# Establishing Cycle Times in a High Variety Manufacturing Environment Using DMAIC Procedure

by

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# DECLARATION

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## ABSTRACT

Today many competitive manufacturing companies use a variety of quantitative metrics to provide them with the means to track and identify problems with performance, and to make good decisions. This explains the need for a weaving and dyeing plant based in Cape Town, South Africa, to establish production performance metrics in general, and the cycle times at various workstations in particular. Also, this research assumes that the establishment of the cycle times at various workstations of the weaving and dyeing plant constitutes an important step toward the adequate management of the manufacturing lead times.

While there exist many generic techniques for establishing the cycle times in a manufacturing environment, there is limited literature on how to establish the cycle times in a high variety production environment, such as a weaving and dyeing plant. Consequently, this research focuses on establishing cycle times at various workstations of a weaving and dyeing plant, while taking into account the entire population of products that has to be produced at each workstation. Furthermore, following the establishment of the cycle times, this research creates a cycle time control sheet to be used by the weaving and dyeing department's managers, in order to better control the manufacturing lead times.

Lastly this research identifies the DMAIC procedure as a viable quality management approach, which can be used to realign the weaving and dyeing production performance measurements with the requirements of its ISO 9001:2008 certification. Therefore DMAIC is used as the most suitable technique for carrying out this research.

# OPSOMMING

In vandag se mededingende vervaardiging omgewing maak maatskappye gebruik van ‘n verskeidenheid van kwantitatiewe statistieke om probleem situasies te identifiseer en op te volg met die doel om beter besluitnemings tegnieke toe te pas.

Dit verklaar die behoefte hoekom ‘n weef en kleur vervaardiger in Kaapstad, Suid Afrika, om produksie prestasie metings in die algemeen te bepaal asook om siklus tye by elke werkstasie te bestudeer. Hierdie navorsing aanvaar dat die siklus tye metings by elke werkstasie ‘n waardevolle stap is in die proses om van die weef en kleur vervaardiger suksesvol te bestuur ten opsigte van vervaardiging lewertye.

Baie generiese tegnieke bestaan alreeds om die siklus tye in die vervaardigings omgewing vas te stel, maar daar is 'n beperkte literatuur hieroor in 'n hoë verskeidenheid produksie-omgewing, soos 'n weef en kleur vervaardiger. Gevolglik gaan hierdie navorsing fokus op die vestiging van siklus tye op verskillende werkstasies, met inagneming van die totale verskeidenheid van produkte wat geproduseer word by elke werkstasie. Nadat die siklus tye vasgevang is, gaan die navorsing voort om 'n siklus tyd kontroleblad te skep vir die gebruik van bestuurders in die weef en kleur afdeling ten einde 'n beter beheer oor die produksie lewertye te hê.

Laastens identifiseer hierdie navorsing die proses DMAIC as 'n lewensvatbare gehalte bestuursbenadering wat gebruik kan word in die weef en kleur produksie omgewing omdat dit aan die prestasiemaatstawwe vereistes van die ISO 9001: 2008 sertifisering voldoen. Dus is hierdie die rede hoekom DMAIC gebruik gaan word as die mees geskikte tegniek vir die uitvoering van hierdie navorsing.

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# 1 CHAPTER I: INTRODUCTION

## 1.1 Background

In many successful and competitive manufacturing businesses today, customer satisfaction increasingly plays as important a role as the generation of profit. This can be seen through the operations managers striving on a daily basis to deliver the best quality product to their customers, at a reasonable price, and within the shortest possible time. The success of an enterprise can therefore be measured simultaneously in terms of the three global economic goals of high quality, low costs as well as low lead times *(Mayer & Nusswald, 2001)*.

In order to meet these three global economic goals, successful manufacturing companies use a variety of quantitative metrics that provide them with the means to track and identify problems with performance and to make good decisions *(Groover, 2008, p. 48)*. The tracking and hence the monitoring of performance on a regular basis, is also thought to be the cornerstone of effective manufacturing strategies *(T. Hill, 2000, p. 45)*. Moreover, performance monitoring is essential to ensure that a company achieves a competitive position *(Gibson, Greenhalgh, & Kerr, 1995, p. 294)*.

This emphasis on the importance of performance measures in the manufacturing industry explains the need for a narrow-fabric manufacturing company based in Cape Town, to establish their production performance metrics in general, and the cycle times at various workstations in particular.

The company's weaving and dyeing department specifically, is the department where the cycle times are to be established. Although many generic techniques for establishing the cycle times in a manufacturing environment exist, there is limited literature on how to establish the cycle times in a high-variety production environment such as a weaving and dyeing plant.

Therefore, given the high variety of the products produced at each workstation, the weaving and dyeing department searched to establish an entire population of cycle times generated at each workstation.

## 1.2 Research environment

### 1.2.1 Company overview

Being one of the industry's largest weavers of narrow fabrics, the manufacturing company is an ISO 9001:2008 certified company, which delivers a broad range of labelling products for many of the world's manufacturers. The company is located in an industrial area of Cape Town. It started its operations 30 years ago and currently has a workforce of 300 employees.

Furthermore, in order to diversify their production outputs, the narrow-fabric manufacturing company's factory consists of three distinct production lines. These production lines are referred to as departments, and are called: the weaving and dyeing department; the woven labels department; and the printing department.

This research was carried out solely in the weaving and dyeing department. This department operates independently from both the woven labels department and the printing department. In spite of this operational independence, the weaving and dyeing department supplies approximately 45% of its total annual production output to the printing department, also identified as its internal client. The remaining 55% of the weaving and dyeing plant's total annual production is shipped to various external clients.

### 1.2.2 Supply chain overview

**The suppliers**

The narrow-fabric manufacturing company purchases raw material from their local or overseas suppliers, which are mostly wholesalers of raw material. Upon arrival at the factory, the raw material is in the form of bobbins, mostly of a whitish colour called 'natural colour', and are contained in boxes in various quantities.

These bobbins fall into two main categories; namely, polyester and cotton. However, each of these two categories of raw material is further subdivided into various grades. For example, within the cotton category there are various grades of cotton bobbins, varying from dense and thick cotton threads, to relatively light and thin ones. Similarly, the polyester category contains various grades of bobbins.

**The manufacturing process**

Once the raw materials have been received, the manufacturing process starts with the aim of either building up stock, or of meeting a specific customer’s demand based on a particular order. The manufacturing process entails moving material in batches through a series of value-added processes, at the end of which raw material threads are transformed into batches of narrow-fabric tapes of various widths, densities, colours, and woven patterns or textures.

Additionally, due to the high variety of products that are created during the manufacturing process, some product groups have been established by the company. These product groups classify the various products into distinct families of products. The various families of products travel along well-established production routings. These production routings vary in three distinct ways as follows:

- Production routing whereby the raw material is dyed first, then woven into narrow fabric;
- Production routing whereby the raw material is first woven into a narrow fabric, then dyed a specific colour;

- Production routing whereby the raw material is dyed first, then woven into narrow fabric, and then washed with water.

The reason for having a production routing whereby the raw material is dyed first, then woven, and then washed with water, is because work-in-progress can often pick up dirt during handling. It could also get wrinkled from being temporarily stored underneath other work-in-progress. Further information on the production routing will be given in subsequent chapters.

Finally, once the manufacturing process is completed by following either one of the above-mentioned production routings, the finished products are sent to the finished goods store where they are temporarily stored in batches consisting of several rolls of narrow-fabric tapes, awaiting to be packaged and subsequently invoiced.

**First tier customers**

From the finished goods store of the weaving and dyeing department, the finished work is invoiced to either the internal client, which as mentioned in Section 1.2.1 is the printing department, or to various external clients of the weaving and dyeing department. Both the internal and external clients would have to perform further operations on the product supplied to them by the weaving and dyeing department before they can supply their respective customers.

The operations performed by the internal clients will consist of printing onto the narrow fabric, whereas the operations performed by the external clients will mainly consist of attaching the narrow fabric supplied to them, to the product that they themselves manufacture.

By attaching the narrow fabric supplied by the weaving and dyeing department to their own manufactured products, the external clients end up creating a unique product relative to their business orientation. Some examples of the use of narrow fabrics by the external client in creating their unique products are:

- Hanger tapes on various garments;
- Label tags on various garments;
- Ribbon bookmarks in diaries;
- Ornaments on bottles of sparkling drinks, etc.

**Second tier customers**

The second tier customers include chain stores, apparel retailers, and many other businesses. Once the chain stores have identified their clients’ needs, or have established new product designs for a specific season, they will pass on the designs to the first tier customers of the narrow-fabric manufacturing company for manufacturing purposes.

Therefore the type of products manufactured by the first tier customers, are all products that are produced based on the requirements or design specifications of the chain stores. This also means that the chain stores' demands to the first tier customers, would somehow dictate the demand of the first tier customers to the narrow-fabric manufacturing company. Consequently, getting to know who the second tier customers are, helps better understand and predict the uncertainty and the variety around the demand.

**Third tier customers**

The third tier customers consist mainly of the end users who purchase the product for consumption. In a similar way to how the first tier customers manufacture products based on the chain stores' requirements, the chain stores or retail stores in their turn, will design their products based on what their target market needs. Hence, the end users’ needs ultimately dictate the demand behaviour throughout the entire supplier chain. Figure 1-1 below shows a summary of the entire supply chain as described above.

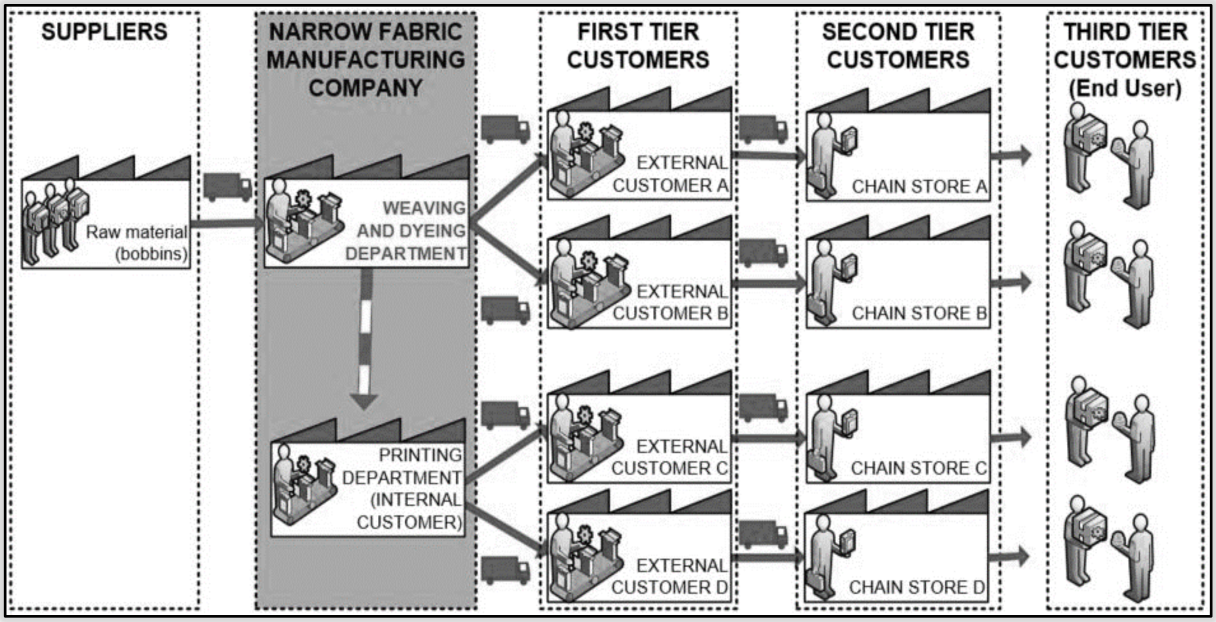



**Figure 1-1 Supply chain overview**

## 1.3 Motivation for the research

In October 2014, the narrow-fabric manufacturing company decided to initiate a research project in the weaving and dyeing plant in order to establish the cycle times for the various production activities of the entire manufacturing process. The decision to undertake such a study was mainly fuelled by the following two factors:

- Frequent customers complaining about the 10–15 days Manufacturing Lead Time (MLT) currently imposed upon them;
- A steady annual decrease in the demand of Make to Order (MTO) products; hence a reduction of the narrow-fabric manufacturing company's market share.

### 1.3.1 Long MLT

**Manufacturing lead time**

The MLT as established in the weaving and dyeing department's service level report, is the duration between the date on which an order is received from a customer, and the date on which the order is invoiced. Figure 1-2 shows a frequency histogram of the MLTs, drawn from the 2014 service level report of the weaving and dyeing department. It illustrates that, collectively, 48% of the orders placed in the year 2014 took 1–2 days of MLT, and the remaining 52% of orders placed that year took between 3 and 15 days of MLT.

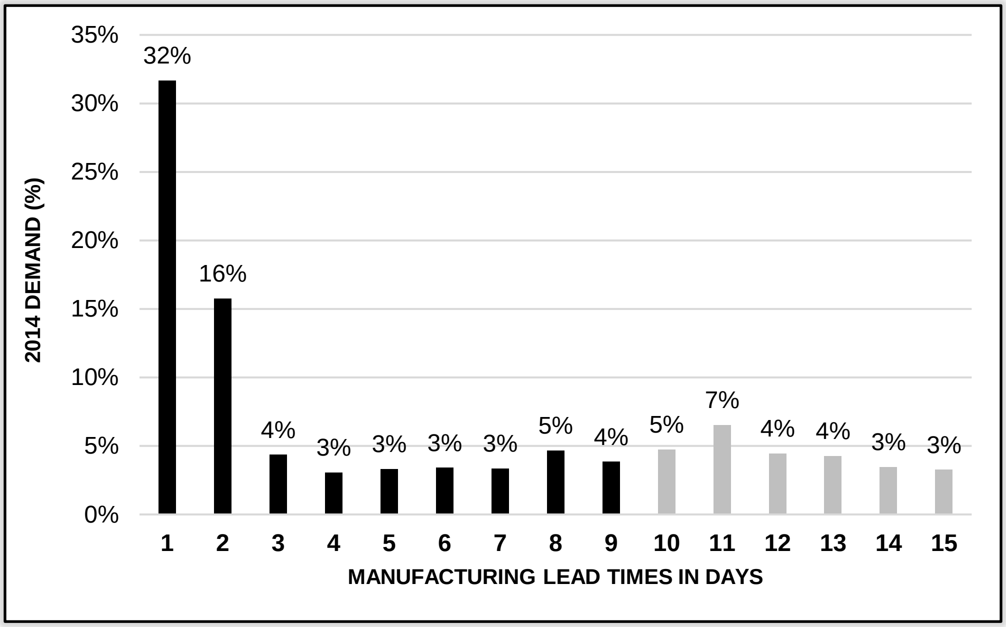



**Figure 1-2 Frequency histogram of 2014 MLT** *(Weaving and dyeing department)*

The main reason that 48% of the orders placed in the year 2014 took 1–2 days of MLT, is mainly due to Make to Stock (MTS) products. MTS in the weaving and dyeing department consists of manufacturing products in order to build up stock, rather than manufacturing to fulfil a particular customer's order. As a result, upon receiving a customer's order which falls within the MTS product category, the weaving and dyeing department would simply have to invoice the work, as the order would have already been manufactured and packaged.

On the other hand, the remaining 52% of orders placed in the year 2014, which took between 3 and 15 days of MLT, consist of MTO products. MTO in the weaving and dyeing department consists of manufacturing products either from the very first operation of the entire manufacturing process, or from a work-in-progress state, in order to fulfil a particular customer's order. Incidentally, the 10–15 days MLT shaded in grey in Figure 1-2 is an estimated MLT window, established by the weaving and dyeing department for MTO products that are to be manufactured from the very first operation of the entire manufacturing process, for various order sizes.

**Order size**

Although the service level report of the weaving and dyeing department shows the MLT of various orders, it doesn’t specify the time it took to manufacture the content of those orders, nor does it specify the content of the orders themselves. When received in the weaving and dyeing department, an order may contain either one line of the product needed by the customer, or several lines of various products needed by the customer. In addition to the line of product in an order, is the corresponding defining characteristic of each line of product in the order, such as the length, the width or the colour. Therefore an order size may vary in two general ways, namely:

- Through the number of products contained in an individual order and;
- Through the defining characteristics of each product.

It can therefore be concluded that by establishing the production activities’ cycle times, the weaving and dyeing department would be able to determine how long a particular order size would take to be manufactured at each and every workstation, hence providing better control and more accuracy over the MLT.

### 1.3.2 Decrease in annual demand

In addition to the many customers complaining over the 10–15 days MLT imposed on them; the weaving and dyeing department noticed, based on the annual generated sales history, a somewhat steady decrease in the annual demand of the MTO products over the past three years as depicted in Figure 1-3 below.

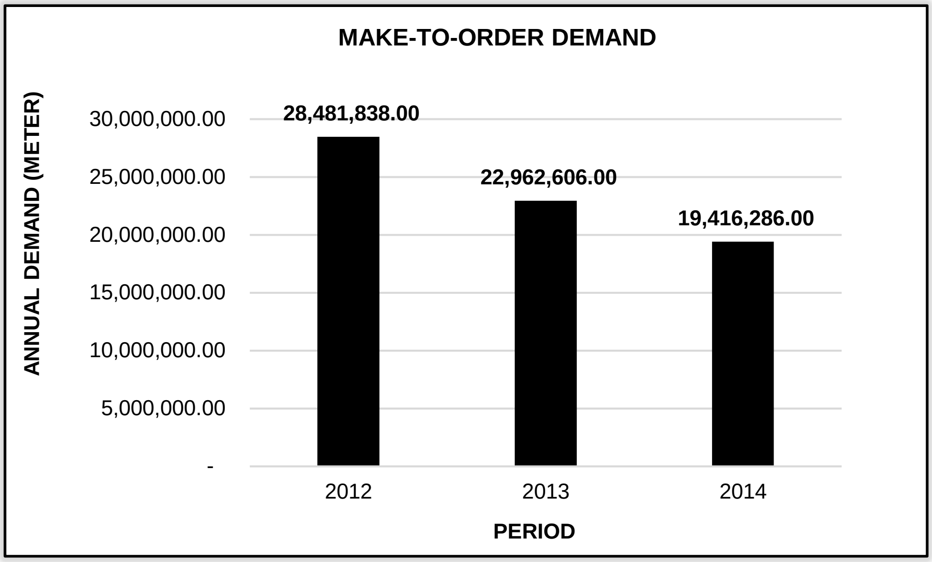



**Figure 1-3 External customers annual demand** *(Weaving and dyeing department)*

Consequently, the management of the narrow-fabric manufacturing company assumed that the lack of information about the cycle times at various workstations occasioned uncontrollably lengthy MLTs, as well as unrelenting customer dissatisfaction; hence the decline in the annual demand.

Such an assumption is supported by *Handfield & Pannesi (1995)* who mention that within the context of a firm's value-added chain, long delivery lead times can have an adverse effect on customer loyalty and market share. This is particularly true for MTO products, which often win orders on the basis of how quickly they can be delivered to the customer from the time they are ordered.

## 1.4 Research problem

The cycle times at various workstations of the weaving and dyeing department are not known, nor are they being measured. As a result, it is difficult for the weaving and dyeing department to determine at any time, how long it would take to produce a given number of products; or how many products can be produced over a specific period of time.

While the research problem as stated in the above paragraph sees the establishment of the cycle times as an important step towards an adequate management of the manufacturing lead times explained under Section 1.3, that is not the only step towards an adequate management of the manufacturing lead times.

## 1.5 Research questions

- Is Define-Measure-Analyse-Improve-Control (DMAIC) a suitable technique for conducting this research?
- How can the cycle times be measured by taking into account the high variety of products produced at each workstation?
- What is the nature of the production activities that are carried out at each workstation?
- How can the establishment of the cycle times help in adequate estimation and management of the MLTs?

## 1.6 Research objective

The ultimate objective of this research is to establish the cycle times at the various workstations of the weaving and dyeing department, in order to help the management team better estimate and manage their MLTs. Furthermore, given the high variety of the products produced at each workstation, an entire population of cycle times should be established at each workstation.

## 1.7 Scope of the research

As mentioned under Section 1.1, this research is carried out in the weaving and dyeing department of the narrow-fabric manufacturing company. Additionally, it focuses specifically on determining the cycle times at the various workstations.

Based on a preliminary observation of the weaving and dyeing department operations, the various workstations were found to mainly encompass the first three primary activities of Porter's value chain diagram; namely, inbound logistics, operations and outbound logistics, as illustrated in Figure 1-4 below.

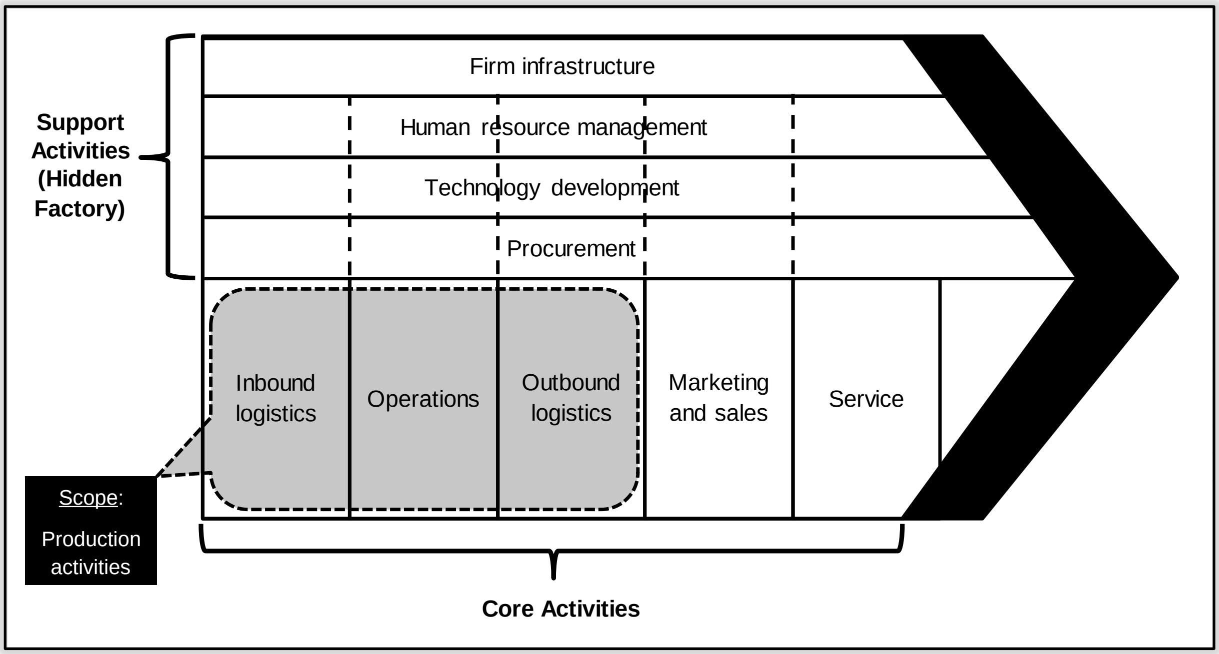



**Figure 1-4 Porter's value chain** *(Foster, 2010, p. 284)*

Further information concerning the nature of the first three core activities of Porter's value chain diagram within the weaving and dyeing department, is provided in Chapter III.

## 1.8 Assumption

Based on the preliminary observation of the weaving and dyeing department operations, the following two assumptions were made:

- The establishment of the cycle times within the weaving and dyeing department is an important step toward an adequate management of the manufacturing lead times;
- The utilisation of the resources, and the working hours in the weaving and dyeing department will vary according to the product demands.

This last assumption is made by virtue of the fact that when the product demand is high, the weaving and dyeing department tends to maximise the use of its resources. However, when the product demand is low, the managers of the weaving and dyeing department tend to minimise labour cost by having operators work shorter production shifts. Consequently, some factors that could be considered as being inefficient under normal operating conditions of the weaving and dyeing department, could become a norm during periods of low demand.

## 1.9 Ethical implications

In adherence with the confidentiality as well as the intellectual property policies of the company in which this research was conducted, the name of the company is not disclosed in this research. The company is therefore referred to only as the 'narrow-fabric manufacturing company' throughout this document, by virtue of its being a weaver and dyer of narrow fabrics in South Africa.

## 1.10 Research design and methodology

In an attempt to provide the overall structure followed for this research, a schematic research methodology is drawn up and illustrated in Figure 1-5 below. However it is important to add to the figure that the type of research conducted in this specific case is a quantitative research as it requires the collection and analysis of numerical data, and the application of various statistical principles to interpret the data.

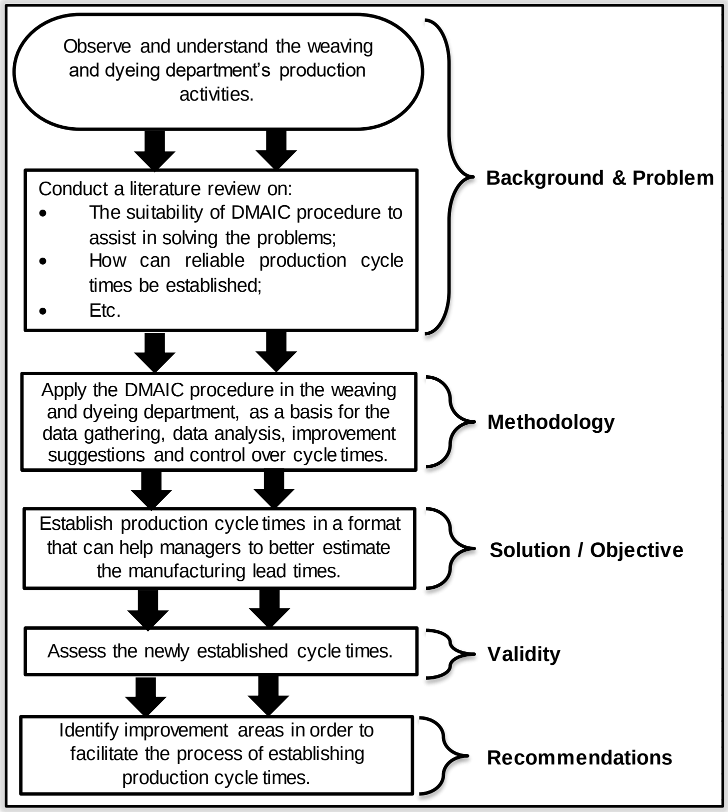



**Figure 1-5 Research methodology**

Moreover, the positivist approach is the one chosen for this research as it holds that the research must be limited to what can be observed and measured objectively; that is, that which exists independently of the feelings and opinions of individuals *(Welman, Kruger, & Mitchell, 2005, p. 6)*.

Therefore this research forms part of an action research as it has the aim of finding a solution for a particular practical problem situation in a specific, applied setting which is the weaving and dyeing department of the narrow-fabric manufacturing company. It makes use of a versatile design that may continually be changed and adapted as a result of information and results obtained during the research project. Furthermore, it places a high premium on involving all of the weaving and dyeing department's staff in all the phases of the research *(Welman et al., 2005, p. 205)*.

## 1.11 Chapter summary

This chapter starts by explaining the importance of establishing firstly, performance measures in the manufacturing industry, and more specifically the cycle times at various workstations of a weaving and dyeing plant.

This chapter then assumes that the establishment of cycle times at various workstations of the weaving and dyeing department is an important step towards an adequate management of the MLTs. It also specifies that given the high variety of the products produced at each workstation, an entire population of cycle times should be established at each workstation.

Furthermore, this chapter identifies inbound logistics, operations, and outbound logistics, otherwise referred to as the first three primary activities of Porter’s value chain diagram, as the scope of activities for which the cycle times are to be established.

Finally, this chapter explains the ethical implications of the research; before providing a schematic diagram of the research methodology and describing the research as being a quantitative action research, which follows a positivist approach.

# 2 CHAPTER II: DMAIC AS THE RESEARCH PROCEDURE

## 2.1 Background

As previously mentioned under Section 1.2.1, the narrow-fabric manufacturing company is an ISO 9001:2008 certified company. However, in spite of having the ISO 9001:2008 certification, the weaving and dyeing department has been battling to keep their production performance measures aligned with some of the requirements of the ISO 9001:2008 certification. ISO 9001:2008 is a quality management system, which falls under the ISO 9000 family of documents, and which consists of five clauses *(Foster, 2010, p. 113)*, namely:

- Clause 4: Quality management system;
- Clause 5: Management system;
- Clause 6: Resource management;
- Clause 7: Product realisation;
- Clause 8: Measurement, analysis, and improvement.

These clauses are documented in more detail in Appendix A. Looking specifically at the points listed under clause 4 as well as clause 8 in Appendix A, it can be noticed that the absence of production cycle time measures in the weaving and dyeing department causes the current quality standards of the department to diverge from the clauses of ISO 9001:2008. Such a divergence therefore highlights the need within the weaving and dyeing department to identify and utilise an alternative quality management approach that would assist in establishing reliable production performance measures, while reinforcing the current ISO 9001:2008.

A study by *Matínez-Lorente & Martínez-Costa (2004)* on the relationship between ISO 9000 and Total Quality Management (TQM), revealed that unlike ISO 9000, TQM is positively related with operational results. Hence, if TQM policies are successfully implemented, the ISO 9000 certification would only be pursued when a company is forced by its clients to do so. *Arumugam, Ooi, & Fong (2008)* second the notion by concluding in their study that TQM has a significant and positive relationship with quality performance.

Furthermore, *Sun (2000)* brings to our attention that a danger for ISO 9000 certification is that a company may regard the certification as a substitute for TQM and may not continue the performance improvement journey after being registered by ISO 9000. Therefore the improvement of performance based on ISO 9000 will depend on how the company would like to use ISO 9000 standards. If it is only for the purpose of getting a certificate and an advertisement, the document and procedures will not contribute to the improvement of performance. This could explain the reason why the narrow-fabric manufacturing company has been battling to establish their production performances despite having an ISO 9001:2008 certification.

Based on the above literature, TQM is considered an appropriate quality management approach in realigning the weaving and dyeing production performance measurements with the requirements of ISO 9001:2008 standards.

## 2.2 TQM review

TQM can be described as a total integrated management approach that addresses system/product quality during all phases of the life cycle and at each level in the overall system hierarchy. It provides a before-the-fact orientation to quality, and it focuses on system design and development activities as well as on production, manufacturing, assembly, construction, logistic support and related functions *(Blanchard, 2004, p. 40)*. In order to better understand TQM, quality expert W. Edwards Deming created 14 points for management as illustrated in Table 2-1 below:

**Table 2-1 Deming's 14 points** *(Foster, 2010, p. 62)*

| Deming's 14 points |
|---|
| 1. Create constancy of purpose. |
| 2. Adopt a new philosophy. |
| 3. Cease mass inspection. |
| 4. End awarding business on the basis of price tag. |
| 5. Constantly improve the system. |
| 6. Institute training on the job. |
| 7. Improve leadership. |
| 8. Drive out fear. |
| 9. Break down barriers between departments. |
| 10. Eliminate slogans. |
| 11. Eliminate work standards. |
| 12. Remove barriers to pride. |
| 13. Institute education and self-improvement. |
| 14. Put everybody to work. |

*Heizer and Render (2006, p. 198)*, summarised these 14 points into 7 concepts for an effective TQM program, namely:

- Continuous improvement;
- Six Sigma DMAIC;
- Employee empowerment;
- Benchmarking;
- Just-In-Time (JIT);
- Taguchi concepts and;
- Knowledge of TQM tools.

The subsequent literature will therefore look at the fundamental particularities in each of the above seven concepts. Then, through the establishment of an evaluation sheet, it will evaluate the concepts, and will illustrate why the DMAIC procedure is the most suitable technique for conducting this research.

**Continuous improvement**

Continuous improvement is defined as the continuous process of improvement in the company done with the participation of all staff *(Sanchez & Blanco, 2014)*. The motivation for doing continuous improvement is built on commonly understood goals and engaged leadership. But it is necessary to have a long-term perspective to it with an underlying understanding of people’s natural need for achieving goals or goal orientation. *(Holtskog, 2013)*.

Walter Shewhart, a pioneer in quality management, developed a circular model known as Plan-Do-Check-Act (PDCA) as his version of continuous improvement, which is a circle stressing the continuous improvement nature of the improvement process The Japanese use the word 'kaizen' to describe this ongoing process of unending improvement. In the US, the term 'zero defects' is also used to describe continuous improvement efforts *(Heizer & Render, 2006, p. 198)*. The continuous improvement philosophy can therefore be implemented through any one of the above concepts; namely PDCA, kaizen, or zero defects.

**Six Sigma DMAIC**

One of the ways to measure the variation of a product or a process is to use a mathematical term called sigma. The name six sigma came from the goal of reducing defects to 3 parts per million, which is ± 6 sigma (including some process drift), as most companies produce at an average ± 3 sigma quality level, which generates 2,700 defects per million parts *(Brussee, 2004, p. 9)*. One of the most important benefits of Six Sigma is that it helps organisations to improve organisational efficiencies and customer satisfaction; furthermore it decreases operating costs and increases profits *(Boon Sin, Zailani, Iranmanesh, & Ramayah, 2015)*.

Six sigma is therefore the foundation for driving breakthrough improvements. It uses a set of statistical and management tools that can make great leaps in improvement. It also uses the DMAIC approach to problem solving *(Dedhia, 2005)*. Although DMAIC is an integral part of six sigma *(Pyzdek, 2003, p. 238)*, the DMAIC process can also be useful as a problem-solving guide, and as a standardised format for project reviews *(Brussee, 2004, p. 15)*. DMAIC is also used when a project’s goal can be accomplished by improving an existing product, process, or service *(Pyzdek, 2003, p. 237)*.

Therefore, the prospects of conducting this research by following the DMAIC procedure, will require that the DMAIC procedure be exclusively used as a framework for establishing production performance measures; rather than as a six sigma project such as the reduction of production defects.

**Employee empowerment**

Various documents describe employee empowerment based on the context in which it is used, however in the context of TQM, *Hill & Huq (2004)* concluded in their research that employee empowerment is about more discretion and responsibility for decision-making within the employee's own work situation and greater scope for utilising their capabilities.

Furthermore, *Zandin & Maynard (2001, p. 2.92)* mention that employee empowerment produces greater employee loyalty and job satisfaction, higher productivity, increased profits, and better products. Of course, simply saying that employees are empowered is not enough. Companies also have to demonstrate an investment in the activities that make empowerment a reality. These include trust, teamwork, training, decentralisation, and linking employee performance to measurable business results.

**Benchmarking**

One definition of benchmarking by *Heizer & Render (2006, p. 200)* is that it involves selecting a demonstrated standard of performance that represents the very best performance for a process or activity. However, regardless of the many definitions that exist, some common characteristics of contemporary benchmarking are: its key purpose is to gather various types of business information about other companies; the purpose of this information is to create new business knowledge; new business knowledge is gained by analysing and comparing the specifics of various business factors of different companies; and on this basis, companies can make better business decisions and consequently enjoy more successful and more effective business *(Prašnikar, Debeljak, & Ahčan, 2005)*.

**Just-in-time**

The term Just-In-Time (JIT) refers to a production system that is organised to deliver exactly the right number of each component to downstream workstations in the manufacturing sequence just at the time when that component is needed *(Groover, 2008, p. 709)*.

In their quest to improve productivity and profitability, Japanese management came to look upon inventory as unnecessary and wasteful. Toyota was the first to develop an approach to cut down drastically on stock, whether for goods-in-progress or for goods in the storeroom; known as Kanban, or JIT inventory management. In JIT, the material is pulled by one workstation from the preceding station and ultimately from the raw material stock. In the same vein, it is also pulled from the suppliers only when it is needed, and in the desired quantities *(Kanawaty, 2006, p. 232)*.

**Taguchi concepts**

Genichi Taguchi has provided three concepts aimed at improving both product and process quality. They are: quality robustness, quality loss function, and target-oriented quality *(Heizer & Render, 2006, p. 202)*. Furthermore, he is renowned for his quality philosophy and his Design of Experiment (DOE) methods. He makes a clear distinction between product characteristics; which are selected to satisfy the customer and make the producer competitive, and quality; which is determined by the deviation of the actual product characteristics, as produced, from the ideal of the specification *(Zandin & Maynard, 2001, p. 13.74)*.

**Knowledge of TQM tools**

To implement TQM as a continuing effort, everyone in the organisation must be trained in the techniques of TQM. Hence *Heiser & Render (2006, p. 203)* introduced seven tools particularly helpful in the TQM effort. These tools are: check sheet which is an organised method of recording data; scatter diagram; cause and effect diagram; Pareto chart; flow chart (process diagram); histogram with distribution showing the frequency of occurrences of variable; and statistical process control chart.

### 2.2.1 TQM concepts evaluation sheet

Now that the seven TQM concepts have been defined, they must be subjected to an evaluation. The purpose of this evaluation is to identify the most suitable procedure or technique to be used in the research study, by weighting six important criteria. These criteria consist of some requirements from the managers of the weaving and dyeing department, which are also thought to be inherently linked to the successful achievement of the research objective as mentioned in Section 1.6, and these are documented in Table 2-2 below:

**Table 2-2 TQM concepts evaluation sheet**

| Criteria | Alternative | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | | 4 | | | 5 | | | 6 | | | 7 | | |
| | Eval. | Wt. | Wt'd. Eval | Eval. | Wt. | Wt'd. Eval | Eval. | Wt. | Wt'd. Eval | Eval. | Wt. | Wt'd. Eval | Eval. | Wt. | Wt'd. Eval | Eval. | Wt. | Wt'd. Eval | Eval. | Wt. | Wt'd. Eval |
| 1. Obtaining accurate operation time data | 5 | 10 | **50** | 10 | 10 | **100** | 10 | 10 | **100** | 1 | 10 | **10** | 1 | 10 | **10** | 5 | 10 | **50** | 10 | 10 | **100** |
| 2. Obtaining accurate number of outputs per day | 1 | 10 | **10** | 10 | 10 | **100** | 10 | 10 | **100** | 1 | 10 | **10** | 1 | 10 | **10** | 5 | 10 | **50** | 10 | 10 | **100** |
| 3. Obtaining data directly from the workstation | 1 | 10 | **10** | 10 | 10 | **100** | 10 | 10 | **100** | 1 | 10 | **10** | 1 | 10 | **10** | 5 | 10 | **50** | 10 | 10 | **100** |
| 4. Manipulating data | 1 | 10 | **10** | 10 | 10 | **100** | 5 | 10 | **50** | 1 | 10 | **10** | 5 | 10 | **50** | 10 | 10 | **100** | 10 | 10 | **100** |
| 5. Displaying data in a neat and clear format | 5 | 10 | **50** | 10 | 10 | **100** | 5 | 10 | **50** | 5 | 10 | **50** | 5 | 10 | **50** | 10 | 10 | **100** | 10 | 10 | **100** |
| 6. Controlling the measurement | 10 | 10 | **100** | 10 | 10 | **100** | 5 | 10 | **50** | 10 | 10 | **100** | 10 | 10 | **100** | 10 | 10 | **100** | 5 | 10 | **50** |
| **Totals** | | | **230** | | | **600** | | | **450** | | | **190** | | | **230** | | | **450** | | | **550** |

**Evaluation**
1 -- Less important
5 -- Moderately important
10 -- Very important

**Legend**
Alternative 1: Continuous improvement
➡ Alternative 2: DMAIC
Alternative 3: Employee empowerment
Alternative 4: Benchmarking
Alternative 5: Just-In-Time
Alternative 6: Taguchi concepts
Alternative 7: Knowledge of TQM tools

Each alternative in Table 2-2 represents one TQM concept. These are evaluated in turn against the six criteria. Each of the criteria has the same weighted value of 10, because they all have equal importance towards achieving the objective of the research. Alternative 2, known as DMAIC, having the highest score of 600, is therefore chosen as the preferred TQM concept, and the most suited technique for this research.

### 2.2.2 DMAIC risk assessment sheet

Following the establishment of DMAIC as the most suited technique for carrying out the research, a DMAIC risk assessment sheet is now developed as shown in Table 2-3. The DMAIC risk assessment sheet is developed by using the weaving and dyeing department's management input to determine a rating of 'yes', 'uncertain', or 'no' for each of the questions established on the risk assessment worksheet.

Each item was weighted on a scale of 1 to 10 for importance, where a 'yes' is 0 points, 'uncertain' is 3 points, and 'no' is valued at 5 points. The 0, 3, and 5 point scale values are then multiplied by their related weights. It can thus be noticed that the weights sum up to 190 points and that the sum of the weighted scale values is 230 points. Because the possible total points is 190 x 5 = 950 points, dividing 230 by 950 gives 24%. Therefore, 24% is the risk factor *(Foster, 2010, p. 432)*. In other words, given the result of the DMAIC risk assessment sheet, there is a 76% chance that the DMAIC procedure would be a successful technique for achieving the objective of this research, and a minor 24% chance that it wouldn't. Thus the DMAIC procedure will be used in this research.

**Table 2-3 Risk assessment worksheet**

| Project name: Estabishing Production Cycle Times | | | |
|---|---|---|---|
| **Category and Criteria** | **Rating** | **Weight** | **Total** |
| | *Yes = 0; Uncertain = 3; No = 5* | *Scale of 1-10* | *(Rating) x (Weight)* |
| **Defining Opportunity** | | | |
| 1 Are we currently measuring the cycle times and capacities? | 5 | 10 | 50 |
| 2 Is historical data currently available? | 3 | 10 | 30 |
| 3 Is it easy to acquire additional data? | 3 | 10 | 30 |
| 4 Are the cycle times and capacities for the process or product defined? | 5 | 5 | 25 |
| 5 Do you know how the cycle times and capacities were defined? | 5 | 5 | 25 |
| 6 Are the cycle times and capacities measured where they occur in the process? | 3 | 10 | 30 |
| 7 Are the cycle times and capacities frequency continuous? | 5 | 5 | 25 |
| **Customer Focus** | | | |
| 8 Has/have the customer(s) been identified? | 0 | 5 | 0 |
| 9 Have you verified what is important to the customer? | 0 | 10 | 0 |
| 10 Are these cycle times and capacities important to the customer? | 0 | 10 | 0 |
| 11 Will the customer see the result of reducing cycle times and increasing capacities? | 0 | 10 | 0 |
| **Company Benefit/Leverage** | | | |
| 12 Do the cycle times and capacities relate to the mission, a business driver, or a reliability measure? | 0 | 10 | 0 |
| 13 Do the cycle times and capacities impact operation? | 0 | 10 | 0 |
| 14 Can the results of the project be applied to other processes or products? | 0 | 5 | 0 |
| 15 Can the impact be quantified in Rands? | 0 | 10 | 0 |
| **Project Leadership/Global Bounding** | | | |
| 16 Are all the managers, at all levels, in agreement that your project is important? | 0 | 5 | 0 |
| 17 Can adequate visibility for the problem and solution be created? | 0 | 10 | 0 |
| 18 Is the team comprised of representatives from only one location/business function? | 0 | 10 | 0 |
| 19 Are appropriate resources available to participate on the team? | 0 | 10 | 0 |
| 20 Can the project be bounded to an effective size? | 0 | 10 | 0 |
| 21 Can the project be completed on schedule within 4-6 months? | 3 | 5 | 15 |
| 22 Do we know the boundaries of the process(es)? | 0 | 5 | 0 |
| 23 Can process changes be implemented within the project schedule? | 0 | 10 | 0 |
| | **Total** | **190** | **230** |
| | **Risk Value** | **230/(190x5)= 24%** | |

## 2.3 DMAIC review

Having chosen DMAIC as the research procedure, this section provides a brief literature review of DMAIC with respect to its application in the weaving and dyeing department for the purpose of establishing the cycle times of production activities.

### 2.3.1 Define phase

In the define phase, a problem is often initially identified very qualitatively. Meaningful measurements or data can only be collected if quantitative values are available, like the specific measurements related to a bearing diameter *(Brussee, 2004, p. 12)*. There are three major elements in the define phase that need to be addressed carefully. These are: firstly, the team charter, which is the most important element of any methodology and comprises elements such as business case, problem statement, project scope, goals and objectives, milestones, roles and responsibilities; secondly, identifying the customers of the project, their needs and requirements; and thirdly, creating a high-level process map for the project *(Eckes, 2001, p. 44)*.

*Pyzdek's (2003, p. 238)* contribution to the definition of the define phase is that at the top level the goals will be the strategic objectives of the organisation, such as greater customer loyalty, a higher Return On Investment (ROI), increased market share, or greater employee satisfaction. At the operations level, a goal might be to increase the throughput of a production department. At the project level, goals might be to reduce the defect level and increase throughput for a particular process. Obtain goals from direct communication with customers, shareholders, and employees.

Another important element of the define phase is project identification and selection, which according to *Foster (2010, p. 431)*, encompasses the following components: development of a business case, project evaluation, Pareto analysis and project definition.

Given the nature of the problem faced in the weaving and dyeing department, and considering the above literature about the define phase, some important elements that have been identified as being essential for the define phase of this research study are: project charter, high-level process maps, quantitative data and Pareto analysis. This list of elements that are essential to the define phase of the research is not exhaustive, as it might be necessary to add more elements later.

### 2.3.2 Measure phase

Following the establishment of the define phase elements such as process maps, the measure phase begins by taking the process map and identifying the measures of effectiveness (output measures of customer requirements). This is followed by identifying the measures of efficiency (measures of the amount of time, or cost or labour or value steps between the start and stop points in the map). The phase then finishes by identifying the measure of the supplier's effectiveness *(Eckes, 2001, p. 71)*.

According to *Foster (2010, p. 435)*, however, the measure phase involves two major steps; namely selecting the process outcomes, which involves the process map and verifying measurements using certain tools such as XY matrix, and capability assessment. *Brussee (2004, p. 13)* adds to this his view that several tools exist that help identify the key process input variables to be considered and/or measured. Samples must be sufficient in number, random, and representative of the process to measure. Consequently, one conclusive definition of the measure phase is that it consists of establishing valid and reliable metrics to help monitor progress towards the goal(s) defined at the in the define phase *(Pyzdek, 2003, p. 238)*.

Based on the above literature of the measure phase, it can be inferred that this phase is the most critical phase to the success of this research study, as it directly addresses the research problem as well as one important part of the objective of the research. Hence most of the elements of the measure phase mentioned in the above literature that are related to the production cycle times, will be used in this research.

### 2.3.3 Analyse phase

One of the objectives of this phase is to see what message the previously measured data are telling. This is achieved by plotting the data to understand the process character, then deciding if the problem as defined is 'real' or just a random event without an assignable cause. These data will also be the base against which any implemented improvement will be measured *(Brussee, 2004, p. 13)*.

Another objective of this phase is to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. This is achieved by firstly determining the current baseline; then using exploratory and descriptive data analysis to understand the data; and lastly using statistical tools to guide the analysis *(Pyzdek, 2003, p. 238)*.

Finally, the goal of the analysis phase is to determine and validate the root cause of the project team's original problem. Once the analysis is completed, there should be greater information about the type of problems that need to be fixed *(Eckes, 2001, p. 137)*.

In the context of this research, the analysis phase is found to be very important as it allows further comprehension of the information obtained in the measure phase, in order to find a method for establishing an entire population of cycle times generated at a particular production activity, using statistical tools.

### 2.3.4 Improve phase

In the improve phase, the focus should be on finding solutions that eliminate, soften, or mitigate the root causes validated at the end of the analysis. The affinity diagram is the primary tool to use to generate and select solutions *(Eckes, 2001, p. 203)*. The improve phase also involves offline experimentation, which in turn entails studying the variables identified and using the Analysis of Variance (ANOVA) model to determine whether these independent variables significantly affect variation in the dependent variable *(Foster, 2010, p. 444)*.

Moreover, the improve phase requires creativity in finding new ways to do things better, cheaper, or faster. Project management and other planning and management tools can also be used to implement the new approach and statistical methods can be used to validate the improvement *(Pyzdek, 2003, p. 238)*.

The fact that the purpose of this research is to establish production cycle times in an environment where production cycle times are currently not being measured, renders the achievement of this objective of the research alone, an improvement. Therefore the ideas conveyed in the above literature of the improve phase, will help finding and implementing a solution, based on the outcome of the analysis phase.

### 2.3.5 Control phase

The control phase must occur at both the tactical level (i.e., the project level) and the strategic level *(Eckes, 2001, p. 241)*. It involves managing the improved processes using process charts *(Foster, 2010, p. 444)*. These control charts can also be implemented to help the operator keep the process in control *(Brussee, 2004, p. 13)*. Lastly, it might be necessary to utilise standardisation such as ISO 9000 to assure that documentation is correct, in addition to the statistical tools to monitor the stability of the new system *(Pyzdek, 2003, p. 238)*.

As mentioned in the improve phase, the establishment of production cycle times alone, in an environment where the information on production cycle times is non-existent, constitutes the improvement phase of this research. As a result, the control phase, based on the above literature, will involve managing this improvement by recording the newly established production cycle times in a format that can be used by the managers in order to better estimate the MLTs of the weaving and dyeing department. Hence, similarly to the measure phase, the control phase is very important to this research as it addresses a part of the research objective.

### 2.3.6 Conclusion

In addition to the above description of the DMAIC process, an overview of the various tools used at each stage of the DMAIC process is provided in Figure 2-1, which is also referred to as the simple six sigma roadmap *(Harry, Mann, De Hodgins, Hulbert, & Lacke, 2010, p. 31)*. Some additional tools mentioned in Figure 2-1 may also be used during the application of DMAIC procedure.

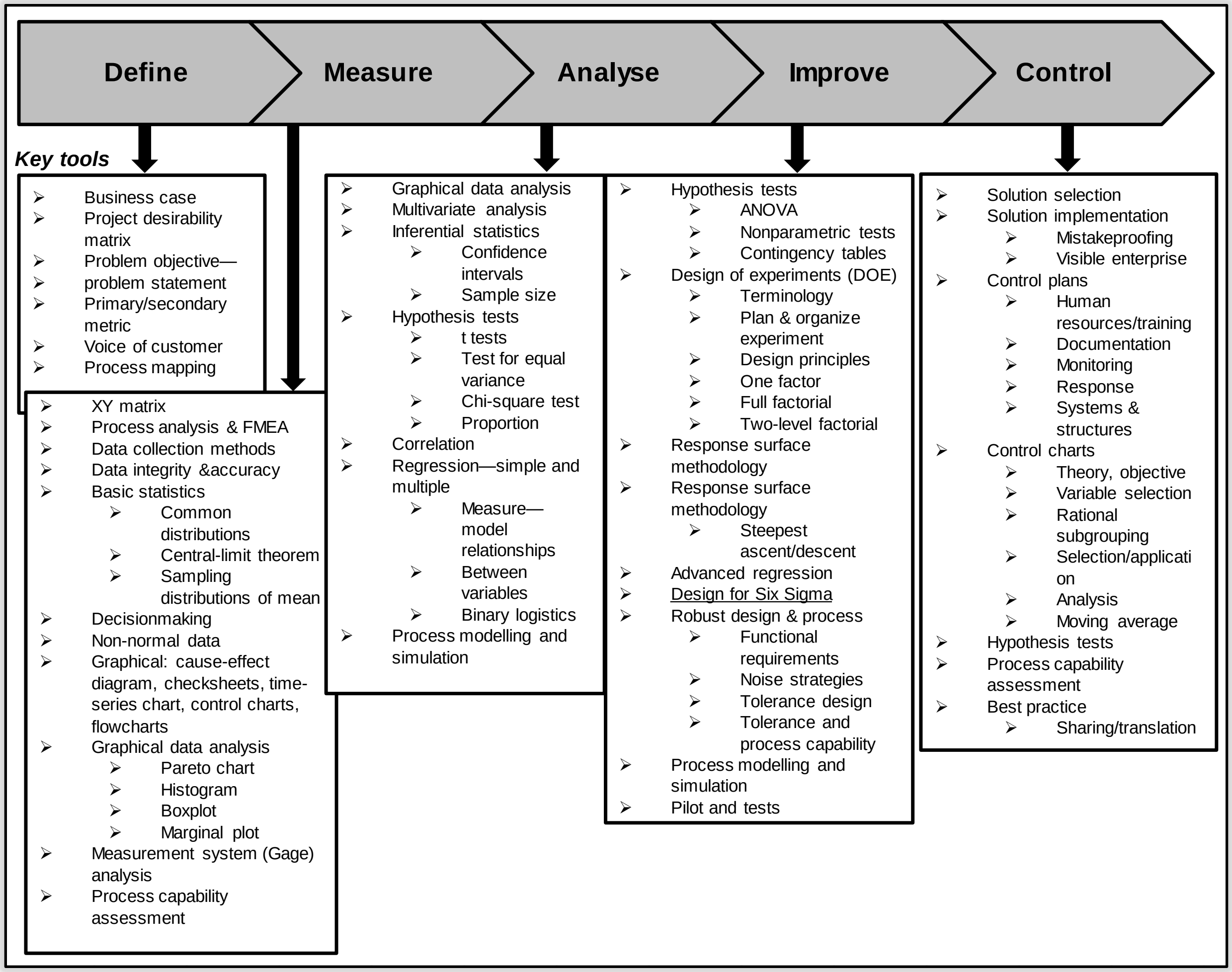



**Figure 2-1 Illustration of a simple six sigma roadmap** *(Harry et al., 2010, p. 31)*

## 2.4 Chapter summary

This chapter starts by revealing that the weaving and dyeing department has been battling to keep their production performance measures aligned with some of the requirements of their ISO 9001:2008 certification.

Then the chapter identifies TQM as an alternative viable quality management approach to realigning the weaving and dyeing performance measurements with the requirements of ISO 9001:2008 standards.

Furthermore, this chapter evaluates various TQM concepts on an evaluation sheet and recognises DMAIC as the preferred TQM concept, and the most suited technique for carrying out this research. Moreover, the DMAIC procedure was evaluated by means of a risk assessment sheet and was found to have a low risk of not achieving the research objective.

Finally, having chosen DMAIC as the research procedure, this chapter provides a brief literature review on DMAIC with respect to its application in the weaving and dyeing department for the purpose of establishing the cycle times at various workstations.

# 3 CHAPTER III: PRODUCTION ACTIVITIES

## 3.1 Background

As briefly mentioned under Section 1.7 of Chapter I, the first three primary activities of Porter's value chain diagram, which are inbound logistics, operations, and outbound logistics, were identified as the scope of activities for which the cycle times are to be established within the weaving and dyeing department.

According to *Sivula & Kantola (2014)*, inbound logistics are processes which are necessary for receiving, storing, and distributing; operations are transformation activities that change all inputs into outputs; and outbound logistics consist of processes which are necessary for delivery of a final product or service to the customer. Similarly, *Finne (1997)*, mentions that inbound logistics is associated with receiving, storing and disseminating inputs to the product the company produces; operations is about transforming inputs into the final product form; and outbound logistics is associated with collecting, storing and physically distributing the product to buyers.

However, prior to establishing the cycle times of the first three primary activities of Porter's value chain diagram within the weaving and dyeing department, the activities themselves must first be systematically recorded, by using a comprehensive recording technique.

## 3.2 Recording techniques

*Heizer & Render (2006, p. 265)* list and define a number of tools that can help record and understand the complexity of various production processes as follows:

- Flow diagrams: a drawing to analyse movement of people or material;
- Time-function mapping: a flow diagram but with time added on the horizontal axis;

- Value stream mapping: helps managers understand how to add value in the flow of material and information through the production process;
- Process charts: a chart using symbols to analyse the movement of people or material;
- Service blueprinting: a process analysis technique that lends itself to a focus on the customer and the provider's interaction with the customer.

On the other hand, *Kanawaty (2006, p. 19)* provides a more comprehensive approach called method study, which is a systematic recording and critical examination of ways of doing things in order to make improvements. The method study is a much preferred approach as it firstly allows for a systematic recording of the activities. Secondly, it makes use of various charts and diagrams which according to *Kanawaty (2006, p. 81),* fall into two groups: those which are used to record a process sequence; and those which record events, also in sequence, but on a timescale. These method study charts and diagrams are further listed, in groups, in Table 3-1 below.

**Table 3-1 Method study charts and diagrams** *(Kanawaty, 2006, p. 82)*

| Method study charts and diagrams | |
|---|---|
| A. CHARTS | Indicating process SEQUENCE |
| | Outline process chart |
| | Flow process chart -- Worker type |
| | Flow process chart -- Material type |
| | Flow process chart -- Equipment type |
| | Two-handed process chart |
| | Procedure flowcharts |
| B. CHARTS | Using a TIME SCALE |
| | Multiple activity chart |
| | Simo chart |
| C. DIAGRAMS | Indication MOVEMENT |
| | Flow diagram |
| | String diagram |
| | Cyclegraph |
| | Chronocyclegraph |
| | Travel chart |

In order to better appreciate and identify the most suitable recording technique that can methodically describe each of the first three primary activities of Porter's value chain diagram within the weaving and dyeing department, Each of the method study charts and diagrams listed under Table 3-1 is briefly defined below, as per *Kanawaty (2006)*.

### 3.2.1 Outline process chart

An outline process chart is a process chart giving an overall picture by recording in sequence only the main operations and inspections. In an outline process chart, only the principal operations carried out and the inspection made to ensure their effectiveness are recorded.

### 3.2.2 Flow process chart

A flow process chart is a process chart setting out the sequence of the flow of a product or a procedure by recording all events under review using the appropriate process chart symbols. A flow process chart worker type records what the operator does; a flow process chart material type records how material is handled or treated; a flow process chart equipment type records how the equipment is used.

The appropriate chart symbols used in the flow process chart, consist of five sets of activities; namely operations, inspection, transport, delay, and storage. These five sets of activities are also referred to as method study symbols.

### 3.2.3 Two-handed process chart

The two-handed process chart is a process chart in which the activities of a worker's hands (or limbs) are recorded in relationship to one another.

### 3.2.4 Procedure flow chart

This is a variation of the flow process chart which can be referred to as a document-type flow process chart, since it charts the progress of a document or series of documents through a procedure.

### 3.2.5 Multiple activity chart

A multiple activity chart is a chart on which the activities of more than one subject (worker, machine or item of equipment) are each recorded on a common timescale to show their interrelationship.

### 3.2.6 Simo chart

The simultaneous-motion cycle chart is a chart used in micromotion study, whereby operations with very short cycle times can be recorded in greater detail in order to determine where movements and efforts can be saved and to develop the best possible pattern of movement.

### 3.2.7 Flow diagram

Diagrams are generally used to indicate movement and/or interrelationships of movement more clearly than charts can do. They usually do not show all the information recorded on charts, which they supplement rather than replace. Having said that, a flow diagram shows the layout of a shop floor, as well as the path taken by the various products from the raw material store until the last operation.

### 3.2.8 String diagram

The string diagram is a scale plan or model on which a thread is used to trace and measure the path of workers, material or equipment during a specified sequence of events.

### 3.2.9 Cyclegraph

The cyclegraph is a record of a path of movement, usually traced by a continuous source of light on a photograph, preferably stereoscopic. The path of movement of a hand, for instance, may be recorded in this way on a photograph, if the worker is asked to wear a ring carrying a small light which will trace a path on the photograph.

### 3.2.10 Chronocyclegraph

The chronocyclegraph is a special form of cyclegraph in which the light source is suitably interrupted so that the path appears as a series of pear-shaped dots, the pointed end indicating the direction of movement and the spacing indicating the speed of movement.

### 3.2.11 Travel chart

A travel chart is a tabular record for presenting quantitative data about the movements of workers, materials or equipment between any number of places over any given period of time.

### 3.2.12 Conclusion

Based on the above explanations of the various methods of studying recording techniques, the flow process chart is the one technique that is found to be the most suited tool to methodically represent the first three primary activities of Porter's value chain in the weaving and dyeing department. The main reason for choosing the flow process chart as the most suited tool is that it makes use of process symbols that are easy to observe and record on the production floor. Furthermore, the symbols encompass the first three primary activities of Porter's value chain, thus enabling a methodical recording of these activities. Hence, further information about the flow process chart is provided below.

**Detailed flow process chart**

The five flow process chart symbols mentioned under Section 3.2.2, are now explained in further detail, starting with a graphical illustration in Figure 3-1 of each symbol, its respective meaning, as well as some examples of each symbol.

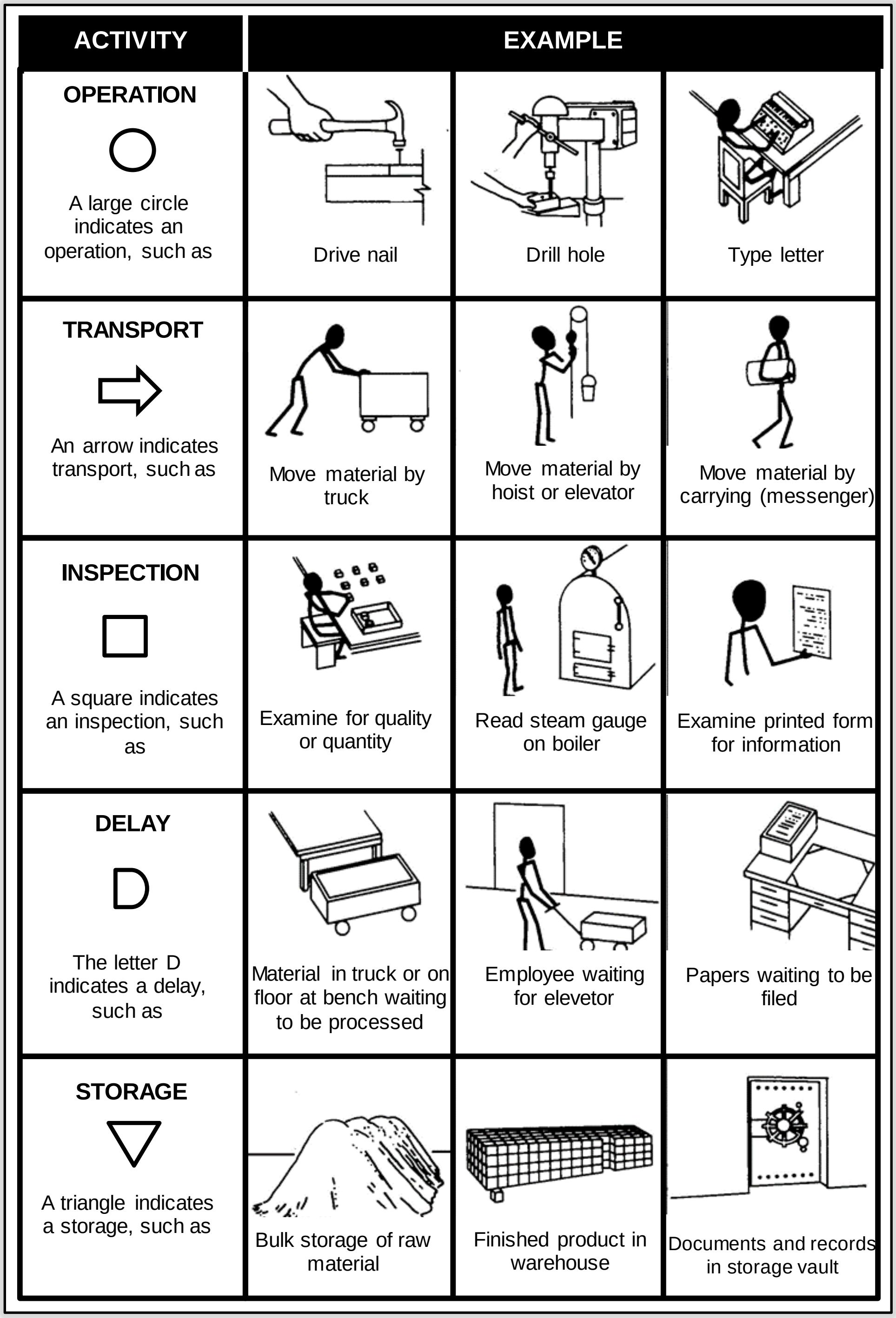



**Figure 3-1 Method study symbols** *(Kanawaty, 2006, p. 85)*

Furthermore, these five sets of activities and their respective symbols, fall naturally into two main categories, namely:

- Those in which something is actually happening to the material or workpiece under consideration;
- Those in which the material or workpiece is not being touched, being either in storage or at a standstill owing to a delay.

Activities in the first category may be further subdivided into three groups as follows:

- Make-ready activities: required to prepare the material or workpiece and set it in position ready to be worked on;
- Do operation: a change is made in the shape, chemical composition or physical condition of the product;
- Put-away activities: the work is moved aside from the machine or workplace.

In order to simplify the above activities categories into a more comprehensive classification, the following activities classes are created:

- Value-added activities which encompass the operation activities, or the 'do operation' group of activities;
- Value-enabling activities which encompass the transport, inspection, and delay activities, or 'make-ready and put-away' group of activities;
- Non-value-added activities which encompass storage activities, or the activities where the material or workpiece is not being touched.

Both the activities categories as well as the derived activities classification are therefore illustrated in Figure 3-2 below.

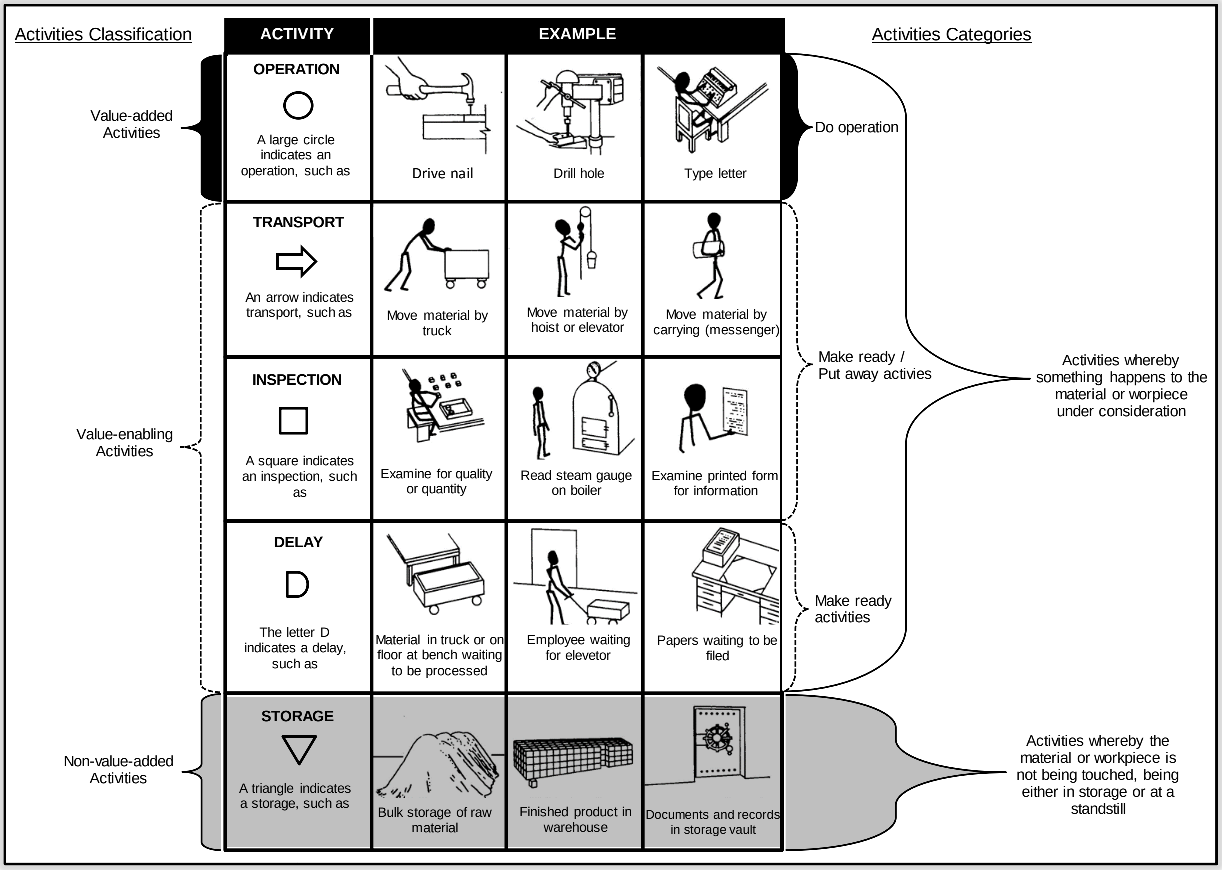



**Figure 3-2 Classification of production activities**

Moreover, while the method study symbols used in the flow process chart consist of operations, transport, inspection, delay, and storage, this research only focuses on the first four activities referred to as value-added activities and value-enabling activities in Figure 3-2. The main reasons for focusing only on these four activities are as follows:

- The value-added activities and value-enabling activities within the weaving and dyeing department consist of activities that directly or indirectly contribute to creating value that is meaningful to the customers. Therefore determining cycle times for such activities would ultimately solve the research problem mentioned under Section 1.4;
- Besides the fact that the storage activity is classified as a non-value-added activity, having to establish the cycle time for such an activity within the weaving and dyeing

department can be a difficult exercise as the quantity associated with each storage activity, whether permanent or temporary, is not always recorded.

## 3.3 Chapter summary

This chapter starts by mentioning that the first three primary activities of Porter’s value chain diagram which consist of inbound logistics, operations, and outbound logistics, are the scope of activities for which the cycle times are to be established within the weaving and dyeing department.

Then, this chapter reviews various recording techniques that can help in systematically recording the first three primary activities of Porter’s value chain diagram within the weaving and dyeing department, therefore providing a detailed understanding of the activities.

Furthermore, this chapter identifies the flow process chart as the most suitable tool to methodically represent the first three primary activities of Porter’s value chain in the weaving and dyeing department.

Finally, this chapter classifies the flow process chart activities into value-added activities which encompass the operation activities, or the 'do operation' group of activities; value-enabling activities which encompass the transport, inspection; delay activities, or 'make-ready and put-away' group of activities; and non-value-added activities which encompass storage activities, or the activities where material or workpiece is not being touched.

# 4 CHAPTER IV: CYCLE TIME DMAIC

## 4.1 Background

Now that the production activities have been identified in Chapter III, their respective cycle times have to be established, so as to achieve the research objective mentioned in Chapter I, under Section 1.6. Further, in Section 1.6 of Chapter I, it was also mentioned that given the high variety of the products produced at each workstation, an entire population of cycle times should be established at each one of them.

Therefore, by following the DMAIC procedure, this chapter explains how the cycle time can be defined, measured, analysed, improved and controlled, in the weaving and dyeing department, as a high variety production environment.

## 4.2 Define

### 4.2.1 Cycle time

The cycle time is the elapsed time for an individual activity from start to completion *(Harry et al., 2010, p. 101)*. The cycle time is further defined, for any production operation, as the time that one work unit spends being processed or assembled. It is the time between when one work unit begins processing (or assembly) and when the next unit begins, but not all of this time is productive *(Groover, 2008, p. 49)*. According to *Monden (1993, p. 304)*, the cycle time is the time necessary for performing manual operations for processes described by the standard operations routine sheet.

It is, however, important to differentiate between cycle time and takt time *(Monden, 1993, p. 303)*, two concepts that are similar, yet different in essence. Unlike the cycle time which focuses on the production of an individual unit, the takt time on the other hand, is the pace (frequency) of production units necessary to meet customer orders *(Heizer & Render, 2006, p. 356)*.

Once the cycle time for the each production activity has been established, a total cycle time can be calculated. This total cycle time will sum up the cycle times for all of the individual activities in the process in the value stream *(Harry et al., 2010, p. 101)*. The total cycle time is also referred to as the total manufacturing cycle time *(Chincholkar & Herrmann, 2008)*, since within that period lie a multitude of discrete activities, each with its own cycle time *(Thomas, 1990, p. 1)*.

Conclusively, both the value-added activities as well as the value-enabling activities must have well-determined cycle times, from which a total cycle time can be determined as shown in Figure 4-1 below.

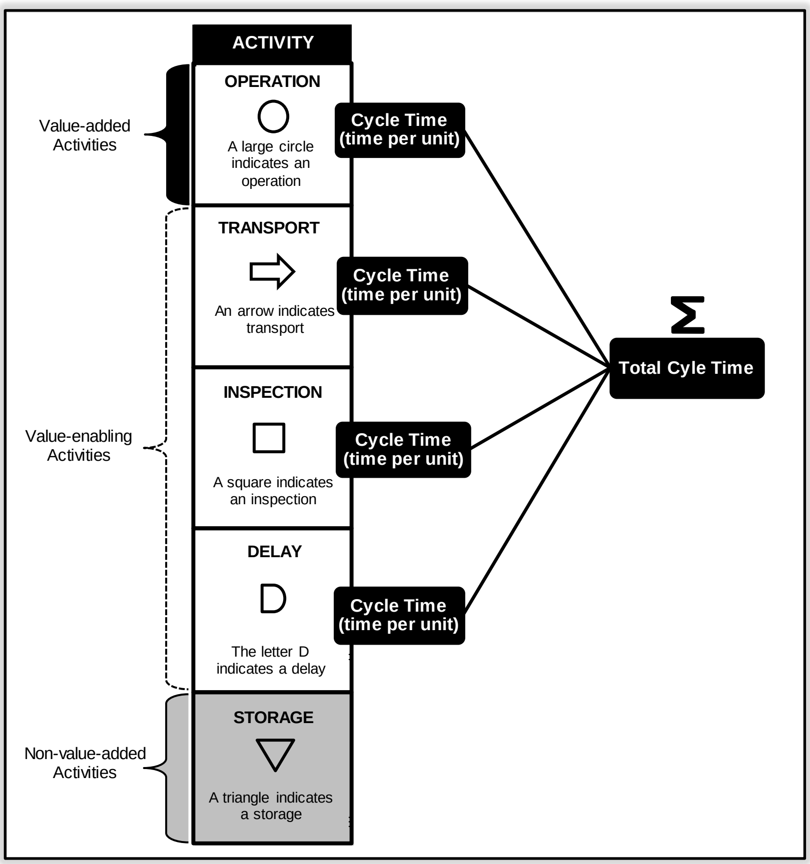



**Figure 4-1 Activities cycle time**

### 4.2.2 Composition

The cycle time is comprised of operation time, loading/unloading time, set-up time and machine idle time *(Han, Lee, & Choi, 2013)*. In general, one can define cycle time as the sum of two variables: the busy time, during which a unit is acted upon to bring it closer to an output, and the idle time, during which a unit of work is waiting to take the next action *(Nadarajah & Kotz, 2008)*. *Groover (2008, p. 49)* further mentions that within the cycle time, there is a proportion of cycle when the part is actually being processed (operation time); there is a proportion of the cycle when the part is being handled (handling time); and there is, on average, a proportion when the tooling is being adjusted or changed (tool handling time).

Based on the above literature, it can be inferred that the cycle time is obtained by summing up the time it takes to complete various elements of a particular task. This gathering of various elements of a specific task can also be referred to as a work cycle, which *Kanawaty (2006, p. 289)* defines as the sequence of elements which are required to perform a job or yield a unit of production.

Therefore, in an attempt to clearly delineate all the various components of the cycle time, with respect to the nature of the production activities in the weaving and dyeing department, two main components of the cycle time are created for each production activity. These two components consist of:

- The run time, which indicates the time of the actual processing or assembly operation *(Groover, 2008, p. 49)* and;
- The Miscellaneous Time (MT) which indicates the time of any other actions that are not a run action. Miscellaneous time may therefore contain such elements as occasional elements; which do not occur in every work cycle, but which may occur at regular or irregular intervals; foreign elements, which do not form part of the operation being studied; or a combination of both *(Kanawaty, 2006, p. 290)*.

The cycle time for the value-added activities, as well as the value-enabling activities defined in Figure 3-2, can thus be analytically established by defining and measuring their respective two main time components and subsequently summing them up as illustrated in Figure 4-2 below.

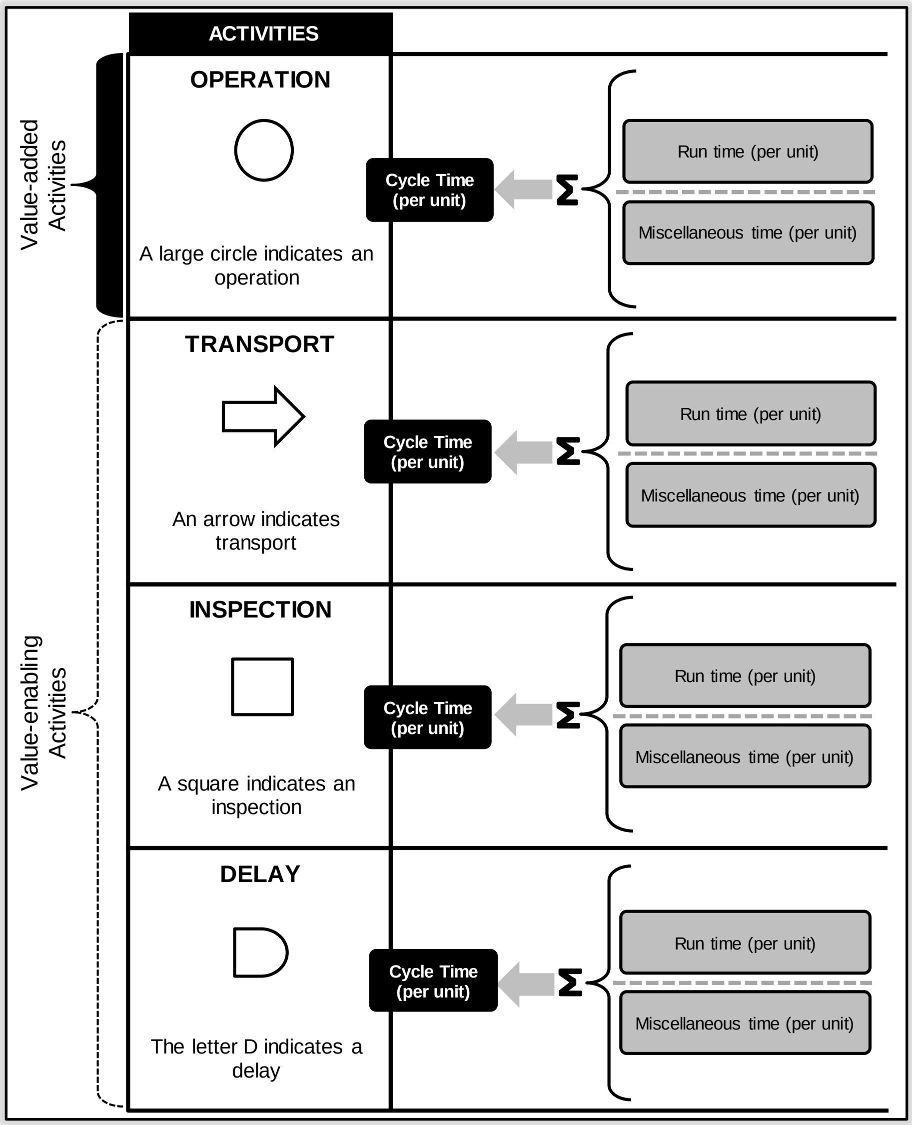



**Figure 4-2 Activities cycle time components**

### 4.2.3 Importance

The key measurement of performance in every company is the cycle time *(Thomas, 1990, p. 27)*. *Maskell (1991, p. 124)* seconds this finding by stating that the measurement of cycle time is a primary feature of performance measurement for world class manufacturers. *Nadarajah & Kotz (2008)* promote these two viewpoints by mentioning that the cycle time is a measure of the efficiency of the production process. It enables one to identify and implement more efficient ways of doing things. Potential benefits could include reduced costs, increased throughput, streamlined processes, improved communications, reduced process variability, schedule integrity and improved on-time delivery.

Furthermore, assessing processes for cycle time is necessary in re-engineering processes for improvement *(Termini, 1996, p. 72)* owing to the widespread recognition of its importance to effective manufacturing operations *(Filho & Uzsoy, 2013)*. Finally, the cycle time has an influence on the overall equipment efficiency, the overall factory effectiveness *(Oechsner et al., 2003)*, as well as on the takt time *(Zammori, Braglia, & Frosolini, 2011)*. It is also needed to calculate the performance efficiency, where it is multiplied by the total parts produced, and divided by the actual operating time *(Puvanasvaran, Mei, & Alagendran, 2013)*.

### 4.3 Measure

According to *Monden (1993, p. 146)* industrial engineering techniques such as time and motion study can be used to determine the cycle time. Similarly, *Harry et al. (2010, p. 101)* states that cycle times are measured by time and motion studies. This is further supported by *Zandin & Maynard (2001, p. 4.14)* who mention that the usual practice for establishing the cycle times is to make measurements using a stopwatch, which according to *Kanawaty (2006, p. 265)* is an essential piece of equipment for time studies.

Based on this above literature, time study is acknowledged to be an appropriate work measurement technique for measuring the cycle time. Time study itself is defined by *Kanawaty (2006, p. 265)* as a work measurement technique for recording the time taken to perform a certain specific job or its elements carried out under specified conditions, and for analysing the data so as to obtain the time necessary for an operator to carry it out at a defined rate of performance. Therefore this section looks at the key steps in conducting successful time studies for the production activities of the weaving and dyeing department.

### 4.3.1 Elements of a job

An element is a distinct part of a specified job selected for convenience of observation, measurement and analysis. Some important reasons for breaking a particular job down into elements are:

- To ensure that productive work (or effective time) is separated from unproductive activity (or ineffective time);
- To permit the rate of working to be assessed more accurately than would be possible if the assessment were made over a complete cycle;
- To enable the different types of elements to be identified and distinguished, so that each may be accorded the treatment appropriate to its type.

Eight types of elements are distinguished when recording a job, and they are: repetitive, occasional, constant, variable, manual, machine, governing and foreign elements. These eight types of elements, based on their respective definitions, are not mutually exclusive as, for example, a repetitive element may also be a constant element, or a variable one, and so on *(Kanawaty, 2006, pp. 289–291)*.

Moreover, these elements can also be considered as extensions of the cycle time components identified in Section 4.2.2; and can therefore be classified into the following two categories, as illustrated in Figure 4-3.

- Elements belonging to the run time and;
- Elements belonging to the Miscellaneous Time (MT).

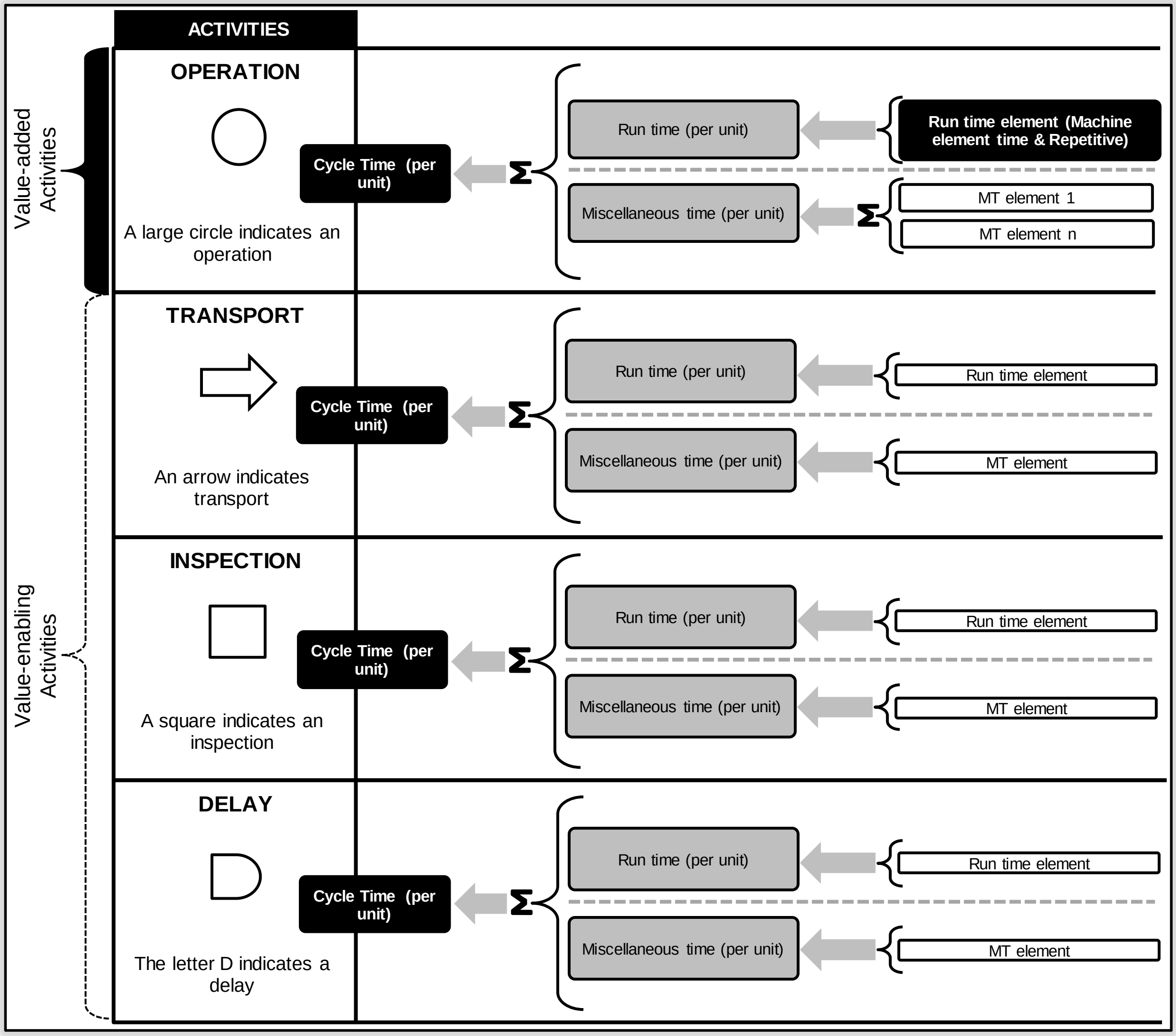



**Figure 4-3 Activities elements**

It is, however, important to specify that the run time of the value-added activities consists of only one element. This element is called the machine element, as shown in Figure 4-3 and which according to *Kanawaty (2006, p. 290)* is an element performed by any process, physical, chemical or otherwise that, once started, cannot be influenced by a worker except by terminating it prematurely. But at the same time, this machine element is also a repetitive element since it is an element which occurs in every work cycle of a job *(Kanawaty, 2006, p. 290)*.

Similarly, the run time of the value-enabling activities also consists of only one element as shown in Figure 4-3. However, unlike the run time of the value-added activities which consists of an element that is a machine element as well as a repetitive element, the run time of the value-enabling activities consists of an element that is only a repetitive one and not a machine element.

On the other hand, the Miscellaneous Time (MT) of the value-enabling activities consists of either one element or none. This is mainly because within the weaving and dyeing department, there is a lack of well-documented operating procedures for carrying out the value-enabling activities. Hence, defining the MT elements for the value-enabling activities can be a difficult exercise.

However, the MT of the value-added activities consists of either one or more elements as deemed necessary. The main reason for defining at least one MT element of the value-added activities, is that the operating procedures for carrying out the value-added activities within the weaving and dyeing department are well documented, hence one or more elements can be defined.

### 4.3.2 Elements measurement format

In order to establish the times for the elements described in Figure 4-3 for each production activity within the time frame allocated to this research, a decision was made to methodically measure only the machine element time, which is the element time comprised within the run time of the value-added activities as shown in Figure 4-3. The remaining elements' times that are not machine element times, on the other hand, are to be estimated. A graphical illustration of how each element is to be established, is shown in Figure 4-4 below.

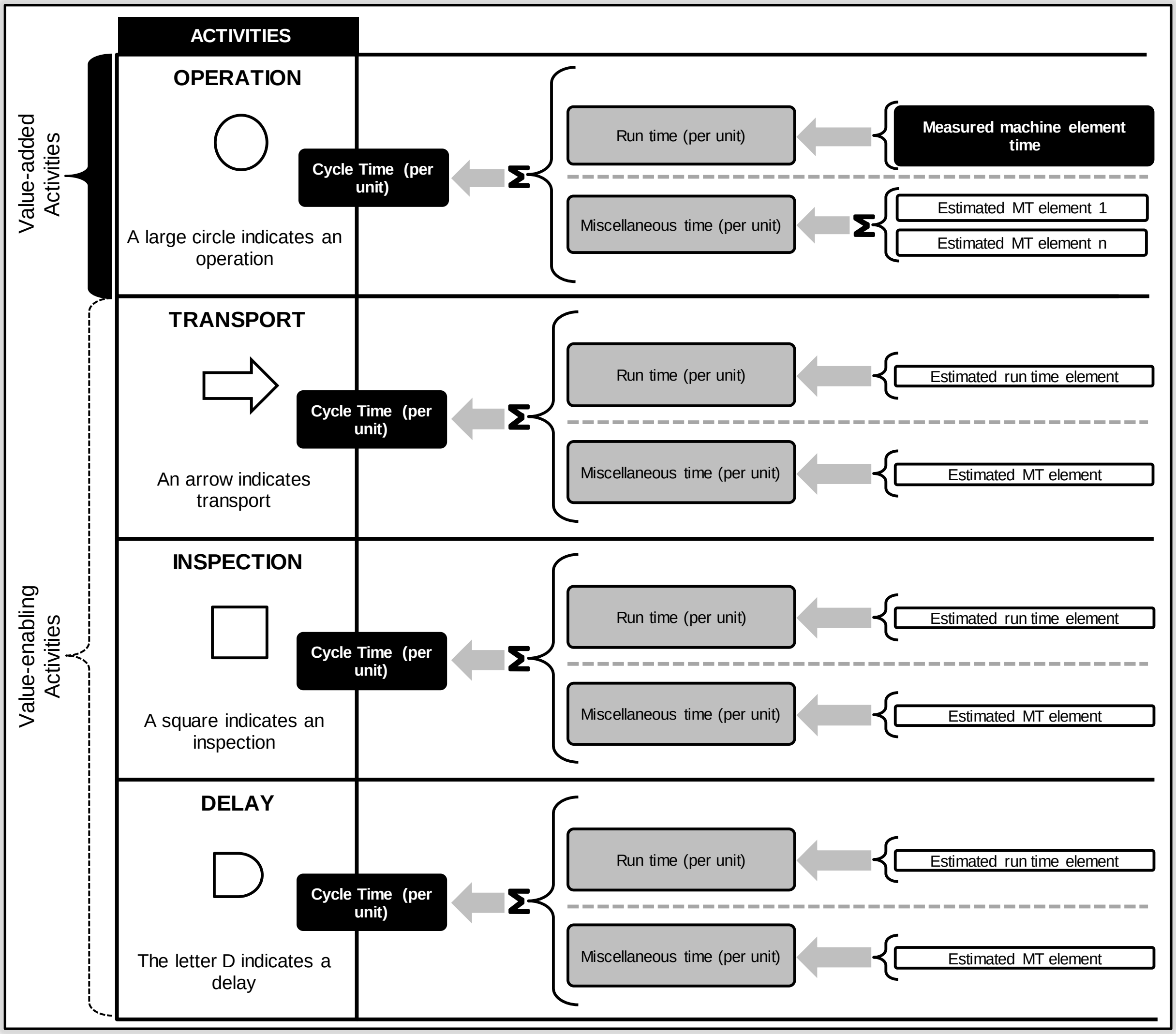



**Figure 4-4 Element measurement format**

Besides the time constraint for carrying out this research, there is another reason for measuring the machine element time, while estimating the remaining elements' times that are not machine element times. This reason is the importance of the value-added activities and therefore the machine element embedded in them, as they consist of converting raw materials into a useful, saleable item *(Maskell, 1991, p. 258)*, as well as forming part of those activities that are valuable from the point of view of the customer *(Harry et al., 2010, p. 90)*. Consequently, only the machine element time that is comprised within the value-added activities will be measured by means of a measuring device.

### 4.3.3 Measuring device

In Section 4.3 it was mentioned that the usual practice for establishing the production activities' cycle times, is to make measurements using a stopwatch. However, given that the machine element time is the only element time to be measured, as shown in Figure 4-4, additional data collection tools that could be better suited for measuring such a job element have to be considered. According to *Zandin (2001, p. 6.209)*, there are many other instruments available for collecting data, such as:

- Force gauge: to measure the push, pull, lift, and carry forces;
- Temperature gauge: to record ambient temperature (environmental condition);
- Grip strength gauge: an indirect way of measuring grip force;
- Light meter: to measure available light to do the task (environmental condition);
- Measuring tape: probably the most important instrument to verify all workstation dimensions;
- Video or still camera: to assist method and posture analysis by others away from the actual workstation.

Although the above instruments are useful in collecting various types of data, their suitability for measuring the machine element time is uncertain. Such a claim is based on the outcome of the preliminary observation of the weaving and dyeing department’s operations, prior to the commencement of this research. During the preliminary observation, it was noticed that the machine element consisted fundamentally of running the machines in the weaving and dyeing department by rotating various spindles or drums. Consequently, in order to measure the machine element time, it is important to make use of a device that is more adapted to measuring the time per rotation of the various spindles or drums.

According to *Takata, Nakajima, Ahn, & Sata (1987)* the spindle rotational speed can be easily obtained via a tachometer generator. Furthermore, in a study by *Yilmaz, AL-Regib, & Ni (2002)*, that presented a new method for varying the spindle speed to suppress chatter in machining, a tachometer was used to measure the spindle speed. The tachometer as shown in Figure 4-5 below is therefore an appropriate data collection device for measuring the speed of a spindle or a drum, which speed can then be converted into a unit of time per rotation, or into a unit generated via a certain number of rotations.

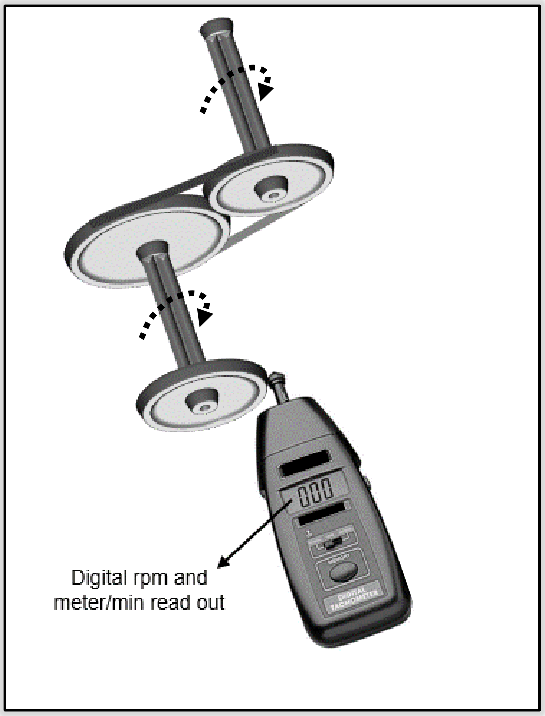



**Figure 4-5 Digital tachometer**

### 4.3.4 Observed time

Now that the tachometer has been identified as the appropriate data collection device for measuring the machine element time, it will be used to repeatedly measure the machine element time, through a series of random observations or measurements.

The observed time is therefore the time taken to perform an element or a combination of elements obtained by means of direct measurement *(Kanawaty, 2006, p. 479)*. In the context of this research, the observed time can be defined as the time taken to perform the machine elements, obtained by means of direct measurement; or the time taken to perform the estimated elements, obtained through the production foremen's estimation.

However, given the high variety of the products produced at each particular production activity, an entire population of cycle times should be established at each of them. Consequently, the observed time should also consist of an entire population of element times, observed at a particular production activity, as illustrated in Figure 4-6 below.

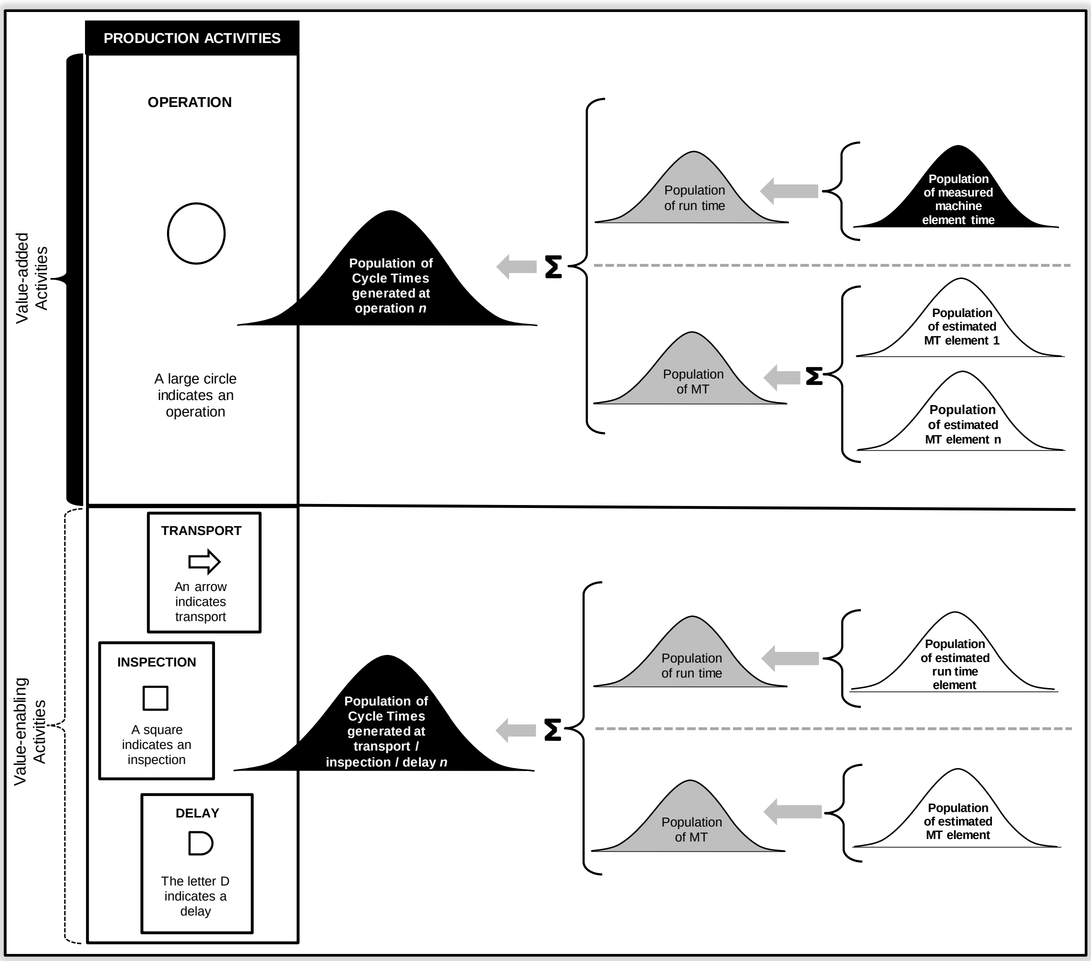



**Figure 4-6 Populations of cycle times and element times**

It is also important to mention that based on the preliminary observation of the weaving and dyeing department's operations, it was noticed that the machine element time remains constant during the production run of a specific job, and only changes when a new job is started. Hence, the direct measurement of the machine element time will be made once for every new job.

### 4.3.5 Confidence level and confidence interval

In Figure 4-6 of Section 4.3.4, two main types of element time populations can be identified:

- The population of the measured machine element time which is obtained by means of direct measurement and;
- The population of the estimated element times which are obtained by means of an estimated value given by the production foremen.

According to *Kanawaty (2006, p. 292)* the measurement of the above population of element times should aim at finding a representative average for each of these element time populations. However, because determining the average or mean of an unknown element time population would require an infinite data collection, it is better to estimate it. The estimation of the mean of an element time population can be made by using the mean of a sample of that element time population *(Joglekar, 2003, p. 29)*.

However, as the mean or average represents an individual data point *(Feng et al., 2008)*, it becomes uncertain that the calculated mean of a sample can hold true for the unknown mean of an entire population. Thus in order to accommodate the uncertainty that the mean of a sample of the element time will hold true for the mean of the corresponding population of that element time, it is necessary to provide a range of plausible values for the mean or average, rather than a point estimate.

According to *Leedy & Ormrod (2013, p. 296)* such a range or interval is often called a confidence interval because it attaches a certain level of confidence that the estimated range includes the population parameter (the population mean in this case). The confidence level in its turn, and according to *Harry et al (2010, p. 365)* can be any number between 0% and 100%, but the most commonly used confidence levels are 90%, 95%, 98%, and 99%. Normally, however, the chosen confidence level is 95% *(Kanawaty, 2006, p. 293)* which will be the confidence level used in this research. Also, a 95% confidence level means that there is 95% of confidence that the mean of the population (generally known as $\mu$) of the machine element time falls within the defined confidence interval. According to *Larson & Farber (2012, p. 307)*, the confidence interval for the population mean can also be written as follows:

$$\bar{x} - Z_c \frac{\sigma}{\sqrt{n}} < \mu < \bar{x} + Z_c \frac{\sigma}{\sqrt{n}}$$ Where

- $\bar{x}$ = sample mean;
- $Z_c$ = Z-score or critical value at the chosen 95% confidence level
- $\sigma$ = population standard deviation (which is unknown in this case);
- $n$ = required minimum sample size to estimate the population mean $\mu$;
- $\mu$ = population mean (which is unknown)

It is however important to mention that the confidence interval and confidence level will be established for the mean of the population of the machine element times only, as it is the only element time that is obtained by means of direct measurements.

To place the above literature into perspective, Figure 4-7 below illustrates how the confidence interval can be established for the mean of the population of the machine element time at a 95% confidence level. Figure 4-7 also shows the population of the estimated element times whose mean will be calculated based on the estimated time value; hence there is no need to establish a confidence level for the population of such element time.

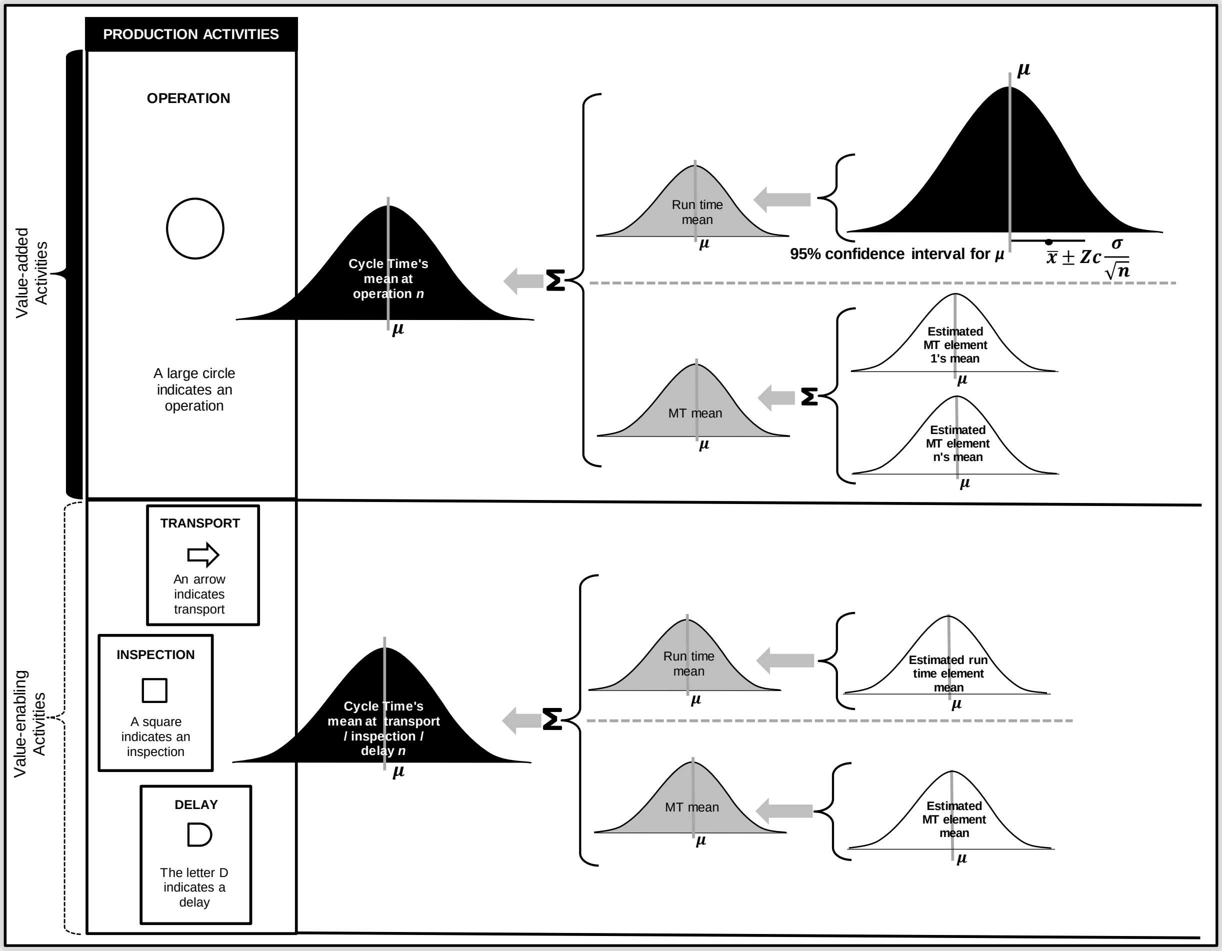



**Figure 4-7 Confidence interval for machine element time**

### 4.3.6 Sample size determination

Section 4.3.5 explained that if the mean of the entire population of the machine element times generated at a particular activity is not known, the mean of a sample of the machine element times at that particular production activity can be used as an approximation, with a well-established confidence interval and confidence level (95% in this case).

The question then becomes, how large should the sample size (generally known as *n*) be for machine element time (see Figure 4-8) in order to estimate the population mean $\mu$ of the machine element time, given a 95% confidence level and a well-established confidence interval. While this question is being asked, it is important to keep in mind that the populations of the estimated element time will not have a sample size determined, as their time values will be estimated with the help of the production foremen, rather than obtained by means of direct measurements.

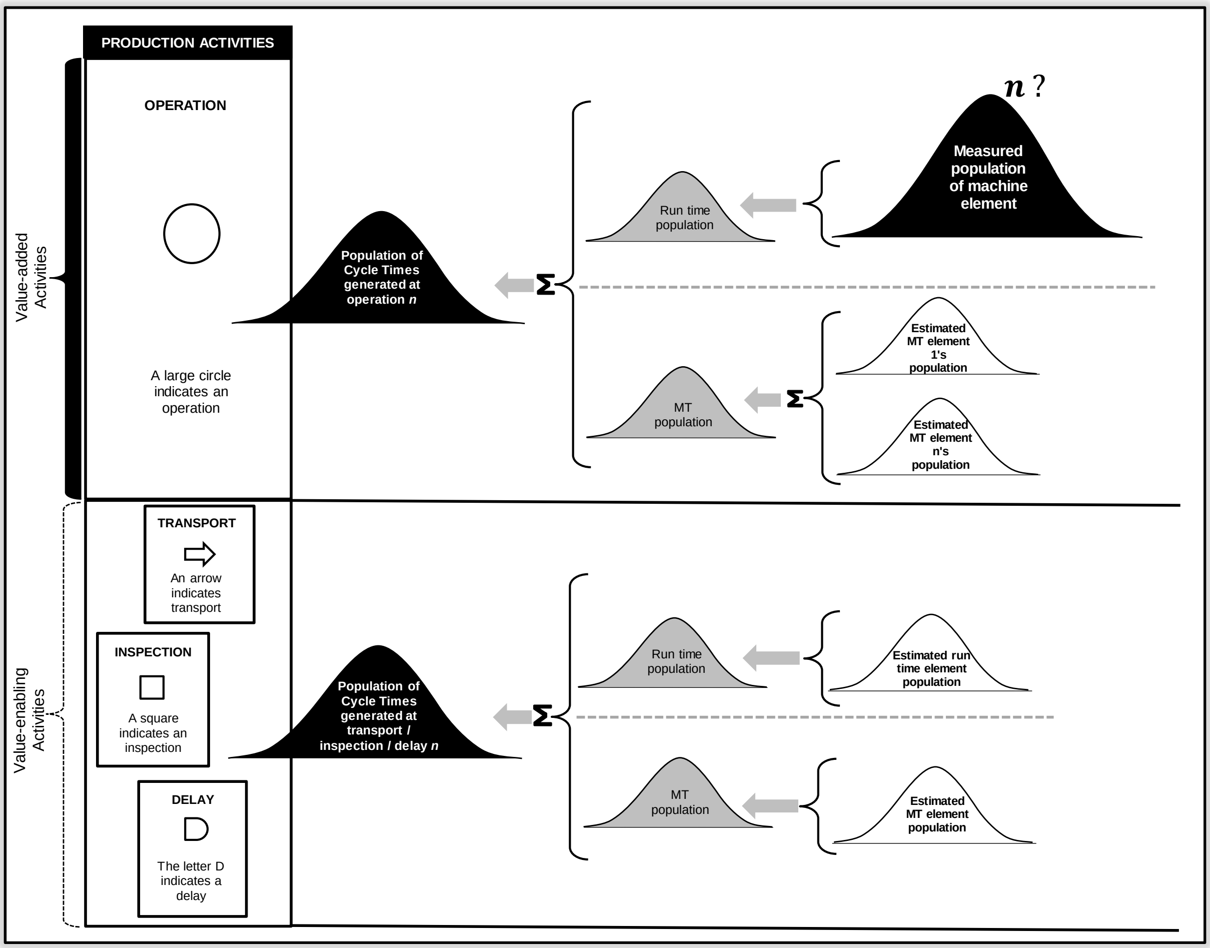



**Figure 4-8 Sample size of machine element time**

Therefore, in order to determine a minimum sample size *n* for the machine element time, such that the mean *μ* of the unknown population of the machine element time, is estimated with the desired confidence interval, the following formula derived by *Larson & Farber (2012, p. 310)* can be used:

$$n = \left(\frac{Z_c \sigma}{E}\right)^2 \text{ Where}$$

- *n* = required minimum sample size to estimate the population mean *μ*;

- $Z_c$ = Z – score or critical value at the desired confidence level
- $\sigma$ = population standard deviation
- $E$ = margin of error

However, it is known from Chapter I, under Section 1.4, that the cycle times of various production activities within the weaving and dyeing department are not being measured. This non-existence of the cycle time data within the weaving and dyeing department also means there is no historical data from which a standard deviation $\sigma$ of the population of the machine element time can be obtained. As a result, the above sample size formula now has two unknowns; namely, the required minimum sample size $n$ to estimate the population mean, and the population standard deviation $\sigma$.

Nevertheless, *Larson & Farber (2012, p. 306)* mentioned that a sample standard deviation (generally known as $s$) can be used in the place of the population standard deviation $\sigma$ provided that the sample size $n \geq 30$. Furthermore, *Larson & Farber (2012, p. 322)* also provide a flowchart describing when to use the normal distribution to construct a confidence interval for the population mean, which is illustrated in Figure 4-9 below.

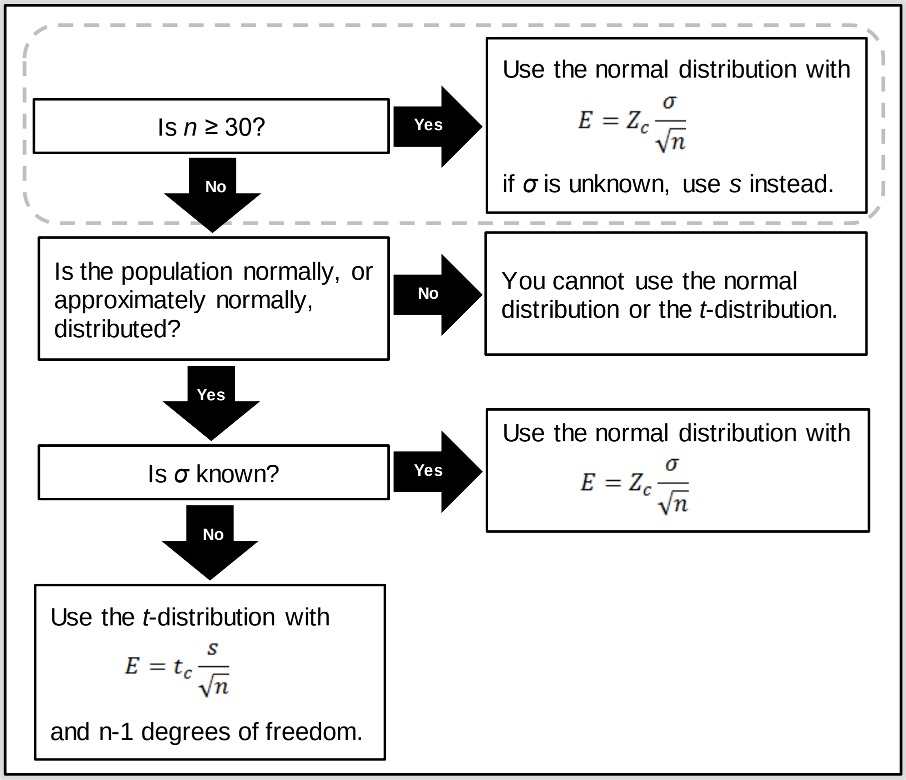



**Figure 4-9 Choosing the normal distribution to construct a confidence interval for the population mean** *(Larson & Farber, 2012, p. 322)*

Therefore, by setting a sample size $n \geq 30$, the sample standard deviation $s$ can be calculated and used to approximate the population standard deviation $\sigma$. In other words, by taking 30 or more measurements of the machine element time of a particular value-added activity, and calculating the standard deviation of those measurements, the value that is obtained can be used in place of the standard deviation $\sigma$ of the entire population of the machine element time of that particular value-added activity.

Based on the above literature, it can be said that a sample size that is 30 or more provides statistical information that can be confidently used to approximate the information or the parameters of the entire population.

*Maskell (1991, p. 135)* furthers this notion by stating that the purpose of sampling is to measure the actual cycle time of a small enough sample that measurement is not a costly burden to production personnel, but yet to have a large enough sample that the information is authoritative. This statement from *Maskell (1991, p. 135)*, also means that although a large sample would provide more confidence in the statistics, some factors may favour a relatively smaller sample size. In the case of the weaving and dyeing department, three factors related to the successful completion of this research favour a sample size that is not too large. Those factors are:

- The time constraint for the completion of this research;
- The number of value-added activities on which measurements are to be taken;
- The fluctuation in the customers' demands throughout the year.

**The time frame for the completion of this research**

Based on the preliminary observation of the weaving and dyeing department’s operations, it was noticed that the machine element of certain value-added activities consisted of running one specific product continuously over an entire production shift or more, before changing over to another product different from the previous one. As a result, the measurement of the machine element time of such production activities can only be made once every production shift or once every two production shifts, so as to obtain a heterogeneous sample of machine element times. Hence, choosing a sample size that is way larger than 30 readings of the machine element times of such production activities would require a very long period of time to collect all the machine element times.

**The number of value-added activities on which measurements are to be made**

As there are several value-added activities from which the machine element times are to be measured, but only one measuring device and one person to obtain the readings from each production activity, the sample size that is chosen for this research must be small enough so that readings can be made at each production activity within a reasonable time frame.

**The fluctuation in customers' demands throughout the year**

The second assumption of this research as mentioned under Section 1.8 of Chapter I, states that the utilisation of resources, and the working hours in the weaving and dyeing department vary according to the product demands. In essence, a period of low customer demand translates into a period of a correspondingly low utilisation of resources and short working hours. A period of high customer demand, on the other hand, translates into a period of high utilisation of resources and long working hours or even working overtime.

The fluctuation in customer demand on a monthly basis can hence be observed from the service level report of the weaving and dyeing department and is shown in Figure 4-10. Based on the second research assumption mentioned under Section 1.8 of Chapter I; as the number of orders increases or decreases from one month to another, so does the production performance of the weaving and dyeing department. Therefore the sample size that is chosen for the machine element time must be small enough so that the measurements are a reflection of the production performance of the weaving and dyeing department during that specific period that the readings are taken, and before the number of orders increases or decreases, hence changing the production performance.

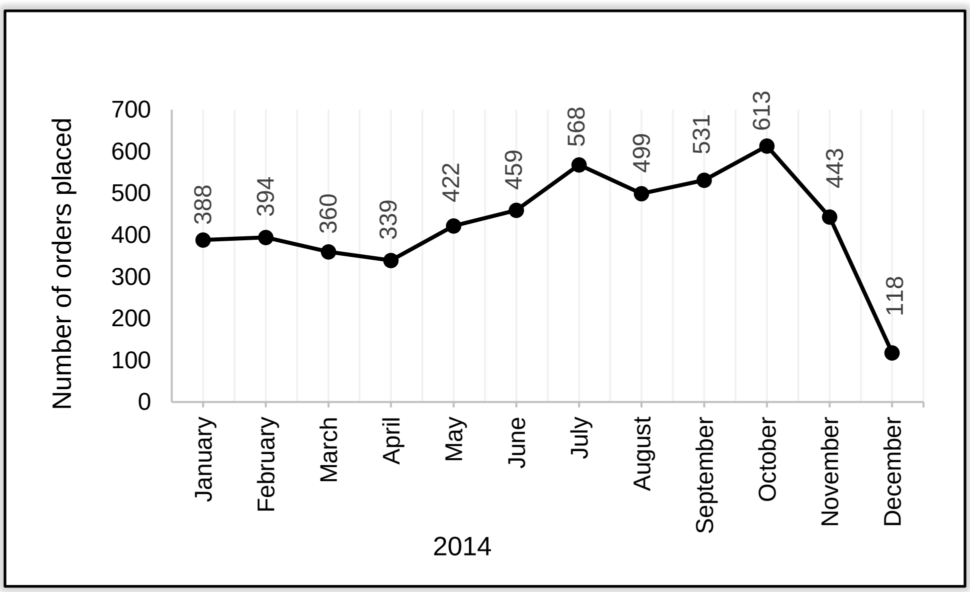



**Figure 4-10 Orders history 2014** *(Weaving and dyeing department)*

### 4.3.7 Acceptable percentage of error

Looking back at the minimum required sample size formula in Section 4.3.6, it is now known that a sample of size $n \geq 30$ can be set, and that the standard deviation $\sigma$ of the population of the machine element time can be approximated through the calculation of the standard deviation *s* of a sample of the machine element time, once *n* readings have been collected.

As a result, when both the minimum required sample size *n* as well as the population standard deviation *σ* of the machine element time are known; and a confidence level of 95% is given as mentioned under Section 4.3.5, the margin of error *E* can be calculated by changing the minimum required sample size formula:

$$n = \left(\frac{Z_c \sigma}{E}\right)^2 \text{ into } E = Z_c \frac{\sigma}{\sqrt{n}}$$

The margin of error, *E,* that is obtained from the above formula, is the greatest possible distance between the point estimate (the mean of the sample of the machine element time in this case) and the value of the parameter (the mean of the population of the machine element time) it is estimating *(Larson & Farber, 2012, p. 306)*. Hence, when dividing the margin of error by the sample mean or the mean of the sample of the machine element time at a given value-added activity (*E*/sample mean), a percentage value can be obtained, which according to *Kelton, Sadowski, & Swets (2010, p. 277)* represents the percentage of error in the point estimate (the mean of a sample of the machine element time in this case).

Consequently, given a well-determined sample size *n*, the resulting percentage or error should not exceed 10%, as it is the maximum acceptable percentage of error for this research. The reason for allowing up to 10% of error in the point estimate is because a 10% error in the mean of the population of the machine element time would not have a considerable impact on the total cycle time or on the overall MLT in the weaving and dyeing department.

However, should the percentage of error, given the chosen sample size *n*, exceed 10%, the sample size will have to be increased until the desired percentage of error is achieved as illustrated in Figure 4-11 below.

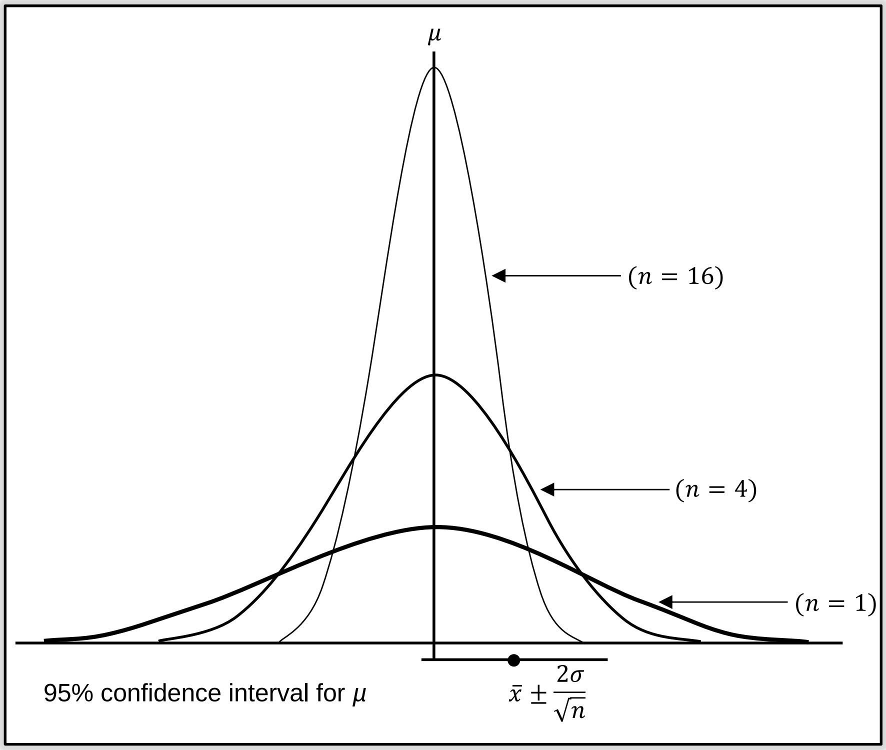



**Figure 4-11 Confidence interval for $\mu$ with known $\sigma$** *(Joglekar, 2003, p. 31)*

### 4.3.8 Standard time

As mentioned under Section 4.3, time study is acknowledged to be an adequate way to determine the cycle time which, according to *Heizer & Render (2006, p. 409)*, consists of timing a sample of a worker's performance and using it as a basis for setting a standard time.

The standard time is, in its turn, defined as the total time in which a job should be completed at a standard performance *(Kanawaty, 2006, p. 336)*. Incidentally, the standard time can be thought of as being a cycle time, as the definitions of both the standard time and the cycle time converge to the time required to produce or complete one specific task or product; though the former has to be done at a standard performance and the latter doesn't necessarily, unless measured by means of time study.

Therefore, as time study is acknowledged to be an appropriate technique for determining the cycle time, and at the same time consists of setting a standard time, the standard time becomes the main unit to be measured in order to determine the cycle time of the production activities in the weaving and dyeing department.

Consequently, the standard time of a given production activity is obtained by adding up the standard times of each element of the given job as shown in Figure 4-12.

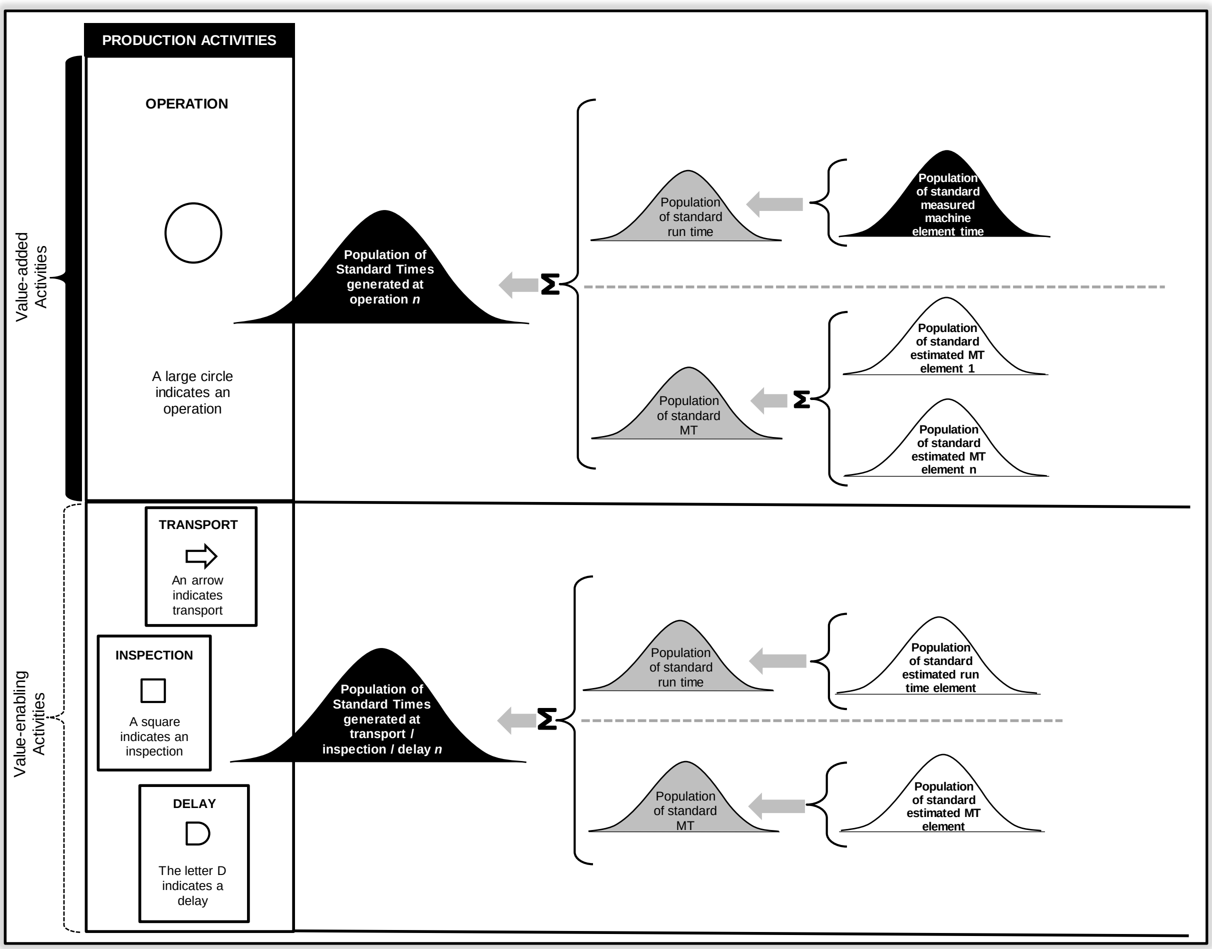



**Figure 4-12 Elements and activities standard time**

Moreover, in order to change the observed time defined under Section 4.3.4 into a standard time as explained above, five main standard time components have to be determined. These five components consist of the rating, the normal time, the basic time, the frequency and the allowance. They are each defined by *Kanawaty (2006)* as follows.

**Rating**

By definition, rating is a comparison of the rate of working observed by the workstudy person with a picture of some standard level in mind. This standard level is the average rate at which qualified workers will naturally work at a job, when using the correct method and when motivated to apply themselves to their work. This rate of working corresponds to what is termed the standard rating, and is denoted by 100 on the standard rating and performance scale.

**Normal time**

The normal time is the observed time, adjusted for pace. In other words, it is equal to the observed time multiplied by the performance rating factor *(Heizer & Render, 2006, p. 409)*.

**Basic time**

The basic time is the time for carrying out an element of work at standard rating. In other words, it is equal to the normal time divided by the standard rating factor of 100.

**Frequency**

The frequency of occurrence of an element is the rate with which that element occurs during a particular job. Repetitive elements, by definition, occur at least once every cycle of the operation so the entry to be made against a repetitive element will read 1/1, or 2/1, etc., indicating that the element concerned occurs once in every cycle (1/1), twice (2/1) or whatever the case may be. Occasional elements may occur only once every ten or 50 cycles, when the entry would be 1/10, 1/50 or as appropriate.

However, because the various element times at various production activities of the weaving and dyeing department should consist of entire populations of the element times generated at those particular production activities, the frequency of occurrence of those elements should also consist of the entire population of frequency of occurrence of the respective elements.

**Allowance**

Because many jobs require the expenditure of human effort, some allowance must therefore be made for recovery from fatigue and for relaxation. Allowance must also be made to enable a worker to attend to personal needs, and other allowances may also have to be added to the basic time in order to obtain the work content.

**Conclusion**

The standard time for a job will therefore be the sum of the standard times for all the elements of which it is made up, due regard being paid to the frequencies with which the elements recur, plus the allowances. The standard time may therefore be represented graphically as shown in Figure 4-13 below.

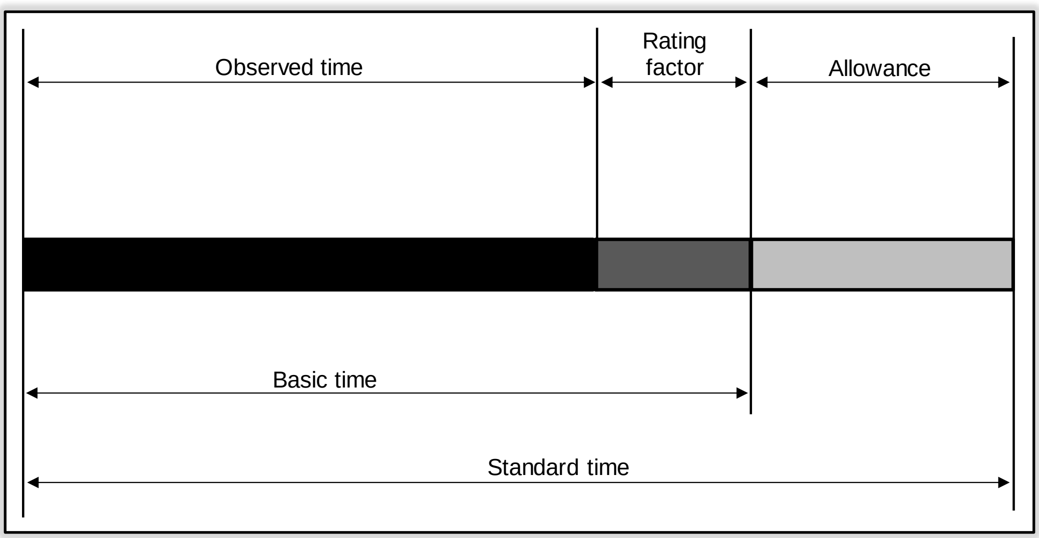



**Figure 4-13 Make-up of standard time**

## 4.4 Analyse

### 4.4.1 Monte Carlo simulation

In Section 4.3.6 it was said that the element time at a particular production activity should consist of the entire population of element times generated at that particular production activity or a representative sample thereof. Furthermore, the population or the sample of the element times is defined by means of a frequency histogram.

Therefore, by creating a frequency histogram for the element times generated at a particular production activity, not only can some patterns be noticed in the dataset, but also a probability density function that best describes the dataset can be identified by conducting a goodness-of-fit test. A goodness-of-fit test measures how well a hypothesised probability density function fits the frequency histogram of a data sample *(Palisade Corporation, 2013, p. 152)*.

The hypothesised probability density function that best fits the dataset can in turn be used to model the frequency histogram of the sample of the element time and generate, through a Monte Carlo simulation, several more possible values that the element times can assume.

Therefore, Monte Carlo simulation in its simplest form is a random number generator that is useful for forecasting, estimation, and risk analysis. A simulation calculates numerous scenarios of a model by repeatedly picking values from a user-predefined probability distribution for the uncertain variables and using those values for the model *(Mun, 2006, p. 74)*.

### 4.4.2 Fitting distribution

Based on the literature in Section 4.3.4 and Section 4.3.8, it can be deduced that fundamentally, three main input distributions are needed in order to obtain the distribution of the cycle times at the various production activities. These three main input distributions are:

- The distribution of the measured machine element time;
- The distributions of the estimated element time and;
- The distributions of the estimated frequency of occurrence of each element.

Nonetheless, finding the most appropriate probability density function that best represents each of the above-mentioned distribution or frequency histograms, can be accomplished in various ways, all depending on the availability of the data. According to *Bekker (2014, p. 45)* the required actions when no data exist and when data are available, can be identified as shown in Figure 4-14 below.

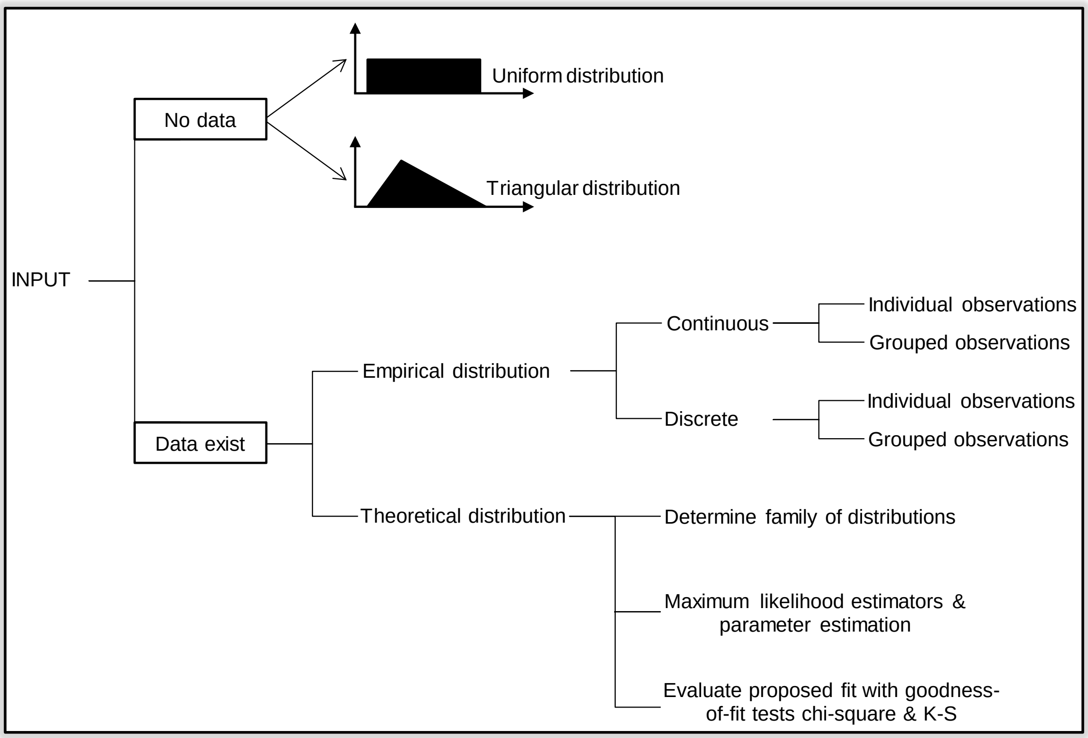



**Figure 4-14 Input data analysis** *(Bekker, 2014, p. 45)*

As seen in Figure 4-14, when data do not exist or are too expensive or disruptive to collect, a uniform or a triangular probability distribution can be used, whereby the former is defined by a minimum and maximum value, and the latter by a minimum, a most likely and a maximum value *(Kelton et al., 2010, pp. 186 – 187)*.

On the other hand, the probability distribution when data exist, can be thought of as falling into two main types; theoretical and empirical. According to *Kelton et al (2010, p. 179)* there aren't any standard rules on whether to use a theoretical or empirical distribution. However an empirical distribution may have irregularities, whereas the theoretical distribution is smooth and provides information on the overall underlying distribution, including values that are not revealed by the empirical distribution *(Bekker, 2014, p. 46)*. Therefore, in order to predict a very wide range of possible values that the machine element time can assume through the Monte Carlo simulation, the theoretical distribution is favoured.

The theoretical distribution can be further broken down into continuous and discrete types *(Kelton et al., 2010, p. 179)*, all depending on the nature of the sample space. The sample space is the set of all possible outcomes of a random experiment. It can be discrete if it consists of a finite or countable infinite set of outcomes; it can be continuous if it contains an interval (either finite or infinite) of real numbers. *(Montgomery & Runger, 2003, p. 19)*.

Consequently, finding the most appropriate probability distribution that can best represent each of the three main input distributions mentioned at the beginning of this Section 4.4.2, can be done by using the following matrix shown in Figure 4-15 below.

| | **Data Exist** (*Theoretical distribution*) | **No Data** (*Uniform distribution / Triangular distribution*) |
|---|---|---|
| **Continuous** | • Distribution of the measured machine element time. | • Distributions of the estimated element time. |
| **Discrete** | | • Distributions of the estimated frequency of ocurrence of each element. |

**Figure 4-15 Finding appropriate distribution**

As can be seen in Figure 4-15, the distribution of the machine element time and the distribution of the other element times are classified as continuous since they consist of time units, hence contain intervals of infinite real numbers; whereas, the distribution of the frequency of occurrence of each element is classified as discrete since it consists of the number of times an element occurs, which is a countable infinite set of outcomes.

On the other hand, a continuous uniform probability distribution or a continuous triangular probability distribution will be used to estimate the distribution of the element times that are not machine element times; whereas a discrete uniform probability distribution or a discrete triangular probability distribution will be used to estimate the distribution of the frequency of occurrence of each element.

## 4.5 Improve

As mentioned under Section 2.3.4, the fact that the purpose of this research is to establish production cycle times in an environment where production cycle times are currently not being measured, renders the achievement of this objective of the research alone, an improvement. Therefore the following section explains how the cycle times can be established through the calculation of the standard times.

**Running the Monte Carlo simulation**

In order to establish the standard times previously explained in Section 4.3.8 for the production activities, given the entire variety of products that are produced at each activity, the Monte Carlo simulation is used in order to calculate numerous scenarios by repeatedly picking values from the predefined probability distributions explained in Section 4.4.2.

Typically, to run a Monte Carlo simulation, the following steps must be performed *(Mun, 2006, p. 88)*:

- Start a new or open an existing simulation profile;
- Define input assumptions in the relevant cells;
- Define output forecasts in the relevant cells;
- Run simulation;
- Interpret the results.

All the steps of the Monte Carlo simulation as mentioned above, will be achieved by making use of the functionalities of the @risk software as well as Microsoft Excel, and will be further explained in Chapter V. However, an overview of the methodology used in order to simulate the standard times for various production activities, is illustrated in Figure 4-16 below.

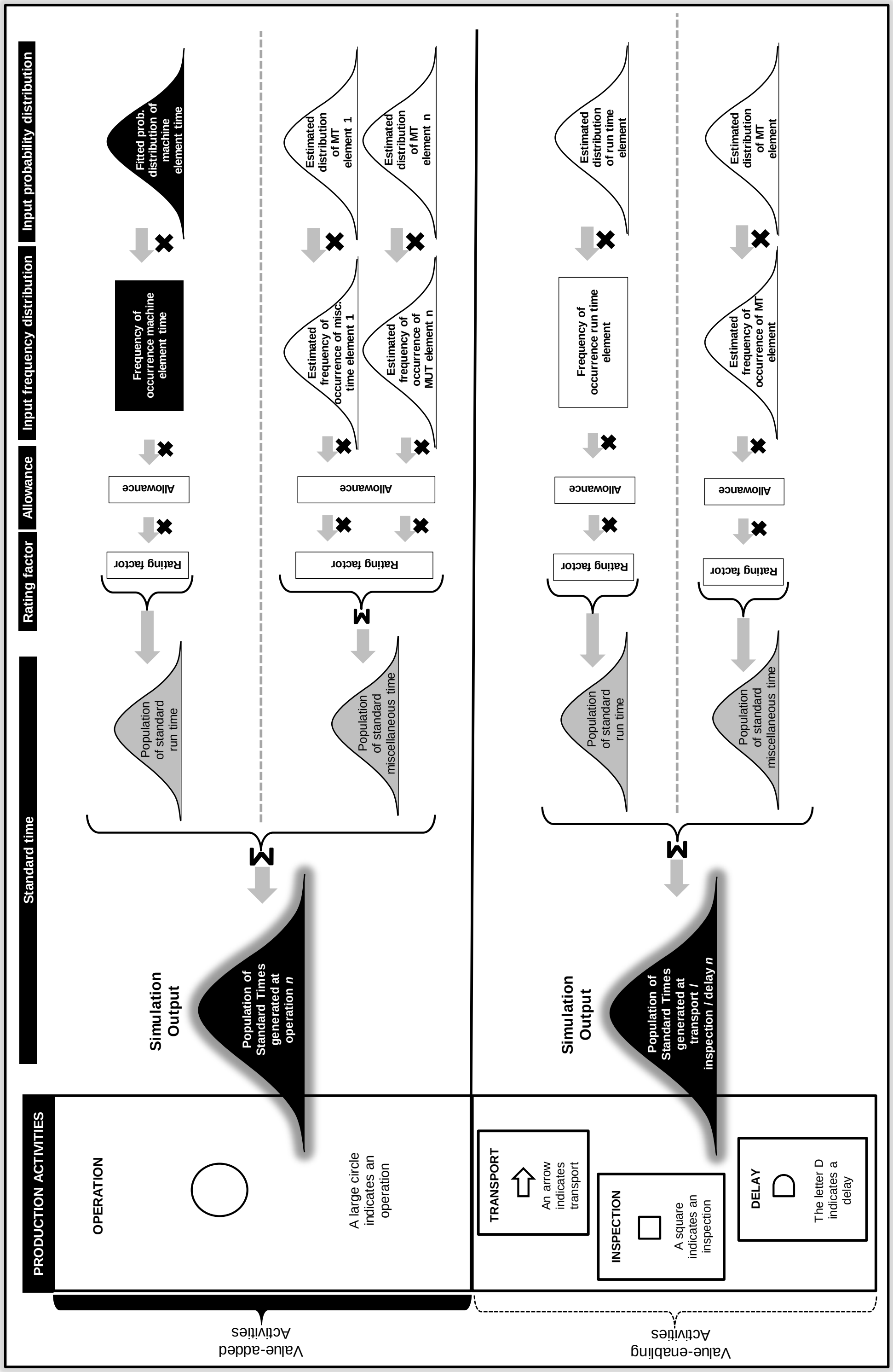



Figure 4-16 Standard simulation methodology

## 4.6 Control

As mentioned under Section 1.6, the objective of this research is to establish cycle times for the production activities of the weaving and dyeing department, so as to help management better estimate and control the Manufacturing Lead Times (MLTs). This section therefore looks at the literature on the MLT, with a view to understanding how the establishment of production cycle times can help in better estimating and controlling the MLT.

### 4.6.1 Manufacturing lead time

The MLT is the total time required to process a given part or product through the plant, including any lost time due to delays, time spent in storage, reliability problems, and so on *(Groover, 2008, p. 54)*. Sometime referred to as the manufacturing throughput time, it can also be defined as the length of time between the release of an order to the factory floor and its receipt into finished goods inventory *(Johnson, 2003)*.

Fundamentally, the MLT comprises operation and non-operation components. Within the operation components are machining times, transfer and positioning times *(Hitomi, 1996, p. 384)*; but also set-up times, running times, queue times, and move or transit times *(Zandin & Maynard, 2001, p. 10.92)*. The non-operation components on the other hand contain procurement times of raw materials *(Samaranayake, 2013)*; as well as the waiting time of a material before its processing starts and the processing time *(Lee, Ik, & Lee, 2007)*.

However, the MLT is not to be confused with the cycle time. Unlike the cycle time which is the time for performing a specific task, activity or operation, as defined in Section 4.2.1, the MLT on the other hand can be thought of as the summation of all the cycle times at various production activities, plus the time the product spent being in storage or in non-value-added activities, as shown in Figure 4-17 below. In other words, the MLT can be obtained by summing the total cycle time as defined in Section 4.2.1, and the non-value-added activities time.

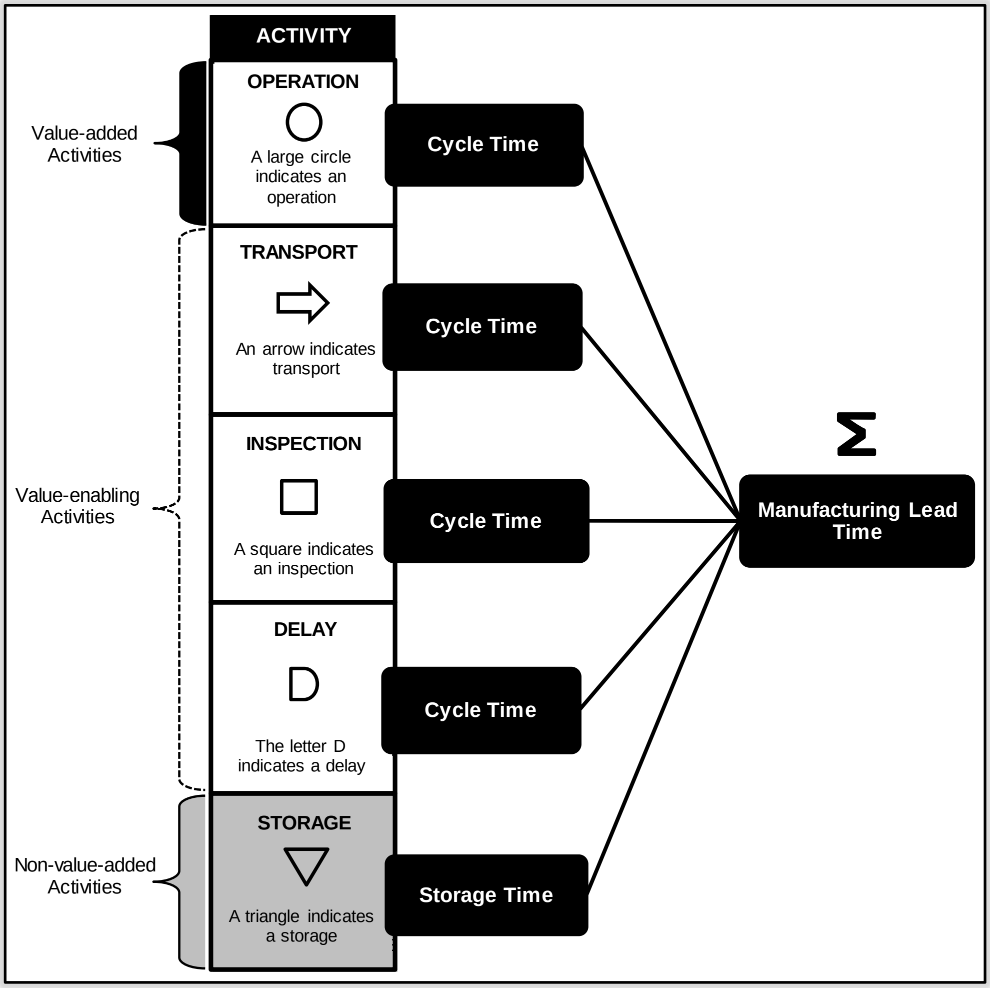



**Figure 4-17 Manufacturing lead time**

Furthermore, although the MLT and the cycle time both signify a lapse of time within which a specific endeavour is carried out; the complexity involved in measuring or establishing each term, varies.

The cycle time can be established by directly measuring its main time components and summing them up as explained under Section 4.2.2; the measurement of the MLT however may first require that bottleneck work centres be identified *(Ruben & Mahmoodi, 2000)* and that manufacturing capacity be established *(Slotnick & Sobel, 2005)*.

**Bottleneck**

According to *Ruben & Mahmoodi (2000)*, because congestion levels at a bottleneck work centre exert more influence on product lead times than congestion levels at other less utilised work centres, it may be possible to produce reliable lead time estimates with information pertaining solely to the bottleneck work centres.

On the other hand, *Pandey & Hasin (1998)* bring to attention the fact that the configuration of a factory, particularly the position of the bottleneck work centre, can have a significant impact on the MLT. Complementing this notion is an illustration in Figure 4-18, from *Öztürk, Kayalıgil, & Özdemirel (2006)*, which describes the different types of bottlenecks and how they affect the establishment of the MLT.

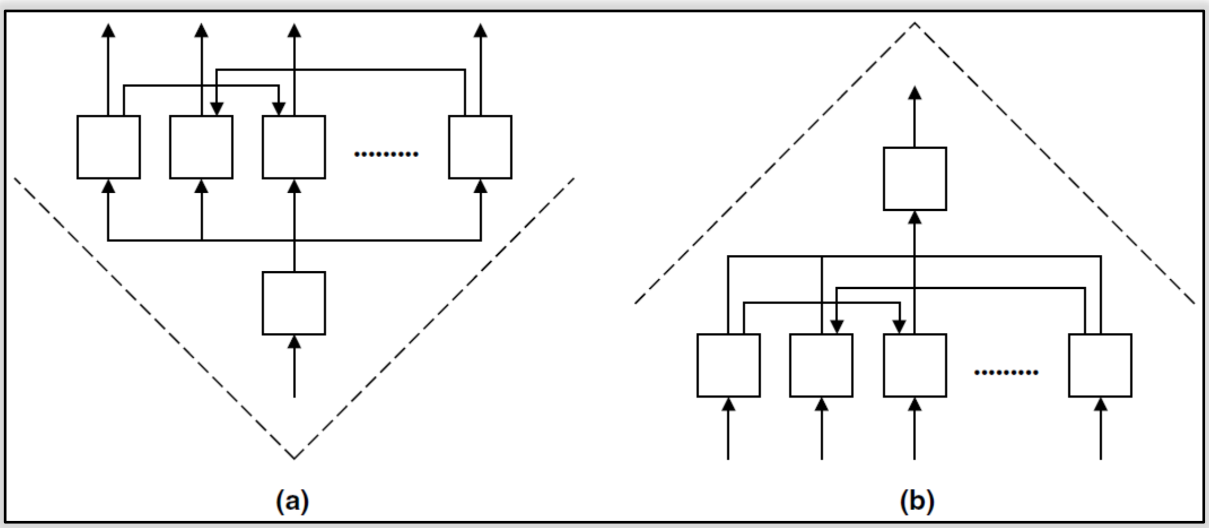



**Figure 4-18 Part flow in Shop – V (a) and Shop – A (b)** *(Öztürk et al., 2006)*

SHOP – V, the bottleneck, is closest to the order release point, hence inferences on the MLT made at the time of release have a high likelihood to hold. Contrary to shop – V, the bottleneck is at the furthest stage in shop – A, hence the MLT is much harder to predict *(Öztürk et al., 2006)*. Therefore to gain control over the MLT, all bottleneck work centres must be identified and their corresponding cycle time measured.

Finally, *Goldratt & Cox (2004, pp. 147 – 148)* mention that a bottleneck resource can be identified by firstly knowing the total market demand for products coming out of the plant; then, measuring the time each resource has to contribute toward filling the demand. Hence, establishing the cycle time for various production activities is crucial to identifying bottleneck resources, which in turn is important to measure the MLT.

**Capacity**

According to *Slotnick & Sobel (2005)* a major reason for inaccurate lead time quotation is lack of information on manufacturing capacity. Therefore good capacity management makes it possible to have the product available when and where the customer demands it *(Blackstone, Jr., 1989, p. 1)*. Furthermore, because the MLTs can be affected by factors such as capacity *(Yücesan & de Groote, 2000)*; decent capacity commitments are vital to achieving properly structured lead times *(Rao, Swaminathan, & Zhang, 2005)*.

However, because capacity is defined to be a rate of output per time unit *(Blackstone, Jr., 1989, p. 20)*, and the cycle time as defined under Section 4.2.1 is the time unit required to complete a specific output, it can be inferred that the reciprocal of the cycle time of a particular production activity is the capacity of that production activity. Hence determining cycle times is necessary in establishing capacities, which is in turn necessary to manage the MLTs.

### 4.6.2 Conclusion

Based on the above literature, it can be inferred that not only will the establishment of the production activities' cycle times provide better control over the MLT through the identification of bottleneck work centres and the measurement of the production capacities, but also, the established cycle times will help to better manage the flow of production units through the entire plant.

## 4.7 Chapter summary

This chapter starts by defining the cycle time as the elapsed time for an individual activity from start to completion. The chapter further explains that the cycle time of an activity is obtained by summing up the run time of that activity, which indicates the time of the actual processing; as well as the Miscellaneous Time (MT) which indicates the time of any other actions that are not a run action.

Secondly, this chapter acknowledges time study as an appropriate work measurement technique for measuring the cycle time, and defines the key steps toward conducting successful time studies for the various production activities of the weaving and dyeing department.

Thirdly, this chapter shows how the information recorded on the time study sheet can be analysed using probabilistic models, so as to establish entire populations of cycle times at each production activity of the weaving and dyeing department, hence creating an improvement in the establishment of the cycle time.

Finally, this chapter explains how the establishment of production cycle times can help in better estimating and controlling the MLT, mainly through the identification of bottleneck work centres and the measurement of the production capacities.

# 5 CHAPTER V: DMAIC WEAVING AND DYEING PLANT

## 5.1 Background

In Chapter II, the DMAIC procedure was recognised as being an appropriate technique to follow in order to establish the cycle times of production activities in the weaving and dyeing department. Later, in Chapter III, the production activities for which the cycle times had to be established were identified. Subsequently, in Chapter IV, a method for measuring the cycle times for an entire population of products manufactured at a specific production activity was established. It went on to explain how the establishment of the production cycle time can help in better estimating and controlling the MLT.

Consequently, in this chapter, the DMAIC procedure is applied in the weaving and dyeing department, by making use of actual production data and information that were collected from the weaving and dyeing department itself during the research; due regard being paid to the literature in Chapters I, II, III, IV and V.

## 5.2 Defining process and products

As the define phase of the DMAIC procedure usually requires a holistic description of the project at hand as explained in Chapter II, under Section 2.3.1, the reader is referred to Chapter I which is considered the first part of this define phase. The remainder of the define phase will therefore unfold as follows.

### 5.2.1 Overview of the weaving and dyeing manufacturing process

In addition to the explanation of the project in Chapter I, a Suppliers, Input, Process, Output, Customers (SIPOC) diagram is established and illustrated in Table 5-1 below.

This summarises the inputs and outputs of the different value-added activities within the weaving and dyeing department.

**Table 5-1 SIPOC of the weaving and dyeing department**

| Suppliers | Inputs | Process | Outputs | Customers |
|---|---|---|---|---|
| Local wholesalers of yarn | Yarns/Bobbins | Yarn Dyeing | Rolls of dyed tapes | Clothes Manufacturers |
| Overseas makers of yarn | Dye stuff | Warping | Boxes of dyed tapes | Liquor manufacturers |
| | Chemical | Weaving | Bags of dyed tapes | Diaries manufacturers |
| | Water | Spooling | | Apparel retailers |
| | | Tape Dyeing/Finishing | | Car seatbelt manufacturer |
| | | Rolling | | |
| | | Cutting | | |

As can be seen in Table 5-1 above, the weaving and dyeing manufacturing process is fundamentally made up of a series of seven distinct value-added activities. Upon receiving a customer's order, the production can start at any one of the seven value-added activities (see Appendix B).

In addition to the value-added activities mentioned in Table 5-1, are the value-enabling activities that will be mentioned in Section 5.2.4. However, regardless of whether a production activity is value-added or value-enabling, most production activities within the weaving and dyeing department comprise more than one resource that operates in parallel. Finally, the raw material and work-in-progress on the production floor travel in batches from one grouping of resources to the next, following a batch production system.

### 5.2.2 Products and production volumes

#### Products overview

As explained in Chapter I, under Section 1.2.2, the weaving and dyeing department manufactures a variety of products that may differ in material type, weaving pattern, density, width, and colour. Therefore a population of products that are manufactured at a specific value-added activity will vary according to those products' characteristics as shown in Figure 5-1 below.

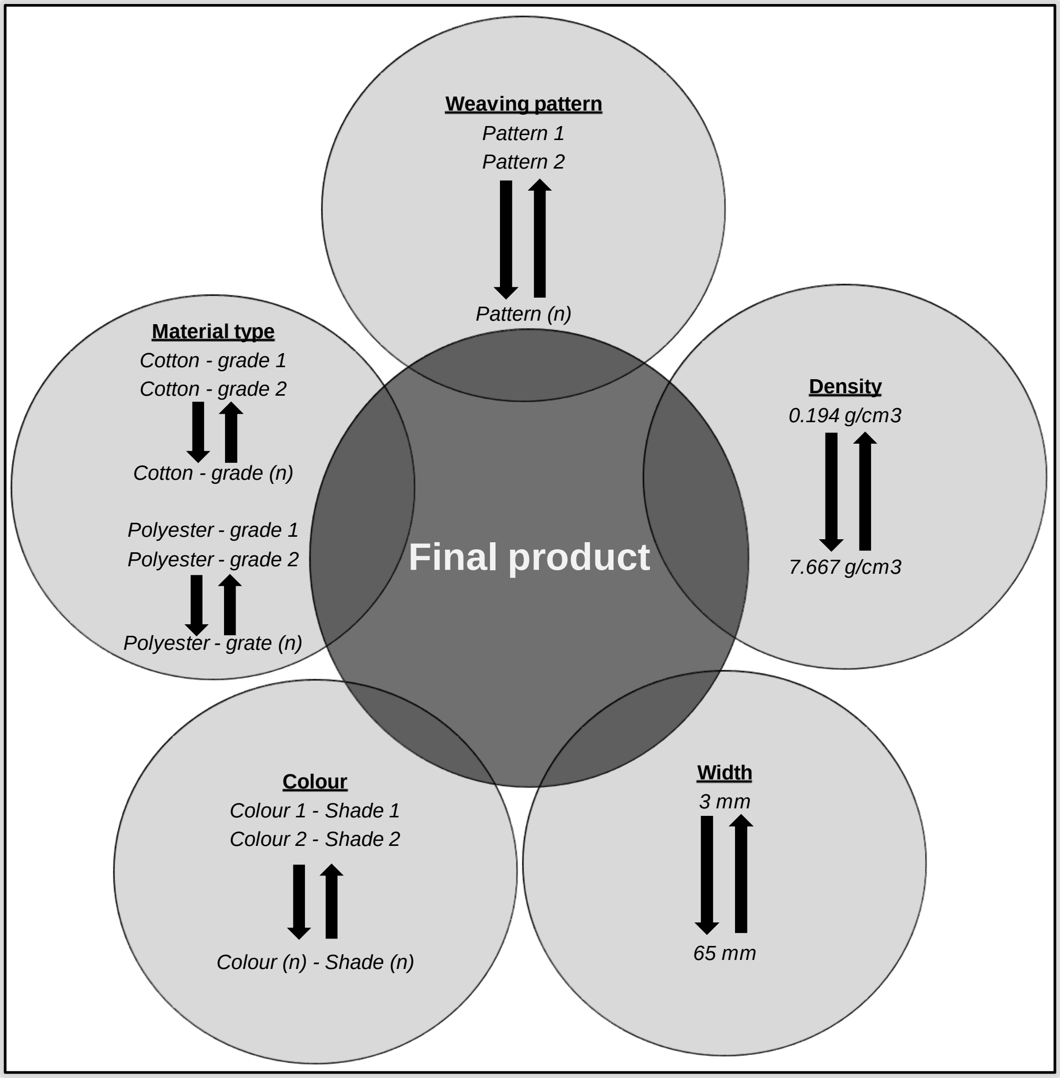



**Figure 5-1 Products' characteristics**

Figure 5-1 further illustrates that within each of the characteristics, there are further attributes that a product may have. These attributes are a range of preset measurements, patterns, shades of colour, and material grades established by the weaving and dyeing department; based on the capabilities of the machines as well as the market's demand.

However, there is an exception when it comes to the colour and shade attributes, whereby despite having preset or standard colours and shades, the weaving and dyeing department also makes provision for matching and producing any other colour and shade that is not on their standard colour card. Such flexibility allows the customers to have their products dyed any possible colour they desire.

Consequently, by combining the preset attributes of some characteristics with the virtually infinite colour and shade attributes to create a finished product, a correspondingly large or infinite number of product profiles or population of products can be produced at certain value-added activities of the weaving and dyeing department.

**Product groups**

In order to easily identify and manage the multitude of product profiles that are created when combining the characteristics shown in Figure 5-1; a need emerges for grouping this multitude of items into fewer distinct categories of product families or product groups as shown in Figure 5-2 below.

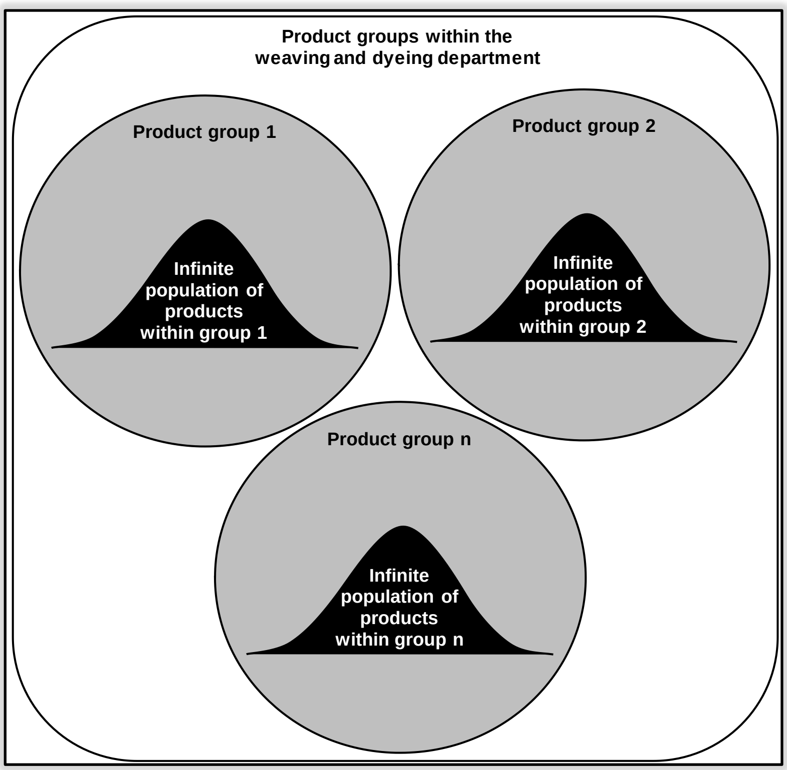



**Figure 5-2 Product groups**

Consequently, there are 70 product groups that are used in the weaving and dyeing department as illustrated in Figure 5-3. These product groups were created internally, and labelled based on either the type of material used in the fabric, the weaving pattern, the density, the width, the length, the product the narrow fabric is intended for, the client's name, or a combination of some of these characteristics.

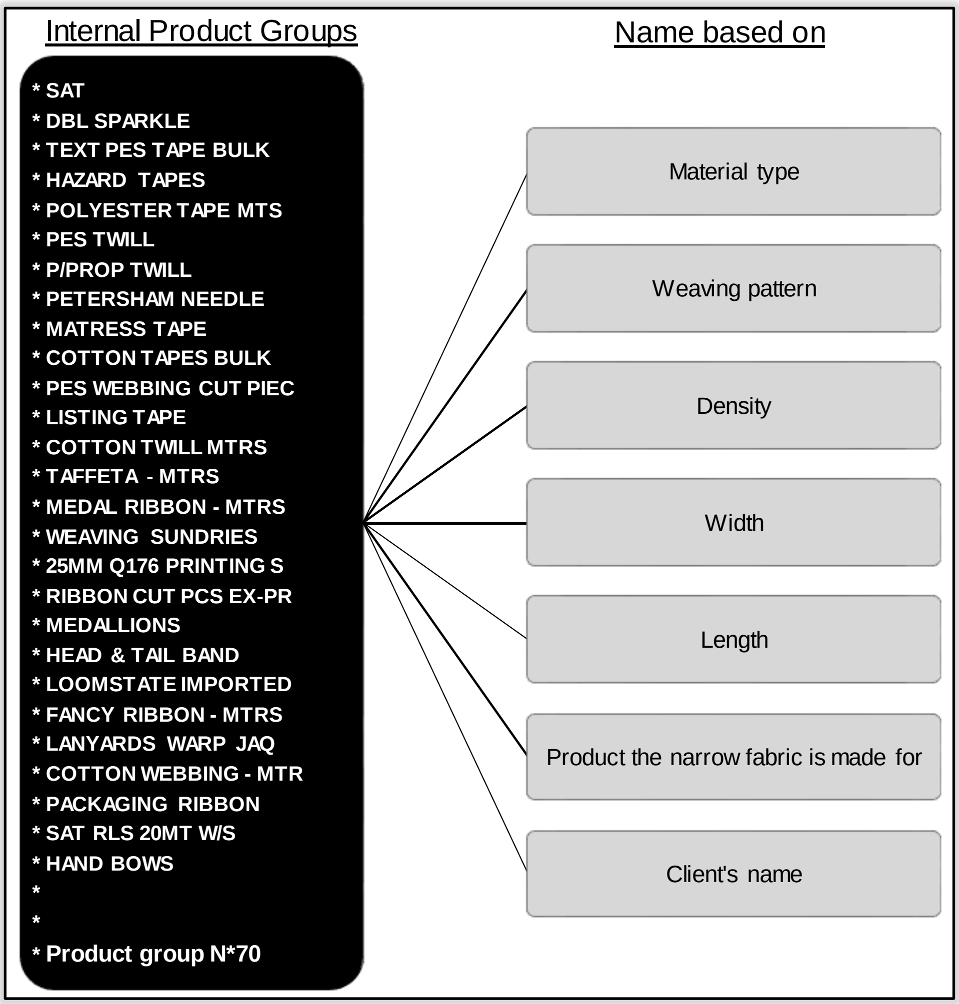



**Figure 5-3 Internal product grouping** *(Weaving and dyeing department)*

In addition to the above product groups used in the weaving and dyeing department, a more general classification of the various products can be established making use of the group technology philosophy *(Singh, 1996, p. 481)*. This product classification is illustrated in Figure 5-4 below and is an indicative hierarchical classification of the entire population of the tapes that can be manufactured in the weaving and dyeing department, based on the various product characteristics alone.

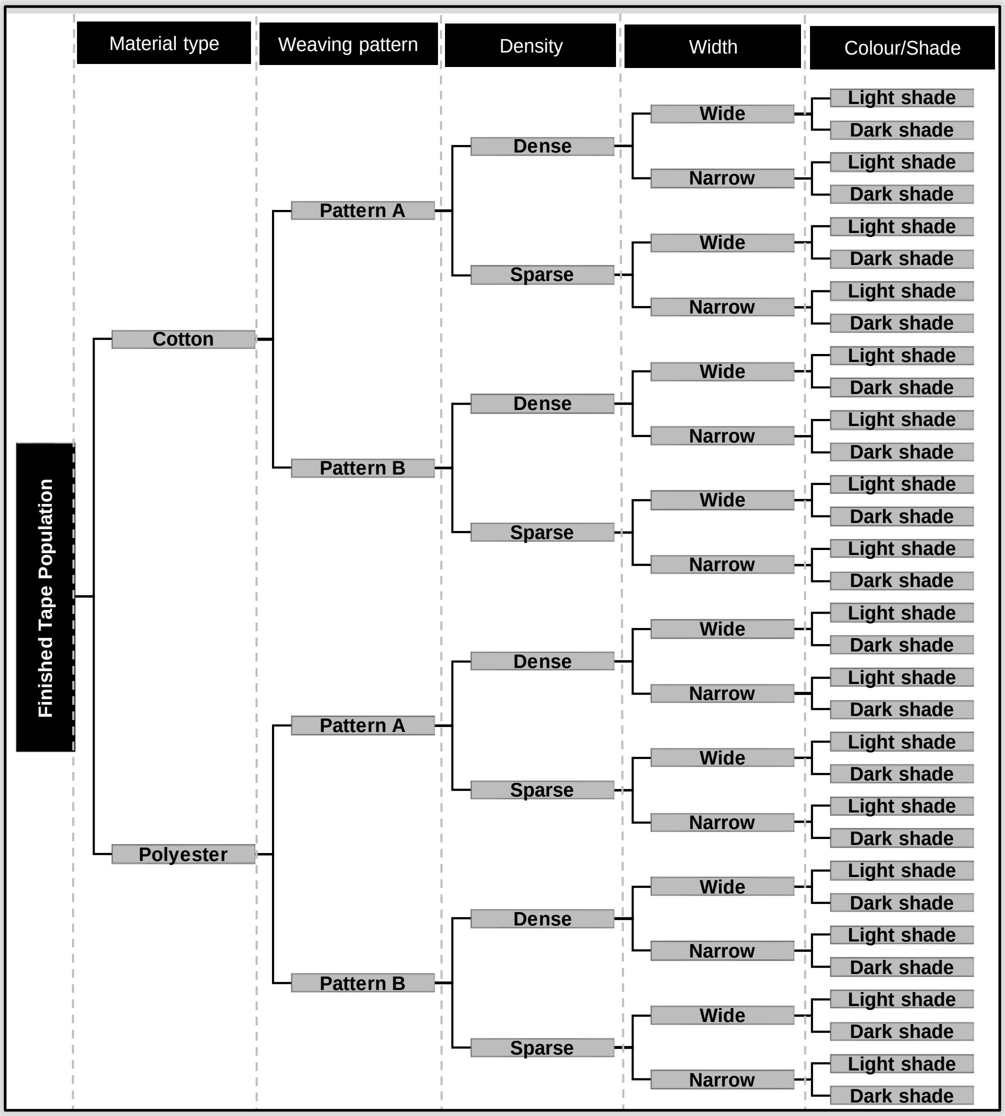



**Figure 5-4 Hierarchical products classification**

## Production volumes

Although the grouping of the products used in the weaving and dyeing department allows us to reduce the multitude of individual items produced into more manageable product groups; not all the product groups are produced in the same annual volume or with the same frequency of order. Some product groups are manufactured in larger volumes than others, just as some product groups are ordered more frequently than others, making some product groups more important than others. Because some product groups are more important than others, they have to be prioritised in order to identify only the most important ones.

The prioritisation of the product groups, is done by firstly making use of a Pareto chart of the annual production volumes of each product group during the year 2014 as shown in Figure 5-5 below.

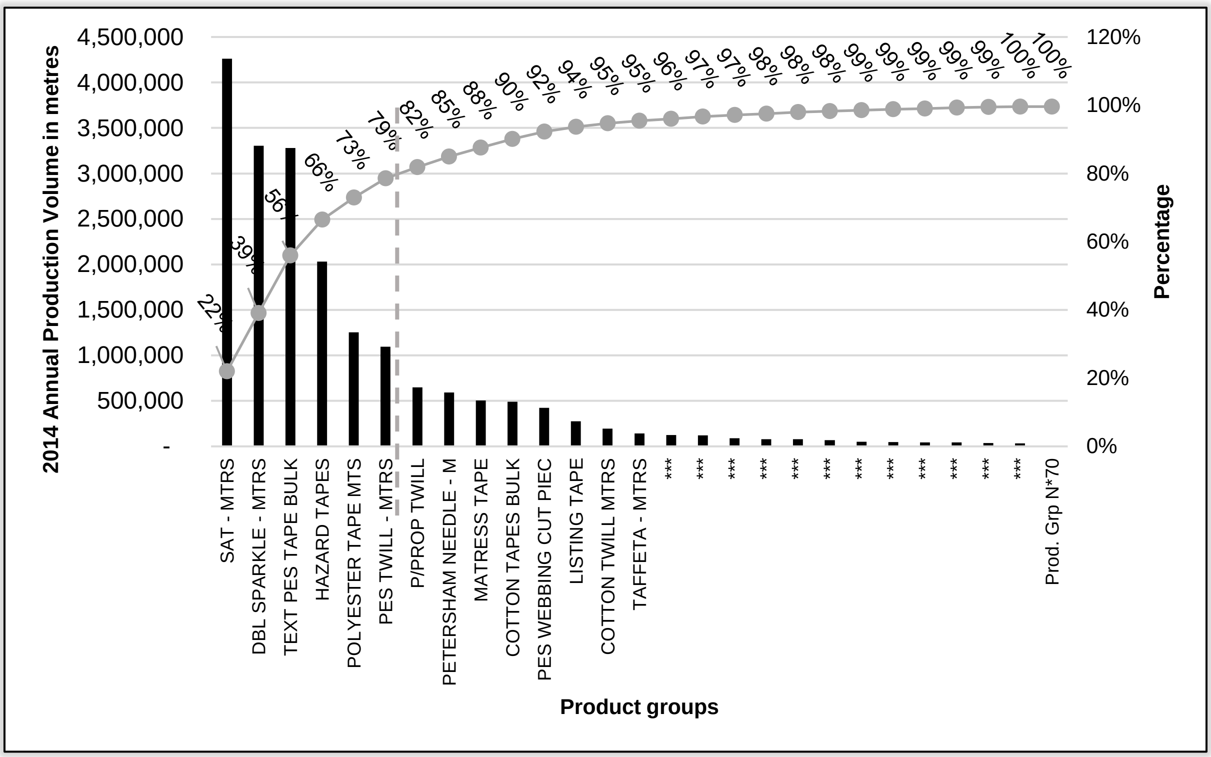



**Figure 5-5 Pareto chart of 2014 annual production volume** *(Weaving and dyeing department)*

As can be seen in the Figure 5-5, the first six product groups' annual volumes represent just over 80% of the total annual production volumes of all 70 product groups within the weaving and dyeing department for the year 2014, making them the top six most important product groups in terms of annual production volume.

However, despite having large production volumes, these top six product groups don’t all have the same frequency of production, as some product groups are ordered more frequently than others regardless of their respective production volumes. Consequently, a product group could have a large production volume but relatively low frequency of orders or vice versa.

Therefore, the prioritisation of product groups will also look at the annual frequency of production of the various product groups as shown in Table 5-2, which narrows the focus to only the product groups which have both high production volumes as well as high frequency of production throughout the year.

**Table 5-2 Production volume vs. order frequency** (*Weaving and dyeing department*)

| Product Groups (top six ★) | 2014 Production Volume (meters) | Production volume rank 2014 | Number of orders placed in 2014 | Order frequency rank |
|---|---|---|---|---|
| ***SAT - MTRS ★*** | ***4260956*** | ***1st*** | ***72*** | ***1st*** |
| ***DBL SPARKLE - MTRS ★*** | ***3306252*** | ***2nd*** | ***68*** | ***2nd*** |
| ***TEXT PES TAPE BULK ★*** | ***3281620*** | ***3rd*** | ***47*** | ***5th*** |
| ***HAZARD TAPES ★*** | ***2031476*** | ***4th*** | ***33*** | ***8th*** |
| ***POLYESTER TAPE MTS ★*** | ***1253941*** | ***5th*** | ***33*** | ***9th*** |
| ***PES TWILL - MTRS ★*** | ***1095064*** | ***6th*** | ***47*** | ***6th*** |
| P/PROP TWILL | 647900 | 7th | 3 | 35th |
| PETERSHAM NEEDLE - M | 593789 | 8th | 52 | 3rd |
| MATRESS TAPE | 503200 | 9th | 2 | 42nd |
| COTTON TAPES BULK | 488772 | 10th | 28 | 10th |
| PES WEBBING CUT PIEC | 424180 | 11th | 6 | 22nd |
| LISTING TAPE | 276100 | 12th | 3 | 33rd |
| COTTON TWILL MTRS | 193663 | 13th | 50 | 4th |
| TAFFETA - MTRS | 142040 | 14th | 6 | 23rd |
| MEDAL RIBBON - MTRS | 123628 | 15th | 25 | 11th |
| *** | *** | *** | *** | *** |
| *** | *** | *** | *** | *** |
| *** | *** | *** | *** | *** |
| *** | *** | *** | *** | *** |
| *** | *** | *** | *** | *** |
| *** | *** | *** | *** | *** |
| *** | *** | *** | *** | *** |
| Prod. Grp N*70 | - | - | - | - |

Table 5-2 shows that out of the top six product groups identified in the Pareto chart in Figure 5-5, the first two, namely, SAT and DBL SPARKLE, have both the highest and second highest production volumes respectively, as well as the highest and second highest number of orders placed throughout the year 2014 respectively.

Therefore, these first two product groups highlighted at the top of Table 5-2 are the only two product groups whose populations will be used to determine the cycle times for various production activities.

### 5.2.3 Production routing and assembly chart

**Production routing**

Knowing the product population that will be used to determine the cycle times for various production activities, it is now necessary to establish the production routing that the population of products travels along. In Chapter I, under Section 1.2.2, it was mentioned that the production routings of various products differ in three distinct ways as follows:

- Production routing whereby the raw material is dyed first, then woven into narrow fabric;
- Production routing whereby the raw material is first woven into a narrow fabric, then dyed into a specific colour;
- Production routing whereby the raw material is dyed first, then woven into narrow fabric, and then cleaned with water.

However, the products that belong to the SAT and DBL SPARKLE groups, travel along the routing whereby the raw material is first woven into a narrow fabric and then dyed into a specific colour. As a result, this particular production routing is the most used in the weaving and dyeing department, and therefore this research focuses only on this particular routing as illustrated in Table 5-3 below.

**Table 5-3 Production routing** *(Weaving and dyeing department)*

| PRODUCTION ROUTING WEAVING AND DYEING DEPARTMENT | | | | |
|---|---|---|---|---|
| **Product Group name: SAT & DBL SPARKLE** | | | | |
| **Operation No** | **Operation description** | **Machine Name** | **Tools** | **Workstation** |
| 1 | Warp the yarns into bigger bobbins called Warps | Warping machines | - | Warping area |
| 2 | Weave Warps into narrow tapes of various width and density | Looms | Rulers, micrometer | Weaving area |
| 3 | Spool the narrow tapes into larger bobbins of tapes called Spools | Spooling machines | Electronic scale | Spooling area |
| 4 | Dye tapes from Spools into desired colour | Continuous Dye Range | - | Dyeing area |
| 5 | Roll required meters of dyed tapes | Rolling machines | Scissors, Sellotape | Rolling area |
| - | Inspection | - | - | - |
| - | Send to store | - | Trolley | - |

Furthermore, comparing the number of operations in Table 5-3 to the total seven value-added activities within the weaving and dyeing department shown in Table 5-1, it can be seen that the SAT and DBL SPARKLE products only require five value-added activities to be completed, as they travel along their designated routing.

Finally, products that fall under the SAT group follow the same production routing as products that fall under the DBL SPARKLE group, for the reason that SAT and DBL SPARKLE are very similar product groups. Besides the fact that both product groups are produced in large quantities, some even stronger similarities between them arise from the fact that they are both made out of the same type of polyester and they both have the same weaving pattern. One minor difference, however, is that the SAT products are somewhat thin and appear shiny only on one side of the tape, whereas the DBL SPARKLE products are denser and appear shiny on both sides of the tape.

**Assembly chart**

By combining the production routing shown in Table 5-3 and the list of input components that go into the manufacture of the narrow fabrics shown in Table 5-1, a graphical representation of the sequence in which each component is assembled to form the final product can be obtained in the assembly chart shown in Figure 5-6 below.

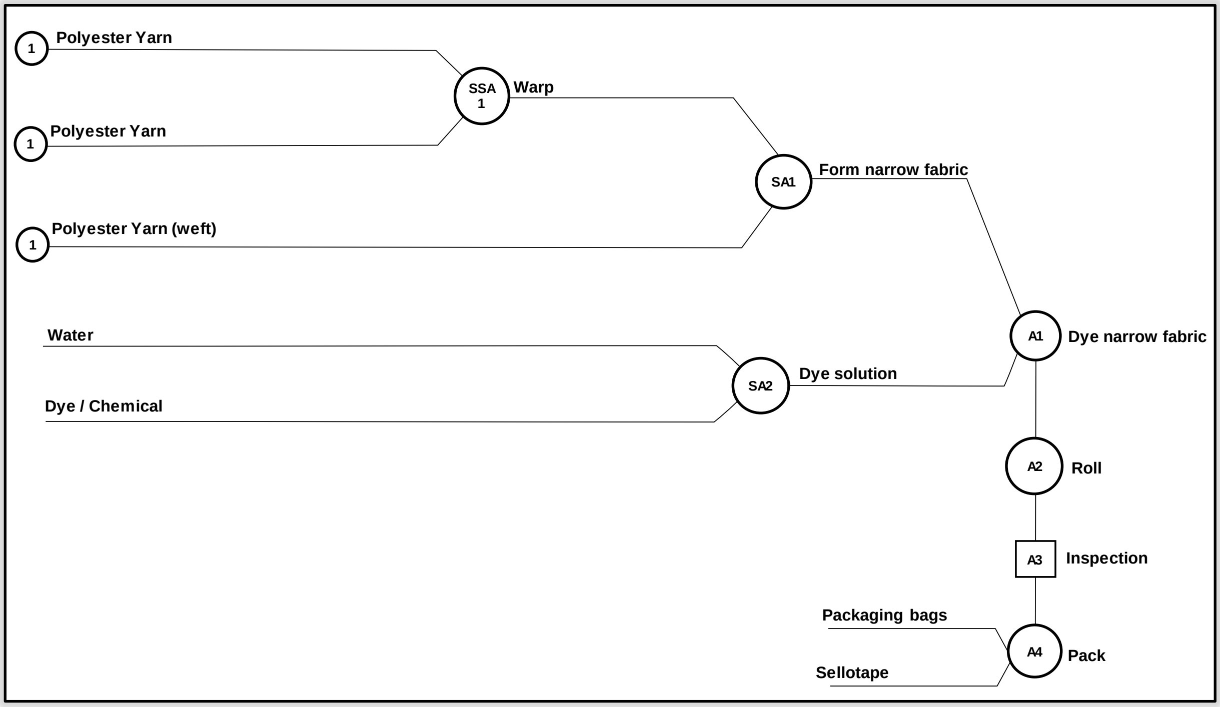



**Figure 5-6 SAT and DBL SPARKLE assembly chart**

### 5.2.4 Flow process chart

As mentioned in the research objective, the production activities' cycle times must be established to help management better estimate their MLTs. Furthermore, the MLT can be obtained by summing the total cycle time and the non-value-added activities time as mentioned in Chapter IV under Section 4.6.1. However because the non-value-added activities are not being measured in this research for reasons explained in the last bullet point of Section 3.2.12 in Chapter III, the total cycle time alone will be used to estimate the MLT.

Hence a preliminary flow process chart is established in Table 5-4 in order to set out the sequence of the flow of value-added activities and value-enabling activities, by recording all events under review using the appropriate process chart symbols.

**Table 5-4 SAT & DBL SPARKLE flow process chart**

| **FLOW PROCESS CHART** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***Activity*** | | ***Present*** | | | | |
| ***Subject charted: SAT & DBL SPARKLE*** | ***Operation:*** ○ ***Value-added*** | | ***6*** | | | | |
| | ***Transport:*** ⇨ ***Value-enabling*** | | ***10*** | | | | |
| ***Activity: Value-added & Value-enabling Activities*** | ***Delay:*** D ***Value-enabling*** | | ***10*** | | | | |
| | ***Inspection:*** □ ***Value-enabling*** | | ***1*** | | | | |
| | ***Storage:*** ▽ ***Non-value-added*** | | ***0*** | | | | |
| ***Method: Present*** | ***Total Cycle time (Hrs)*** | | | | | | |
| | ***Total Cycle time (days)*** | | | | | | |
| | ***Total Quantity:*** | | | | | | |
| ***Description*** | ***Qty (meter)*** | ***Cycle Time (min)*** | ***Symbols*** | | | | |
| | | | ○ | ⇨ | D | □ | ▽ |
| **1 Sales coordinator loads order** | | | | | 1 | | |
| **2 Take order to planner** | | | | 1 | | | |
| **3 Planner creates requisition note for yarn** | | | | | 1 | | |
| **4 Planner takes requisition to yarn store** | | | | 1 | | | |
| **5 Storeman processes requisition** | | | | | 1 | | |
| **6 Storeman takes yarn to warping area** | | | | 1 | | | |
| ***7 Warp setup*** | | | | | 1 | | |
| ***7 Warp*** | | | 1 | | | | |
| **8 Take warp to Warp rack** | | | | 1 | | | |
| ***9 Weave setup*** | | | | | 1 | | |
| ***9 Weave*** | | | 1 | | | | |
| **10 Take tapes from looms to scale** | | | | 1 | | | |
| **11 Weigh batches of tapes** | | | | | 1 | | |
| **12 Take tapes from scale to spooling area** | | | | 1 | | | |
| ***13 Spool setup*** | | | | | 1 | | |
| ***13 Spool*** | | | 1 | | | | |
| **14 Take spools from spooling to dyeing m/c** | | | | 1 | | | |
| ***15a Dyeing (dark shades) setup*** | | | | | 1 | | |
| ***15a Dyeing (dark shades)*** | | | 1 | | | | |
| ***15b Dyeing (light shades) setup*** | | | | | 1 | | |
| ***15b Dyeing (light shades)*** | | | 1 | | | | |
| **16 Take work from dyeing area to Rolling** | | | | 1 | | | |
| ***17 Rolling setup*** | | | | | 1 | | |
| ***17 Rolling*** | | | 1 | | | | |
| **18 Take work to inspection bay** | | | | 1 | | | |
| **19 Inspect** | | | | | | 1 | |
| **20 Take work to finished goods store** | | | | 1 | | | |

Table 5-4 also specifies that the dyeing activity, which was generalised under Table 5-3, is actually separated into two categories known as the dark shades dyeing and the light shades dyeing. Despite being very similar in the method and machine used, the time it takes to perform the element of each activity varies. Hence the need to keep the two activities separate.

### 5.2.5 Daily working hours

In order to perform all the production activities illustrated in Table 5-4, the weaving and dyeing department operates 5 days a week; 8.25 hours a day (day shift) at some production activities, and 19.5 hours a day (day and night shift) at other production activities as illustrated in Table 5-5 below.

**Table 5-5 Weaving and dyeing department's daily working hours**

| Activities | Working Hours | |
|---|---|---|
| | Day shift | Night shift |
| Warping | 8.25 Hours | -- |
| Weaving | 8.25 Hours | 11.25 Hours |
| Spooling | 8.25 Hours | -- |
| Dyeing | 8.25 Hours | 11.25 Hours |
| Rolling | 8.25 Hours | -- |
| Value-enabling activities | 8.25 Hours | -- |

## 5.3 Measuring performance

Since time study is used as a technique to measure the cycle time, and at the same time requires that a standard time be calculated as mentioned in Chapter IV under Section 4.3.8, all the key components of the standard time have to be measured first. These key components consist of:

- The observed time;
- The rating;
- The normal time;
- The basic time;
- The frequency of occurrence of the various job elements and;
- The allowance.

All the above components must therefore be recorded on a time study sheet as illustrated in Table 5-6 below. Table 5-6 also provides a brief explanation of the above listed components of the standard time, in the 'Remarks' box, as well as under the 'Formula' heading.

**Table 5-6 Time study sheet**

| ACTIVITY NAME: | | | | | | | | | | | | TIME STUDY SHEET No | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyst: | Hory Chikez | Resource name: | | | | | | | | Batch size: | | | | |
| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) | | | | | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run Time | Miscellaneous time |
| | | | 1 | 2 | 3 | 4 | 5 | | | | | | | |
| 1 | Measured element | R | 100% | 100% | 100% | 100% | 100% | — | — | — | 15% | — | ● | |
| | | O | — | — | — | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Estimated element | R | 100% | 100% | 100% | 100% | 100% | — | — | — | 15% | — | | ● |
| | | O | — | — | — | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | | 0.000 | Std seconds per meter | | | 1 | 1 |
| | | | | | | | | | 0.000 | Std minutes per meter | | | Total Count | |
| | | | | | | | | | 0.0 | Meters per day | | | | |

| Formula | Unit |
|---|---|
| Distribut.= distribution based on observed times | seconds |
| Dist. Of Freq.= distribution of frequency with which the element occurs over the number of cycles | count |
| BMV= (Distribut.) x (Dist. Of Freq.) | seconds |
| VRA= 15% as fixed by the company | percent |
| SMV= BMV + (15% of BMV) | std seconds |
| [Σ(SMV)]/60= standard time | std minutes |
| R= Standard rating (100% as measured by the company) | % |
| O= Observed time | seconds |
| N= Normal time [O x (100% / R)] | seconds |
| BP= Breaking point | |

Though Table 5-6 provides an overview of the time study sheet used in this research, Appendix D goes even further and illustrates the time study sheets of each production activity mentioned in the 'Description' column of Table 5-4, containing the actual values that were collected from the weaving and dyeing department.

Furthermore, of all the six key components of the standard time mentioned above, the observed time as well as the frequency of occurrence of the various job elements are in this research, considered to be the most important components needed in order to establish the cycle times in the weaving and dyeing department. Mainly because they are the only two components of the standard time that the weaving and dyeing department had no record of, they had to be obtained on the production floor, either through direct measurements or by estimation.

**Observed time**

The observed time, as mentioned in Chapter IV under Section 4.3.4, is the time taken to perform the machine elements, obtained by means of direct measurement; or the time taken to perform the estimated elements, given by the production foremen. It therefore consists of:

- The population of the measured machine element time and;
- The population of the estimated element times.

**Frequency of occurrence**

On the other hand, the frequency of occurrence of the various job elements consists of two main components which are explained under Section 5.3.3. These components are:

- The estimated number of times a given element occurs over the production period of the specific batch quantity and;
- The estimated batch quantity.

### 5.3.1 Machine element time measurement

Because the populations of the various machine element times are unknown in the weaving and dyeing department, some representative samples of those populations can be taken, from which some statistics can be calculated including the confidence intervals and confidence levels as explained in Chapter IV under Section 4.3.5.

Consequently, a sample size of $n$ = 30 was chosen for the machine element times. This means that at each of the six value-added activities illustrated in Table 5-4, a sample of the machine element times is taken which contains 30 data entries as shown in Appendix C. Based on the data recorded in the 'Run time per unit (sec)' columns of Appendix C, as well as the literature in Section 4.3.6 and Section 4.3.7 of Chapter IV, a percentage of error is calculated to see if a sample size larger than $n$ = 30 would be necessary as shown in Table 5-7 below.

**Table 5-7 Sample size and percentage of error**

| | Warping | Weaving | Spooling | Dyeing (dark) | Dyeing (light) | Rolling |
|---|---|---|---|---|---|---|
| ***Sample size, n,*** **(n = 30)** | 30 | 30 | 30 | 30 | 30 | 30 |
| ***Confidence level, C*** | 95% | 95% | 95% | 95% | 95% | 95% |
| ***Critical value @ 95%,*** $Z_c$ | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 | 1.96 |
| ***Sample mean,*** $\bar{x}$ **, (in seconds)** | **0.234** | **85.332** | **0.257** | **6.454** | **4.617** | **0.332** |
| ***Sample standard deviation, s*** **, (in seconds)** | **0.024** | **16.239** | **0.067** | **1.577** | **0.310** | **0.091** |
| ***Margin of error,*** $E = Z_c \frac{s}{\sqrt{n}}$ **, (in seconds)** | 0.008 | 5.811 | 0.024 | 0.564 | 0.111 | 0.033 |
| ***Percentage of error, H = E/s,*** **(H ≤ 10%)** | 3.63% | 6.81% | 9.33% | 8.74% | 2.41% | 9.85% |

The resulting percentages or error in estimating the mean of the populations of machine element times or run times of all six value-added activities, are all acceptable as they are all less than the 10% threshold explained in Chapter IV under Section 4.3.7. Therefore the sample size *n* = 30 can be maintained.

Additionally, the sampling technique used for the machine element times is the random sampling technique whereby each run time measurement or each machine element time measurement, were taken at random time intervals as can be seen in the 'Time of the observation' columns of Appendix C.

### 5.3.2 Estimated element time measurement

The population of the estimated element times, as previously mentioned in Chapter IV under Section 4.3.4, is obtained by asking the production foremen for an estimated value of the concerned element time. Each estimated value consists of either three inputs; namely a minimum, a most likely, and a maximum value; or two inputs, a minimum and a maximum value. The estimated inputs' values are then recorded directly onto the time study sheet as exemplified in Table 5-8 below, under the 'Elemental times' column.

**Table 5-8 Estimated element time**

| ACTIVITY NAME: | | | | | |
|---|---|---|---|---|---|
| Element No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) | | |
| | | | 1 | 2 | 3 |
| 1 | Estimated element 1 | R | 100% | 100% | 100% |
| | | O | Min | Likely | Max |
| | B.P: | N | | | |
| 2 | Estimated element 2 | R | 100% | 100% | 100% |
| | | O | Min | Max | |
| | B.P: | N | | | |

However, the actual estimated times collected from the production foremen at various production activities are illustrated in Appendix D under the 'Elemental times' column of each time study sheet.

### 5.3.3 Estimated frequency of occurrence measurement

As mentioned in Chapter IV, Section 4.3.8, under the 'Frequency' subheading, the frequency of occurrence of an element is the rate at which that element occurs during a particular job. A particular job within the weaving and dyeing department consists of performing a value-added or value-enabling activity on a specific batch quantity of either raw material units, or work-in-progress units.

Consequently, the frequency of occurrence of an element within the weaving and dyeing department is the number of times that element occurs during the production of a specific batch quantity, and is obtained in dividing the estimated number of times a job element occurs, by the estimated batch quantity of that job.

Furthermore, the estimated number of times an element occurs during a given activity, as well as the various estimated batch quantities processed during that activity, are each obtained by asking the production foremen for an estimated value. The estimation of the number of times an element occurs during a given activity consists of a single point estimate, due to the fact that its spread of variation is very small. However, the estimation of the various batch quantities processed for each activity consists of two inputs, namely a minimum and a maximum value.

The estimated inputs' values for both the estimated number of times an element occurs during a given activity, as well as the various batch quantities processed during that activity; are thus recorded directly onto the time study sheet, as shown in Figure 5-7 below.

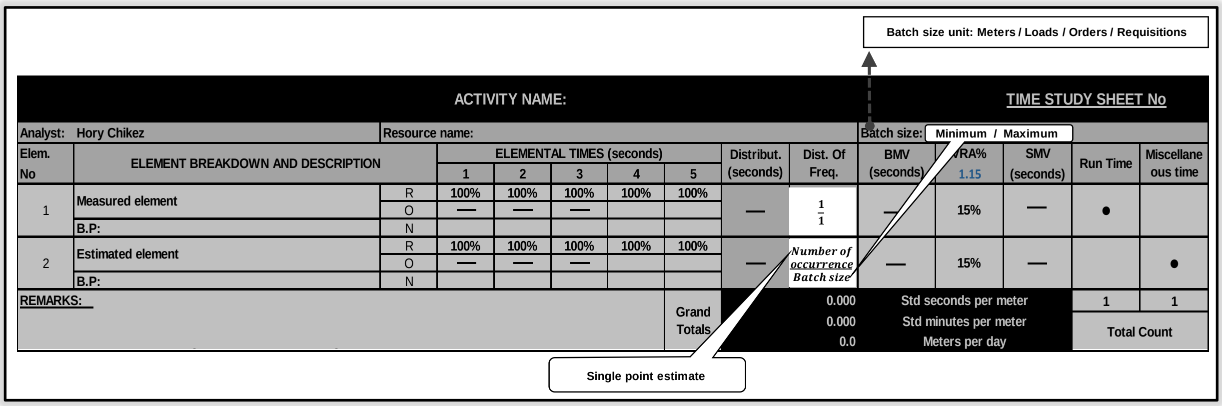



**Figure 5-7 Estimated frequency of occurrence**

It is, however, important to mention that although the frequency of occurrence of most elements is estimated as explained above, the frequency of occurrence of the repetitive element times or run time elements are not estimated; they are equal to 1 or 1/1 as explained in Chapter IV, Section 4.3.8, under the 'Frequency' subheading; and can be seen in Figure 5-7 above, as well as in the time study sheet in Appendix D.

Finally, the actual estimated batch quantity values at the all various activities of the weaving and dyeing department are all illustrated in Appendix D alongside the 'Batch size' heading of each time study sheet.

## 5.4 Analysing the measurement

As mentioned in Chapter II, under Section 2.3.3, analysing the measurements allows us to further comprehend them. Therefore, by analysing the measurements obtained in Section 5.3, a method for establishing an entire population of cycle times generated at a particular production activity can be found.

Additionally, based on the literature in Section 4.4.2 of Chapter IV, generating an entire population of the cycle times at a particular production activity can be obtained in two distinctive ways; namely, when data is available, and when data is not available.

**Available data**

When data is available, which is the case of the machine element times or run time element, the following steps are taken:

- Create a frequency histogram of the measurements obtained in Section 5.3;
- Perform a goodness-of-fit test using @risk to measure how well a hypothesised probability density function fits the sample data or measurement obtained in Section 5.3. For this purpose, five types of tests that are available in the @risk software will be used; namely, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), Chi-Square test, Kolmogorov-Smirnov test, Anderson-Darling test, and root mean squared error;
- Identify and select the probability density function that best describes the dataset with its corresponding parameters and;
- Record the selected probability density function that best describes the dataset in the 'Distribut.' column of the concerned activity's time study sheet as shown in Appendix D.

**No data**

When data were not available, which is the case of the estimated element times or miscellaneous time elements, as well as the estimated frequency of occurrence, the following steps are taken:

- Create a uniform probability distribution of the estimated element time if the estimated element time consists of only a minimum and a maximum value; or create a triangular probability distribution of the estimated element time if the estimated element time itself consists of a minimum, a most likely, and a maximum value by using @risk;

- Record the created appropriate probability distribution in the 'Distribut.' column of the concerned activity's time study sheet as shown in Appendix D.

### 5.4.1 Machine element time analysis

The analysis of the machine element times at each one of the six value-added activities shown in Appendix C, will therefore be done by following the steps listed in Section 5.4, under the 'Available data' subheading; while making use of the functionalities of the @risk software and Microsoft Excel as follows.

**Warping measurements analysis**

Creating a frequency histogram of the Warping's run time per unit shown in Appendix C, as well as fitting a number of theoretical distributions to it, is done as shown in Figure 5-8 below.

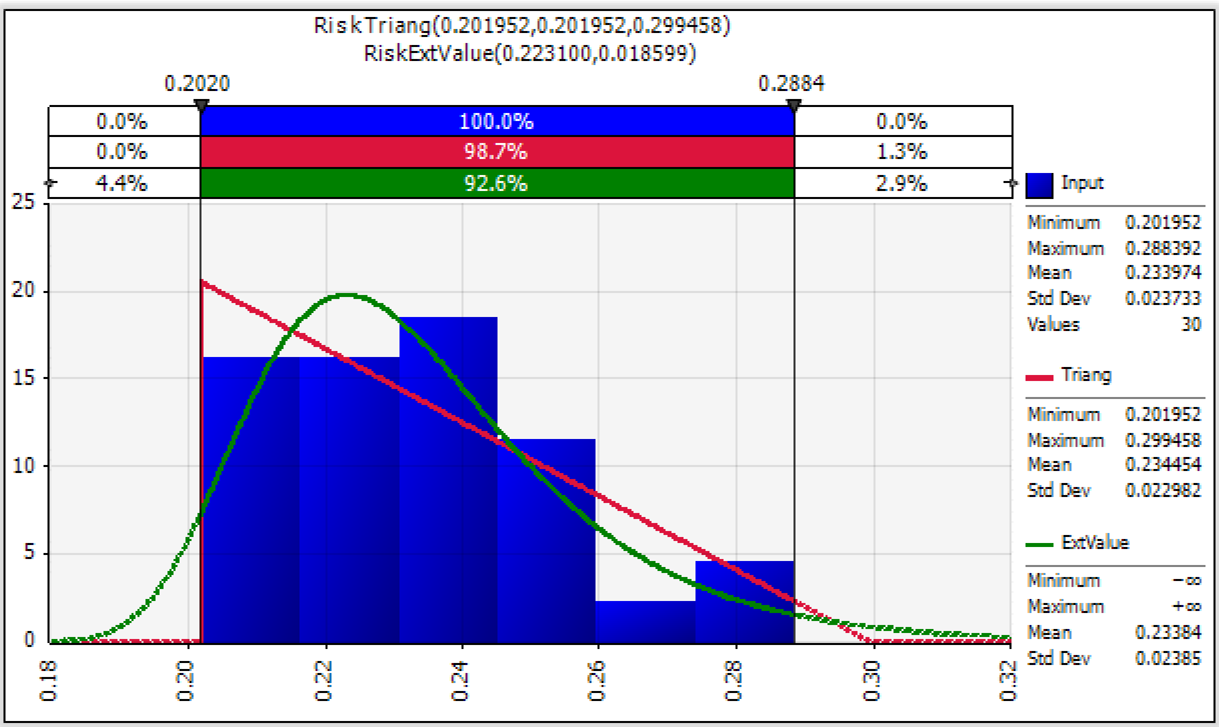



**Figure 5-8 Fitting distributions to Warping's run time per unit dataset**

From Figure 5-8 it can be seen that the blue frequency histogram represents the distribution of all 30 data entries or 100% of the Warping's run time per unit shown in

Appendix C. Also, on top of the blue histogram are two fitted probability density functions; namely, a triangular distribution (red line) labelled RiskTriang with its respective parameters, as well as an extreme value distribution (green line) labelled RiskExtValue with its respective parameters.

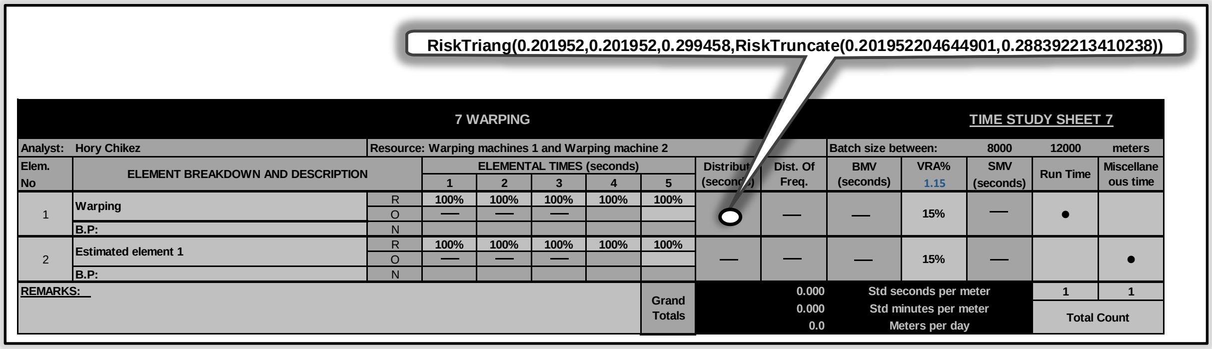
Consequently, the probability density function that is selected as best describing the dataset represented by the blue histogram, is the one that covers as close to 100% of the histogram area as possible. Therefore, because the triangular distribution (red line) covers 98.7% (red horizontal bar in Figure 5-8) of the histogram area of the Warping measurements, it is the chosen probability density function that will be used to model the Warping measurements, with the parameters:

- RiskTriang(0.201952,0.201952,0.299458) (Figure 5-8).

However in order to ensure that the chosen triangular distribution and its respective parameters model only values that fall within the range of the observed Warping's run time per unit dataset shown in Appendix C; the distribution will be truncated on the minimum and the maximum entries of the Warping's run time per unit dataset, hence becoming:

- RiskTriang(0.201952,0.201952,0.299458,RiskTruncate(0.201952204644901,0.288392213410238))

This truncated distribution is subsequently recorded in the 'Distribut.' column of the Warping time study sheet in Appendix D as shown in Figure 5-9 below.




| 7 WARPING | | | | | | | | | | | | | TIME STUDY SHEET 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyst: | Hory Chikez | Resource: Warping machines 1 and Warping machine 2 | | | | | | | | Batch size between: | | 8000 | 12000 | meters |
| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run Time | Miscellaneous time |
| 1 | Warping | R | 100% | 100% | 100% | 100% | 100% | ○ | — | — | 15% | — | ● | |
| | | O | — | — | — | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Estimated element 1 | R | 100% | 100% | 100% | 100% | 100% | — | — | — | 15% | — | | ● |
| | | O | — | — | — | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | | 0.000 | Std seconds per meter | | | 1 | 1 |
| | | | | | | | | | 0.000 | Std minutes per meter | | | Total Count | |
| | | | | | | | | | 0.0 | Meters per day | | | | |

**Figure 5-9 Distribution of the machine element time of Warping activity**

Finally, the analysis of the Warping measurements as done above, will be performed in the same manner for the machine element times of the remaining value-added activities shown in Appendix C.

Therefore, the analysis of the machine element times of the remaining value-added activities will not be explained in detail again as for the Warping measurements, but will simply consist of:

- Producing a figure such as Figure 5-8 showing various probability density functions being fitted to the concerned activity's measurements and;
- Mentioning the name of the probability density function that best describes the concerned data, with its respective parameters and;
- Writing the truncated expression of the chosen probability density function as recorded in the 'Distribut.' column of the concerned activity's time study sheet in Appendix D.

**Weaving measurements analysis**

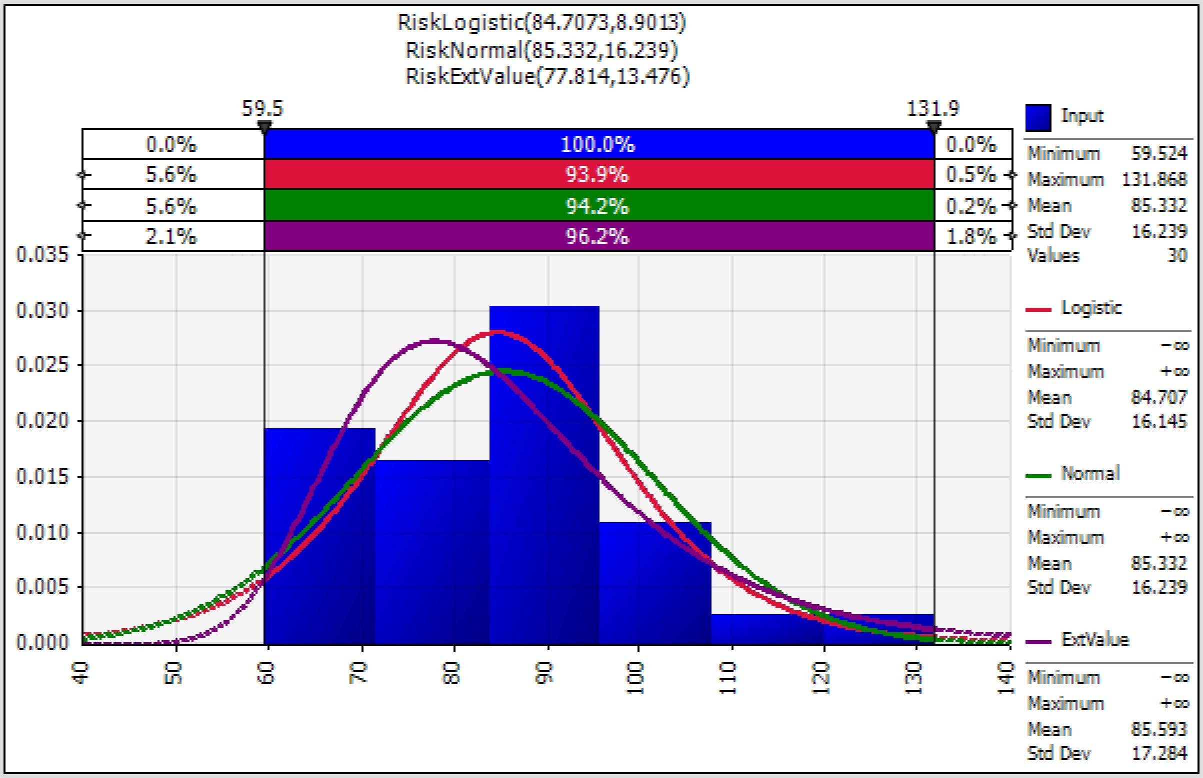



**Figure 5-10 Fitting distributions to Weaving's run time per unit dataset**

Because the extreme value distribution (purple line) covers 96.2% (purple horizontal bar in Figure 5-10) of the Weaving measurements; it is the chosen probability density function that will be used to model the Weaving measurements, with the parameters:

- RiskExtvalue(77.814,13.476)

However, in order to ensure that the chosen extreme value distribution and its respective parameters model only values that fall within the range of the observed Weaving's run time per unit dataset shown in Appendix C, the distribution will be truncated on the minimum and the maximum entries of the Weaving's run time per unit dataset, hence becoming:

- RiskExtvalue(77.814,13.476,RiskTruncate(59.5238095238095,131.868131868132))

This truncated distribution is subsequently recorded in the 'Distribut.' column of the Weaving time study sheet in Appendix D.

**Spooling measurements analysis**

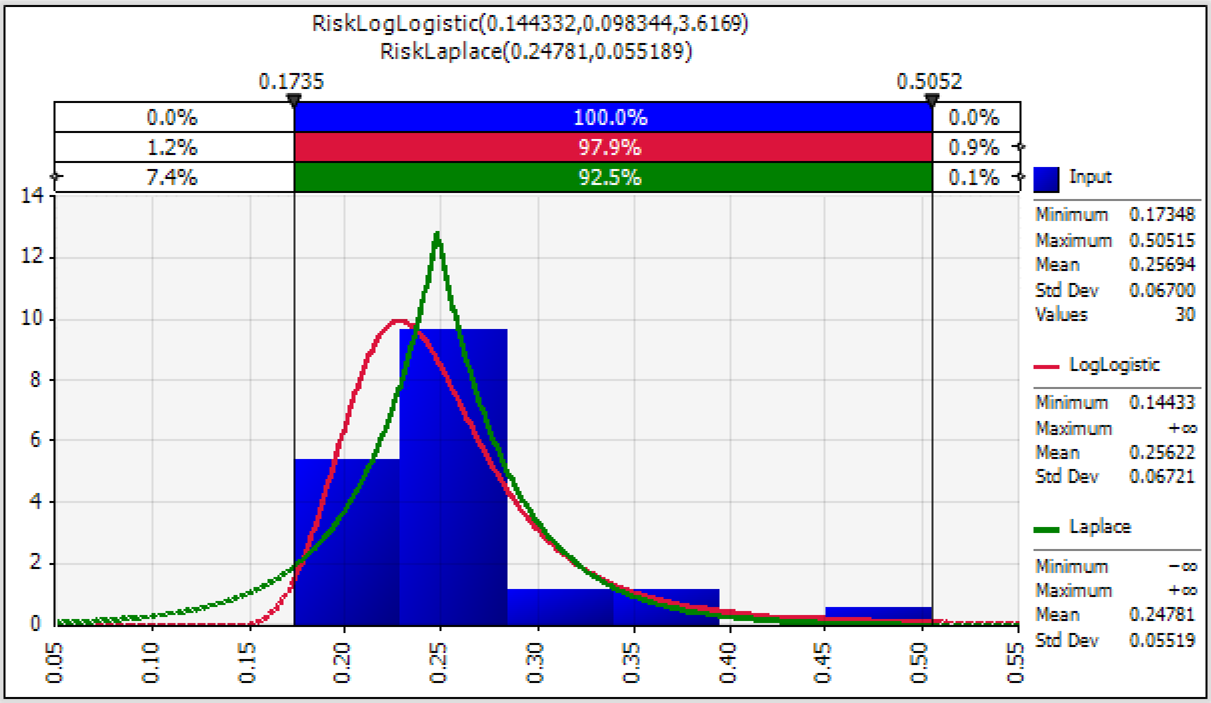



**Figure 5-11 Fitting distributions to Spooling's run time per unit dataset**

Because the LogLogistic distribution (red line) covers 97.9% (red horizontal bar in Figure 5-11) of the Spooling measurements, it is the chosen probability density function that will be used to model the Spooling measurements, with the parameters:

- RiskLoglogistic(0.144332,0.098344,3.6169)

However in order to ensure that the chosen LogLogistic distribution and its respective parameters model only values that fall within the range of the observed Spooling's run time per unit dataset shown in Appendix C; the distribution will be truncated on the minimum and the maximum entries of the Spooling's run time per unit dataset, hence becoming:

- RiskLoglogistic(0.144332,0.098344,3.6169,RiskTruncate(0.173475583311649,0.505152556071934))

This truncated distribution is subsequently recorded in the 'Distribut.' Column of the Spooling time study sheet in Appendix D.

**Dark dyeing measurements analysis**

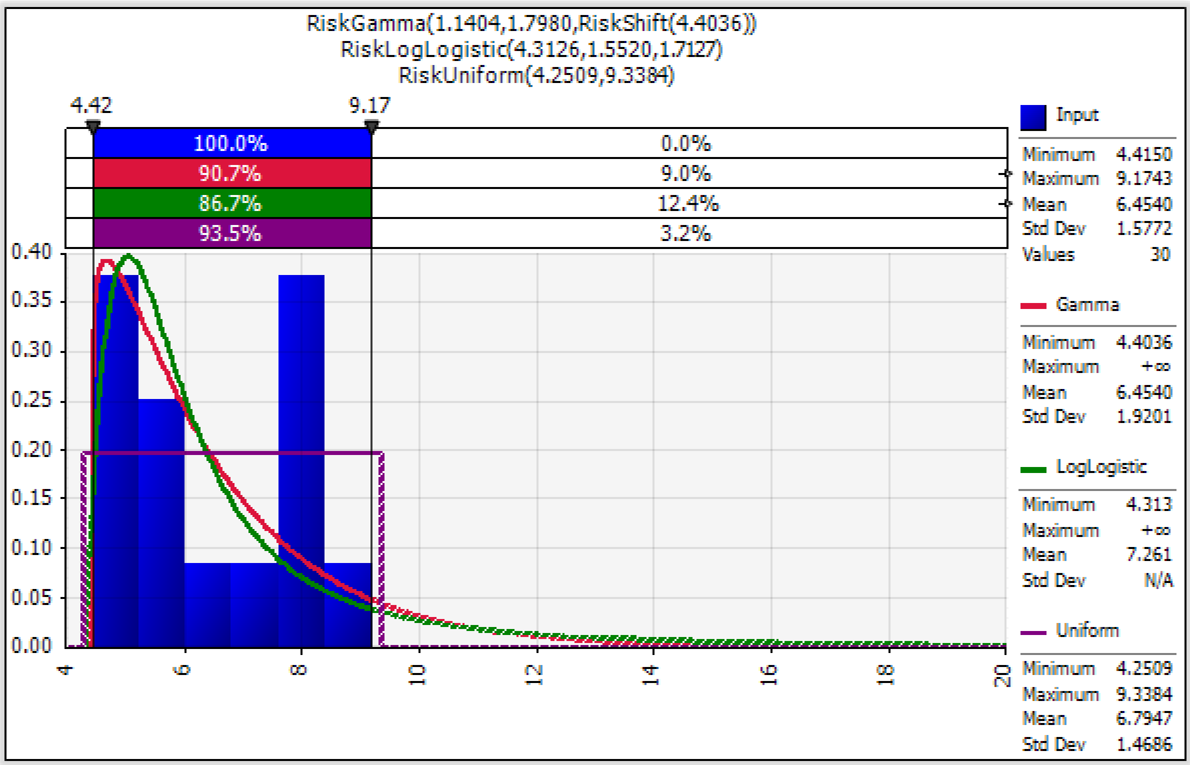



**Figure 5-12 Fitting distributions to Dark dyeing's run time per unit dataset**

Because the uniform distribution (purple line) covers 93.5% (purple horizontal bar in Figure 5-12) of the Dark dyeing measurements, it is the chosen probability density function that will be used to model the Dark dyeing measurements, with the parameters:

- RiskUniform(4.2509,9.3384)

However, in order to ensure that the chosen uniform distribution and its respective parameters model only values that fall within the range of the observed Dark dyeing's run time per unit dataset shown in Appendix C, the distribution will be truncated on the minimum and the maximum entries of the Dark dyeing's run time per unit dataset, hence becoming:

- RiskUniform(4.2509,9.3384,RiskTruncate(4.41501103752759,9.1743119266055))

This truncated distribution is subsequently recorded in the 'Distribut.' Column of the Dark dyeing time study sheet in Appendix D.

**Light dyeing measurements analysis**

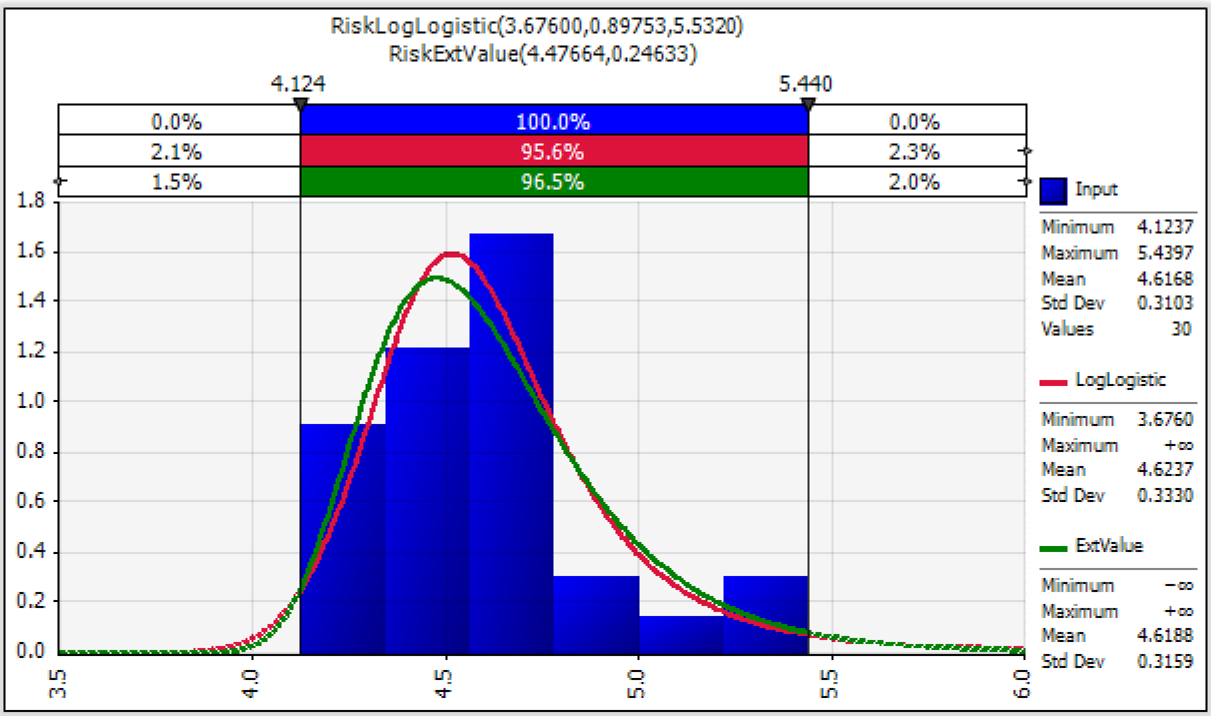



**Figure 5-13 Fitting distributions to Light dyeing's run time per unit dataset**

Because the extreme value distribution (green line) covers 96.5% (green horizontal bar in Figure 5-13) of the Light dyeing measurements, it is the chosen probability density function that will be used to model the Light dyeing measurements, with the parameters:

- RiskExtvalue(4.47664,0.24633)

However in order to ensure that the chosen extreme value distribution and its respective parameters, model only values that fall within the range of the observed Light dyeing's run time per unit dataset shown in Appendix C, the distribution will be truncated on the minimum and the maximum entries of the Light dyeing's run time per unit dataset, hence becoming:

- RiskExtvalue(4.47664,0.24633,RiskTruncate(4.12371134020619,5.43970988213962))

This truncated distribution is subsequently recorded in the 'Distribut.' Column of the Light dyeing time study sheet in Appendix D.

**Rolling dyeing measurements analysis**

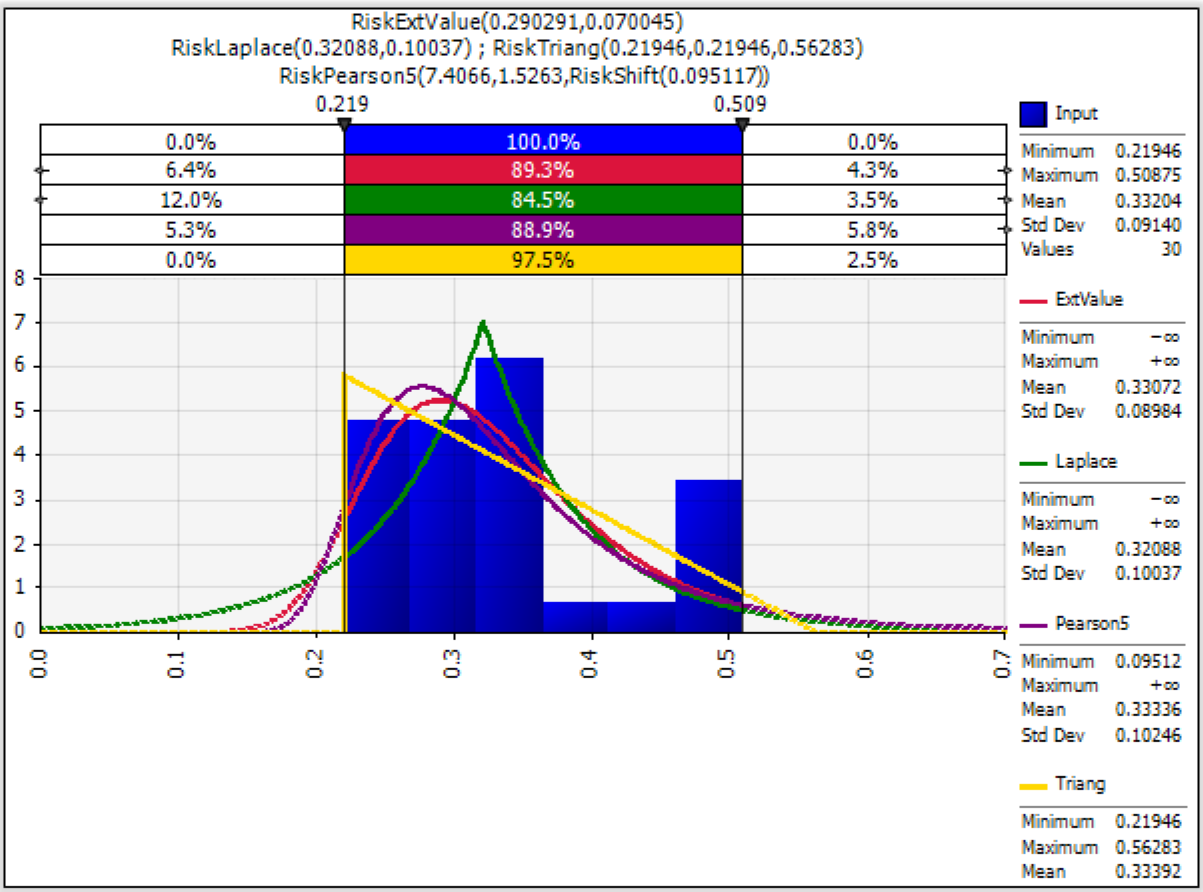



**Figure 5-14 Fitting distributions to Rolling's run time per unit dataset**

Because the triangular distribution (yellow line) covers 97.5% (yellow horizontal bar in Figure 5-14) of the Rolling measurements, it is the chosen probability density function that will be used to model the Rolling measurements, with the parameters:

- RiskTriang(0.21946,0.21946,0.56283)

However in order to ensure that the chosen triangular distribution and its respective parameters model only values that fall within the range of the observed Rolling's run time per unit dataset shown in Appendix C, the distribution will be truncated on the minimum and the maximum entries of the Rolling's run time per unit dataset, hence becoming:

- RiskTriang(0.21946,0.21946,0.56283,RiskTruncate(0.21945866861741,0.508754822571756))

This truncated distribution is subsequently recorded in the 'Distribut.' Column of the Rolling time study sheet in Appendix D.

### 5.4.2 Estimated element time analysis

In Section 5.3.2, it was mentioned that each estimated element time value consists of either a minimum, a most likely, and a maximum value; or a minimum and a maximum value. It was further specified that these estimated values would then be recorded in the 'Elemental times' column of each one of the activities time study sheet shown in Appendix C.

Therefore the first step in analysing the estimated element time, as mentioned in Section 5.4, under the 'No data' subheading, is to create either a triangular probability distribution or a uniform probability distribution depending on whether the recorded data consisted of a minimum, a most likely, and a maximum value; or a minimum and a maximum value only.

However, in order to ensure that the created triangular distribution or uniform distribution and its respective parameters, model only values that fall within the range of the estimated element time values, the distribution will be truncated on the minimum and the maximum entries of the respective element time values.

### Triangular distribution

When the estimated element times consist of a minimum, a most likely, and a maximum value, then the triangular probability distribution of that estimated element time would be created using capabilities of @risk, and recorded in the 'Distribut.' column of the appropriate activity's time study sheet in Appendix D as shown in Figure 5-15 below.

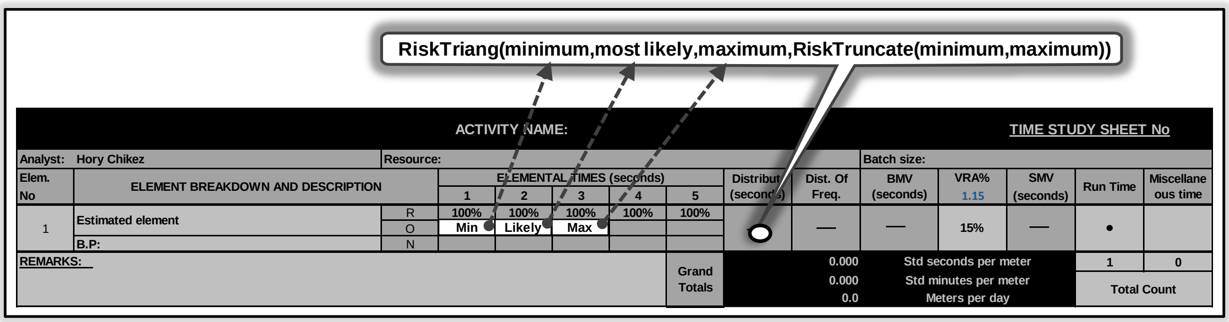



**Figure 5-15 Triangular probability distribution of estimated element time**

### Uniform distribution

When the estimated element times consist of a minimum and a maximum value only, then the uniform probability distribution of that estimated element would be created using capabilities of @risk and recorded in the 'Distribut.' column of the appropriate activity's time study sheet in Appendix D as depicted in the Figure 5-16 below.

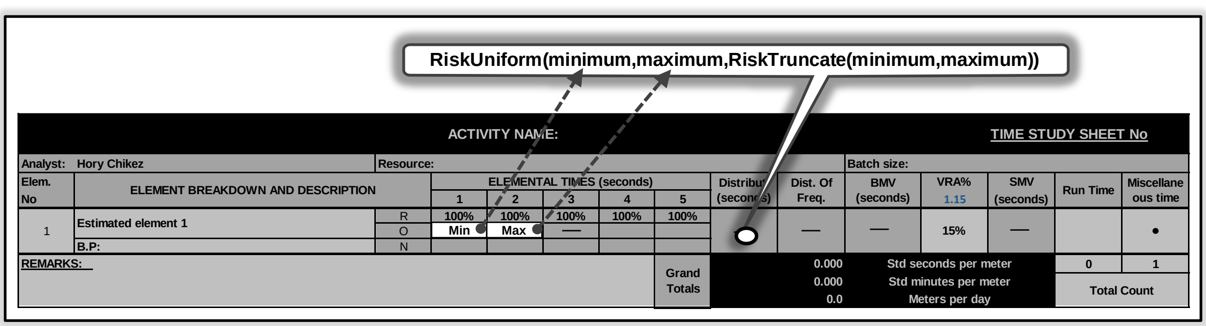



**Figure 5-16 Uniform probability distribution of estimated element time**

### 5.4.3 Estimated frequency of occurrence analysis

In Section 5.3.3, it was mentioned that the estimated frequency of occurrence is obtained by dividing the estimated number of times a job element occurs, by the estimated batch quantity of that given job. Section 5.3.3 further mentioned that both the estimated number of times an element occurs at a given activity, as well as the various batch quantities processed at that activity, are obtained by asking the production foremen for estimated values. While the former requires a single point estimate, the latter makes use of an estimated minimum and maximum value.

Therefore, in order to analyse the estimated frequency of occurrence, a single point estimate representing the number of times a job element occurs in a specific activity, is recorded as the numerator. Then, a uniform probability distribution is created for the various batch quantities processed at the same activity, and is recorded as the denominator.

However, it is important to recall that the distribution of the frequency of occurrence of each element is classified as discrete since it consists of the number of times an element occurs, which is a countable infinite set of outcomes as explained in Chapter IV, under Section 4.4.2. Hence, following the same train of thought, the uniform probability distribution of the batch quantities processed at that activity must also be discrete.

Consequently, using the capabilities of @risk, a discrete uniform distribution is created in the form of RiskIntUniform(minimum,maximum) and recorded as a denominator in the 'Dist. Of freq.' column of the various activities time study sheets, as shown in Figure 5-17 below, and for which the actual results are shown in Appendix D.

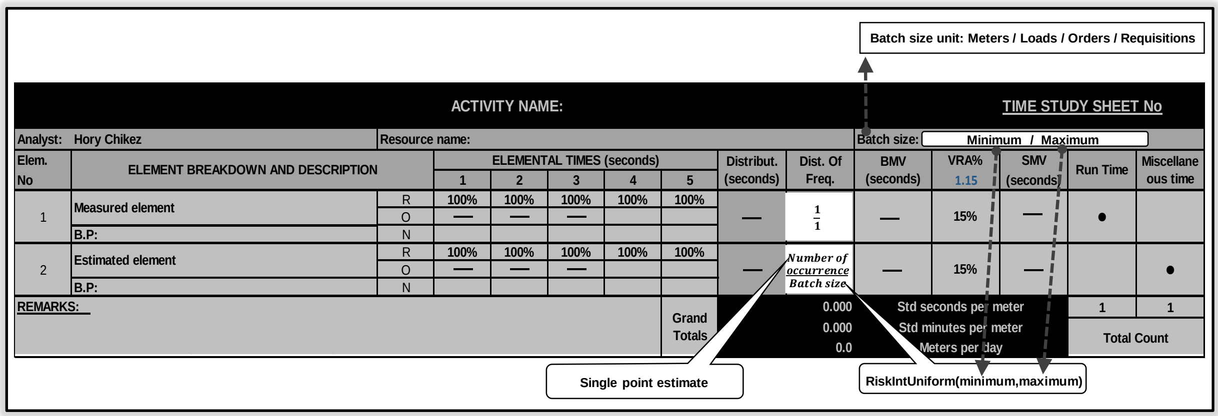



**Figure 5-17 Estimated frequency of occurrence**

## 5.5 Improving method

Now that all measurements have been analysed, and the appropriate probability distributions of the observed times as well as that of the frequency of occurrence have been identified, the improvement phase will consist of establishing the standard times at each production activity of the weaving and dyeing department.

The standard time at each production activity is established by making use of the Monte Carlo simulation, which as mentioned in Chapter IV, under Section 4.4.1, consists of calculating numerous scenarios of a model by repeatedly picking values from the predefined probability distribution.

However, because the objective of this research is to establish cycle times for the production activities of the weaving and dyeing department, so as to help management better estimate the Manufacturing Lead Times (MLTs), decent capacity commitments are also vital as mentioned in Chapter IV, under Section 4.6.1.

Hence, in addition to calculating the standard times in 'Std minutes per unit'; the improvement phase will also consist of establishing daily production capacities in 'units per day', which as mentioned in Chapter IV, under Section 4.6.1 is the reciprocal of the standard times, and its population is also generated via the Monte Carlo simulation.

Consequently, to run the Monte Carlo simulation by making use of the @risk software and Microsoft Excel, as mentioned in Chapter IV, under Section 4.5, the following steps are performed

- Opening an individual activity's time study sheet one at a time;
- Highlighting cells in which a probability distribution has been inserted;
- Defining output forecasts in the cell adjacent to the 'Std minutes per units' cell, as well as the cell adjacent to the 'units per day' cell, found in the time study sheets;
- Running a simulation of 100 000 iterations for each time study;
- Interpreting the results.

After following the above steps, and simulating the standard minutes per unit, as well as the number of units per day of each activity's time study shown in Appendix D, the population of standard minutes per unit is established at each activity as shown in Appendix E. The population of the number of units producible per day, at each activity, is established as shown in Appendix F.

It is, however, important to mention that the populations of the number of units producible per day, otherwise referred to as the calculated daily production capacity shown in Appendix F, is established with the assumption that all resources operate at a 100% utilisation. Consequently, should the resource utilisation at a given activity decrease, so would the calculated daily capacity or number of units producible per day at that particular activity and vice versa.

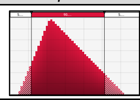
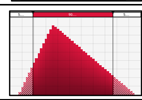
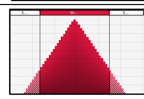
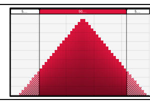
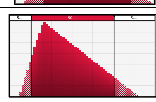
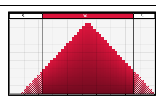
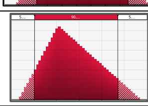
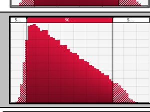
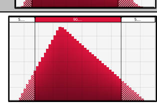
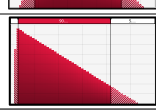
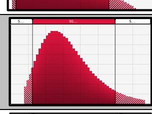
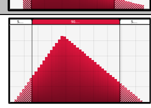
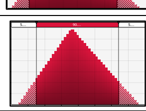
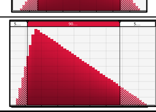
Furthermore, the populations of the standard minutes per unit, can be recorded in a flow process chart alongside their respective production activities, as shown in Table 5-9, in order to visualise the distribution of standard times of each production activity.

## Table 5-9 Flow process chart with standard time population

Continued

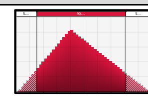
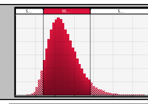
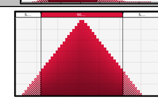
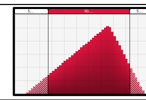
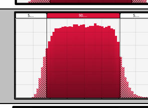
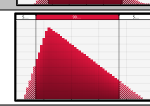
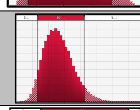
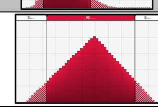
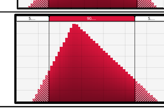
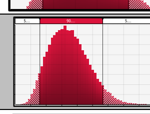
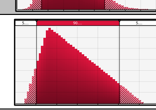
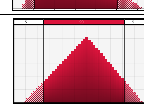
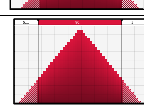
**FLOW PROCESS CHART (Activity 1 to Activity 12)**

| | Activity | | Present |
|---|---|---|---|
| *Subject charted: SAT & DBL SPARKLE* | *Operation:* | ◯ *Value-added* | *2* |
| | *Transport:* | ⇨ *Value-enabling* | *6* |
| *Activity: Value-added & Value-enabling Activities* | *Delay:* | D *Value-enabling* | *6* |
| | *Inspection:* | ☐ *Value-enabling* | *0* |
| | *Storage:* | ▽ *Non-value-added* | *0* |

| Description | Standard min. per unit distribution | ◯ | ⇨ | D | ☐ | ▽ |
|---|---|---|---|---|---|---|
| 1 Sales coordinator loads order |  | | | 1 | | |
| 2 Take order to planner |  | | 1 | | | |
| 3 Planner creates requisition note for yarn |  | | | 1 | | |
| 4 Planner takes requisition to yarn store |  | | 1 | | | |
| 5 Storeman processes requisition |  | | | 1 | | |
| 6 Storeman takes yarn to warping area |  | | 1 | | | |
| 7 Warp setup |  | | | 1 | | |
| ***7 Warp*** |  | 1 | | | | |
| 8 Take warp to Warp rack |  | | 1 | | | |
| 9 Weave setup |  | | | 1 | | |
| ***9 Weave*** |  | 1 | | | | |
| 10 Take tapes from looms to scale |  | | 1 | | | |
| 11 Weigh batches of tapes |  | | | 1 | | |
| 12 Take tapes from scale to spooling area |  | | 1 | | | |

**FLOW PROCESS CHART (Activity 13 to Activity 20)**

| | Activity | | Present |
|---|---|---|---|
| *Subject charted: SAT & DBL SPARKLE* | *Operation:* | ◯ *Value-added* | *4* |
| | *Transport:* | ⇨ *Value-enabling* | *4* |
| *Activity: Value-added & Value-enabling Activities* | *Delay:* | D *Value-enabling* | *4* |
| | *Inspection:* | ☐ *Value-enabling* | *1* |
| | *Storage:* | ▽ *Non-value-added* | *0* |

| Description | Standard time distribution | ◯ | ⇨ | D | ☐ | ▽ |
|---|---|---|---|---|---|---|
| 13 Spool setup |  | | | 1 | | |
| ***13 Spool*** |  | 1 | | | | |
| 14 Take spools from spooling to dyeing m/c |  | | 1 | | | |
| 15a Dyeing (dark shades) setup |  | | | 1 | | |
| ***15a Dyeing (dark shades)*** |  | 1 | | | | |
| 15b Dyeing (light shades) setup |  | | | 1 | | |
| ***15b Dyeing (light shades)*** |  | 1 | | | | |
| 16 Take work from dyeing area to Rolling |  | | 1 | | | |
| 17 Rolling setup |  | | | 1 | | |
| ***17 Rolling*** |  | 1 | | | | |
| 18 Take work to inspection bay |  | | 1 | | | |
| 19 Inspect |  | | | | 1 | |
| 20 Take work to finished goods store |  | | 1 | | | |

As can be seen in Table 5-9, the standard times of all value-enabling activities follow a triangular distribution, by virtue of the fact that their respective job elements were estimated using a triangular distribution. On the other hand, the standard times of the value-added activities follow a distribution based on the sum of:

- The distribution of their respective measured element times, plus;
- The distribution of their respective estimated element times.

## 5.6 Validity of results

In order to ensure that the calculated population of the standard times shown in Appendix E is representative of the actual standard times at various production activities of the weaving and dyeing department; a comparison is made between the calculated daily capacity or calculated number of units producible per day at a given value-added activity shown in Appendix F, and the actual quantity of units produced per day at that particular value-added activity illustrated in Appendix G (values randomly selected).

By doing so, an ecological validity which according to *Welman et al (2005, p. 127)* is used to generalise the results obtained in a specific laboratory situation to all real-life situations in which such behaviour is manifested, will be established for the calculated number of units producible per day at a given value-added activity.

Therefore, the ecological validity as illustrated in Figure 5-18, Figure 5-19, Figure 5-20, Figure 5-21, Figure 5-22 and Figure 5-23 is established only for the value-added activities and not for the value-enabling activities. This is mainly due to the fact that the workload at the value-enabling activities is generally relatively smaller than the one at the value-added activities, as far as the processing of a particular order is concerned.

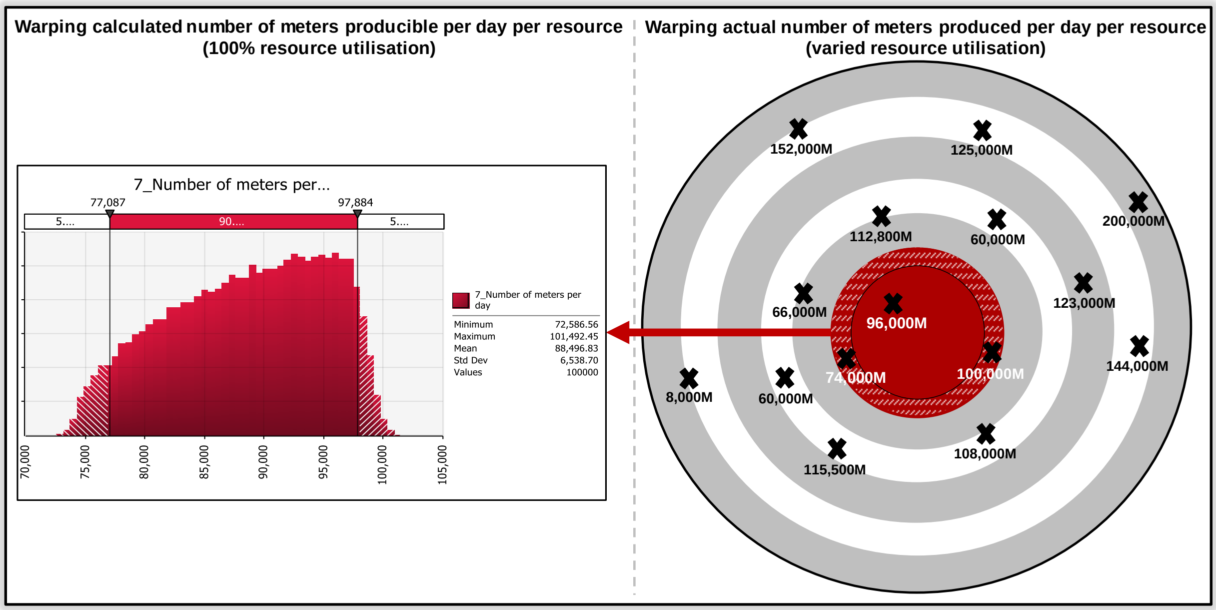



**Figure 5-18 Warping validity**

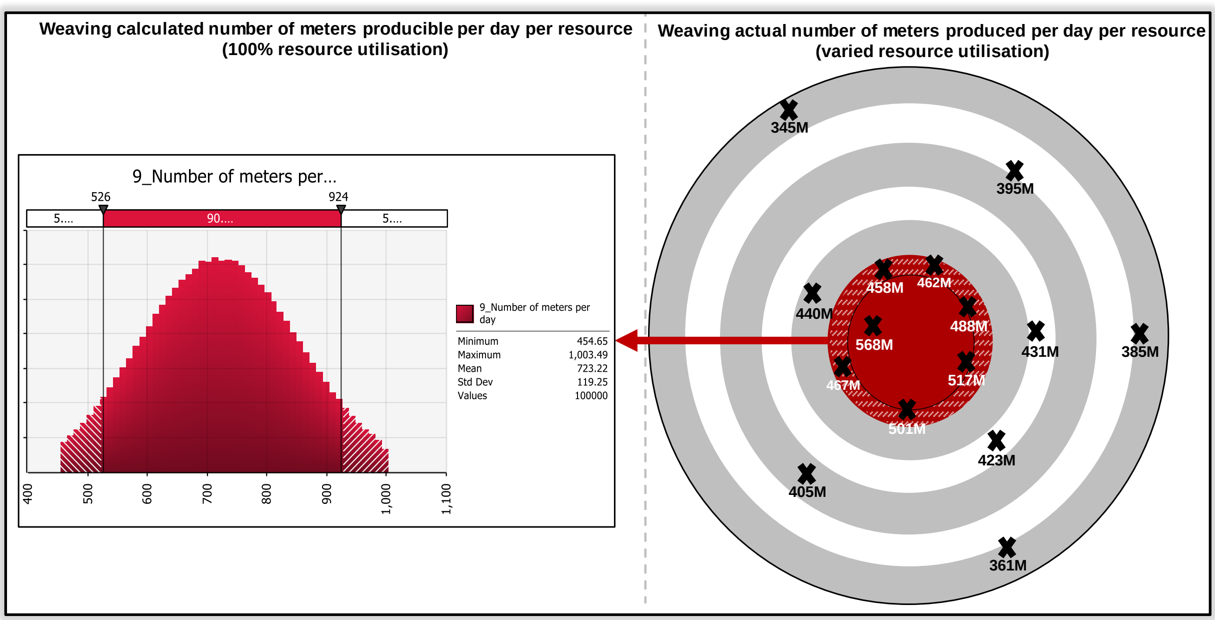



**Figure 5-19 Weaving validity**

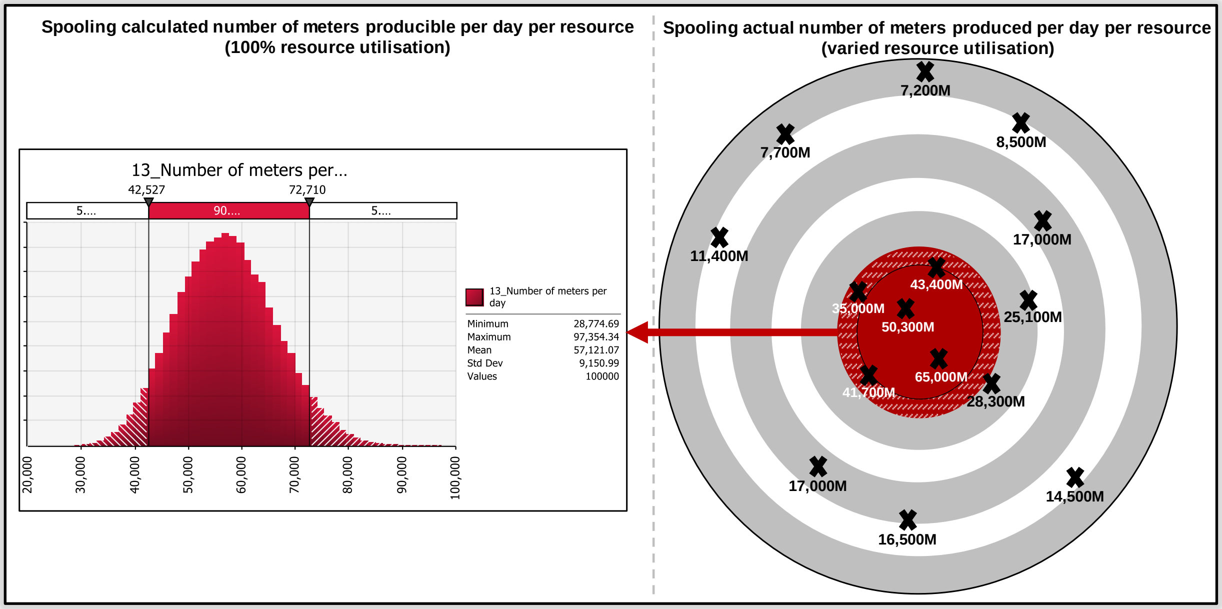



**Figure 5-20 Spooling validity**

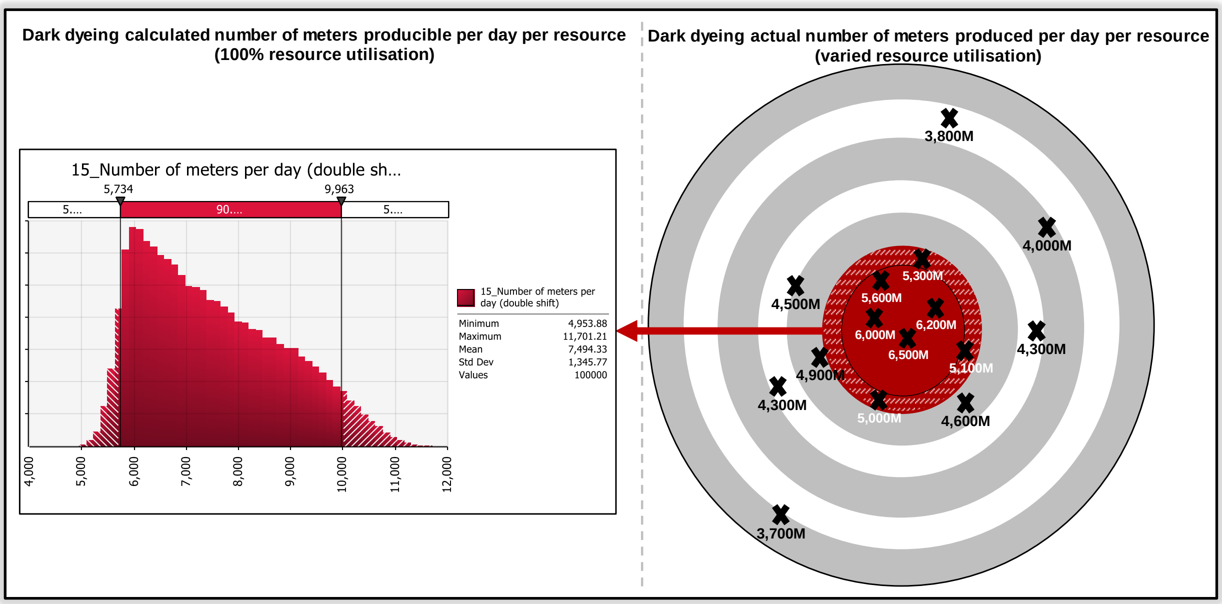



**Figure 5-21 Dark dyeing validity**

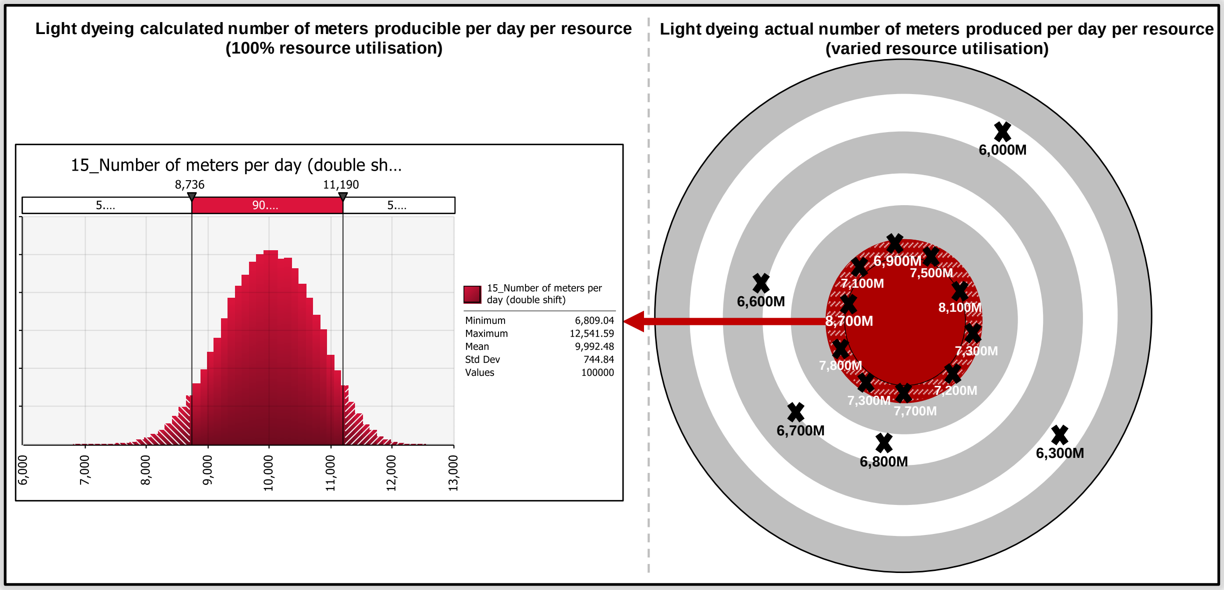



**Figure 5-22 Light dyeing validity**

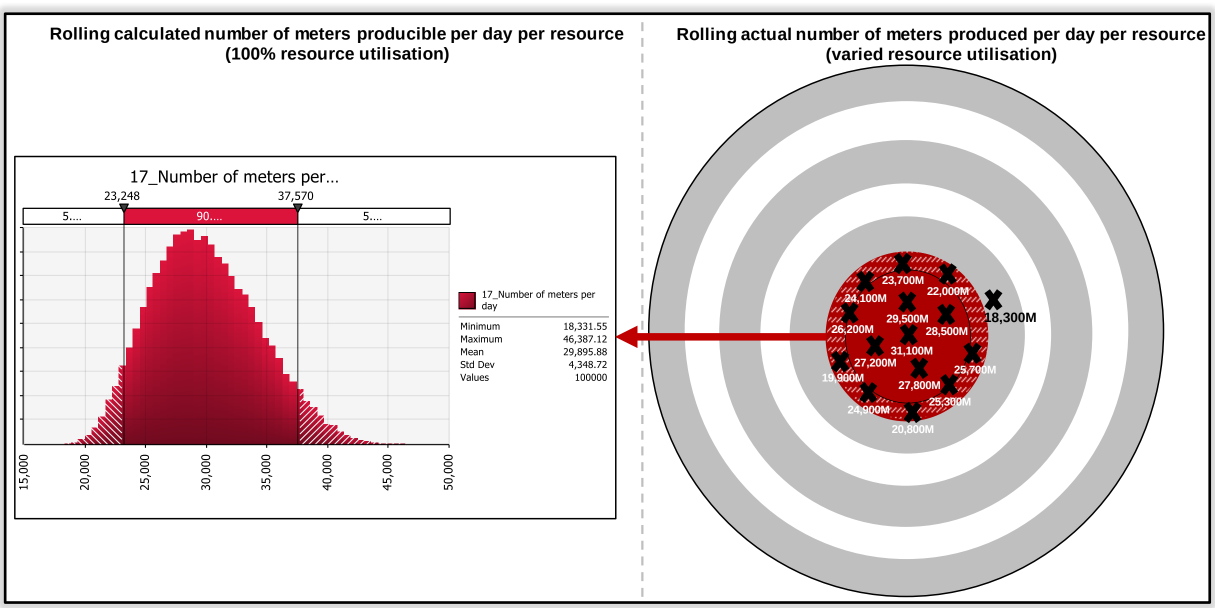



**Figure 5-23 Rolling validity**

Figure 5-18, Figure 5-19, Figure 5-20, Figure 5-21, Figure 5-22 and Figure 5-23 also show that the calculated daily capacity at the various value-added activities is valid but sometimes unreliable.

The calculated daily capacity is valid because, at each value-added activity, there are some values obtained from the actual number of units produced per day, and highlighted in grey in Appendix G, that fall inside the red central region representing the calculated daily capacity of the respective activity. The values of the actual number of units produced per day are however not represented to scale, as the focus is to rather look at how many values fall within the red central region versus how many values do not.

On the other hand, the reliability of the calculated daily capacity was assessed by asking the operator working at a particular value-added activity, to provide a comment next to each actual number of units produced per day that does not fall inside the red central region representing the calculated daily capacity. As shown in Appendix G, the comment aimed at specifying whether the recorded actual daily output was achieved through working overtime, or through working at low utilisation. It was then noticed that the actual number of units produced per day that fall outside the red central region, were achieved either when the resource is overutilised (overtime) or underutilised (low utilisation).

## 5.7 Controlling the improvement

As mentioned in Chapter II, under Section 2.3.5, the establishment of production cycle times in an environment where the production cycle times are non-existent, constitutes a considerable improvement. However, this improvement has to be managed, so as to help the weaving and dyeing department managers better estimate and control their MLTs.

Therefore, knowing from Chapter IV, under Section 4.6.1 that the MLT can be obtained by summing the total cycle time and the non-value-added activities time, a spreadsheet aiming at calculating the total cycle time is developed in a detailed flow process chart format as shown in Table 5-10 below.

## Table 5-10 Cycle time control sheet

**FLOW PROCESS CHART**

| | Activity | | Present |
|---|---|---|---|
| *Subject charted: SAT & DBL SPARKLE* | *Operation:* ○ | *Value-added* | *6* |
| | *Transport:* ⇨ | *Value-enabling* | *10* |
| *Activity: Value-added & Value-enabling Activities* | *Delay:* D | *Value-enabling* | *10* |
| | *Inspection:* □ | *Value-enabling* | *1* |
| | *Storage:* ▽ | *Non-value-added* | *0* |
| *Method: Present* | | | |

| | 5th perc. | mean | 95th perc. |
|---|---|---|---|
| *8. Total cycle time. (standard hours)* | *3* | *3* | *4* |
| *8. Total cycle time. (days)* | *0* | *0* | *0* |

| *Description* | *1. Unit.* | *2. Unit quantity input field. (variable)* | *3. Maximum available resources. (variable)* | *4. Calculated standard time. (std min/unit)* | | | *5. Standard time relative to the unit quantity. (std min)* | | | *6. Average daily utilisation of resources. (variable)* | *7. Daily working hours left given (5) and (6). (min)* | | | *Symbols* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *5th perc.* | *mean* | *95th perc.* | *5th perc.* | *mean* | *95th perc.* | | *5th perc.* | *mean* | *95th perc.* | ○ | ⇨ | D | □ | ▽ |
| 1 Sales coordinator loads order | Number of orders | | 2 | 4.15 | 5.94 | 8.12 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| 2 Take order to planner | Number of orders | | 1 | 1.46 | 2.97 | 4.83 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 3 Planner creates requisition note for yarn | Number of requisitions | | 1 | 2.66 | 3.45 | 4.24 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| 4 Planner takes requisition to yarn store | Number of requisitions | | 1 | 1.51 | 2.30 | 3.09 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 5 Storeman processes requisition | Number of requisitions | | 1 | 2.01 | 2.88 | 4.03 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| 6 Storeman takes yarn to warping area | Number of loads | | 1 | 7.63 | 9.20 | 10.77 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 7 Warp setup | Number of setups | | 1 | 102.00 | 270.25 | 471.00 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| *7 Warp* | Number of meters | *70000* | 2 | 0.01 | 0.01 | 0.01 | 177 | 197 | 225 | 38% | 11 | -9 | -37 | 1 | | | | |
| 8 Take warp to Warp rack | Number of warps | | 2 | 1.95 | 2.49 | 3.14 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 9 Weave setup | Number of setups | | 1 | 149.00 | 941.72 | 2081.00 | 0 | 0 | 0 | 100% | 1155 | 1155 | 1155 | | | 1 | | |
| *9 Weave* | Number of meters | | 432 | 1.25 | 1.64 | 2.20 | 0 | 0 | 0 | 60% | 693 | 693 | 693 | 1 | | | | |
| 10 Take tapes from looms to scale | Number of loads | | 1 | 3.56 | 6.52 | 9.87 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 11 Weigh batches of tapes | Number of loads | | 1 | 5.01 | 9.78 | 14.84 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| 12 Take tapes from scale to spooling area | Number of loads | | 1 | 2.07 | 3.26 | 4.92 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 13 Spool setup | Number of setups | | 1 | 0.21 | 0.24 | 0.27 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| *13 Spool* | Number of meters | | 5 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 64% | 317 | 317 | 317 | 1 | | | | |
| 14 Take spools from spooling to dyeing m/c | Number of loads | | 1 | 1.61 | 2.59 | 3.57 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 15a Dyeing (dark shades) setup | Number of setups | | 1 | 7.42 | 14.69 | 20.65 | 0 | 0 | 0 | 100% | 1155 | 1155 | 1155 | | | 1 | | |
| *15a Dyeing (dark shades)* | Number of meters | | 6 | 0.12 | 0.16 | 0.20 | 0 | 0 | 0 | 61% | 705 | 705 | 705 | 1 | | | | |
| 15b Dyeing (light shades) setup | Number of setups | | 1 | 3.53 | 10.03 | 18.68 | 0 | 0 | 0 | 100% | 1155 | 1155 | 1155 | | | 1 | | |
| *15b Dyeing (light shades)* | Number of meters | | 6 | 0.10 | 0.12 | 0.13 | 0 | 0 | 0 | 64% | 739 | 739 | 739 | 1 | | | | |
| 16 Take work from dyeing area to Rolling | Number of loads | | 1 | 3.32 | 6.71 | 10.00 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 17 rolling setup | Number of setups | | 1 | 0.32 | 0.42 | 0.52 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | 1 | | |
| *17 Rolling* | Number of meters | | 3 | 0.01 | 0.02 | 0.02 | 0 | 0 | 0 | 46% | 228 | 228 | 228 | 1 | | | | |
| 18 Take work to inspection bay | Number of loads | | 1 | 2.01 | 2.88 | 4.03 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |
| 19 Inspect | Number of loads | | 1 | 8.93 | 15.72 | 22.30 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | | | 1 | |
| 20 Take work to finished goods store | Number of loads | | 1 | 1.88 | 3.45 | 5.02 | 0 | 0 | 0 | 100% | 495 | 495 | 495 | | 1 | | | |

Table 5-10 can be seen as a combination of the flow process chart illustrated in Table 5-4 and the flow process chart illustrated in Table 5-9. However, in Table 5-10 further information is included in order to better calculate the total cycle time, and hence better estimate and control the MLTs. This additional information is:

**The unit**

The unit column describes the various quantities and types of outputs produced or processed at a given production activity. Essentially a given production output can be quantified in orders, requisitions, loads, set-up actions, or metres as can be seen in Table 5-9.

**The unit quantity input field**

In this column the operations manager of the weaving and dyeing department may insert or plug in a given quantity of units needed to be produced, in order to determine how many standard minutes it would take to produce that specific quantity of units.

**The number of resources at a given production activity**

As mentioned in Section 5.2.1, each production activity possesses one or more resources in terms of machines and personnel. This also means that the time it takes to produce a given quantity of units may vary depending on whether one or more resources are used. Therefore, it becomes important to record the number of available resources at each production activity in order to allow the operations manager to see how more or less resources impact on the time it takes to produce a desired quantity of units.

**The standard minutes per unit produced**

The standard minutes per unit produced consists of three values which summarise the calculated populations of standard time shown in Appendix E, for each production activity. These three values are the 5$^{th}$ percentile, the mean, and the 95$^{th}$ percentile of each production activity's standard time.

**The standard minutes relative to the unit quantity**

The values in this column are the product of multiplying the 'unit quantity input field' values by the 'calculated standard time' values, with due regard being paid to the number of resources available. Mathematically, this can be written as follows:

$$\frac{(Unit\ qty\ input\ field) \times (Calculated\ std\ time)}{Max.\ available\ resource}$$

This calculation therefore cancels all units mentioned in the 'unit' column for the production activity concerned, leaving only the standard minutes required to produce or process the quantity inserted in the 'unit quantity input field'.

**The average daily utilisation of the resources**

This column allows the operations manager to vary the average daily utilisation of the resources at a given production activity and see its impact on the available number of working hours in a shift. By default the average daily utilisation is set to 100%, which also means that 100% of the available working hours are being used to produce a given quantity inserted in the 'unit quantity input field'.

However, should the average daily utilisation of resources at a given production activity change, so would the available number of working hours in a shift. For example, in order to produce 70 000 metres at the Warping activity given a 100% average daily utilisation, it would take 197 std min on average, with 177 std min representing the 5$^{th}$ percentile, and 225 std min representing the 95$^{th}$ percentile. Furthermore, there will be some additional time left from the 495 minutes available for a Warping activity working hours mentioned in Section 5.2.5. This additional time is obtained as follows:

$$\big((Daily\ working\ hours) \times (Average\ daily\ utilisation)\big) - Std\ minutes$$

On the other hand, by reducing the average daily utilisation of resources at the Warping activity from the defaulted 100% to 38% shown in Table 5-10, the resulting standard minutes would still be of 197 std min on average, with 177 std min representing the 5$^{th}$

percentile, and 225 std min representing the 95$^{th}$ percentile. However, this time the operator would have to work 9 minutes overtime for the mean std min, and 37 minutes overtime for the std min representing the 95$^{th}$ percentile as shown in the 'daily working hours left' column of Table 5-10.

**The total cycle time**

As described in Chapter IV under Section 4.2.1, the total cycle time sums up all the cycle times for all of the individual activities in the process. Therefore the total cycle time is found by adding up all the standard minutes obtained, and it can be used to later estimate the MLT.

## 5.8 Chapter summary

Firstly, this chapter starts by providing an overview of the weaving and dyeing department's operations in the form of a SIPOC table. It also defines the variety of products that are produced in the weaving and dyeing department as well as their corresponding volumes. It then provides more details on the various products and the production process by establishing a production routing, an assembly chart, and a flow process chart.

Secondly, this chapter shows and defines all the key components of the standard time on a time study sheet, and further describes the only two key components of the standard time that were obtained on the production floor of the weaving and dyeing department, either through direct measurements or by estimation.

Thirdly, by using the statistical tools in @risk, this chapter analyses the obtained measurements of the main two key components of the standard time. Then through a Monte Carlo simulation of the analysed measurements, this chapter establishes populations of cycle times at each production activity of the weaving and dyeing department, therefore making an improvement.

Fourthly, in order to ensure that the calculated population of the cycle times are representative of the actual standard times at various production activities of the weaving and dyeing department, this chapter establishes an ecological validity for the calculated number of units producible per day at a given value-added activity.

Finally, this chapter creates a cycle time control sheet which is a Microsoft Excel spreadsheet that the weaving and dyeing department managers can use to better estimate and control their MLTs.

# 6 CHAPTER VI: CONCLUSION AND RECOMMENDATIONS

## 6.1 Background

Based on the previous five chapters, this chapter provides a summary of why this research was important, and how the research outcome addressed the research questions. Moreover, this chapter provides some recommendations on how the achievement of the research objective could be made easier, reliable, and less time-consuming. Finally this chapter shows how some outcomes of this research pave the way for further research endeavours in the reduction of the production cycle times.

## 6.2 Conclusion

This research shows how the cycle times of various production activities in a weaving and dyeing plant can be established in a systematic way. Furthermore, given the high variety of the products to be manufactured at each production activity, this research shows how the cycle times can be measured and established at each production activity by taking into account the entire population of products manufactured at each production activity.

In order to establish the cycle times for an entire population of products manufactured at each specific production activity, the following steps were followed:

- The DMAIC procedure was evaluated along with other TQM concepts, and was found to be the most suitable procedure for carrying out this research. Further, a DMAIC risk assessment sheet was developed in order to assess the risk associated with the use of DMAIC for achieving the research objective. The risk was found to be minimal, with a 76% chance of success and 24% chance of failure.

- The production activities for which the cycle times had to be established, were then identified as being the first three primary activities of Porter's value chain. Consequently, the flow process chart was identified, among many other recording techniques, as being the most suitable study technique to methodically represent the first three primary activities of Porter's value chain in the weaving and dyeing department. Fundamentally the production activities in the flow process chart consisted of value-added, value-enabling, and non-value-added activities.
- The cycle times were then measured, recorded and analysed for the various production activities identified in the flow process chart, by means of a time study sheet which required that data be collected first. The collection of the data was completed in two distinctive ways. One manner was to make use of a device called the tachometer, and the other was to ask the production foremen for estimated values based on their expertise. Based on the data obtained, various probability distributions were hypothesised and used to run a Monte Carlo simulation, in order to determine the standard times for the entire population of products processed at various activities.
- From the calculated populations of standard times, a calculated number of units producible per day or calculated daily production capacity was obtained, as a reciprocal of the already calculated standard time. The calculated daily production capacity was then compared to the actual number of units produced daily for ecological validity reasons. It was then noticed that the calculated daily production capacity was valid, but sometimes unreliable due to frequent changes in the utilisation of resources at some production activities.
- Finally, a production control sheet was established. Although this final step was not taken toward the establishment of the production cycle times per se, it was however, an important one as it allowed better control of the total cycle time. This in its turn is used to estimate the MLT, by taking into account variables such as the desired output quantity, the number of resources available and the average daily utilisation.

Lastly, the approach followed in every step of this research has been documented and explained in such a manner that the research is repeatable not only in the weaving and dyeing plant, but also in any other similar production environments whereby particular machines or resources used to produce high variety of products have unknown cycle times.

## 6.3 Recommendations

Based on the above conclusion of the research, five main recommendations could be made as follows:

- Standard operating procedures for carrying out each production activity should be clearly defined, well explained to the operators, rigorously enforced and regularly updated. Such a strategy would help in describing and understanding various job elements, rendering the timing of those job elements and consequently the measurement of cycle time easy.
- The weaving and dyeing plant should employ a work study practitioner on a full-time basis, whose job description will mainly focus on regularly conducting time studies and establishing standard times for as many of the high priority products as possible. Such a strategy would help by replacing the previously estimated time values obtained from the production foremen, with calculated time values obtained from the work study practitioner, hence increasing accuracy in the establishment of the standard times.
- For the purpose of the validity of the measurements, electronic metre counters should be adequately mounted on the machines located at value-added activities, and used to measure and record the actual number of units produced on the machines over a given period of time. The values obtained from the metre counters will then be compared to the calculated values in order to assess the validity and reliability of the measurements.
- Finally, as explained in Section 5.6, when the utilisation of the resources over a given period of time is not being measured or is unknown, then the calculated

number of units produced at a particular production activity over a given period of time seems unreliable when compared to the actual number of units produced at the same production activity. Therefore the weaving and dyeing department should regularly measure and record the utilisation of resources over a given period of time.

- While this research identified the establishment of the cycle times as one important step toward an adequate management of the manufacturing lead times, other important steps should also be explored, and used in conjunction with the already established cycle times, in order to enhance the establishment of the MLTs.

## 6.4 Further research

Being an action research, this research study focused on establishing cycle times at various production activities in a weaving and dyeing plant. However, following the establishment of the cycle times, it was noticed that the miscellaneous time component of the cycle time of the value-added activities takes longer to execute than the run time component. However, while the former occurs only a few times during a production run, the latter occurs in every cycle of the production run.

Therefore, based on this above mentioned observation, the following questions arise:

- If the weaving and dyeing department decided to shorten the calculated and newly established cycle times at value-added activities, would it be more beneficial to focus on reducing ineffective time by eliminating unproductive job elements?
- Or would it rather be more advantageous to focus on reducing the frequency of occurrence of unproductive job elements, and increasing the frequency of occurrence of productive job elements?

These questions pave the way for further research that could be carried out, either still within the weaving and dyeing plant, or within any other facility where found appropriate.

# REFERENCES

Arumugam, V., Ooi, K.-B., & Fong, T.-C. (2008). TQM practices and quality management performance. *The TQM Journal*, *20*(6), 636–650. http://doi.org/10.1108/17542730810909383

Bekker, J. (2014). *Introduction to discrete-event simulation*. Stellenbosch: Department of Industrial Engineering Stellenbosch University.

Blackstone, Jr., J. H. (1989). *Capacity Management*. Cincinnati, Ohio: South-Western Publishing Co.

Blanchard, B. S. (2004). *Logistics Engineering and Management International Edition.* (6th ed.). Upper Saddle River, NJ: Pearson Education Inc.

Boon Sin, A., Zailani, S., Iranmanesh, M., & Ramayah, T. (2015). Structural equation modelling on knowledge creation in Six Sigma DMAIC project and its impact on organizational performance. *International Journal of Production Economics*, *168*, 105–117. http://doi.org/10.1016/j.ijpe.2015.06.007

Brussee. (2004). *Statistics for Six Sigma Made Easy!* New York, NY: McGraw-Hill.

Chincholkar, M., & Herrmann, J. W. (2008). Estimating manufacturing cycle time and throughput in flow shops with process drift and inspection. *International Journal of Production Research*, *46*(24), 7057–7072. http://doi.org/10.1080/00207540701513893

Dedhia, N. S. (2005). Six sigma basics. *Total Quality Management & Business Excellence*, *16*(5), 567–574. http://doi.org/10.1080/14783360500077468

Eckes, G. (2001). *The Six Sigma Revolution: How General Electric and Others Turned Process Into Profits*. New York, NY: John Wiley & Sons, Inc.

Feng, C.-X. J., Yu, Z.-G. S., Emanuel, J. T., Li, P.-G., Shao, X.-Y., & Wang, Z.-H. (2008). Threefold versus fivefold cross-validation and individual versus average data in predictive regression modelling of machining experimental data. *International Journal of Computer Integrated Manufacturing*, *21*(6), 702–714. http://doi.org/10.1080/09511920701530943

Filho, M. G., & Uzsoy, R. (2013). The impact of simultaneous continuous improvement in setup time and repair time on manufacturing cycle times under uncertain conditions. *International Journal of Production Research*, *51*(2), 447–467. http://doi.org/10.1080/00207543.2011.652261

Finne, T. (1997). Information security implemented in: The theory on stock market efficiency, Markowitz's portfolio theory and porter's value chain. *Computers & Security*, *16*(6), 469–479. http://doi.org/10.1016/S0167-4048(97)84641-X

Foster, S. T. (2010). *Managing Quality: Integrating The Supply Chain International Edition.* (4th ed.). Upper Saddle River, NJ: Pearson Education Inc.

Gibson, P., Greenhalgh, G., & Kerr, R. (1995). *Manufacturing Management Principles and Concepts*. London: Chapman & Hall.

Goldratt, E. M., & Cox, J. (2004). *The goal: A Process of Ongoing Improvement* (3rd ed.). Great Barrington, MA: The North River Press Publishing Corporation.

Groover, M. P. (2008). *Automation, Production Systems, and Computer-Integrated Manufacturing.* (3rd ed.). Upper Saddle River, NJ: Pearson Education Inc.

Han, K. H., Lee, G., & Choi, S. H. (2013). Manufacturing cycle time reduction for batch production in a shared worker environment. *International Journal of Production Research*, *51*(1), 1–8. http://doi.org/10.1080/00207543.2011.631604

Handfield, R. B., & Pannesi, R. T. (1995). Antecedents of leadtime competitiveness in make-to-order manufacturing firms. *International Journal of Production Research*, *33*(2), 511–537. http://doi.org/10.1080/00207549508930163

Harry, M. J., Mann, P. S., De Hodgins, O. C., Hulbert, R. L., & Lacke, C. J. (2010). *Practitioner's guide to Statistics and Lean Six Sigma for Process Improvements*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Heizer, J., & Render, B. (2006). *Principles of Operations Management.* (6th ed.). Upper Saddle River, NJ: Pearson Education Inc.

Hill, F., & Huq, R. (2004). Employee Empowerment: Conceptualizations, Aims and Outcomes. *Total Quality Management & Business Excellence*, *15*(8), 1025–1041. http://doi.org/10.1080/1478336042000255505

Hill, T. (2000). *Manufacturing Strategy Text and Cases.* (3rd ed.). London: McGraw-Hill Companies.

Hitomi, K. (1996). *Manufacturing Systems Engineering: A Unified Approach to Manufacturing and Industrial Economics.* (2nd ed.). London: CRC Press Taylor&Francis.

Holtskog, H. (2013). Continuous Improvement Beyond the Lean Understanding. *Procedia CIRP*, *7*, 575–579. http://doi.org/10.1016/j.procir.2013.06.035

Joglekar, A. M. (2003). *Statistical Methods for Six Sigma In R&D and Manufacturing*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Johnson, D. J. (2003). A framework for reducing manufacturing throughput time. *Journal of Manufacturing Systems*, *22*(4), 283–298. http://doi.org/10.1016/S0278-6125(03)80009-2

Kanawaty, G. (2006). *Introduction to Work Study.* (4th ed.). Johannesburg: Skotaville Publishers.

Kelton, W. D., Sadowski, R. P., & Swets, N. B. (2010). *Simulation with Arena International Edition.* (5th ed.). New York: McGraw-Hill.

Larson, R., & Farber, B. (2012). *Elementary Statistics: Picturing the World* (5th ed.). Prentice Hall.

Lee, H. W., Ik, N., & Lee, S. W. (2007). Analysis of the manufacturing lead time in a production system with non-renewal batch input, threshold policy and post-operation. *Applied Mathematical Modelling*, *31*(10), 2160–2171. http://doi.org/10.1016/j.apm.2006.08.022

Leedy, P. D., & Ormrod, J. E. (2013). *Practical Research Planning and Design International Edition.* (10th ed.). Cape Town: Pearson Education.

Martínez-Lorente, A. R., & Martínez-Costa, M. (2004). ISO 9000 and TQM: substitutes or complementaries? *International Journal of Quality & Reliability Management*, *21*(3), 260–276. http://doi.org/10.1108/02656710410522711

Maskell, B. H. (1991). *Performance Measurement for World Class Manufacturing: A Model for American Companies*. Cambridge, Massachusetts: Productivity Press, Inc.

Mayer, M., & Nusswald, M. (2001). Improving manufacturing costs and lead times with quality-oriented operating curves. *Journal of Materials Processing Technology*, *119*(1-3), 83–89. http://doi.org/10.1016/S0924-0136(01)00881-0

Monden, Y. (1993). *Toyota Production System: An Integrated Approach to Just-In-Time* (2nd ed.). Norcross, Georgia: Institute of Industrial Engineers.

Montgomery, D. C., & Runger, G. C. (2003). *Applied Statistics and Probability for Engineers* (3rd ed.). New York, NY: John Wiley & Sons, Inc.

Mun, J. (2006). *Modeling Risk: Applying Monte Carlo Simulation, Real Options Analysis, Forecasting, and Optimization Techniques*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Nadarajah, S., & Kotz, S. (2008). The cycle time distribution. *International Journal of Production Research*, *46*(11), 3133–3141. http://doi.org/10.1080/00207540601186071

Oechsner, R., Pfeffer, M., Pfitzner, L., Binder, H., Müller, E., & Vonderstrass, T. (2003). From overall equipment efficiency (OEE) to overall Fab effectiveness (OFE). *Materials Science in Semiconductor Processing*, *5*(4-5 SPEC.), 333–339. http://doi.org/10.1016/S1369-8001(03)00011-8

Öztürk, A., Kayalıgil, S., & Özdemirel, N. E. (2006). Manufacturing lead time estimation using data mining. *European Journal of Operational Research*, *173*(2), 683–700. http://doi.org/10.1016/j.ejor.2005.03.015

Palisade Corporation. (2013). *Users Guide @Risk: Risk Analysis and Simulation Add-In for Microsoft Excel*. Ithaca, New York: Palisade Corporation.

Pandey, P. C., & Hasin, M. A. A. (1998). Lead time adjustment through scrap management. *Production Planning & Control: The Management of Operations*, *9*(2), 138–142. http://doi.org/10.1080/095372898234352

Prašnikar, J., Debeljak, Ž., & Ahčan, A. (2005). Benchmarking as a tool of strategic management. *Total Quality Management & Business Excellence*, *16*(2), 257–275. http://doi.org/10.1080/14783360500054400

Puvanasvaran, A. P., Mei, C. Z., & Alagendran, V. A. (2013). Overall Equipment Efficiency Improvement Using Time Study in an Aerospace Industry. *Procedia Engineering*, *68*, 271–277. http://doi.org/10.1016/j.proeng.2013.12.179

Pyzdek, T. (2003). *The Six Sigma Handbook: Revised and Expanded* (2nd ed.). New York, NY: McGraw-Hill.

Rao, U. S., Swaminathan, J. M., & Zhang, J. (2005). Demand and Production

Management with Uniform Guaranteed Lead Time. *Production and Operations Management*, *14*(4), 400–412. http://doi.org/10.1111/j.1937-5956.2005.tb00229.x

Ruben, R. a., & Mahmoodi, F. (2000). Lead time prediction in unbalanced production systems. *International Journal of Production Research*, *38*(7), 1711–1729. http://doi.org/10.1080/002075400188816

Samaranayake, P. (2013). Improving manufacturing lead time using holistic approach to planning and execution with integrated data structures: numerical simulation and comparison. *International Journal of Production Research*, *51*(15), 4484–4501. http://doi.org/10.1080/00207543.2013.765076

Sanchez, L., & Blanco, B. (2014). Three decades of continuous improvement. *Total Quality Management & Business Excellence*, *25*(9), 986–1001. http://doi.org/10.1080/14783363.2013.856547

Singh, N. (1996). *Systems Approach to Computer-Integrated Design and Manufacturing* (1st ed.). New York: John Wiley & Sons, Inc.

Sivula, A., & Kantola, J. (2014). Combining crowdsourcing and Porter's value chain. *International Journal of Advanced Logistics*, *3*(1-2), 17–26. http://doi.org/10.1080/2287108X.2014.956977

Slotnick, S. a., & Sobel, M. J. (2005). Manufacturing lead-time rules: Customer retention versus tardiness costs. *European Journal of Operational Research*, *163*(3), 825–856. http://doi.org/10.1016/j.ejor.2003.07.023

Sun, H. (2000). Total quality management, ISO 9000 certification and performance improvement. *International Journal of Quality & Reliability Management*, *17*(2), 168–179. http://doi.org/10.1108/02656710010304573

Takata, S., Nakajima, T., Ahn, J. H., & Sata, T. (1987). Tool Breakage Monitoring by

Means of Fluctuations in Spindle Rotational Speed. *CIRP Annals - Manufacturing Technology*, *36*(1), 49–52. http://doi.org/10.1016/S0007-8506(07)62551-7

Termini, M. J. (1996). *The New Manufacturing Engineer: Coming of age in an agile environment*. Dearborn, Michigan: Society of Manufacturing Engineers.

Thomas, P. R. (1990). *Competitiveness Through Total Cycle Time: An Overview for CEO's*. New York: McGraw-Hill Publishing Company.

Welman, Kruger, & Mitchell. (2005). *Research Methodology* (3rd ed.). Cape Town: Oxford University Press Southern Africa.

Yilmaz, A., AL-Regib, E., & Ni, J. (2002). Machine Tool Chatter Suppression by Multi-Level Random Spindle Speed Variation. *Journal of Manufacturing Science and Engineering*, *124*(2), 208–216. http://doi.org/10.1115/1.1378794

Yücesan, E., & de Groote, X. (2000). Lead times, order release mechanisms, and customer service. *European Journal of Operational Research*, *120*(1), 118–130. http://doi.org/10.1016/S0377-2217(98)00393-2

Zammori, F., Braglia, M., & Frosolini, M. (2011). Stochastic overall equipment effectiveness. *International Journal of Production Research*, *49*(21), 6469–6490. http://doi.org/10.1080/00207543.2010.519358

Zandin, K. B., & Maynard, H. (2001). *Maynard's Industrial Engineering Handbook* (5th ed.). New York: McGraw-Hill.

# APPENDICES

## Appendix A

ISO 9001:2008 clauses *(Foster, 2010, p. 113)*

**ISO 9001:2008 Quality Management System Requirements**

Clause

4.0 **Quality Management System**

4.1 **General Requirements**

The organisation shall establish, document, implement, and maintain a quality management system and continually improve its effectiveness in accordance with the requirements of the international standard.

4.2 **General Requirements**

Quality management system documentation will include a quality policy and quality objectives; a quality manual; documented procedures; documents to ensure effective planning, operation, and control of process; and records required by the international standard.

**ISO 9001:2008 Management Requirements**

Clause

5.0 **Management System**

5.1 **Management Commitment**

a. Communication of meeting customer, statutory, and regulatory

b. Establishing a quality policy

c. Establishing quality objectives

d. Conducting management reviews

e. Ensuring that resources are available

5.2 Top management shall ensure that customer requirements are determined and are met with the aim of enhancing customer satisfaction.

5.3 Management shall establish a quality policy.

5.4 Management shall ensure that quality objectives shall be established

5.5 Management shall ensure that responsibilities and authorities are defined and communicated.

5.6 Management shall review the quality management system at regular intervals.

**ISO 9001:2008 Resource Management Requirements**

Clause

6.0 **Resource Management**

6.1 The organisation shall determine and provide needed resources.

6.2 Workers will be provided necessary education, training, skills, and experience.

6.3 The organisation shall determine, provide, and maintain the infrastructure needed to achieve conformity to product requirements.

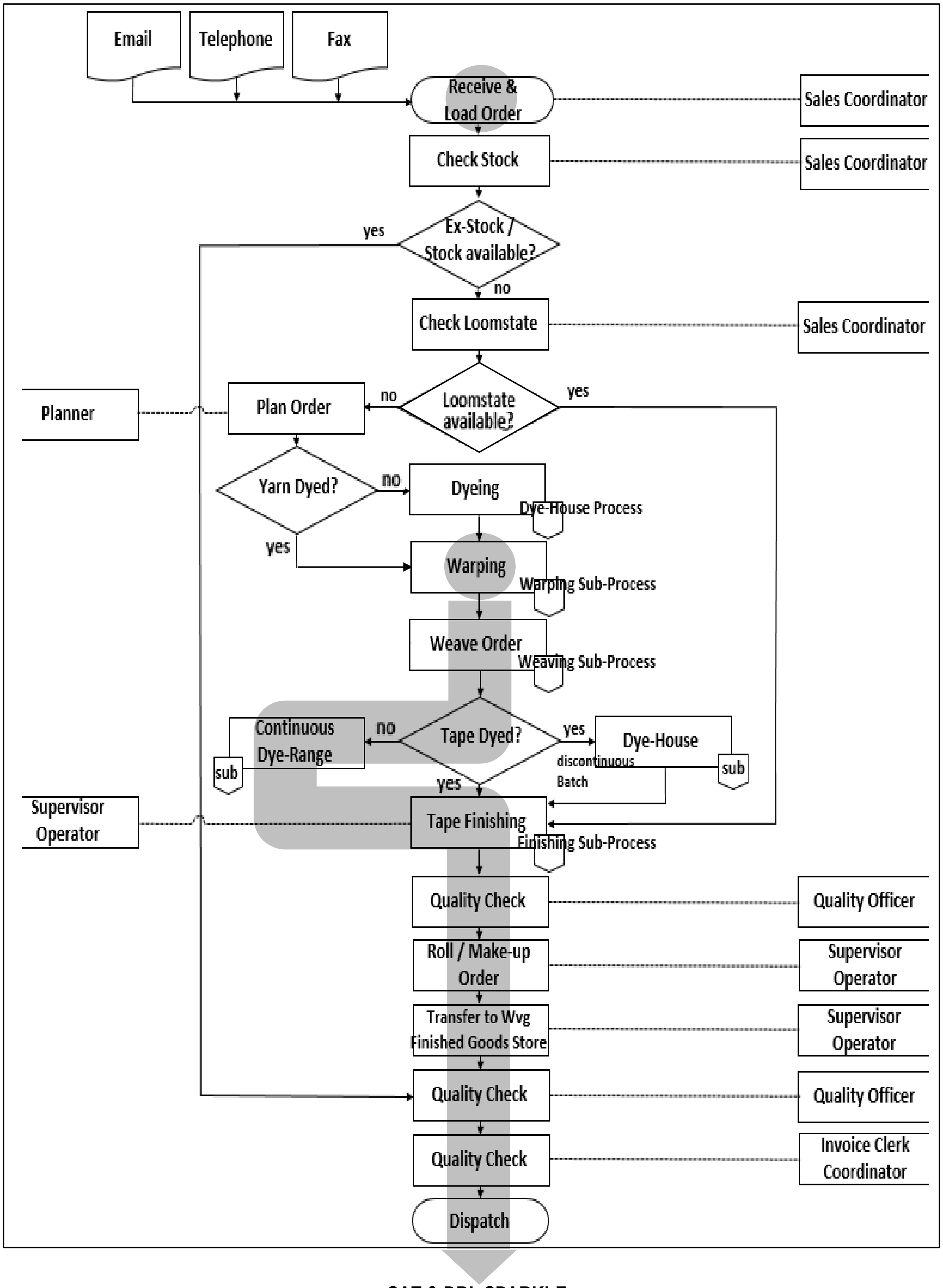
6.4 The organisation shall determine and manage the work environment needed to achieve conformity to product requirements.

| ISO 9001:2008 Product Realisation Requirements | |
|---|---|
| Clause | |
| 7.0 | **Product Realisation** |
| 7.1 | The organisation shall plan and develop processes needed for product realisation. |
| 7.2 | The organisation shall determine requirements as specified by customers. |
| 7.3 | The organisation shall plan and control the design and development for its products |
| 7.4 | The organisation shall ensure that purchased product conforms to specified purchse requirements. |
| 7.5 | The organisation shall plan and carry out production and service under controlled conditions. |
| 7.6 | The organisation shall determine the monitoring and measurements to be undertaken and the monitoring and measuring devices needed to provide evidence of conformity of product to determine requirements. |

| ISO 9001:2008 Measurements, Analysis, and Improvement Standards | |
|---|---|
| Clause | |
| 8.0 | **Measurement, Analysis, and Improvement** |
| 8.1 | The organisation shall plan and implement the monitoring, measurement, analysis, and improvement process as needed. |
| 8.2 | The organisation shall monitor information relating to customer perceptions. |
| 8.3 | The organisation shall ensure that product that does not conform to requirements is identified and controlled to prevent its unintended use or delivery. |
| 8.4 | The organisation shall determine, collect, and analyse data to demonstrate the suitability and effectiveness of the quality management system, including:<br>a. Customer satisfaction<br>b. Conformance data<br>c. Trend data<br>d. Supplier data |
| 8.5 | The organisation shall continually improve the effectiveness of the quality management system. |

**Appendix B**

High-level Process Map




SAT & DBL SPARKLE

# Appendix C

Observed Machine Element Time

| Warping Observed Machine Element Time | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** | **Obs #** | **M/c #** | **Yarn type** | **Time of the observation** | **Run Speed (m/min)** | **Run time per unit (min)** | **Run time per unit (sec)** |
| 5-May-15 | 1 | m/c 1 | 80/200 | 11:47 | 270.30 | 0.0037 | 0.2220 |
| 5-May-15 | 2 | m/c 2 | 80/200 | 11:49 | 293.65 | 0.0034 | 0.2043 |
| 6-May-15 | 3 | m/c 2 | 80/200 | 7:45 | 294.40 | 0.0034 | 0.2038 |
| 6-May-15 | 4 | m/c 2 | 80/200 | 9:27 | 219.95 | 0.0045 | 0.2728 |
| 6-May-15 | 5 | m/c 2 | 80/200 | 9:30 | 244.90 | 0.0041 | 0.2450 |
| 6-May-15 | 6 | m/c 1 | 80/200 | 11:11 | 252.85 | 0.0040 | 0.2373 |
| 6-May-15 | 7 | m/c 2 | 80/200 | 11:45 | 257.50 | 0.0039 | 0.2330 |
| 8-May-15 | 8 | m/c 2 | 80/200 | 11:49 | 241.95 | 0.0041 | 0.2480 |
| 8-May-15 | 9 | m/c 1 | 80/200 | 13:47 | 245.60 | 0.0041 | 0.2443 |
| 11-May-15 | 10 | m/c 1 | 80/200 | 13:40 | 245.25 | 0.0041 | 0.2446 |
| 12-May-15 | 11 | m/c 1 | 80/200 | 10:55 | 273.90 | 0.0037 | 0.2191 |
| 12-May-15 | 12 | m/c 2 | 80/200 | 13:59 | 208.05 | 0.0048 | 0.2884 |
| 12-May-15 | 13 | m/c 1 | 80/200 | 14:51 | 233.00 | 0.0043 | 0.2575 |
| 12-May-15 | 14 | m/c 2 | 80/200 | 15:34 | 232.65 | 0.0043 | 0.2579 |
| 14-May-15 | 15 | m/c 1 | 80/200 | 14:58 | 274.50 | 0.0036 | 0.2186 |
| 14-May-15 | 16 | m/c 2 | 80/200 | 15:02 | 232.50 | 0.0043 | 0.2581 |
| 15-May-15 | 17 | m/c 2 | 80/200 | 11:29 | 209.20 | 0.0048 | 0.2868 |
| 15-May-15 | 18 | m/c 2 | 80/200 | 12:07 | 270.60 | 0.0037 | 0.2217 |
| 18-May-15 | 19 | m/c 1 | 80/200 | 11:33 | 238.30 | 0.0042 | 0.2518 |
| 18-May-15 | 20 | m/c 2 | 80/200 | 11:35 | 295.75 | 0.0034 | 0.2029 |
| 18-May-15 | 21 | m/c 2 | 80/200 | 11:40 | 258.70 | 0.0039 | 0.2319 |
| 18-May-15 | 22 | m/c 2 | 80/200 | 15:12 | 282.30 | 0.0035 | 0.2125 |
| 19-May-15 | 23 | m/c 2 | 80/200 | 13:18 | 282.40 | 0.0035 | 0.2125 |
| 19-May-15 | 24 | m/c 2 | 80/200 | 13:19 | 270.45 | 0.0037 | 0.2219 |
| 19-May-15 | 25 | m/c 2 | 80/200 | 13:40 | 260.00 | 0.0038 | 0.2308 |
| 19-May-15 | 26 | m/c 2 | 80/200 | 14:49 | 258.80 | 0.0039 | 0.2318 |
| 21-May-15 | 27 | m/c 1 | 80/200 | 14:23 | 297.10 | 0.0034 | 0.2020 |
| 22-May-15 | 28 | m/c 1 | 80/200 | 14:05 | 288.50 | 0.0035 | 0.2080 |
| 22-May-15 | 29 | m/c 1 | 80/200 | 14:07 | 272.15 | 0.0037 | 0.2205 |
| 25-May-15 | 30 | m/c 2 | 80/200 | 14:02 | 261.30 | 0.0038 | 0.2296 |

| Weaving Obseverd Machine Element Time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Obs # | M/c # | Tapes type | Width (mm) | Colour | Process | qty on M/c (tapes) | Time of the observation | Run Speed (m/min) | Run time per unit (min) | Run time per unit (sec) |
| 16-Mar-15 | 1 | shed-440 | sat | 44 | white | weave | 4 | 12:50 | 0.635 | 1.575 | 94.488 |
| 16-Mar-15 | 2 | shed-439 | sat | 36 | white | weave | 4 | 12:52 | 0.700 | 1.429 | 85.714 |
| 17-Mar-15 | 3 | shed-433 | sat | 63 | white | weave | 4 | 6:40 | 0.655 | 1.527 | 91.603 |
| 17-Mar-15 | 4 | shed-429 | sat | 10 | white | weave | 8 | 6:45 | 0.900 | 1.111 | 66.667 |
| 17-Mar-15 | 5 | shed-427 | sat | 7 | white | weave | 8 | 6:52 | 0.760 | 1.316 | 78.947 |
| 17-Mar-15 | 6 | shed-401 | sat | 6 | white | weave | 6 | 6:58 | 0.843 | 1.186 | 71.174 |
| 17-Mar-15 | 7 | shed-425 | sat | 7 | white | weave | 8 | 7:03 | 0.510 | 1.961 | 117.647 |
| 17-Mar-15 | 8 | shed-450 | sat | 12 | white | weave | 6 | 7:09 | 0.755 | 1.325 | 79.470 |
| 17-Mar-15 | 9 | shed-452 | dbl spkl | 22 | white | weave | 6 | 7:12 | 0.643 | 1.555 | 93.313 |
| 17-Mar-15 | 10 | shed-453 | dbl spkl | 22 | white | weave | 6 | 7:20 | 1.005 | 0.995 | 59.701 |
| 17-Mar-15 | 11 | shed-454 | sat | 12 | white | weave | 8 | 7:26 | 0.655 | 1.527 | 91.603 |
| 17-Mar-15 | 12 | shed-456 | dbl spkl | 28 | white | weave | 6 | 7:31 | 0.750 | 1.333 | 80.000 |
| 17-Mar-15 | 13 | shed-457 | dbl spkl | 4 | white | weave | 8 | 7:38 | 0.865 | 1.156 | 69.364 |
| 17-Mar-15 | 14 | shed-461 | dbl spkl | 4 | white | weave | 8 | 7:45 | 0.645 | 1.550 | 93.023 |
| 17-Mar-15 | 15 | shed-466 | dbl spkl | 4 | white | weave | 10 | 7:55 | 0.785 | 1.274 | 76.433 |
| 17-Mar-15 | 16 | shed-467 | sat | 60 | white | weave | 2 | 8:00 | 0.889 | 1.125 | 67.492 |
| 25-Mar-15 | 17 | shed-445 | sat | 24 | white | weave | 6 | 21:26 | 0.675 | 1.481 | 88.889 |
| 26-Mar-15 | 18 | shed-416 | dbl spkl | 7 | white | weave | 6 | 20:50 | 0.830 | 1.205 | 72.289 |
| 1-Apr-15 | 19 | shed-445 | sat | 27 | white | weave | 6 | 7:07 | 0.605 | 1.653 | 99.174 |
| 1-Apr-15 | 20 | shed-416 | dbl spkl | 7 | white | weave | 6 | 7:59 | 0.825 | 1.212 | 72.727 |
| 1-Apr-15 | 21 | shed-429 | sat | 16 | white | weave | 8 | 9:16 | 0.665 | 1.504 | 90.226 |
| 1-Apr-15 | 22 | shed-427 | sat | 7 | white | weave | 8 | 9:50 | 0.588 | 1.701 | 102.041 |
| 1-Apr-15 | 23 | shed-402 | dbl spkl | 7 | white | weave | 6 | 10:03 | 0.610 | 1.639 | 98.361 |
| 1-Apr-15 | 24 | shed-401 | sat | 6 | white | weave | 6 | 10:07 | 0.645 | 1.550 | 93.023 |
| 1-Apr-15 | 25 | shed-425 | sat | 7 | white | weave | 8 | 10:08 | 1.008 | 0.992 | 59.524 |
| 23-Apr-15 | 26 | shed-450 | sat | 12 | white | weave | 6 | 20:57 | 0.625 | 1.600 | 96.000 |
| 23-Apr-15 | 27 | shed-454 | sat | 12 | white | weave | 8 | 21:16 | 0.715 | 1.399 | 83.916 |
| 23-Apr-15 | 28 | shed-455 | dbl spkl | 4.5 | white | weave | 8 | 21:17 | 0.895 | 1.117 | 67.039 |
| 23-Apr-15 | 29 | shed-460 | dbl spkl | 4.5 | white | weave | 8 | 21:31 | 0.680 | 1.471 | 88.235 |
| 23-Apr-15 | 30 | shed-422 | sat | 37 | white | weave | 6 | 22:03 | 0.455 | 2.198 | 131.868 |

| Spooling Observed Machine Element Time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Obs # | M/c # | Tapes type | Width (mm) | Colour | Process | qty on M/c (meter) | Time of the observation | Run Speed (m/min) | Run time per unit (min) | Run time per unit (sec) |
| 17-Mar-2015 | 1 | SPL4 | dbl spkl | 6 | white | spool | 1800 | 8:45 | 319.75 | 0.00 | 0.1876 |
| 17-Mar-2015 | 2 | SPL3 | sat | 6 | white | spool | 3400 | 9:20 | 231.00 | 0.00 | 0.2597 |
| 25-Mar-2015 | 3 | SPL5 | sat | 10 | white | spool | 4000 | 10:29 | 237.70 | 0.00 | 0.2524 |
| 25-Mar-2015 | 4 | SPL5 | sat | 10 | white | spool | 1800 | 10:33 | 252.40 | 0.00 | 0.2377 |
| 25-Mar-2015 | 5 | SPL5 | sat | 10 | white | spool | 1800 | 11:13 | 159.35 | 0.01 | 0.3765 |
| 30-Mar-2015 | 6 | SPL4 | sat | 10 | white | spool | 4000 | 12:30 | 238.70 | 0.00 | 0.2514 |
| 30-Mar-2015 | 7 | SPL4 | sat | 25 | white | spool | 7000 | 15:28 | 268.20 | 0.00 | 0.2237 |
| 30-Mar-2015 | 8 | SPL2 | dbl spkl | 4 | white | spool | 5200 | 15:31 | 302.70 | 0.00 | 0.1982 |
| 6-May-2015 | 9 | SPL1 | sat | 6 | white | spool | 44000 | 7:59 | 285.85 | 0.00 | 0.2099 |
| 6-May-2015 | 10 | SPL4 | sat | 6 | white | spool | 500 | 8:57 | 314.74 | 0.00 | 0.1906 |
| 6-May-2015 | 11 | SPL4 | sat | 14 | white | spool | 5000 | 9:15 | 258.06 | 0.00 | 0.2325 |
| 6-May-2015 | 12 | SPL4 | sat | 14 | white | spool | 5000 | 9:16 | 345.87 | 0.00 | 0.1735 |
| 6-May-2015 | 13 | SPL4 | sat | 8 | white | spool | 4000 | 11:57 | 235.92 | 0.00 | 0.2543 |
| 8-May-2015 | 14 | SPL4 | sat | 6 | white | spool | 110000 | 13:54 | 118.78 | 0.01 | 0.5052 |
| 11-May-2015 | 15 | SPL4 | sat | 25 | white | spool | 13000 | 14:02 | 318.24 | 0.00 | 0.1885 |
| 11-May-2015 | 16 | SPL4 | sat | 25 | white | spool | 13000 | 14:09 | 274.04 | 0.00 | 0.2189 |
| 11-May-2015 | 17 | SPL4 | sat | 25 | white | spool | 13000 | 14:42 | 263.12 | 0.00 | 0.2280 |
| 12-May-2015 | 18 | SPL4 | sat | 14 | white | spool | 2400 | 10:51 | 248.52 | 0.00 | 0.2414 |
| 12-May-2015 | 19 | SPL4 | sat | 7 | white | spool | 1200 | 11:48 | 231.33 | 0.00 | 0.2594 |
| 12-May-2015 | 20 | SPL4 | sat | 10 | white | spool | 45000 | 12:17 | 233.62 | 0.00 | 0.2568 |
| 12-May-2015 | 21 | SPL4 | sat | 12 | white | spool | 5000 | 13:48 | 180.94 | 0.01 | 0.3316 |
| 13-May-2015 | 22 | SPL4 | sat | 10 | white | spool | 1000 | 10:19 | 243.57 | 0.00 | 0.2463 |
| 13-May-2015 | 23 | SPL4 | sat | 10 | white | spool | 3400 | 10:35 | 158.87 | 0.01 | 0.3777 |
| 13-May-2015 | 24 | SPL4 | dbl spkl | 12 | white | spool | 1800 | 11:06 | 238.17 | 0.00 | 0.2519 |
| 13-May-2015 | 25 | SPL4 | dbl spkl | 4 | white | spool | 3000 | 12:05 | 240.70 | 0.00 | 0.2493 |
| 14-May-2015 | 26 | SPL4 | dbl spkl | 3 | white | spool | 1300 | 12:15 | 243.92 | 0.00 | 0.2460 |
| 14-May-2015 | 27 | SPL4 | dbl spkl | 12 | white | spool | 2400 | 13:47 | 244.26 | 0.00 | 0.2456 |
| 14-May-2015 | 28 | SPL3 | dbl spkl | 3 | white | spool | 2400 | 15:13 | 237.45 | 0.00 | 0.2527 |
| 21-May-2015 | 29 | SPL1 | dbl spkl | 6 | white | spool | 3300 | 12:15 | 195.72 | 0.01 | 0.3066 |
| 21-May-2015 | 30 | SPL2 | dbl spkl | 6 | white | spool | 1200 | 12:17 | 236.20 | 0.00 | 0.2540 |

**Dark Shade Dyeing Observed Machine Element Time**

| Date | Obs # | M/c # | Tapes type | Width (mm) | Colour | Process | qty on M/c (tapes) | Time of the observation | Run Speed (m/min) | Run time per unit (min) | Run time per unit (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16-Mar-15 | 1 | CD5 | dbl spkl | 3 | charcoal par | dye | 2 | 9:18 | 11.4 | 0.088 | 5.263 |
| 17-Mar-15 | 2 | CD6 | dbl spkl | 4 | black | dye | 3 | 6:22 | 6.99 | 0.143 | 8.584 |
| 17-Mar-15 | 3 | CD5 | sat | 8 | col 17 | dye | 2 | 6:25 | 12.13 | 0.082 | 4.946 |
| 18-Mar-15 | 4 | CD5 | sat | 50 | brown 17 | dye | 1 | 6:25 | 12.04 | 0.083 | 4.983 |
| 18-Mar-15 | 5 | CD6 | dbl spkl | 4 | black | dye | 3 | 6:35 | 6.54 | 0.153 | 9.174 |
| 25-Mar-15 | 6 | CD5 | sat | 25 | col 57 | dye | 1 | 10:12 | 12.71 | 0.079 | 4.721 |
| 25-Mar-15 | 7 | CD6 | dbl spkl | 4 | black | dye | 2 | 10:16 | 7.31 | 0.137 | 8.208 |
| 25-Mar-15 | 8 | CD6 | sat | 7 | black | dye | 2 | 21:54 | 7.35 | 0.136 | 8.163 |
| 26-Mar-15 | 9 | CD6 | dbl spkl | 3 | black | dye | 2 | 20:20 | 7.23 | 0.138 | 8.299 |
| 26-Mar-15 | 10 | CD1 | sat | 14 | orange (28) | dye | 1 | 20:25 | 12.95 | 0.077 | 4.633 |
| 27-Mar-15 | 11 | CD1 | sat | 14 | red | dye | 3 | 14:00 | 11.25 | 0.089 | 5.333 |
| 30-Mar-15 | 12 | CD5 | dbl spkl | 4 | cerise 53 | dye | 2 | 15:40 | 9.97 | 0.100 | 6.018 |
| 07-Apr-15 | 13 | CD6 | dbl spkl | 4 | black | dye | 3 | 9:59 | 7.61 | 0.131 | 7.884 |
| 07-Apr-15 | 14 | CD1 | dbl spk | 15 | pink | dye | 2 | 10:01 | 10.93 | 0.091 | 5.489 |
| 07-Apr-15 | 15 | CD6 | sat | 6 | black | dye | 2 | 12:36 | 7.43 | 0.135 | 8.075 |
| 07-Apr-15 | 16 | CD5 | dbl spk | 3 | col 17 | dye | 2 | 12:39 | 11.7 | 0.085 | 5.128 |
| 08-Apr-15 | 17 | CD6 | sat | 10 | col 52 | dye | 2 | 9:56 | 7.28 | 0.137 | 8.242 |
| 09-Apr-15 | 18 | CD5 | dbl spkl | 3 | orange | dye | 2 | 12:19 | 11.47 | 0.087 | 5.231 |
| 09-Apr-15 | 19 | CD6 | sat | 6 | red 11 | dye | 3 | 12:21 | 7.46 | 0.134 | 8.043 |
| 10-Apr-15 | 20 | CD5 | sat | 10 | turg p2995c | dye | 1 | 10:20 | 11.16 | 0.090 | 5.376 |
| 13-Apr-15 | 21 | CD5 | sat | 14 | maroon | dye | 1 | 11:56 | 11.16 | 0.090 | 5.376 |
| 13-Apr-15 | 22 | CD6 | sat | 5 | black 07 | dye | 2 | 12:08 | 7.29 | 0.137 | 8.230 |
| 14-Apr-15 | 23 | CD6 | sat | 6 | col 32 | dye | 3 | 14:49 | 7.3 | 0.137 | 8.219 |
| 16-Apr-15 | 24 | CD5 | sat | 25 | red | dye | 1 | 12:06 | 12.76 | 0.078 | 4.702 |
| 21-Apr-15 | 25 | CD5 | sat | 25 | navy | dye | 1 | 10:52 | 9.84 | 0.102 | 6.098 |
| 22-Apr-15 | 26 | CD5 | sat | 10 | parmi | dye | 1 | 12:32 | 12.61 | 0.079 | 4.758 |
| 05-May-15 | 27 | CD6 | sat | 25 | dark purpple | dye | 1 | 10:59 | 7.94 | 0.126 | 7.557 |
| 06-May-15 | 28 | CD6 | dbl spkl | 4 | crimson | dye | 3 | 8:48 | 8.17 | 0.122 | 7.344 |
| 06-May-15 | 29 | CD1 | dbl spkl | 4 | red | dye | 3 | 9:12 | 13.59 | 0.074 | 4.415 |
| 06-May-15 | 30 | CD5 | dbl spkl | 3 | mocca par 018601 | dye | 2 | 10:58 | 11.71 | 0.085 | 5.124 |

| Light Shade Dyeing Observed Machine Element Time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Obs # | M/c # | Tapes type | Width (mm) | Colour | Process | qty on M/c (tapes) | Time of the observation | Run Speed (m/min) | Run time per unit (min) | Run time per unit (sec) |
| 16-Mar-15 | 1 | CD1 | sat | 25 | col258 | dye | 1 | 11:28 | 11.03 | 0.091 | 5.440 |
| 18-Mar-15 | 2 | CD2 | dbl spkl | 3 | off white | dye | 2 | 6:15 | 13.04 | 0.077 | 4.601 |
| 24-Mar-15 | 3 | CD2 | sat | 25 | col 68 | dye | 1 | 14:41 | 12.58 | 0.079 | 4.769 |
| 25-Mar-15 | 4 | CD2 | sat | 16 | old gold 46 | dye | 2 | 10:10 | 14.07 | 0.071 | 4.264 |
| 25-Mar-15 | 5 | CD1 | sat | 14 | col41 | dye | 2 | 11:50 | 12.58 | 0.079 | 4.769 |
| 25-Mar-15 | 6 | CD1 | sat | 25 | col258 | dye | 1 | 21:58 | 12.73 | 0.079 | 4.713 |
| 27-Mar-15 | 7 | CD2 | sat | 33 | Markhams grey | dye | 1 | 14:03 | 13.82 | 0.072 | 4.342 |
| 30-Mar-15 | 8 | CD6 | dbl spkl | 3 | off White | dye | 2 | 11:45 | 13.32 | 0.075 | 4.505 |
| 30-Mar-15 | 9 | CD1 | sat | 10 | col32 | dye | 2 | 11:50 | 12.67 | 0.079 | 4.736 |
| 07-Apr-15 | 10 | CD2 | dbl spkl | 6 | col 32 | dye | 3 | 10:04 | 14 | 0.071 | 4.286 |
| 08-Apr-15 | 11 | CD5 | sat | 14 | col41 | dye | 2 | 10:20 | 13.71 | 0.073 | 4.376 |
| 08-Apr-15 | 12 | CD1 | sat | 25 | col54 | dye | 1 | 10:25 | 11.52 | 0.087 | 5.208 |
| 08-Apr-15 | 13 | CD2 | dbl sat | 3 | taupe | dye | 2 | 11:22 | 12.96 | 0.077 | 4.630 |
| 08-Apr-15 | 14 | CD2 | dbl spkl | 3 | col 65 | dye | 1 | 14:47 | 12.58 | 0.079 | 4.769 |
| 09-Apr-15 | 15 | CD1 | dbl spkl | 3 | cream | dye | 2 | 12:23 | 12.98 | 0.077 | 4.622 |
| 09-Apr-15 | 16 | CD2 | dbl spkl | 6 | col 32 | dye | 3 | 12:25 | 13.89 | 0.072 | 4.320 |
| 10-Apr-15 | 17 | CD6 | sat | 8 | col54 | dye | 1 | 10:12 | 13.32 | 0.075 | 4.505 |
| 10-Apr-15 | 18 | CD2 | sat | 8 | col 36 | dye | 2 | 10:15 | 13.63 | 0.073 | 4.402 |
| 13-Apr-15 | 19 | CD2 | sat | 14 | pink par 0469 | dye | 2 | 11:45 | 11.35 | 0.088 | 5.286 |
| 14-Apr-15 | 20 | CD2 | sat | 14 | yellow | dye | 1 | 12:33 | 12.16 | 0.082 | 4.934 |
| 14-Apr-15 | 21 | CD1 | sat | 25 | col54 | dye | 1 | 12:36 | 12.48 | 0.080 | 4.808 |
| 15-Apr-15 | 22 | CD2 | sat | 33 | grey | dye | 1 | 15:15 | 13.73 | 0.073 | 4.370 |
| 21-Apr-15 | 23 | CD2 | dbl spkl | 4 | col 12 | dye | 1 | 10:45 | 12.73 | 0.079 | 4.713 |
| 21-Apr-15 | 24 | CD1 | dbl spkl | 4 | Cream | dye | 1 | 10:48 | 13.18 | 0.076 | 4.552 |
| 21-Apr-15 | 25 | CD6 | dbl spkl | 4 | Cream | dye | 2 | 11:55 | 12.93 | 0.077 | 4.640 |
| 22-Apr-15 | 26 | CD2 | sat | 25 | blue par 1418 | dye | 1 | 12:51 | 13.37 | 0.075 | 4.488 |
| 22-Apr-15 | 27 | CD6 | dbl spkl | 3 | Aqua | dye | 2 | 13:05 | 12.88 | 0.078 | 4.658 |
| 22-Apr-15 | 28 | CD1 | sat | 25 | col32 | dye | 1 | 14:25 | 13.28 | 0.075 | 4.518 |
| 05-May-15 | 29 | CD2 | sat | 14 | camel gold | dye | 1 | 6:30 | 14.55 | 0.069 | 4.124 |
| 05-May-15 | 30 | CD1 | sat | 25 | col33 | dye | 1 | 11:06 | 14.44 | 0.069 | 4.155 |

| Rolling Observed Machine Element Time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Obs # | M/c # | Tapes type | Width (mm) | Colour | Process | qty on M/c (meters on roll) | Time of the observation | Run Speed (m/min) | Run time per unit (min) | Run time per unit (sec) |
| 16-Mar-15 | 1 | RL4 | sat | 10 | new camel 31 | roll | 500 | 9:30 | 170.3 | 0.006 | 0.352 |
| 16-Mar-15 | 2 | RL4 | dbl spkl | 3 | charcoal | roll | 500 | 10:27 | 183.6 | 0.005 | 0.327 |
| 16-Mar-15 | 3 | RL4 | dbl spkl | 3 | burgundy | roll | 500 | 11:40 | 126 | 0.008 | 0.476 |
| 16-Mar-15 | 4 | RL4 | sat | 14 | col grey | roll | 500 | 12:25 | 273.4 | 0.004 | 0.219 |
| 17-Mar-15 | 5 | RL4 | dbl spkl | 3 | red col 11 | roll | 500 | 9:03 | 117.935 | 0.008 | 0.509 |
| 18-Mar-15 | 6 | RL4 | dbl spkl | 3 | off white | roll | 500 | 13:45 | 119.65 | 0.008 | 0.501 |
| 24-Mar-15 | 7 | RL4 | dbl spkl | 3 | fantango pink | roll | 500 | 12:21 | 201.15 | 0.005 | 0.298 |
| 26-Mar-15 | 8 | RL4 | sat | 8 | col 54 | roll | 200 | 20:10 | 151.805 | 0.007 | 0.395 |
| 27-Mar-15 | 9 | RL4 | dbl spkl | 3 | white 01 | roll | 500 | 14:25 | 198.8 | 0.005 | 0.302 |
| 30-Mar-15 | 10 | RL4 | sat | 6 | grey | roll | 150 | 15:11 | 213.9 | 0.005 | 0.281 |
| 1-Apr-15 | 11 | RL4 | dbl spkl | 4 | cerise 53 | roll | 500 | 12:01 | 134.64 | 0.007 | 0.446 |
| 7-Apr-15 | 12 | RL4 | sat | 6 | grey | roll | 500 | 10:38 | 255.55 | 0.004 | 0.235 |
| 7-Apr-15 | 13 | RL4 | sat | 6 | grey | roll | 500 | 12:19 | 253.55 | 0.004 | 0.237 |
| 7-Apr-15 | 14 | RL4 | sat | 6 | grey | roll | 500 | 14:20 | 271.4 | 0.004 | 0.221 |
| 8-Apr-15 | 15 | RL3 | sat | 6 | white | roll | 500 | 9:49 | 165.165 | 0.006 | 0.363 |
| 8-Apr-15 | 16 | RL4 | sat | 10 | Aztec blue | roll | 500 | 9:51 | 264.95 | 0.004 | 0.226 |
| 8-Apr-15 | 17 | RL4 | dbl spkl | 3 | silver | roll | 500 | 11:06 | 177.55 | 0.006 | 0.338 |
| 8-Apr-15 | 18 | RL4 | dbl spkl | 3 | silver | roll | 500 | 11:56 | 120.6 | 0.008 | 0.498 |
| 8-Apr-15 | 19 | RL4 | sat | 6 | grey | roll | 150 | 14:13 | 200.3 | 0.005 | 0.300 |
| 8-Apr-15 | 20 | RL4 | dbl spkl | 4 | navy 10 | roll | 500 | 14:20 | 218.5 | 0.005 | 0.275 |
| 9-Apr-15 | 21 | RL4 | sat | 10 | dark grey 52 | roll | 500 | 14:25 | 263.15 | 0.004 | 0.228 |
| 9-Apr-15 | 22 | RL4 | sat | 10 | dark grey 52 | roll | 500 | 14:57 | 186.3 | 0.005 | 0.322 |
| 13-Apr-15 | 23 | RL8 | sat | 6 | lemon 4 | roll | 200 | 12:24 | 185.665 | 0.005 | 0.323 |
| 21-Apr-15 | 24 | RL4 | dbl spkl | 3 | charcoal par 020953 | roll | 500 | 11:37 | 271.7 | 0.004 | 0.221 |
| 22-Apr-15 | 25 | RL4 | dbl spkl | 4 | white01 | roll | 500 | 12:25 | 125.8 | 0.008 | 0.477 |
| 22-Apr-15 | 26 | RL3 | dbl spkl | 4 | col15 | roll | 500 | 13:18 | 167.335 | 0.006 | 0.359 |
| 22-Apr-15 | 27 | RL4 | dbl spkl | 6 | grey32 | roll | 500 | 14:05 | 166.95 | 0.006 | 0.359 |
| 22-Apr-15 | 28 | RL4 | dbl spkl | 6 | grey32 | roll | 500 | 15:02 | 220.55 | 0.005 | 0.272 |
| 5-May-15 | 29 | RL3 | dbl spkl | 3 | red col 11 | roll | 500 | 10:21 | 187.68 | 0.005 | 0.320 |
| 5-May-15 | 30 | RL4 | sat | 6 | m. purple par 017863 | roll | 500 | 10:24 | 212.6 | 0.005 | 0.282 |

**Appendix D**

Time Study

| Formula | Unit |
|---|---|
| Distribut.= distribution based on observed times | seconds |
| Dist. Of Freq.= distribution of frequency with which the element occurs over the number of cycles | count |
| BMV= (Distribut.) x (Dist. Of Freq.) | seconds |
| VRA= 15% as fixed by the company | percent |
| SMV= BMV + (15% of BMV) | std seconds |
| [Σ(SMV)]/60= standard time | std minutes |
| R= Standard rating (100% as measured by the company) | % |
| O= Observed time | seconds |
| N= Normal time [O x (100% / R)] | seconds |
| BP= Breaking point | |

**1 SALES COORDINATOR LOADS ORDER** — TIME STUDY SHEET 1

Analyst: Hory Chikez | Resource: 2 Sales coordinators | Batch size: 15 orders

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Receive order and load order on the system | R | 100% | 100% | 100% | 100% | 100% | 310 | 1 | 310.000 | 15% | 356.500 | ● | |
| | | O | 180 | 270 | 480 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous Time |
|---|---|---|---|---|
| | 356.5 | Std seconds per order | 1 | 0 |
| | 5.9 | Std minutes per order | Total Count | |
| | 83.3 | Orders per day | | |

**2 TAKE ORDER TO PLANNER** — TIME STUDY SHEET 2

Analyst: Hory Chikez | Resource: Sales coordinator | Batch size: Order form_not physical

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Take order to planner | R | 100% | 100% | 100% | 100% | 100% | 155 | 1 | 155 | 15% | 178.250 | ● | |
| | | O | 45 | 120 | 300 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous Time |
|---|---|---|---|---|
| | 178.3 | Std seconds per order | 1 | 0 |
| | 3.0 | Std minutes per order | Total Count | |
| | 166.6 | Orders per day | | |

**3 PLANNER CREATES REQUISITION NOTE** — TIME STUDY SHEET 3

Analyst: Hory Chikez | Resource: Planner | Batch size: Requisition note_not physical

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Planner creates requisition for undyed yarn | R | 100% | 100% | 100% | 100% | 100% | 180 | 1 | 180.0 | 15% | 207.0 | ● | |
| | | O | 120 | 180 | 240 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous Time |
|---|---|---|---|---|
| | 207.0 | Std seconds per requisition | 1 | 0 |
| | 3.5 | Std minutes per requisition | Total Count | |
| | 143.5 | Requisitions per day | | |

**4 TAKE REQ. TO YARN STORE** — TIME STUDY SHEET 4

Analyst: Hory Chikez | Resource: Planner | Batch size: Order form_not physical

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Take requisition to yarn store | R | 100% | 100% | 100% | 100% | 100% | 120 | 1 | 120.0 | 15% | 138.0 | ● | |
| | | O | 60 | 120 | 180 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous Time |
|---|---|---|---|---|
| | 138.0 | Std seconds per req. | 1 | 0 |
| | 2.3 | Std minutes per req. | Total Count | |
| | 215.2 | Req. per day | | |

**5 PROCESS REQUISITION OF YARN** — TIME STUDY SHEET 5

Analyst: Hory Chikez | Resource: Yarn Storeman | Batch size: Order form_not physical

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Process requisition | R | 100% | 100% | 100% | 100% | 100% | 150 | 1 | 150.0 | 15% | 172.5 | ● | |
| | | O | 90 | 120 | 240 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous Time |
|---|---|---|---|---|
| | 172.5 | Std seconds per req. | 1 | 0 |
| | 2.9 | Std minutes per req. | Total Count | |
| | 172.2 | Requisitions per day | | |

**6 TAKE YARN TO WARPING AREA** — **TIME STUDY SHEET 6**

Analyst: Hory Chikez | Resource: Yarn storeman | Batch size: 1 Load = approx. 12 boxes of yarn = 156 yarns

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Transport boxes of yarn to warping area, as per the requisition | R | 100% | 100% | 100% | 100% | 100% | 480 | 1 | 480.0 | 15% | 552.0 | ● | |
| | | O | 360 | 480 | 600 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | 552.0 | Std seconds per load | 1 | 0 |
|---|---|---|---|---|---|
| | | 9.2 | Std minutes per load | Total Count | |
| | | 53.8 | Loads per day | | |

**7 WARPING SETUP** — **TIME STUDY SHEET 7**

Analyst: Hory Chikez | Resource: Warping machines 1 and Warping machine 2 | Batch size between: 8000 12000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run Time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Setup | R | 100% | 100% | 100% | 100% | 100% | 14100 | 1 | 14100 | 15% | 16215.000 | ● | |
| | | O | 1800 | 10800 | 29700 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | 16215 | Std seconds per setup | 1 | 0 |
|---|---|---|---|---|---|
| | | 270 | Std minutes per setup | Total Count | |
| | | 1.8 | Setups per day | | |

**7 WARPING** — **TIME STUDY SHEET 7**

Analyst: Hory Chikez | Resource: Warping machines 1 and Warping machine 2 | Batch size between: 8000 12000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run Time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Load beam on machine and lock beam holder | R | 100% | 100% | 100% | 100% | 100% | 50 | 0.0001 | 0.005 | 15% | 0.006 | | ● |
| | | O | 48 | 49 | 53 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Remove and throw away debris of previous work from beam | R | 100% | 100% | 100% | 100% | 100% | 18 | 0.0001 | 0.002 | 15% | 0.002 | | ● |
| | | O | 13 | 18 | 22 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 3 | Place clamp on the machine and clamp the beam | R | 100% | 100% | 100% | 100% | 100% | 45 | 0.0001 | 0.004 | 15% | 0.005 | | ● |
| | | O | 39 | 40 | 55 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 4 | Place ends over empty beam and turn it around for first layer, and adjust | R | 100% | 100% | 100% | 100% | 100% | 67 | 0.0001 | 0.007 | 15% | 0.008 | | ● |
| | | O | 47 | 73 | 80 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 5 | Adjust the reed to the correct size of the beam width | R | 100% | 100% | 100% | 100% | 100% | 21 | 0.0001 | 0.002 | 15% | 0.002 | | ● |
| | | O | 13 | 16 | 33 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 6 | Type number of meters to be warped on warper control board | R | 100% | 100% | 100% | 100% | 100% | 13 | 0.0001 | 0.001 | 15% | 0.001 | | ● |
| | | O | 10 | 14 | 15 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 7 | Fetch blue pressure roller | R | 100% | 100% | 100% | 100% | 100% | 28 | 0.0001 | 0.003 | 15% | 0.003 | | ● |
| | | O | 27 | 27 | 31 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 8 | Place blue pressure roller on beam and adjust | R | 100% | 100% | 100% | 100% | 100% | 85 | 0.0001 | 0.008 | 15% | 0.010 | | ● |
| | | O | 80 | 86 | 88 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 9 | Warping | R | 100% | 100% | 100% | 100% | 100% | 0.234 | 1 | 0.234 | 15% | 0.269 | ● | |
| | | O | | | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 10 | Cut and tie up finished warp | R | 100% | 100% | 100% | 100% | 100% | 122 | 0.0001 | 0.012 | 15% | 0.014 | | ● |
| | | O | 117 | 120 | 129 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 11 | Put a cross in the warp | R | 100% | 100% | 100% | 100% | 100% | 79 | 0.0001 | 0.008 | 15% | 0.009 | | ● |
| | | O | 75 | 79 | 82 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 12 | Throw away debris from cross | R | 100% | 100% | 100% | 100% | 100% | 7 | 0.0001 | 0.001 | 15% | 0.001 | | ● |
| | | O | 5 | 8 | 8 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 13 | Remove clamp holding the beam, lower the beam and remove it from machine | R | 100% | 100% | 100% | 100% | 100% | 28 | 0.0001 | 0.003 | 15% | 0.003 | | ● |
| | | O | 20 | 25 | 40 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 14 | Remove warp and Place on the side of machine | R | 100% | 100% | 100% | 100% | 100% | 12 | 0.0001 | 0.001 | 15% | 0.001 | | ● |
| | | O | 10 | 12 | 14 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 15 | Fill in warp ID ticket, cut it and place on finished warp | R | 100% | 100% | 100% | 100% | 100% | 16 | 0.0001 | 0.002 | 15% | 0.002 | | ● |
| | | O | 15 | 15 | 18 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | 0.337 | Std seconds per meter | 1 | 14 |
|---|---|---|---|---|---|
| | | 0.006 | Std minutes per meter | Total Count | |
| | | 88243.3 | Meters per day | | |

**8 TRANSPORT WARPS TO WARP RACK** — **TIME STUDY SHEET 8**

Analyst: Hory Chikez | Resource: Warpers | Batch size: 1 Warp at a time

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Take warp to rack | R | 100% | 100% | 100% | 100% | 100% | 130 | 1 | 130.000 | 15% | 149.500 | ● | |
| | | O | 90 | 120 | 180 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | 149.500 | Std seconds per warp | 1 | 0 |
|---|---|---|---|---|---|
| | | 2.492 | Std minutes per warp | Total Count | |
| | | 198.7 | Warp per day | | |

**9 WEAVING SETUP** — TIME STUDY SHEET 9

Analyst: Hory Chikez | Resource: 432 looms | Batch size between: 8000 12000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Setup (Qulaity change, Knotting, Drawing) | R | 100% | 100% | 100% | 100% | 100% | 49133 | 1 | 49133 | 15% | 56503 | • | |
| | | O | 3600 | 5200 | 138600 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | | | |
|---|---|---|---|---|
| | | 56503 | Std seconds per setup | 1 / 0 |
| | | 942 | Std minutes per setup | Total Count |
| | | 1 | Setups per day | |

**9 WEAVING** — TIME STUDY SHEET 9

Analyst: Hory Chikez | Resource: 432 looms | Batch size between: 8000 12000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bring and place empty boxes / bags close to machine to collect finished product | R | 100% | 100% | 100% | 100% | 100% | 94 | 0.001 | 0.094 | 15% | 0.108 | | • |
| | | O | 68 | 93 | 120 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Write up and place notification stickers on the boxes | R | 100% | 100% | 100% | 100% | 100% | 418 | 0.001 | 0.418 | 15% | 0.480 | | • |
| | | O | 300 | 453 | 500 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 3 | Weaving operation | R | 100% | 100% | 100% | 100% | 100% | 85 | 1.000 | 85.094 | 15% | 97.858 | • | |
| | | O | | | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 4 | Weaver takes full boxes of finished material to corridor space | R | 100% | 100% | 100% | 100% | 100% | 118 | 0.001 | 0.118 | 15% | 0.136 | | • |
| | | O | 89 | 115 | 150 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | | | |
|---|---|---|---|---|
| | | 99 | Std seconds per meter | 1 / 3 |
| | | 2 | Std minutes per meter | |
| | | 703 | Meters per day | |

**10 TRANSPORT TAPES FROM LOOMS TO SCALE** — TIME STUDY SHEET 10

Analyst: Hory Chikez | Resource: WIP storeman | Batch size: 1 load = 1 to 10 bags/box = 2000 to 50000 mtrs

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Moving work from looms to electronic scale | R | 100% | 100% | 100% | 100% | 100% | 340 | 1 | 340.0 | 15% | 391.0 | • | |
| | | O | 120 | 300 | 600 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | | | |
|---|---|---|---|---|
| | | 391.0 | Std seconds per load | 1 / 0 |
| | | 6.5 | Std minutes per load | Total Count |
| | | 76.0 | Loads per day | |

**11 WEIGH THE TAPES** — TIME STUDY SHEET 11

Analyst: Hory Chikez | Resource: WIP storeman | Batch size: 1 load = 1 to 10 bags/box = 2000 to 50000 mtrs

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Weigh work | R | 100% | 100% | 100% | 100% | 100% | 510 | 1 | 510.0 | 15% | 586.5 | • | |
| | | O | 150 | 480 | 900 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | | | |
|---|---|---|---|---|
| | | 586.5 | Std seconds per load | 1 / 0 |
| | | 9.8 | Std minutes per load | Total Count |
| | | 50.6 | Loads per day | |

**12 MOVE TAPES FROM SCALE TO SPOOLING M/Cs** — TIME STUDY SHEET 12

Analyst: Hory Chikez | Resource: WIP storeman | Batch size: 1 load = 1 to 10 bags/box = 2000 to 50000 mtrs

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Moving tapes from scale to spooling area | R | 100% | 100% | 100% | 100% | 100% | 170 | 1 | 170.0 | 15% | 195.5 | • | |
| | | O | 90 | 120 | 300 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | | | |
|---|---|---|---|---|
| | | 195.5 | Std seconds per load | 1 / 0 |
| | | 3.3 | Std minutes per load | Total Count |
| | | 151.9 | Loads per day | |

**13 SPOOLING SETUP** — TIME STUDY SHEET 13

Analyst: Hory Chikez | Resource: 5 spooling machines | Batch size between: 500 3500 Meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mount spool on M/C and place material on spool | R | 100% | 100% | 100% | 100% | 100% | 12 | 1.0 | 12.333 | 15% | 14.183 | • | |
| | | O | 10 | 12 | 15 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

| REMARKS: | Grand Totals | | | |
|---|---|---|---|---|
| | | 14.183 | Std seconds per setup | 1 / 0 |
| | | 0.236 | Std minutes per setup | Total Count |
| | | 2094.0 | Setups per day | |

| 13 SPOOLING | | | | | | | | | | | | | | TIME STUDY SHEET 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyst: | Hory Chikez | Resource: 5 spooling machines | | | | | | | | Batch size between: | | 500 | 3500 | Meters |
| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) | | | | | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous Time |
| | | | 1 | 2 | 3 | 4 | 5 | | | | | | | |
| 1 | Move box to area close to rail | R | 100% | 100% | 100% | 100% | 100% | 28 | 0.0001 | 0.002 | 15% | 0.002 | | ● |
| | | O | 20 | 25 | 38 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Fetch Spools and order | R | 100% | 100% | 100% | 100% | 100% | 17 | 0.0005 | 0.009 | 15% | 0.010 | | ● |
| | | O | 14 | 16 | 21 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 3 | Stop and fix tangled material | R | 100% | 100% | 100% | 100% | 100% | 35 | 0.0005 | 0.018 | 15% | 0.020 | | ● |
| | | O | 6 | 30 | 70 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 4 | Remove waste | R | 100% | 100% | 100% | 100% | 100% | 68 | 0.0005 | 0.034 | 15% | 0.039 | | ● |
| | | O | 25 | 60 | 120 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 5 | Stop M/C for joint | R | 100% | 100% | 100% | 100% | 100% | 60 | 0.0005 | 0.030 | 15% | 0.034 | | ● |
| | | O | 30 | 60 | 89 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 6 | Remove spool and place on the floor | R | 100% | 100% | 100% | 100% | 100% | 14 | 0.0005 | 0.007 | 15% | 0.008 | | ● |
| | | O | 12 | 14 | 16 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 7 | Remove boxes to create space | R | 100% | 100% | 100% | 100% | 100% | 34 | 0.0001 | 0.002 | 15% | 0.002 | | ● |
| | | O | 25 | 33 | 45 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 8 | Spooling process | R | 100% | 100% | 100% | 100% | 100% | 0 | 1 | 0.254 | 15% | 0.292 | ● | |
| | | O | | | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 9 | Spooling operator weighs finished spool | R | 100% | 100% | 100% | 100% | 100% | 68 | 0.0005 | 0.034 | 15% | 0.039 | | ● |
| | | O | 33 | 60 | 111 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 10 | Spooling operator transports finished spool with dyeing order doc. in finished spools area | R | 100% | 100% | 100% | 100% | 100% | 54 | 0.0005 | 0.027 | 15% | 0.031 | | ● |
| | | O | 25 | 50 | 88 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | | 0.478 | Std seconds per meter | | | 1 | 9 |
| | | | | | | | | | 0.008 | Std minutes per meter | | | Total Count | |
| | | | | | | | | | 62085.7 | Meters per day | | | | |

| 14 MOVE SPOOLS TO DYEING MACHINES | | | | | | | | | | | | | | TIME STUDY SHEET 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyst: | Hory Chikez | Resource: Dyeing machines foreman | | | | | | | | Batch size: 1 load = 1 to 5 spools = 500 to 10000 meters | | | | |
| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) | | | | | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
| | | | 1 | 2 | 3 | 4 | 5 | | | | | | | |
| 1 | Move spools to dyeing machines | R | 100% | 100% | 100% | 100% | 100% | 135 | 1 | 135.0 | 15% | 155.3 | ● | |
| | | O | 60 | 135 | 210 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | | 155.3 | Std seconds per load | | | 1 | 0 |
| | | | | | | | | | 2.6 | Std minutes per load | | | Total Count | |
| | | | | | | | | | 191.3 | Loads per day | | | | |

| 15(a) DYEING DARK SHADES SETUP | | | | | | | | | | | | | | TIME STUDY SHEET 15(a) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyst: | Hory Chikez | Resource: 3 machines x 2 tapes per machine | | | | | | | | Batch size between: | | 500 | 3500 | meters |
| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) | | | | | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
| | | | 1 | 2 | 3 | 4 | 5 | | | | | | | |
| 1 | Mount spool on machine, prepare dye stuff in the dyeing kitchen, and start machine | R | 100% | 100% | 100% | 100% | 100% | 767 | 1.0 | 766.667 | 15% | 881.667 | ● | |
| | | O | 200 | 900 | 1200 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | | 881.667 | Std seconds per setup | | | 1 | 0 |
| | | | | | | | | | 14.694 | Std minutes per setup | | | Total Count | |
| | | | | | | | | | 78.6 | Setups per day | | | | |

## 15(a) DYEING DARK SHADES — TIME STUDY SHEET 15(a)

Analyst: Hory Chikez | Resource: 3 machines x 2 tapes per machine | Batch size between: 500 3500 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Collect empty boxes/crates for finished work | R | 100% | 100% | 100% | 100% | 100% | 19 | 0.0005 | 0.010 | 15% | 0.011 | | ● |
| | | O | 12 | 20 | 25 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Clean the drums to remove spots | R | 100% | 100% | 100% | 100% | 100% | 316 | 0.0005 | 0.158 | 15% | 0.182 | | ● |
| | | O | 248 | 300 | 400 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 3 | Start the machine and wait for the drums to heatup | R | 100% | 100% | 100% | 100% | 100% | 6600 | 0.0000 | 0.110 | 15% | 0.127 | | ● |
| | | O | 6000 | 7200 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 4 | Clean bucket at machine | R | 100% | 100% | 100% | 100% | 100% | 527 | 0.0005 | 0.263 | 15% | 0.303 | | ● |
| | | O | 480 | 500 | 600 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 5 | Fetch dye stuff from dyehouse | R | 100% | 100% | 100% | 100% | 100% | 487 | 0.0000 | 0.016 | 15% | 0.019 | | ● |
| | | O | 360 | 400 | 700 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 6 | Final tuning on the machine | R | 100% | 100% | 100% | 100% | 100% | 117 | 0.0015 | 0.175 | 15% | 0.201 | | ● |
| | | O | 50 | 120 | 180 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 7 | Run the machine to make sample (first off) | R | 100% | 100% | 100% | 100% | 100% | 234 | 0.0010 | 0.234 | 15% | 0.269 | | ● |
| | | O | 100 | 368 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 8 | Dyeing process | R | 100% | 100% | 100% | 100% | 100% | 7 | 1.0000 | 6.795 | 15% | 7.814 | ● | |
| | | O | | | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 9 | Readjust colour for continuity (continuity card) | R | 100% | 100% | 100% | 100% | 100% | 137 | 0.0010 | 0.137 | 15% | 0.157 | | ● |
| | | O | 93 | 180 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 10 | Move box of finished work to appropriate area | R | 100% | 100% | 100% | 100% | 100% | 105 | 0.0005 | 0.052 | 15% | 0.060 | | ● |
| | | O | 89 | 120 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | 9.142 | Std seconds per meter | | | | 1 | 9 |
| | | | | | | | | 0.152 | Std minutes per meter | | | | Total Count | |
| | | | | | | | | 7580.5 | Meters per day | | | | | |

## 15(b) DYEING LIGHT SHADES SETUP — TIME STUDY SHEET 15(b)

Analyst: Hory Chikez | Resource: 3 machines x 2 tapes per machine | Batch size between: 500 3500 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mount spool on machine, prepare dye stuff in the dyeing kitchen, and start machine | R | 100% | 100% | 100% | 100% | 100% | 523 | 1 | 523.333 | 15% | 601.833 | ● | |
| | | O | 70 | 300 | 1200 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | 601.833 | Std seconds per setup | | | | 1 | 0 |
| | | | | | | | | 10.031 | Std minutes per setup | | | | Total Count | |
| | | | | | | | | 115.1 | Setups per day | | | | | |

## 15(b) DYEING LIGHT SHADES — TIME STUDY SHEET 15(b)

Analyst: Hory Chikez | Resource: 3 machines x 2 tapes per machine | Batch size between: 500 3500 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Collect empty boxes/crates for finished work | R | 100% | 100% | 100% | 100% | 100% | 23 | 0.0005 | 0.012 | 15% | 0.013 | | ● |
| | | O | 13 | 20 | 36 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Clean the drums to remove spots | R | 100% | 100% | 100% | 100% | 100% | 343 | 0.0005 | 0.171 | 15% | 0.197 | | ● |
| | | O | 248 | 360 | 420 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 3 | Start the machine and wait for the drums to heatup | R | 100% | 100% | 100% | 100% | 100% | 6900 | 0.0000 | 0.115 | 15% | 0.132 | | ● |
| | | O | 6600 | 7200 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 4 | Clean bucket at machine | R | 100% | 100% | 100% | 100% | 100% | 527 | 0.0005 | 0.263 | 15% | 0.303 | | ● |
| | | O | 480 | 500 | 600 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 5 | Fetch dye stuff from dyehouse | R | 100% | 100% | 100% | 100% | 100% | 480 | 0.0000 | 0.016 | 15% | 0.018 | | ● |
| | | O | 360 | 600 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 6 | Final tuning on the machine | R | 100% | 100% | 100% | 100% | 100% | 83 | 0.0015 | 0.125 | 15% | 0.144 | | ● |
| | | O | 50 | 80 | 120 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 7 | Run the machine to make sample (first off) | R | 100% | 100% | 100% | 100% | 100% | 234 | 0.0010 | 0.234 | 15% | 0.269 | | ● |
| | | O | 100 | 368 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 8 | Dyeing process | R | 100% | 100% | 100% | 100% | 100% | 5 | 1.0000 | 4.605 | 15% | 5.296 | ● | |
| | | O | | | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 9 | Readjust colour for continuity (continuity card) | R | 100% | 100% | 100% | 100% | 100% | 137 | 0.0010 | 0.137 | 15% | 0.157 | | ● |
| | | O | 93 | 180 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 10 | Move box of finished work to appropriate area | R | 100% | 100% | 100% | 100% | 100% | 105 | 0.0005 | 0.052 | 15% | 0.060 | | ● |
| | | O | 89 | 120 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| REMARKS: | | | | | | | Grand Totals | 6.590 | Std seconds per meter | | | | 1 | 9 |
| | | | | | | | | 0.110 | Std minutes per meter | | | | Total Count | |
| | | | | | | | | 10516.2 | Meters per day | | | | | |

## 16 MOVE DYED TAPE FROM DYEING M/Cs TO ROLLING — TIME STUDY SHEET 16

Analyst: Hory Chikez | Resource: Rolling foreman | Batch size: 1 load = 1 to 2 boxes = 500 to 10000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Take dyed tapes to rolling station | R | 100% | 100% | 100% | 100% | 100% | 350 | 1 | 350.0 | 15% | 402.5 | • | |
| | | O | 90 | 360 | 600 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous time |
|---|---|---|---|---|
| | 402.5 | Std seconds per load | 1 | 0 |
| | 6.7 | Std minutes per load | Total Count | |
| | 73.8 | Loads per day | | |

## 17 ROLLING SETUP — TIME STUDY SHEET 17

Analyst: Hory Chikez | Resource: 2 rolling machines | Batch size between: 200 500 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mount roll machine | R | 100% | 100% | 100% | 100% | 100% | 22 | 1 | 21.667 | 15% | 24.917 | • | |
| | | O | 15 | 20 | 30 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous time |
|---|---|---|---|---|
| | 24.917 | Std seconds per setup | 1 | 0 |
| | 0.415 | Std minutes per setup | Total Count | |
| | 1192.0 | Setups per day | | |

## 17 ROLLING — TIME STUDY SHEET 17

Analyst: Hory Chikez | Resource: 2 rolling machines | Batch size between: 200 500 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Rolling operator moves dyed work closer to rolling machine | R | 100% | 100% | 100% | 100% | 100% | 59 | 0.0001 | 0.006 | 15% | 0.006 | | • |
| | | O | 30 | 60 | 88 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 2 | Rolling operator collects working equipment (sello tape, tickets) from office, core | R | 100% | 100% | 100% | 100% | 100% | 103 | 0.0001 | 0.010 | 15% | 0.011 | | • |
| | | O | 94 | 111 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 3 | Rolling | R | 100% | 100% | 100% | 100% | 100% | 0.329 | 1.0000 | 0.329 | 15% | 0.378 | • | |
| | | O | | | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 4 | Remove roll from machine and place on bench | R | 100% | 100% | 100% | 100% | 100% | 18 | 0.0029 | 0.050 | 15% | 0.058 | | • |
| | | O | 8 | 15 | 30 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 5 | Write up tickets and stick to work | R | 100% | 100% | 100% | 100% | 100% | 50 | 0.0029 | 0.143 | 15% | 0.164 | | • |
| | | O | 40 | 60 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |
| 6 | Untagnle work | R | 100% | 100% | 100% | 100% | 100% | 108 | 0.0029 | 0.309 | 15% | 0.355 | | • |
| | | O | 96 | 120 | | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous time |
|---|---|---|---|---|
| | 0.973 | Std seconds per meter | 1 | 5 |
| | 0.016 | Std minutes per meter | Total Count | |
| | 30515.4 | Meters per day | | |

## 18 MOVE ROLLED TAPES TO INSPECTION BAY — TIME STUDY SHEET 18

Analyst: Hory Chikez | Resource: Quality inspection officer | Batch size: 1 load = 3 to 50 rolls = 1500 to 20000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Move work from rolling benches to inspection bay | R | 100% | 100% | 100% | 100% | 100% | 150 | 1 | 150.0 | 15% | 172.5 | • | |
| | | O | 90 | 120 | 240 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous time |
|---|---|---|---|---|
| | 172.5 | Std seconds per load | 1 | 0 |
| | 2.9 | Std minutes per load | Total Count | |
| | 172.2 | Loads per day | | |

## 19 INSPECTION — TIME STUDY SHEET 19

Analyst: Hory Chikez | Resource: Quality inspection officer | Batch size: 1 load = 3 to 50 rolls = 1500 to 20000 meters

| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Inspect ion of the work | R | 100% | 100% | 100% | 100% | 100% | 410 | 2 | 820.0 | 15% | 943.0 | • | |
| | | O | 150 | 420 | 660 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

REMARKS:

| Grand Totals | | | Run time | Miscellaneous time |
|---|---|---|---|---|
| | 943.0 | Std seconds per load | 1 | 0 |
| | 15.7 | Std minutes per load | Total Count | |
| | 31.5 | Loads per day | | |

## 20 TAKE INSPECTED ROLLS TO FINISHED GOODS STORE — TIME STUDY SHEET 20

Analyst: Hory Chikez | Resource: Quality inspection officer | Batch size: 1 load = 3 to 50 rolls = 1500 to 20000 meters

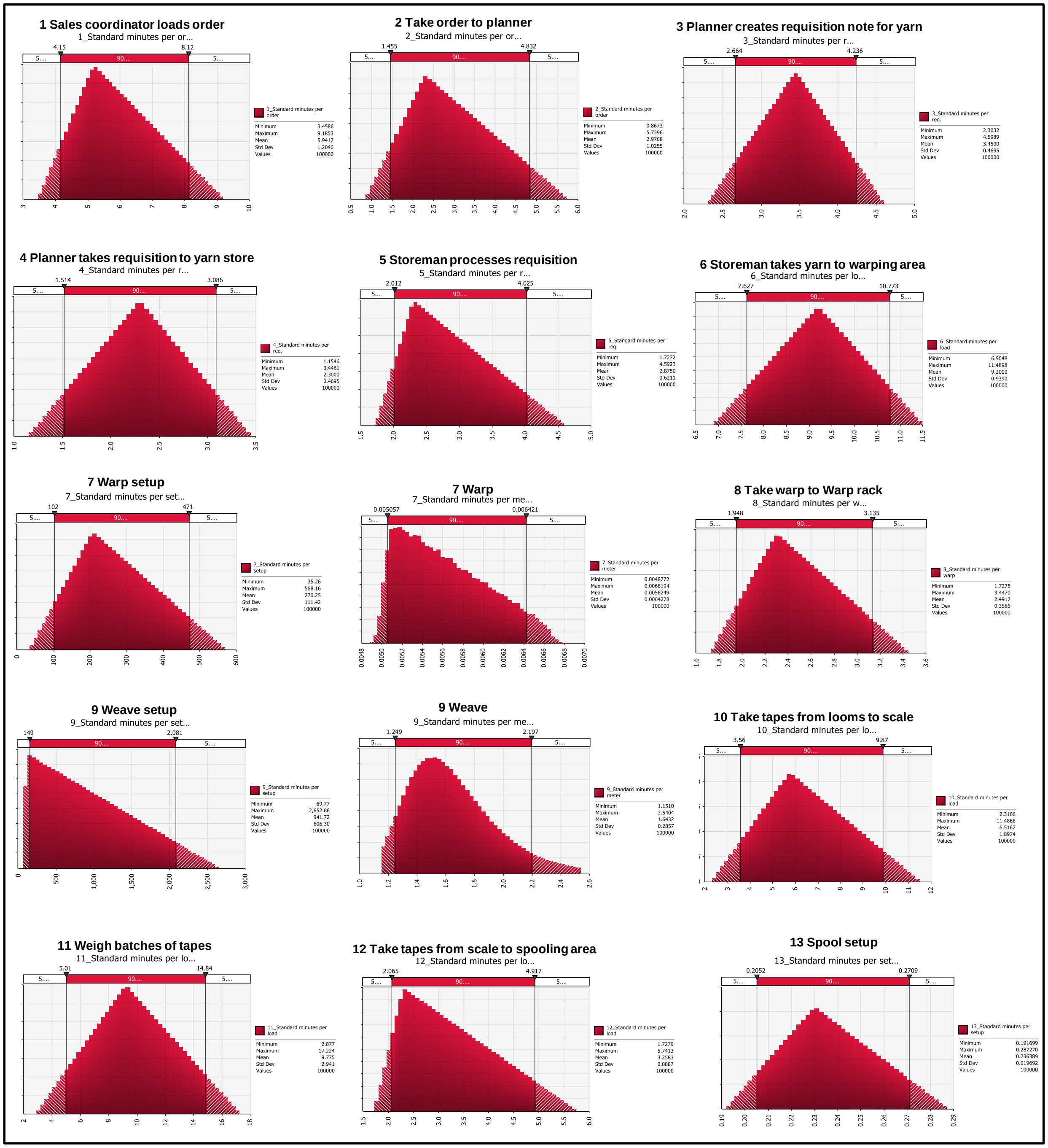
| Elem. No | ELEMENT BREAKDOWN AND DESCRIPTION | | ELEMENTAL TIMES (seconds) 1 | 2 | 3 | 4 | 5 | Distribut. (seconds) | Dist. Of Freq. | BMV (seconds) | VRA% 1.15 | SMV (seconds) | Run time | Miscellaneous time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Move inspected rolls to finished goods store | R | 100% | 100% | 100% | 100% | 100% | 180 | 1 | 180.0 | 15% | 207.0 | • | |
| | | O | 60 | 180 | 300 | | | | | | | | | |
| | B.P: | N | | | | | | | | | | | | |

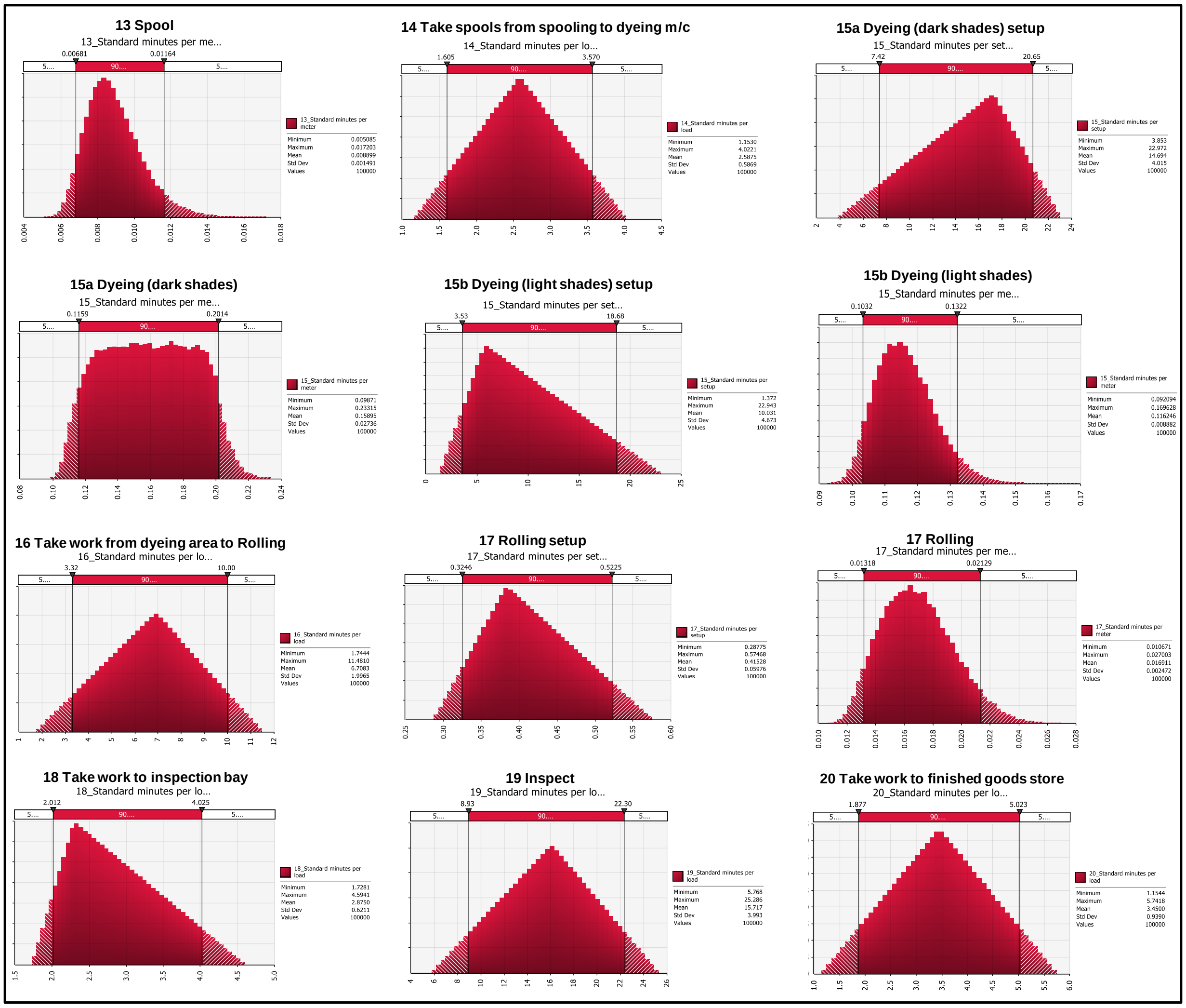
REMARKS:

| Grand Totals | | | Run time | Miscellaneous time |
|---|---|---|---|---|
| | 207.0 | Std seconds per load | 1 | 0 |
| | 3.5 | Std minutes per load | Total Count | |
| | 143.5 | Loads per day | | |

**Appendix E**

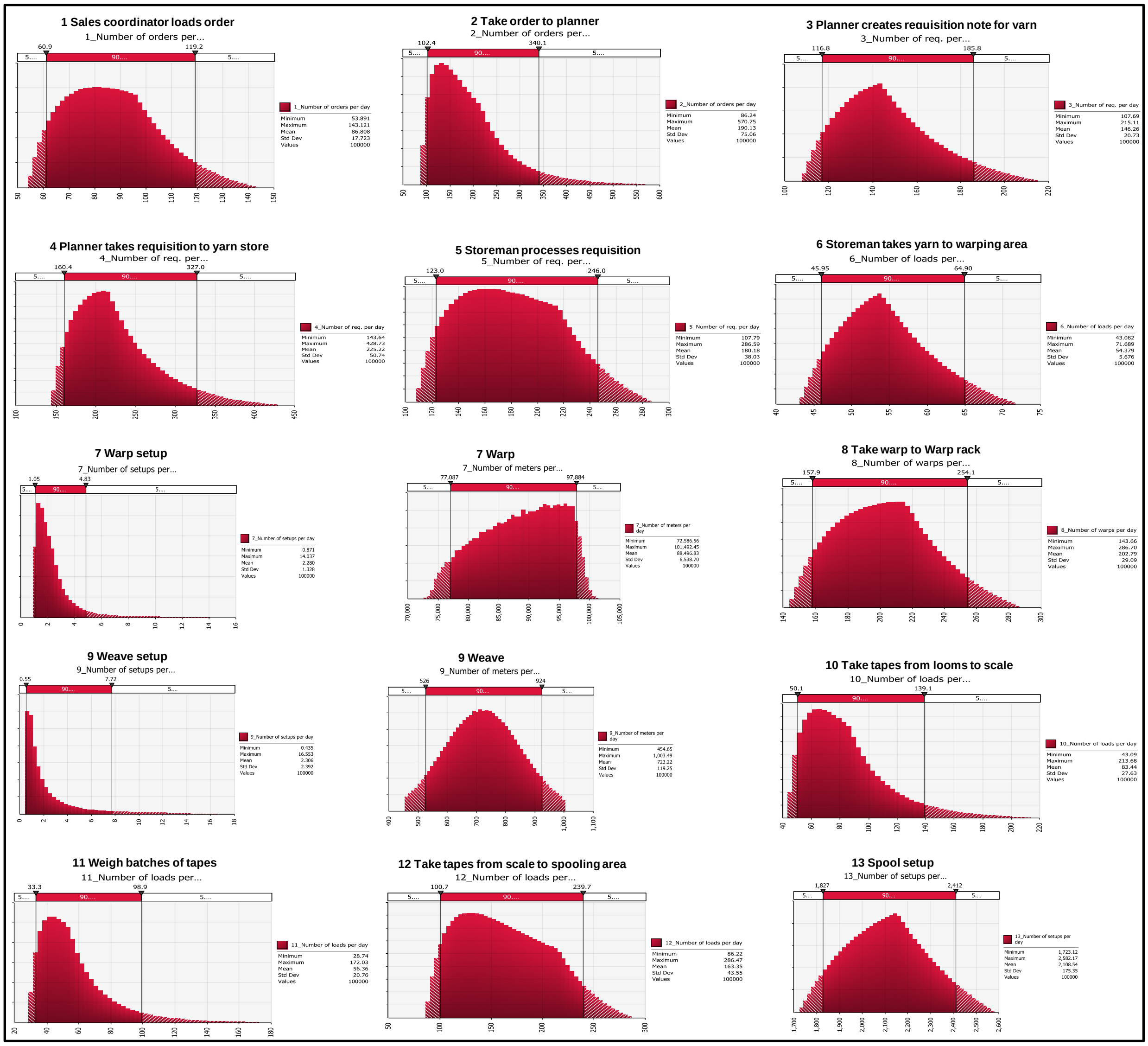
Standard time per unit

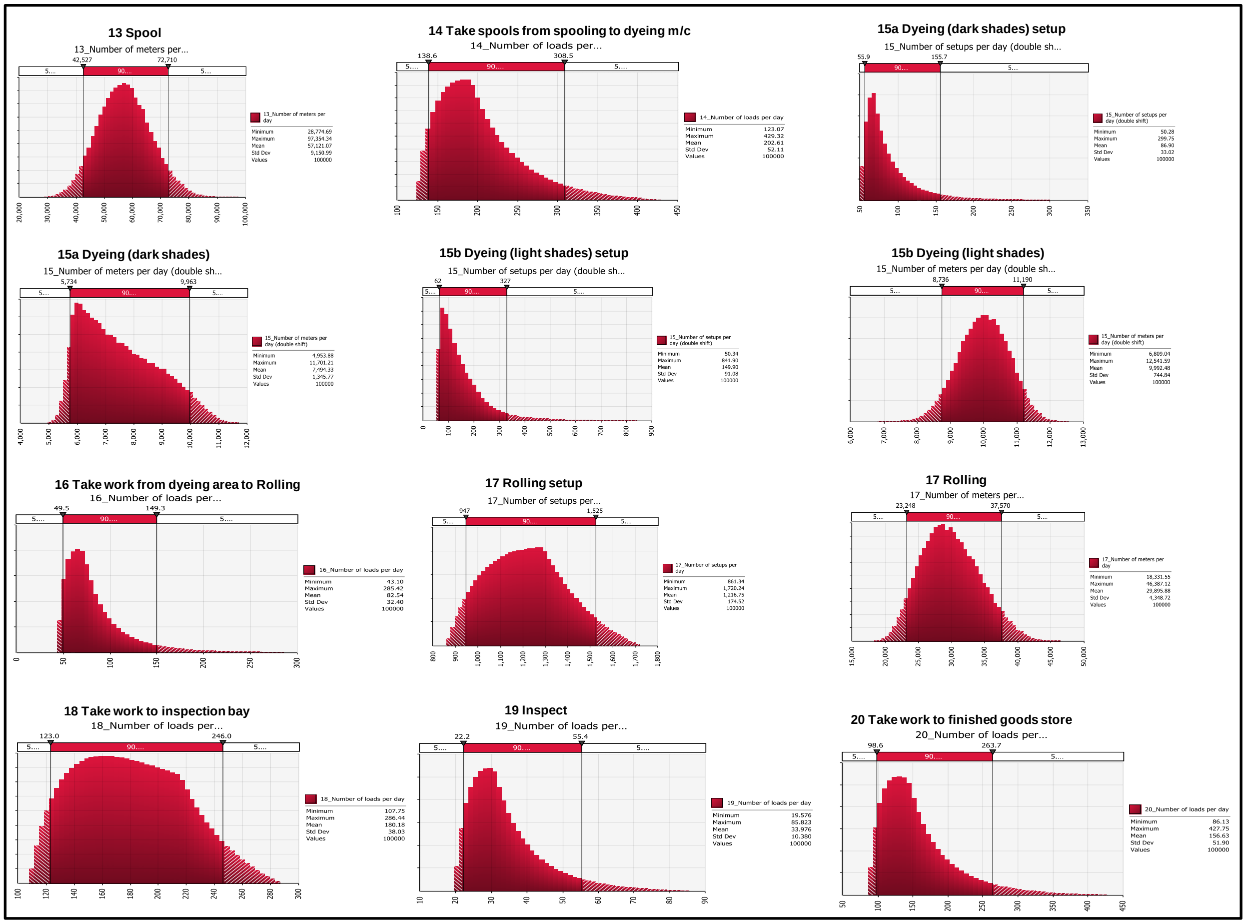

1 Sales coordinator loads order
1_Standard minutes per or...
2 Take order to planner
2_Standard minutes per or...
3 Planner creates requisition note for yarn
3_Standard minutes per r...
4 Planner takes requisition to yarn store
4_Standard minutes per r...
5 Storeman processes requisition
5_Standard minutes per r...
6 Storeman takes yarn to warping area
6_Standard minutes per lo...
7 Warp setup
7_Standard minutes per set...
7 Warp
7_Standard minutes per me...
8 Take warp to Warp rack
8_Standard minutes per w...
9 Weave setup
9_Standard minutes per set...
9 Weave
9_Standard minutes per me...
10 Take tapes from looms to scale
10_Standard minutes per lo...
11 Weigh batches of tapes
11_Standard minutes per lo...
12 Take tapes from scale to spooling area
12_Standard minutes per lo...
13 Spool setup
13_Standard minutes per set...


13 Spool
13_Standard minutes per me...
0.00681
0.01164
13_Standard minutes per meter
Minimum 0.005085
Maximum 0.017203
Mean 0.008899
Std Dev 0.001491
Values 100000
14 Take spools from spooling to dyeing m/c
14_Standard minutes per lo...
1.605
3.570
14_Standard minutes per load
Minimum 1.1530
Maximum 4.0221
Mean 2.5875
Std Dev 0.5869
Values 100000
15a Dyeing (dark shades) setup
15_Standard minutes per set...
7.42
20.65
15_Standard minutes per setup
Minimum 3.853
Maximum 22.972
Mean 14.694
Std Dev 4.015
Values 100000
15a Dyeing (dark shades)
15_Standard minutes per me...
0.1159
0.2014
15_Standard minutes per meter
Minimum 0.09871
Maximum 0.23315
Mean 0.15895
Std Dev 0.02736
Values 100000
15b Dyeing (light shades) setup
15_Standard minutes per set...
3.53
18.68
15_Standard minutes per setup
Minimum 1.372
Maximum 22.943
Mean 10.031
Std Dev 4.673
Values 100000
15b Dyeing (light shades)
15_Standard minutes per me...
0.1032
0.1322
15_Standard minutes per meter
Minimum 0.092094
Maximum 0.169628
Mean 0.116246
Std Dev 0.008882
Values 100000
16 Take work from dyeing area to Rolling
16_Standard minutes per lo...
3.32
10.00
16_Standard minutes per load
Minimum 1.7444
Maximum 11.4810
Mean 6.7083
Std Dev 1.9965
Values 100000
17 Rolling setup
17_Standard minutes per set...
0.3246
0.5225
17_Standard minutes per setup
Minimum 0.28775
Maximum 0.57468
Mean 0.41528
Std Dev 0.05976
Values 100000
17 Rolling
17_Standard minutes per me...
0.01318
0.02129
17_Standard minutes per meter
Minimum 0.010671
Maximum 0.027003
Mean 0.016911
Std Dev 0.002472
Values 100000
18 Take work to inspection bay
18_Standard minutes per lo...
2.012
4.025
18_Standard minutes per load
Minimum 1.7281
Maximum 4.5941
Mean 2.8750
Std Dev 0.6211
Values 100000
19 Inspect
19_Standard minutes per lo...
8.93
22.30
19_Standard minutes per load
Minimum 5.768
Maximum 25.286
Mean 15.717
Std Dev 3.993
Values 100000
20 Take work to finished goods store
20_Standard minutes per lo...
1.877
5.023
20_Standard minutes per load
Minimum 1.1544
Maximum 5.7418
Mean 3.4500
Std Dev 0.9390
Values 100000

# Appendix F

Calculated number of units producible per day: Calculated daily production capacity


1 Sales coordinator loads order
1_Number of orders per...
2 Take order to planner
2_Number of orders per...
3 Planner creates requisition note for yarn
3_Number of req. per...
4 Planner takes requisition to yarn store
4_Number of req. per...
5 Storeman processes requisition
5_Number of req. per...
6 Storeman takes yarn to warping area
6_Number of loads per...
7 Warp setup
7_Number of setups per...
7 Warp
7_Number of meters per...
8 Take warp to Warp rack
8_Number of warps per...
9 Weave setup
9_Number of setups per...
9 Weave
9_Number of meters per...
10 Take tapes from looms to scale
10_Number of loads per...
11 Weigh batches of tapes
11_Number of loads per...
12 Take tapes from scale to spooling area
12_Number of loads per...
13 Spool setup
13_Number of setups per...


13 Spool
13_Number of meters per...
14 Take spools from spooling to dyeing m/c
14_Number of loads per...
15a Dyeing (dark shades) setup
15_Number of setups per day (double sh...
15a Dyeing (dark shades)
15_Number of meters per day (double sh...
15b Dyeing (light shades) setup
15_Number of setups per day (double sh...
15b Dyeing (light shades)
15_Number of meters per day (double sh...
16 Take work from dyeing area to Rolling
16_Number of loads per...
17 Rolling setup
17_Number of setups per...
17 Rolling
17_Number of meters per...
18 Take work to inspection bay
18_Number of loads per...
19 Inspect
19_Number of loads per...
20 Take work to finished goods store
20_Number of loads per...

## Appendix G

Actual number of units produced per day per resource

**Warping actual number of output produced per day**

| Date | Machine No | Meters | Remarks |
|---|---|---|---|
| 10-Mar-15 | m/c 1 | 112800 | Overtime |
| 11-Mar-15 | m/c 1 | **96000** | |
| 19-Mar-15 | m/c 1 | 60000 | Low Utilisation |
| 24-Mar-15 | m/c 1 | 144000 | Overtime |
| 28-Mar-15 | m/c 1 | 115500 | Overtime |
| 30-Mar-15 | m/c 1 | 66000 | Low Utilisation |
| 31-Mar-15 | m/c 1 | 108000 | Overtime |
| 1-Apr-15 | m/c 1 | 60000 | Low Utilisation |
| 13-Apr-15 | m/c 1 | **100000** | |
| 14-Apr-15 | m/c 1 | 8000 | Low Utilisation |
| 20-Apr-15 | m/c 1 | 125000 | Overtime |
| 4-Mar-15 | m/c 2 | 200000 | Overtime |
| 7-Mar-15 | m/c 2 | **74000** | |
| 13-Mar-15 | m/c 2 | 152000 | Overtime |
| 19-Mar-15 | m/c 2 | 123000 | Overtime |

**Weaving actual number of output produced per day**

| Date | Machine No | Meters produced | Remarks |
|---|---|---|---|
| 16-Mar-2015 | 440 | **501** | |
| 16-Mar-2015 | 439 | 405 | Low Utilisation |
| 17-Mar-2015 | 433 | **467** | |
| 17-Mar-2015 | 429 | 440 | Low Utilisation |
| 17-Mar-2015 | 427 | **458** | |
| 17-Mar-2015 | 401 | 385 | Low Utilisation |
| 17-Mar-2015 | 425 | **568** | |
| 17-Mar-2015 | 450 | 345 | Low Utilisation |
| 17-Mar-2015 | 452 | 423 | Low Utilisation |
| 17-Mar-2015 | 453 | 395 | Low Utilisation |
| 17-Mar-2015 | 454 | **488** | |
| 17-Mar-2015 | 456 | 361 | Low Utilisation |
| 17-Mar-2015 | 457 | **517** | |
| 17-Mar-2015 | 461 | 431 | Low Utilisation |
| 17-Mar-2015 | 463 | **462** | |

**Spooling actual number of output produced per day**

| Date | Machine No | Meters produced | Remarks |
|---|---|---|---|
| 6-May-15 | 1 | **35000** | |
| 7-May-15 | 1 | 7200 | Low Utilisation |
| 14-May-15 | 2 | 8500 | Low Utilisation |
| 15-May-15 | 2 | 16500 | Low Utilisation |
| 8-May-15 | 3 | 17000 | Low Utilisation |
| 12-May-15 | 3 | 11400 | Low Utilisation |
| 13-May-15 | 3 | 7700 | Low Utilisation |
| 14-May-15 | 3 | 14500 | Low Utilisation |
| 18-May-15 | 3 | 17000 | Low Utilisation |
| 19-May-15 | 3 | **65000** | |
| 6-May-15 | 4 | **50300** | |
| 7-May-15 | 4 | 28300 | Low Utilisation |
| 8-May-15 | 4 | **43400** | |
| 11-May-15 | 4 | **41700** | |
| 12-May-15 | 4 | 25100 | Low Utilisation |

**Dark dyeing actual number of output produced per day**

| Date | Machine No | Meters produced | Remarks |
|---|---|---|---|
| 16-Mar-15 | CD5 | 4000 | Low Utilisation |
| 17-Mar-15 | CD6 | 4300 | Low Utilisation |
| 18-Mar-15 | CD5 | 3800 | Low Utilisation |
| 18-Mar-15 | CD6 | **5100** | |
| 25-Mar-15 | CD5 | **6200** | |
| 26-Mar-15 | CD6 | **5000** | |
| 26-Mar-15 | CD1 | 4500 | Low Utilisation |
| 30-Mar-15 | CD1 | 4300 | Low Utilisation |
| 30-Mar-15 | CD5 | 3700 | Low Utilisation |
| 7-Apr-15 | CD6 | 4900 | Low Utilisation |
| 7-Apr-15 | CD5 | **5600** | |
| 9-Apr-15 | CD5 | **6000** | |
| 9-Apr-15 | CD6 | 4600 | Low Utilisation |
| 10-Apr-15 | CD5 | **6500** | |
| 22-Apr-15 | CD5 | **5300** | |

**Light dyeing actual number of output produced per day**

| Date | Machine No | Meters produced | Remarks |
|---|---|---|---|
| 24-Mar-15 | CD2 | **7800** | |
| 8-Apr-15 | CD2 | 6600 | Low Utilisation |
| 10-Apr-15 | CD2 | **7500** | |
| 13-Apr-15 | CD6 | **7300** | |
| 14-Apr-15 | CD2 | 6700 | Low Utilisation |
| 14-Apr-15 | CD6 | 6000 | Low Utilisation |
| 15-Apr-15 | CD2 | **7700** | |
| 21-Apr-15 | CD2 | **7300** | |
| 21-Apr-15 | CD5 | **6900** | |
| 22-Apr-15 | CD5 | 6800 | Low Utilisation |
| 22-Apr-15 | CD2 | **8100** | |
| 5-May-15 | CD2 | **7200** | |
| 5-May-15 | CD6 | 6300 | Low Utilisation |
| 6-May-15 | CD1 | **8700** | |
| 6-May-15 | CD5 | **7100** | |

**Rolling actual number of output produced per day**

| Date | Machine No | Meters produced | Remarks |
|---|---|---|---|
| 16-Mar-15 | RL4 | **24100** | |
| 17-Mar-15 | RL4 | **25700** | |
| 18-Mar-15 | RL4 | **23700** | |
| 24-Mar-15 | RL4 | **27200** | |
| 26-Mar-15 | RL4 | **26200** | |
| 1-Apr-15 | RL4 | **31100** | |
| 7-Apr-15 | RL3 | **24900** | |
| 7-Apr-15 | RL8 | **27800** | |
| 8-Apr-15 | RL3 | **19900** | |
| 8-Apr-15 | RL4 | 18300 | Low Utilisation |
| 13-Apr-15 | RL8 | **28500** | |
| 16-Apr-15 | RL3 | **22000** | |
| 21-Apr-15 | RL4 | **20800** | |
| 22-Apr-15 | RL3 | **29500** | |
| 5-May-15 | RL4 | **25300** | |