figure: 3.1 was developed on the initial phase of the study to find out possible factors for selecting prominent segment for optimization in the textile production process.

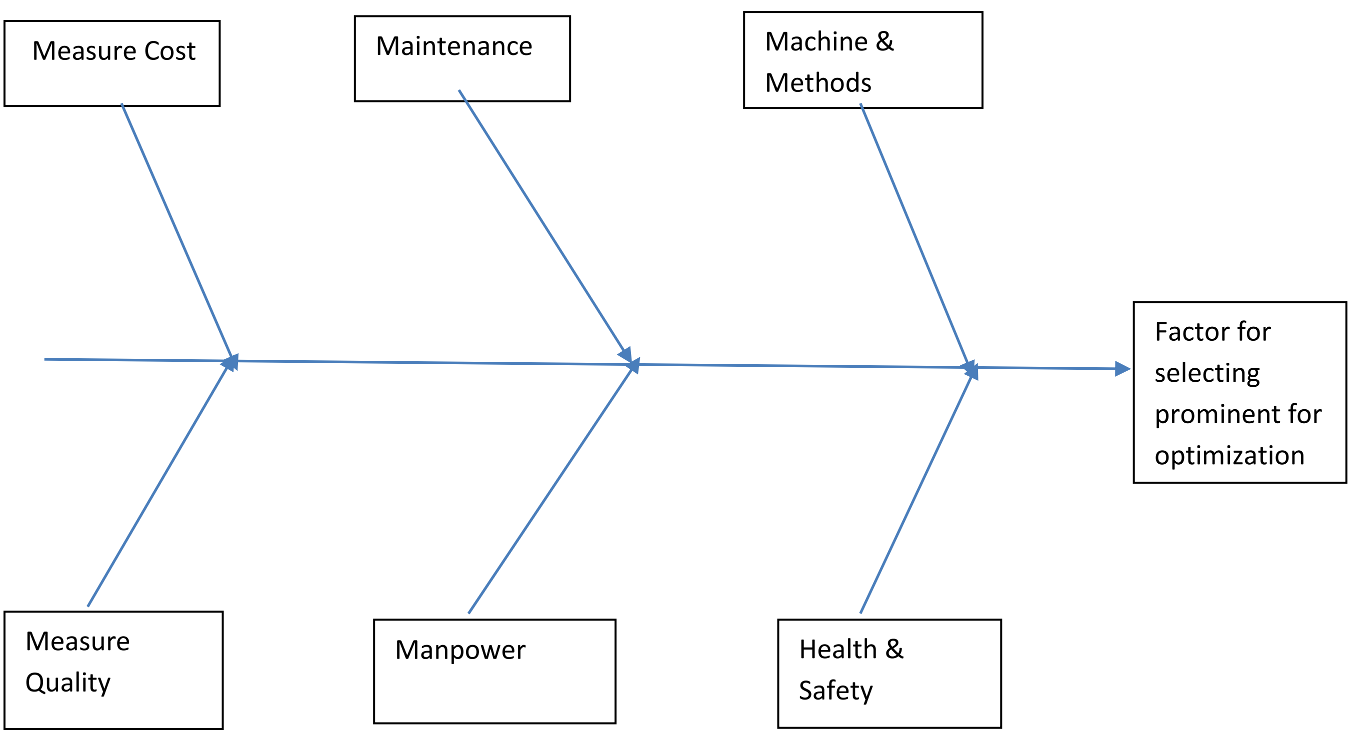

Figure 3.1: Ishikawa Diagram used in yarns production

3.2 5 whys method

The 5 Whys may be used textiles production process or as a part of the fishbone (also known as the cause and effect or Ishikawa) diagram. The fishbone diagram helps to explore all potential or real causes that result in a single defect or failure. Once all inputs are established on the fishbone, the 5 Whys technique is to be drilled down to find out the root causes. The 5 Whys approach to root cause analysis is by no means new, nor does it originate in Six Sigma [36, 37].

5why method was used in this project. To get an idea about the prominent segment. We used the 5 why method in the textile production process. According to the 5 why procedure a why question is asked to the participants. Then each response will be converted to the next why question. In this study, 5why questions as shown in Figure 3.2 were asked to experts.

This way we have continued 5 questions.

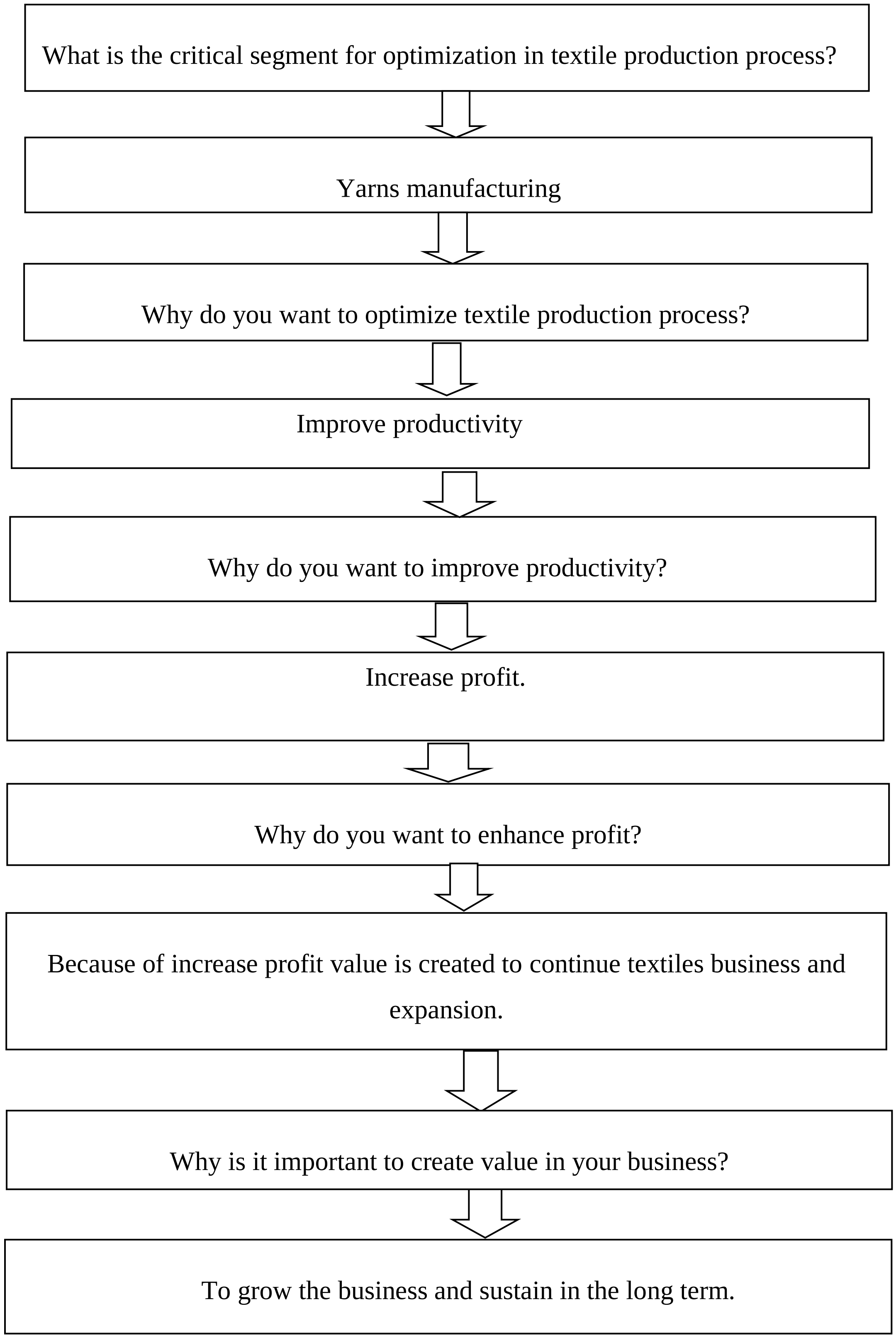

Figure 3.2 5why question asked in study

3.3 Procedure for using AHP

The critical segment for the most appropriate segment of the production process of the textile industry is a qualitative decision that may vary from engineer to engineer. AHP is used to convert qualitative decisions into a quantitative decision. Thus responses from various engineers may lead to a conclusion on the most appropriate segment production process for textile production on the current perspectives of Bangladesh.

In this research, the following steps of AHP were used to find out the most appropriate critical segment of the production process of the textile industry [17]

I. Define the decision problem and determine its object [17].

II. Define the decision criteria in the form of a hierarchy of objectives. This hierarchical structure consists of different levels. The top-level is the objective to be achieved. This top-level consists of intermediate levels of criteria and sub-criteria, which depend on subsequent levels. The lowest level consists of a list of alternatives [18].

III. For making pair-wise comparisons, structure a matrix of size (n x n). The number of judgments required to develop the set of the matrix is given by n (n – 1) / 2 [18].

IV. Obtain the importance of the criteria and sub-criteria from experts' judgment by making a pairwise comparison. This comparison is made for all levels. Verbal judgments of preferences are shown in table 3.1.

V. Determine the weight of each criterion. By hierarchical synthesis, the priority vectors are calculated. These values are then normalized to eigenvectors of the matrix [18]

VI. The consistency is determined by using the eigenvalue, λmax. For finding the consistency index, CI, the formula used is; $CI = (\lambda max - n) / (n - 1)$, where n is the size of the matrix. The consistency ratio (CR) is simply the ratio of CI to average random consistency (RI). The CR is acceptable if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent; then the matrix has to be reviewed to obtain a consistent matrix. These are calculated for all the matrices structured from the hierarchy. Some computer packages are available nowadays to implement this calculation procedure. [19,20,21]

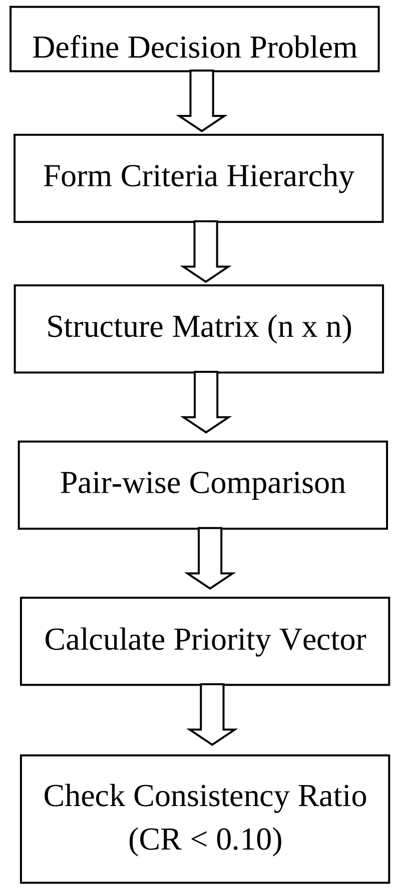

Figure 3.3: Flow of Steps for AHP Analysis

3.4 Decision Criteria

In the beginning, a few criteria were through brainstorming with Ishikawa diagrams and the Five Whys method. According to most production experts, four criteria were adopted for AHP analysis because they placed more importance on them.

The choice of the most appropriate segment for a particular product in a particular market/country may depend on the following criteria as suggested by the experts. There are different textiles production segments in a typical textile industry. They are as described below

a) Raw Material collection: Valuable raw material collection is characterized by an extensive range of valuable merino wool yarns and noble fibers (Cashmere, silk, angora, cotton), pure or blended with man-made fibers used in low percentage to modernized classical products

b) Yarns manufacturing: Yarn is an assemblage of fibers that are twisted or laid together to form a continuous strand that can be made into a textile fabric. So a yarn is a strand of natural or manmade fibers or filaments that have been twisted or grouped for use in weaving, knitting, or other methods of constructing textile fabrics.

c) Finish product & Packaging: Yarn is packaged (or put up) in different forms. For example, balls, skeins (rhymes with canes), and hanks. The differences in yarn packaging shouldn't have much effect on the yarn you choose, but the shape does determine how you work with them. There are various types of yarn are being produced in textiles industries such as viscose, modal, polyester, etc.

According to the opinion of the production experts as derived from initial brainstorming, four criteria were taken to be incorporated in the AHP analysis.

a) Workforce: It basically involves the people who make the workforce in an organization. It is the total supply of personnel available to complete a particular task. The workforce is the most important as well as the main resource for any organization to function or work properly and achieve high productivity.

b) Maintenance: Maintenance management is a concept that describes the successful and efficient management of maintenance issues involved in the upkeep, operation, and productivity of a factory, manufacturing facility, or plant. So, a better maintenance plan is to increase productivity and profits through improved operations. It is also an important component of the yarn production process [22].

c) Cost: Costing for a product directly influences the price & profit as well as it also affects the lifetime, ergonomics, and environmental outcome of the product.

d) Quality: The yarn has a stable quality only when it is formed by the fiber of close length and relatively uniform. To get such fibers, the fibers from different production areas and batches must be mixed. Use cotton opener, cotton mixer, and cotton cleaning machine to open, remove, and mix all kinds of fibers.

3.5 Questionnaires

Analytical Hierarchy Process (AHP) is a method for situations in which ideas, feelings, and emotions affecting the decision process are quantified to provide a numeric scale for prioritizing the alternatives. And this scale might be best captured by a questionnaire which fulfills the following two objectives:

i. To maximize the proportion of subjects answering our questionnaire that is, the response rate.

ii. To obtain accurate relevant information for our study & analysis.

A questionnaire with the above two objectives was prepared for data collection. It consists of several tables that were developed according to AHP. It starts with a few sentences explaining the purpose of the questionnaire, and what the data will be used for. Much effort was given to provide a clear structure to the questionnaire and much concentration was also given to make the questionnaire simple and easy**.** (Actual Questionnaire is presented with details in Appendix A)

3.6 Validation

The validity of the questionnaire was established as follows:

i. It was scrutinized by experienced engineers & experts. Detailed biography of the engineers are given in Appendix B.

ii. The supervisor of the study provided advice on items to be reshaped, deleted, or added questions.

3.7 Population

Many engineers are working in different textile industries. It should be kept in mind that, many other production engineers are working on different products other than the textiles industry in Bangladesh. In this study, only five engineers were selected for data collection and survey for the company's confidential policy. Besides, those experts were experience through various organization on textiles production.

3.8 Data Collection Procedure

The questionnaire was sent to the researcher's fellow engineers, with whom he worked before. It was also explained to the participants over prolonged telephonic discussions. As it was voluntary work and somewhat lengthy/critical, many of the engineers did not respond promptly. In those cases, the participants were given follow-up.

3.9 AHP Calculation

This section presents the method used in finding out the most appropriate segment for the production process of the textiles industry in the current aspects of Bangladesh by using AHP. The data from the questionnaire were tabulated on a scale of 0 to 5. Separate tables were used to compare segments based on different criteria. Before these segment comparisons, those criteria were also compared among themselves in tabulated format.

Assessment Criteria Hierarchy is as followed:

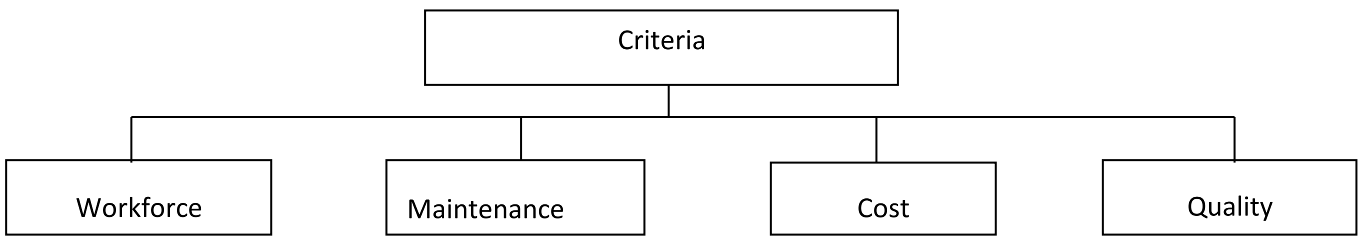

Figure 3.4: Hierarchy for Choice of segment textiles production process

3.10 Data Analysis

Following the standard AHP methodology, the textiles production process segments have been compared with each other in turn for each criterion and their preferential weights have been determined. The result of the analysis according to the participants is presented in Tables 3.A.1 – 3.E.6 in detail before the detailed calculation of Table 3.A.1 & 3.A.6.

In Table 3.A.1 Pair-wise Comparison Matrix for Criteria by Participant A and corresponding Priority Vectors are shown together. By the calculation shown in Tables 3.1 & 3.2, Priority Vectors were found. For example, based on the response of participant ‘A’ the Table 3.1 is created. Here participant A prefers workforce 1.5 times than maintenance and 1.25 times than cost when maintenance vs. workforce comparison comes up in the first cell of the second row than the reciprocal value of workforce vs. maintenance is used, i.e 1/1.5=.66 . Then priority vectors are calculated in the following way: (¡) Divide each cell item by corresponding column summation. For example, the summation of values in the column ‘workforce’ is 4.46. Than each value of that column is divided by 4.46,i.e 1/4.46= 0.22422

(¡¡) Find the average of row values, which is weight or Priority Vector. For example, the priority vector of the first row ‘workforce’ is the average of values in the first row, i.e average of 0.2242, 0.36585, 0.30048, 0.11765

Table 3.1 Pair-wise Comparison Matrix for Criteria (by Participant A)
Find Column Summation (n = 4)

	Workforce	**Maintenance**	**Cost**	**Quality**
Workforce	1	1.5	1.25	.5
Maintenance	.66	1	1.25	1.25
Cost	.8	.8	1	1.5
Quality	2	.8	.66	1
Column Sum	4.46	4.1	4.16	4.25

Table 3.2: Priority Vector Calculation from Table 3.1

	Workforce	**Maintenance**	**Cost**	**Quality**	Avg. of Row/weight/priory vector
Workforce	0.22422	0.36585	0.30048	0.11765	0.25205
Maintenance	0.14798	0.24390	0.30048	0.29412	0.24662
Cost	0.17937	0.19512	0.24038	0.35294	0.24195
Quality	0.44843	0.19512	0.15865	0.23529	0.25938

So, the comparison matrix, A =

$$A = \begin{pmatrix} 1 & 1.5 & 1.25 & .5 \\ .66 & 1 & 1.25 & 1.25 \\ .8 & .8 & 1 & 1.5 \\ 2 & .8 & .66 & 1 \end{pmatrix}$$

And the Weight Matrix, W =

$$W = \begin{pmatrix} 0.25205 \\ 0.24662 \\ 0.24195 \\ 0.25938 \end{pmatrix}$$

$$\lambda max = \begin{pmatrix} 1 & 1.5 & 1.25 & .5 \\ .66 & 1 & 1.25 & 1.25 \\ .8 & .8 & 1 & 1.5 \\ 2 & .8 & .66 & 1 \end{pmatrix} \begin{pmatrix} 0.25205 \\ 0.24662 \\ 0.24195 \\ 0.25938 \end{pmatrix} = \begin{pmatrix} 1.0523075 \\ 1.0384475 \\ 1.028516 \\ 1.116863 \end{pmatrix}$$

λmax= 1.0523075 +1.0384475+1.028516 +1.116863=4.236134

CI = (λmax – n) / (n – 1) = (4.236134-4)/(4-1)=0.236134/3= 0.078711333

RI = 1.98(n – 2) / n = 0.99

RI=1.98(4-2)/4=0.99

Consistency Ratio, CR = CI / RI = 0.079506396

Now, Priority Vectors & CR values are found from Table 4.A.2, 4.A.3, 4.A.4, 4.A.5 & 4.A.6 according to the calculation shown for Table 4.A.1. And from the Priority Vectors of Table 4.A.2, 4.A.3, 4.A.4 & 4.A.5 Priority Matrix or Table 4.A.6 is formed.

Participant A

Table 3.A.1: Pair-wise Comparison Matrix for Criteria

	Workforce	**Maintenance**	**Cost**	**Quality**	**Weight/ priority vector**
Workforce	1	1.5	1.25	.5	0.25205
Maintenance	.66	1	1.25	1.25	0.24662
Cost	.8	.8	1	1.5	0.24195
Quality	2	.8	.66	1	0.25938
CR=0.822					$\sum =1$

Table 3.A.2: Pair-wise Comparison Matrix for workforce

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1.00	2	3	0.53929
Yarns manufacturing	.5	1.00	2	0.29742
Finish product & Packaging	.33	.5	1	0.16328
CR=0.0058				∑ =1

Table 4.A.3: Pair-wise Comparison Matrix for maintenance

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	1.25	1.5	0.39813
Yarns manufacturing	.8	1	2	0.37776
Finish product & Packaging	.66	.5	1	0.22411
CR=0.0203				∑ =1

Table 4.A.4: Pair-wise Comparison Matrix for cost

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	**1**	**1.25**	**1.8**	0.41836
Yarns manufacturing	**0.8**	**1**	**2**	0.37358
Finish product & Packaging	**0.55**	**0.5**	**1**	0.20806
CR=0.0070				∑ =1

Table 4.A.5: Pair-wise Comparison Matrix for quality

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	1.75	1.25	0.42282
Yarns manufacturing	.57	1	1.5	0.31125
Finish product & Packaging	.8	.66	1	0.26592
CR=0.046				∑ =1

Table 3.A.6: Priority Matrix for Choice of Appropriate Segment Final Result

	Workforce	**Maintenance**	**Cost**	**Quality**	Overall Priority Vector
Raw Material collection	0.54	0.40	0.42	0.42	0.45
Yarns manufacturing	0.30	0.38	0.37	0.31	0.34
Finish product & Packaging	0.16	0.22	0.21	0.27	0.22
CR=0.03					∑ =1

The overall priority vector is calculated by multiplying the criteria weight with the corresponding segment weight for that alternative option as shown in Table 3.A.6. For example Overall priority vector also known as composite weight is calculated for row material collection option as follows: 0.25025*0.53929+0.24662*0.39813+ 0.24195*0.41836+ 0.25938*0.4228= 0.45

Participant B

Criteria Matrix: Table 3.B.1: Pair-wise Comparison Matrix for Criteria

	Workforce	**Maintenance**	**Cost**	**Quality**	**Weight/ priority vector**
Workforce	1	1.5	1.25	1.75	0.32706
Maintenance	.66	1	1.4	1.8	0.27653
Cost	.8	.71	1	1.5	0.23320
Quality	.57	.55	.66	1	0.16320
CR=0.0078					∑ =1

Table 3.B.2: Pair-wise Comparison Matrix for workforce

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.66	1.25	0.30838
Yarns manufacturing	1.51	1	1.33	0.41421
Finish product & Packaging	.8	.75	1	0.27741
CR=0.0092				∑ =1

Table 4.B.3: Pair-wise Comparison Matrix for maintenance

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.8	.75	0.27706
Yarns manufacturing	1.25	1	1.75	0.42370
Finish product & Packaging	1.33	.57	1	0.29924
CR=0.0329				∑ =1

Table 4.B.4: Pair-wise Comparison Matrix for cost

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.57	1.25	0.28888
Yarns manufacturing	1.75	1	1.6	0.45505
Finish product & Packaging	.8	.62	1	0.25607
CR=0.0060				∑ =1

Table 4.B.5: Pair-wise Comparison Matrix for quality

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.54	1.25	0.28080
Yarns manufacturing	1.85	1	1.75	0.47276
Finish product & Packaging	.8	.57	1	0.24644
CR=0.0062				∑ =1

Table 4.B.6: Priority Matrix for Choice of Appropriate Segment Final Result

	Workforce	Maintenance	Cost	Quality	Overall Priority Vector
Raw Material collection	0.31	0.28	0.29	0.28	0.29
Yarns manufacturing	0.41	0.42	0.46	0.47	0.44
Finish product & Packaging	0.28	0.30	0.26	0.25	0.27
CR=0.01					∑ =1

Participant C

Table 3.C.1: Pair-wise Comparison Matrix for Criteria

	Workforce	**Maintenance**	**Cost**	**Quality**	**Weight/ priority vector**
Workforce	1	1.5	1.25	1.85	0.33048
Maintenance	.66	1	1.5	1.8	0.28059
Cost	.8	.66	1	1.5	0.22881
Quality	.54	.55	.66	1	0.16013
CR=0.0088					$\sum =1$

Table 3.C.2: Pair-wise Comparison Matrix for workforce

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.57	1.25	0.29218
Yarns manufacturing	1.75	1	1.33	0.43183
Finish product & Packaging	.8	.75	1	0.27599
CR=0.0205				∑ =1

Table 4.C.3: Pair-wise Comparison Matrix for maintenance

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.66	.75	0.25712
Yarns manufacturing	1.50	1	1.75	0.44669
Finish product & Packaging	1.33	.57	1	0.29619
CR=0.0133				∑ =1

Table 3.C.4: Pair-wise Comparison Matrix for cost

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.51	1.25	0.27693
Yarns manufacturing	1.95	1	1.6	0.46836
Finish product & Packaging	.8	.62	1	0.25472
CR=0.0127				∑ =1

Table 3.C.5: Pair-wise Comparison Matrix for quality

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.51	1.25	0.27479
Yarns manufacturing	1.95	1	1.75	0.47942
Finish product & Packaging	.8	.57	1	0.24579
CR=0.0082				∑ =1

Table 3.C.6: Priority Matrix for Choice of Appropriate Segment Final Result

	Workforce	**Maintenance**	**Cost**	**Quality**	Overall Priority Vector
Raw Material collection	0.29	0.26	0.28	0.27	0.28
Yarns manufacturing	0.43	0.45	0.47	0.48	0.45
Finish product & Packaging	0.28	0.30	0.25	0.25	0.27
CR=0.01					$\sum = 1$

Participant D

Table 3.D.1: Pair-wise Comparison Matrix for Criteria

	Workforce	Maintenance	Cost	Quality	Weight/ priority vector
Workforce	1	1.5	1.25	1.85	0.33148
Maintenance	.66	1	1.5	1.8	0.28107
Cost	.8	.66	1	1.25	0.21905
Quality	.54	.55	.8	1	0.16839
CR=0.0092					$\sum =1$

Table 3.D.2: Pair-wise Comparison Matrix for workforce

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.51	1.25	0.27344
Yarns manufacturing	1.95	1	1.85	0.48634
Finish product & Packaging	.8	.54	1	0.24022
CR=0.0055				∑ =1

Table 3.D.3: Pair-wise Comparison Matrix for maintenance

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.57	1.25	0.28557
Yarns manufacturing	1.75	1	1.85	0.47270
Finish product & Packaging	.8	.54	1	0.24173
CR=0.0017				∑ =1

Table 3.D.4: Pair-wise Comparison Matrix for cost

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.50	1.25	0.27104
Yarns manufacturing	2	1	1.85	0.48924
Finish product & Packaging	.8	.54	1	0.23971
CR=0.0082				∑ =1

Table 3.D.5: Pair-wise Comparison Matrix for quality

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.50	1.25	0.27240
Yarns manufacturing	2	1	1.75	0.48230
Finish product & Packaging	.8	.57	1	0.24530
CR=0.0111				∑ =1

Table 3.D.6: Priority Matrix for Choice of Appropriate segment Final Result

	Workforce	Maintenance	Cost	Quality	Overall Priority Vector
Raw Material collection	0.27	0.29	0.27	0.27	0.28
Yarns manufacturing	0.49	0.47	0.49	0.48	0.48
Finish product & Packaging	0.24	0.24	0.24	0.25	0.24
CR=0.01					∑ =1

Participant E

Table 3.E.1: Pair-wise Comparison Matrix for Criteria

	Workforce	**Maintenance**	**Cost**	**Quality**	**Weight/ priority vector**
Workforce	1	1.5	1.25	1.85	0.33109
Maintenance	.66	1	1.5	1.8	0.28090
Cost	.8	.66	1	1.35	0.22307
Quality	.54	.55	.74	1	0.16493
CR=0.0090					$\sum =1$

Table 3.E.2: Pair-wise Comparison Matrix for workforce

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.51	1.25	0.27479
Yarns manufacturing	1.95	1	1.75	0.47942
Finish product & Packaging	.8	.57	1	0.24579
CR=0.0082				$\sum = 1$

Table 3.E.3: Pair-wise Comparison Matrix for maintenance

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.51	1.25	0.27151
Yarns manufacturing	1.95	1	2	0.49603
Finish product & Packaging	.8	.5	1	0.23246
CR=0.0024				$\sum = 1$

Table 3.E.4: Pair-wise Comparison Matrix for cost

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.54	1.25	0.27760
Yarns manufacturing	1.85	1	2	0.48921
Finish product & Packaging	.8	.5	1	0.23319
CR=0.0017				∑ =1

Table 3.E.5: Pair-wise Comparison Matrix for quality:

	Raw Material collection	Yarns manufacturing	Finish product & Packaging	Weight/ priority vector
Raw Material collection	1	.51	1.25	0.27151
Yarns manufacturing	1.95	1	2	0.49603
Finish product & Packaging	.8	.5	1	0.23246
CR=0.0024				∑ =1

Table 3.E.6: Priority Matrix for Choice of Appropriate Segment Final Result

	Workforce	**Maintenance**	**Cost**	**Quality**	Overall Priority Vector
Raw Material collection	0.27	0.27	0.28	0.27	0.27
Yarns manufacturing	0.48	0.50	0.49	0.50	0.49
Finish product & Packaging	0.25	0.23	0.23	0.23	0.24
CR=0.0047					$\sum =1$

3.11 Procedure for 5S Implementation

Following things are to be done for 5S implementation:

- Establishment of a strong Quality Assurance Department.
- At least one or two persons are experts in 5S.
- Experts in the 5S implementation process will coordinate the whole implementation process.

"Red Tagging" of unnecessary items

Experts in 5S should conduct a factory wise audit to find out unnecessary items.

These unnecessary items need to be red-tagged.

Using of Quarantine zone and alternative locations

- Unwanted items need to be placed in a quarantine area.
- Other items may be deemed necessary, but used infrequently and so an alternative location needs to be found.

Properly organized factory & storage area

- Items in factory and storage areas are kept in shelves, racks, or bins and marked.
- Shelf grids are marked with reference numbers/ names for easy retrieval of items.
- All stationery in the cupboards is kept in places, identified with symbols and marks.
- Items are stored in alphabetical order and a logical manner (left to right, top to bottom).

Cleaning schedules available and displayed

- Keeping records that show what type of cleaning was completed, when it was completed, who did the cleaning, and who checked and signed off the cleaning as acceptable.
- Clear instructions outlining the step-by-step process which staff responsible for cleaning.
- The frequency of cleaning e.g. daily, weekly, monthly, or annually.

5s Gap Analysis

- Gap analysis needs to be done on monthly basis.
- Finding the difference between the desired 5s score and achieved score.
- Sort out the reasons for the gap and minimizing it.

Reward and appreciation scheme

- Assessment criteria for the 5s competition are prepared and practiced.
- An event to appreciate best employers is carried out annually.
- Assessment criteria to measure the performance is prepared to select the best units and the best workers.
- An event to appreciate best performing workers and executives need to be carried out annually.

Training of the workers and executives

- Training of both the workers and executives on the 5s process needs to be done.
- The Quality department in charge will take the training of the executives.
- One or two selected executives will take the training of the workers.
- Training needs to be done on monthly basis.

Safety & Security Measures

- Electric wires need to be sealed or bundled to prevent accidental contact with human beings.
- All electric devices are required to be placed safely.
- Danger sign needs to be applied.
- Functional fire extinguishers should be available.
- The guideline or protocol for the fire event should also be available.

3.12 Use of Statistical control chart

The data required for the statistical control chart was collected from records of the industry for January 2020 as shown in table 3. Then control charts are drawn and validated. From here we found a standard X bar and R chart. In February 2020 relevant data required to check the product quality were collected as shown in table 4. Use this control chart the quality of the product was checked for February 2020.

The formula for X bar and R charts as follows:

$$\text{Upper Control Limit} = \bar{\bar{x}} + A_2 (\bar{R}) \qquad \text{Upper Control Limit} = UCL = D_4 (\bar{R})$$

$$\text{Lower Control Limit} = \bar{\bar{x}} - A_2 (\bar{R}) \qquad \text{Lower Control Limit} = LCL = D_3 (\bar{R})$$

Table 3.7 Yarn CSP quality inspection

Date	Morning Shift CSP	Afternoon shift CSP	Night Shift CSP	X bar,I.E. avg CSP of that day	R=Range	Highest Value	Lowest Value	UCL= X bar	LCL=X bar
1/7/2019	2390	2395	2405	2396.666667	15	2405	2390	2422.44	2376.81
2/7/2019	2395	2397	2403	2398.333333	8	2403	2395	UCL= Rbar	LCL=R bar
3/7/2019	2385	2395	2410	2396.666667	25	2410	2385	57.42	0
4/7/2019	2386	2396	2411	2397.666667	25	2411	2386		
5/7/2019	2387	2397	2412	2398.666667	25	2412	2387		
6/7/2019	2388	2398	2413	2399.666667	25	2413	2388		
7/7/2019	2389	2399	2414	2400.666667	25	2414	2389		
8/7/2019	2390	2400	2415	2401.666667	25	2415	2390		
9/7/2019	2391	2401	2416	2402.666667	25	2416	2391		
10/7/2019	2392	2402	2417	2403.666667	25	2417	2392		

Table 3.8 Production quality inspection

S/N	X bar, I.E. avg CSP of that day	CL	UCL	LCL
1	2396.667	2399.63333	2422.44	2376.81
2	2398.333	2399.63333	2422.44	2376.81
3	2396.667	2399.63333	2422.44	2376.81
4	2397.667	2399.63333	2422.44	2376.81
5	2398.667	2399.63333	2422.44	2376.81
6	2399.667	2399.63333	2422.44	2376.81
7	2400.667	2399.63333	2422.44	2376.81
8	2401.667	2399.63333	2422.44	2376.81
9	2402.667	2399.63333	2422.44	2376.81
10	2403.667	2399.63333	2422.44	2376.81

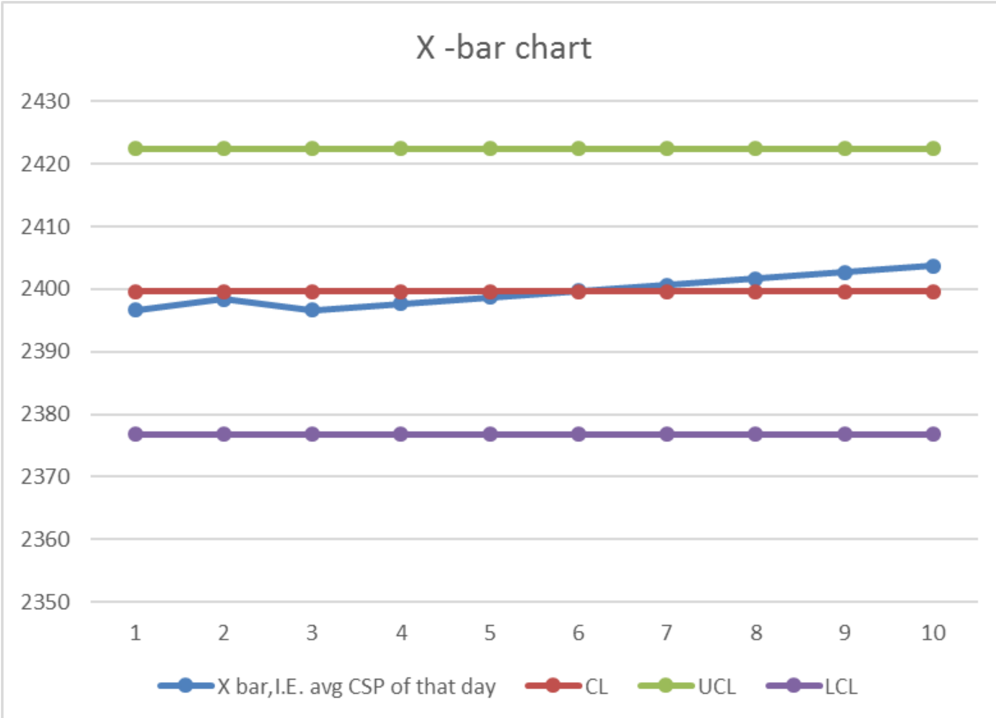

Figure 3.5: X bar used in yarns CSP test

Table 3.8.1 Production quality inspection

S/N	R=Range	CL	UCL	LCL
1	15	22.3	57.42	0
2	8	22.3	57.42	0
3	25	22.3	57.42	0
4	25	22.3	57.42	0
5	25	22.3	57.42	0
6	25	22.3	57.42	0
7	25	22.3	57.42	0
8	25	22.3	57.42	0
9	25	22.3	57.42	0
10	25	22.3	57.42	0

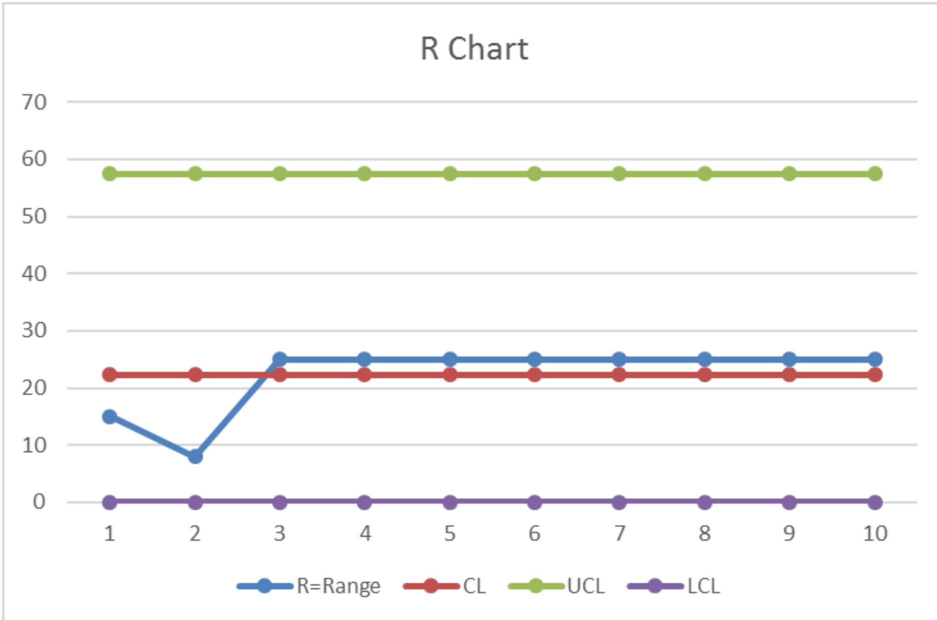

Figure 3.6: R chart used in CSP test

Chapter 4 Result and Discussion

This chapter describes of Ishikawa Diagram, 5 why method, Result of AHP analysis, Summarized Biography of Respondents, Discussion, the impact of optimization, statistical control chart, and 5s method.

4.1 Ishikawa: Ishikawa diagram has been provided in the previous chapter 03.

4.2 5why: 5why method has been described in previous chapter 03.

4.3 Result of AHP analysis: AHP questionnaires and data analysis have been provided in chapter 03.

Data analysis in Table - 1.6, 2.6, 3.6, 4.6, 5.6, 6.6 & 7.6 show the final results for each participant. The overall priority vector shows the preferential ranking of all segments. It appears that textiles manufacturing is the most preferred option for yarn manufacturing (participant - A, C, D& E). Besides, an engineer (participant - B) prefers for Raw material collection. So, analysis from most of the participant's data (4 out of 5) shows that textiles manufacturing is the most preferred option for the textiles production process in the context of Bangladesh.

4.4 Summarized Biography of Respondents

Five participants experienced in the textile production process responded to the questionnaires administered. The biographical details of the engineers have been tabulated (refer to Appendix B). The engineers who responded to the questionnaires were Bangladeshi males. Their age group ranged above the 30 plus category. Their experience as production experts ranged between 5 to 12 years. Each engineer has intensive experience in the field with the full ability to answer the questionnaire. And they have provided effective information to complete the questionnaire according to their experiences. (Details biography is presented in Appendix C)

4.5 Final result of AHP Analysis

Based on the 5 expert opinions as derived from AHP analysis, it was found that 20% preferred the raw material collection segment, **and** 80 % preferred the yarns manufacturing segment. As shown in figure 4.1.

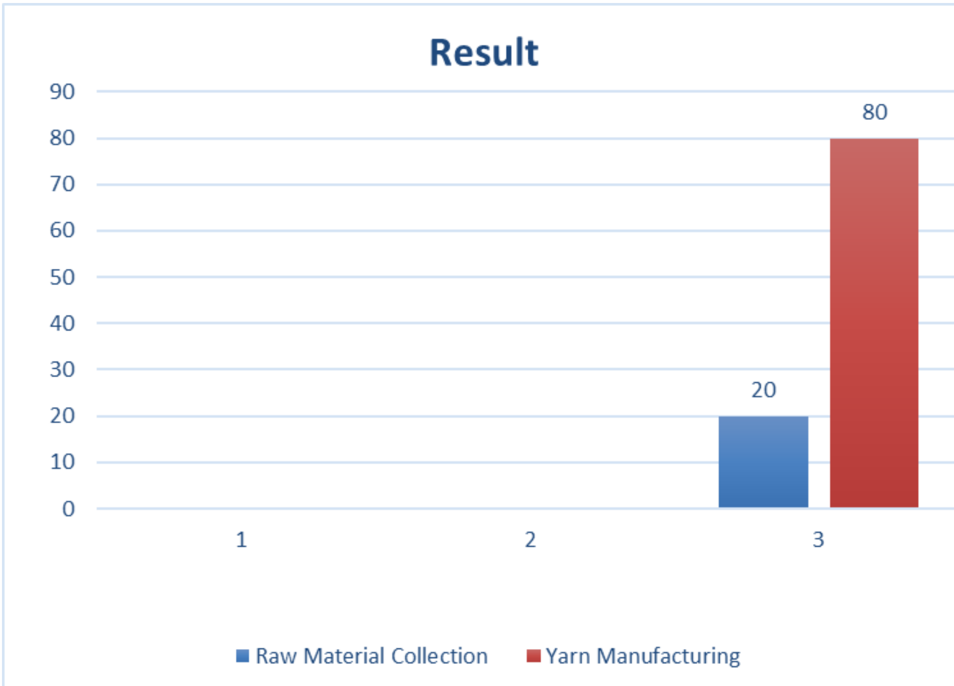

Figure 4.1: Segment criteria preference ratio

Here most of the production engineers preferred textiles manufacturing. A comparative study is shown in Chart 4.1. However, if we analyze the main criteria matrix from table 4.A.1, 4.B.1, 4.C.1, 4.D.1, 4.E.1; we see that the most important factor for prioritizing segment was taken ‘textiles production or yarns manufacturing’ by the most prominent segment of the engineers (Chart: 4.1). And the importance of the factors behind prioritizing textiles production is very much influenced by the working environment & resource availability of the organization.

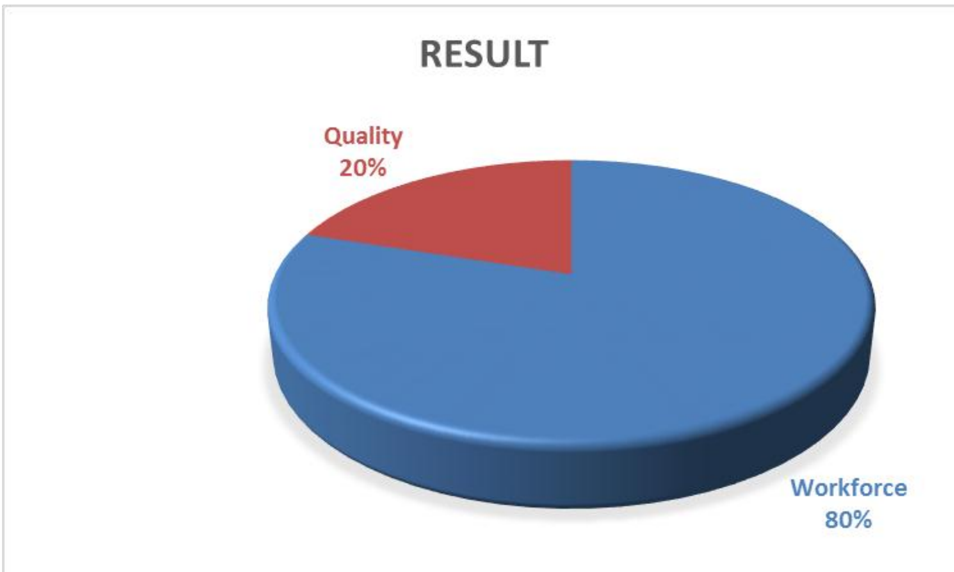

Figure 4.2: Main criteria preference ratio

4.6 5S Result

The following works were done through 5s methods.

“Red Tagging” of unnecessary items:

a) Unnecessary tools and materials have been shorted.

b) Labeling was done to help visual control.

Using of Quarantine zone and alternative locations:

The quarantine zone and alternative zone have been arranged. Unnecessary items were moved into the quarantine zone and infrequently used items were shifted into the alternative zone.

Properly organized factory & storage area:

a) Raw materials and finished goods (cotton) were being kept in the warehouse.

b) Items in stores and storage areas were kept in shelves, racks, or bins and marked.

Figure 5.1: Before 5S implementation of textile factory

Figure 5.2: After 5S implementation Textile factory

Cleaning schedules available and displayed

A cleaning schedule was made and it was displayed in a convenient location.

Gap Analysis

A Monthly meeting was conducted to find out actual and desired 5s implementation.

Reward and appreciation scheme

An award was given annually to a department which implemented 5s successfully.

Training of the workers and executives

According to the schedule, training programs of the workers and executive were conducted about 5s.

Safety & Security Measures

Properly insulated electric warring and fire extinguisher were placed according to safety guidelines. Danger signs were placed to alert the staff members. A fire drill was arranged for all staff members for every month.

4.7 Control Chart

Using in standard control chart derive from chapter 03 we checked the quality of yarns in February 2020. The data collected in this regard are shown in table 10. All are under control.

Table 4.1: Quality inspection by benchmark X bar and R chart:

SL	Date	Morning Shift CSP	Afternoon shift CSP	Night Shift CSP	X bar,I.E. avg CSP of that day	R=Range	Highest Value	Lowest Value	Remarks
1	1/8/2019	2390	2395	2405	2396.666667	15	2405	2390	under control
2	2/8/2019	2395	2397	2403	2398.333333	8	2403	2395	under control
3	3/8/2019	2385	2395	2408	2396	23	2408	2385	under control
4	4/8/2019	2386	2396	2410	2397.333333	24	2410	2386	under control
5	5/8/2019	2387	2397	2412	2398.666667	25	2412	2387	under control
6	6/8/2019	2388	2398	2413	2399.666667	25	2413	2388	under control
7	7/8/2019	2389	2399	2412	2400	23	2412	2389	under control
8	8/8/2020	2390	2400	2414	2401.333333	24	2414	2390	under control
9	9/8/2019	2391	2401	2416	2402.666667	25	2416	2391	under control
10	10/8/2019	2392	2402	2417	2403.666667	25	2417	2392	under control
11	11/8/2019	2393	2403	2418	2404.666667	25	2418	2393	under control
12	12/8/2019	2394	2404	2419	2405.666667	25	2419	2394	under control
13	13/8/2019	2395	2405	2420	2406.666667	25	2420	2395	under control
14	14/8/2019	2396	2406	2421	2407.666667	25	2421	2396	under control
15	15/8/2019	2397	2407	2422	2408.666667	25	2422	2397	under control
16	16/8/2019	2398	2408	2423	2409.666667	25	2423	2398	under control
17	17/8/2019	2399	2409	2424	2410.666667	25	2424	2399	under control
18	18/8/2019	2400	2410	2425	2411.666667	25	2425	2400	under control
19	19/8/2019	2401	2411	2426	2412.666667	25	2426	2401	under control
20	20/8/2019	2402	2412	2427	2413.666667	25	2427	2402	under control
21	21/8/2019	2403	2413	2428	2414.666667	25	2428	2403	under control
22	22/8/2019	2404	2414	2429	2415.666667	25	2429	2404	under control
23	23/8/2019	2405	2415	2430	2416.666667	25	2430	2405	under control
24	24/8/2019	2406	2415	2431	2417.333333	25	2431	2406	under control
25	25/8/2019	2407	2417	2432	2418.666667	25	2432	2407	under control
26	26/8/2019	2408	2418	2433	2419.666667	25	2433	2408	under control
27	27/8/2019	2409	2419	2434	2420.666667	25	2434	2409	under control
28	28/8/2019	2410	2420	2435	2421.666667	25	2435	2410	under control

UCL= X bar	LCL=X bar
2422.4	2376.81
UCL= R bar	LCL=R bar
57.42	0

Table 4.1.1: Quality inspection by benchmark X bar and R chart:

4.8 Impact of optimization

A comparison of selected parameters before optimization and after optimization is presented in Table 4.2

Table 4.2: Before optimization and after optimization

S/N	Topic	Before optimization	After optimization
1	Productivity	2.27	2.29
2	Maintenance frequency	5 per month	4 per month
3	Defective number	5	4
4	Occupational Safety & Health record	12 per year	10 per year

Material productivity: Output /Input.

Input =110 ton (raw material cotton) =110*$2000=220000

Output=100 ton *$5000=500000

Input=110 ton=110*2000=220000

Input =110 ton (raw material cotton) =110*2000=220000,

Output=101 ton *$5000=505000

Before implementation of optimization in the most critical segment for the textiles production, i.e. yarn manufacturing segment, different performance parameter values were not satisfactory. So, the 5s and statistical process control charts were implemented to improve these performance parameters. These performance parameters were productivity, maintenance frequency, defective number, and Occupational Safety & Health record. Significant improvement on these parameters was recorded as shown in table 4.6. Data collected shows that productivity increased by 0.88%, maintenance frequency decreased by 20%, the defective number decreased by 20%, and decreased injured number by 16.66 %.

Chapter 5 Conclusions

5.1 Conclusions

From this study the following conclusions may be drawn:

1. According to the AHP analysis yarn manufacturing is the most critical segment for the production process of the textiles industry for optimization.

2. Based on the findings optimization were done in the yarn manufacturing segment using the relevant method like 5s and statistical process control chart. Significant improvement was found as measured by different metrics like productivity, maintenance frequency, defective number, occupational safety & health record.

3. Selection of the most appropriate segment of the textiles production process in Bangladesh was not done before. So, it would be helpful for the textiles industries to use findings from this study.

5.2 Recommendation for further studies

i. Similar study and analysis might be performed for any other specific manufacturing industry segment like air-conditioner, fan, motor car, LPG, etc.

ii. Other Countries, developing as well as developed countries, may do similar study and analysis in the relevant manufacturing sectors.

iii. Criteria other than this study might be used based on requirements and objectives.

Appendix A

There are different textile production methodologies. A brief of them are:

Raw Material collection: Valuable raw material collection is characterized by an extensive range of valuable merino wool yarns and noble fibers (Cashmere, silk, angora, cotton), pure or blended with man-made fibers used in low percentage to modernized classical products.

Yarns manufacturing: An assemblage of fibers that are twisted or laid together to form a continuous strand that can be made into a textile fabric. So a yarn is a strand of natural or manmade fibers or filaments that have been twisted or grouped for use in weaving, knitting, or other methods of constructing textile fabrics.

Finish product & Packaging: Yarn is packaged (or put up) in different forms: balls, skeins (rhymes with canes), and hanks. The differences in yarn packaging shouldn't have much effect on the yarn you choose, but the shape does determine how you work with them. There are various types of yarn are being produced in textiles industries such as viscose, modal, polyester, etc.

The criteria for this study as follows:

Workforce: It basically involves the people who make the workforce in an organization. It is the total supply of personnel available to complete a particular task. The workforce is the most crucial resource for any organization to function or work properly and achieve high productivity. Workforce for Production might be defined as the general engineering concept of the production process where the main concern of a production engineer is to increase productivity.

Maintenance: Maintenance management is a business concept that describes the successful and efficient management of maintenance issues involved in the upkeep, operation, and productivity of a factory, manufacturing facility, or plant. So, a better maintenance plan is to increase productivity and profits through improved operations. It is also an important component of the yarn production process.

Cost: Costing for a product directly influences the price & profit as well as it also affects the lifetime, ergonomics, and environmental outcome of the product.

Quality: The yarn has a stable quality only when it is formed by the fiber of close length and relatively uniform. To get such fibers, the fibers from different production areas and batches must be mixed. Use cotton opener, cotton mixer, and cotton cleaning machine to open, remove, and mix all kinds of fibers.

Please fill out the following table with a scale of 0 to 5. Read from the left of a row with respect to the column. If the topic of row and topic of the column seems equally important to you, just put 1. If row item is 2 times more important than column topic, write 2. If the column item is 2 times important than the row item please put 1/2 and so on.

	Workforce	**Maintenance**	**Cost**	**Quality**
Workforce	1			
Maintenance		1		
Cost			1	
Quality				1

Please fill out the following table in the same manner (at a scale 0 to 5) considering Workforce

	Raw Material collection	**Yarns manufacturing**	**Finish product & Packaging**
Raw Material collection	1.00		
Yarns manufacturing		1.00	
Finish product & Packaging			1.00

Please fill out the following table in the same manner (at a scale 0 to 5) considering

Maintenance

	Raw Material collection	Yarns manufacturing	Finish product & Packaging
Raw Material collection	1		
Yarns manufacturing		1	
Finish product & Packaging			1

Please fill out the following table in the same manner (at a scale 0 to 5) considering **Cost**

	Raw Material collection	**Yarns manufacturing**	**Finish product & Packaging**
Raw Material collection	1		
Yarns manufacturing		1	
Finish product & Packaging			1

Please fill out the following table in the same manner (at a scale 0 to 5) considering Quality

	Raw Material collection	**Yarns manufacturing**	**Finish product & Packaging**
Raw Material collection	1		
Yarns manufacturing		1	
Finish product & Packaging			1

Appendix B

Table: Biographic Details of Respondents (up to July, 2019)

Sl.	Name	Qualification	Approximate Engineering Experience (Years)	Approximate Textiles Industry Experience (Years)
1	Md Aminul Islam	BSc. in EEE	12	7
2	Saad Md Salman	BSc. in ME	10	6
3	Md.Tahmid Anjum Nabil	BSc. in Textile	4	4
4	Md. Ziaul Haque Shovon	BSc in ME	6	6
5	Md Abu Zafor	BSc. in ME	5	5

References

1. Hossain I, Hossain A, Choudhury IA, Mamun AA. Fuzzy knowledge based expert system for prediction of color strength of cotton knitted fabrics. Journal of Engineered Fibers and Fabrics. 2016 Sep; `11 (3):155892501601100306.

2. Junior ML, Godinho Filho M. Variations of the kanban system: Literature review and classification. International Journal of Production Economics. 2010 May 1; 125 (1):13-21.

3. Kavanagh S, Krings D. The 8 Sources of Waste and How to Eliminate Them. Government Finance Review. 2011 Dec; 27 (6 s 18).

4. Stengg W. The textile and clothing industry in the EU. Enterprise papers. 2001 Jun; 2:4.

5. Rashid MA. Rise of readymade garments industry in Bangladesh: entrepreneurial ingenuity or public policy. In workshop on Governance and Development, Dhaka 2006 Nov 11 (pp. 11-12).

6. Islam MS. Faculty of Technology Lean Practices in Bangladeshi Textile Industry A Literature Review.

7. Winston WL, Goldberg JB. Operations research: applications and algorithms. Belmont^ eCalif Calif: Thomson/Brooks/Cole; 2004 Jan.

8. Ghosh A, Mal P, Majumdar A. Advanced Optimization and Decision-Making Techniques in Textile Manufacturing. CRC Press; 2019 Mar 18.

9. Tobler-Rohr MI. Handbook of sustainable textile production. Elsevier; 2011 Jun 27.

10. Shetty D, Ali A, Cummings R. Survey- based spreadsheet model on lean implementation. International Journal of Lean Six Sigma. 2010 Nov 22.

11. Modi DB, Thakkar H. Lean thinking: reduction of waste, lead time, cost through lean manufacturing tools and technique. International journal of emerging technology and advanced engineering. 2014 Mar; 4 (3):339-4.

12. Pattnaik P, Dangayach GS. Sustainability of Textile Wastewater Management by Using Fuzzy AHP Method. In Proceedings of International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), Amity University Rajasthan, Jaipur-India 2019 Feb 26.

13. Bhamu J, Sangwan KS. A framework for lean manufacturing implementation. International Journal of Services and Operations Management. 2016;25(3):313-33.

14. Motwani J. A business process change framework for examining lean manufacturing: a case study. Industrial Management & Data Systems. 2003 Jul 1.

15. Baral P. Implementation of 5S methodology on slot line assembly for a Manufacturing Company located in Minnesota (Doctoral dissertation, University of Wisconsin—Stout, 2012).

16. Taha, H., Operations Research: An Introduction, 10th Edition, Pearson, New Jersey, 2017.

17 .Kabir, A and Shihan, S , Selection of Renewable Energy Sources Using Analytic Hierarchy Process, Proceedings of ISAHP 2003, Bali, Indonesia, pp. 267-276, August 7-9, 2003

18. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, New Edition 2001 (Analytic Hierarchy Process Series, Vol. 2); Saaty, Thomas L. (June 2008).

19. Kumar, S. Anil, and N. Suresh. Production and operations management. New Age International, 2006.

20. Mustafi, Chandan Kumar. Operations Research methods and practice. New Age International, 1996.

21. Mustafi, Chandan Kumar. Operations Research methods and practice. New Age International, 1996.

22. Total Productive Maintenance. Portland, OR: Productivity Press. Office of Quality Improvement, 2010. Survey Fundamentals: A Guide to Designing and Implementing Surveys. Madison: University of Wisconsin. Ortiz, C., 2006.

23. Classification Scheme for Lean Manufacturing Tools, International Journal of Production Research, 41(13), pp.3075-3090. Pedersen, E.R.G., Huniche, M., 2011.

24. Determinants of lean success and failure in the Danish public sector: A negotiated order perspective", International Journal of Public Sector Management, 24 (5), pp.403-420, https://doi.org/10.1108/09513551111147141 Petersson, P., Johansson, O., Broman, M., Blucher, D. and Alsterman, H., 2010.

25. Lean- Turn deviations into success! Bromma, Sweden: Part Media, Gronviksvagen. Phan, A. and Matsui, Y., 2007.

26. Effect of Total Quality Management and Just-In-Time practices on Competitive Performance - Empirical Evidence. Proceedings of the 18th Annual Conference of Production and Operations Management Society. Piercy, N. and Rich, N., 2009.

27. Sobuj, M., and Rahman, C., Study and Analysis of the Scope of Value Stream Mapping (VSM) Technique Application in a Selected Garments Factory of Bangladesh, International Journal of Engineering Research and General Science, vol. 3, no. 2, pp. 998-1007, 2015.

28. Piercy, Niall, and Nick Rich. "High quality and low cost: the lean service centre." European Journal of Marketing (2009).

29. Henderson, Kim M., and James R. Evans. "Successful implementation of Six Sigma: benchmarking general electric company." Benchmarking: an international journal (2000).

30. HINNES, P., M. HOLWEG, and N. RICH. "Learning to evolve: a review of contemporary lean thinking International Journal of Operations & Production Management." (2004): 994-1011.

31. Hirano, H., 1996. 5s for Operators: 5 Pillars of the Visual Workplace, Portland OR: Productivity Press. Islam, M.M., Khan, A.M. and Islam, A.M., 2013.

32. International Journal of Scientific & Engineering Research, 4(2). James P. Womack, Daniel T. Jones, Daniel Roos, & Massachusetts Institute of Technology. (1991).

33. The machine that changed the world: The story of lean production. Harper Collins. Jones, R. M., 2002.

34. Lean Production in Changing Competitive World: A Japanese Perspective, International Journal of Operations and Production Management, 16(2), pp. 8-23. Kavanagh, S. and Krings, D., 2011.

35. Toward A Theory of Business Process Change Management. Journal of Management Information Systems, 12 (1), pp.1-30. Kilpatrick, J., 2003.

36. Gockeln, L. (2014). Fashion Industry Analysis from the Perspective of Business Model Dynamics.

37. Goyal, M. and Netessine, S..(2011), "Volume Flexibility, Product Flexibility, or Both: The Role of Demand Correlation and Product Substitution", Manufacturing & Service Operations Management, Vol. 13, No. 2, pp. 180-193.

38. Hayes, R. and Wheelwright, S. (1984), Restoring Our Competitive Edge: Competing Through Manufacturing, Wiley, New York, NY

39. Koberg, J., & Bagnell J. (1991). The universal traveler: A soft systems guide to creativity, problem-solving and the process of reaching goals. W. Kaufmann.

40. Archer, B. (1974). Design awareness and planned creativity in industry. (p. 87). Toronto: Thorn Press Limited.

41. Hekkert, P., & Schifferstein, H. (2008). Product experience. Amsterdam: Elsevier Science.

42. Norman, D. (2002). The design of everyday things. (p. 28). New York: Basic Books.

43. Pirkl, James J. (1994). Trans generational Design: Products for an Aging Population. New York: Vn Nostrand Reinhold. p. 24. ISBN 0-442-01065-6.

44. HungLin, Chi, 5S implementation in Wan Cheng Industry Manufacturing Factory in Taiwan, MS Technology Management (2011).

45. J. Michalska, The usage of the quality-cost analysis in a production process, Journal of Achievements in Materials and Manufacturing Engineering 16 (2006) 190-198.

46. By Melesse Workneh Wakjira, Ajit Pal Singh, Total Productive Maintenance: A Case Study in Manufacturing Industry, Global Journal of researches in engineering Industrial engineering, Volume 12 Issue 1 Version 1.0 February 2012.

47.T. Ahmed and S.M. Ali, M.M Allama, M.S. Parvez, A Total Productive Maintenance (TPM) Approach to Improve Production Efficiency and Development of Loss Structure in a Pharmaceutical Industry, Global Journal of Management and Business Research, Vol. 10 Issue 2 (Ver 1.0), April 2010.

48. J.J. Dahlgaard, K. Kristensen, G.K. Kanji, Basis of Quality Management, PWN, Warsaw, 2000.

49.T. Karkoszka, M.Roszak, Quality and environmental aspects in the technological process management, Proceedings of Conference "Projecting & Managing of the realization of the production", Zielona Góra (2005) 63-68 .

50. J. Michalska, 2005 ''Factors creating quality management in the company'' '*Proceedings of the Conference INTELLECT*'' Intellectual capital as a chance to improve the quality management in the global circumstances" UMCS, Lublin, (2005) 187-191.