2005

A FUNCTION-BASED APPROACH TO ESTABLISHING STANDARDIZATION AND FLEXIBLE WORK CELLS FOR HIGH-VARIETY, LOW-VOLUME MANUFACTURING

Yamkelani Moyo
University of Kentucky, ymdewa@yahoo.com

ABSTRACT

A FUNCTION-BASED APPROACH TO ESTABLISHING STANDARDIZATION AND FLEXIBLE WORK CELLS FOR HIGH-VARIETY, LOW-VOLUME MANUFACTURING

Certain types of high-variety, low-volume manufacturing operations employ clusters of machines to execute general classes of operations in the manufacture of their product mix, but those operations differ significantly from job to job. Consequently operations are not standardized and batch and queue operational strategies are employed with all attendant shortcomings. However, closer examination reveals that these operations largely consist of a small number of elemental machine functions that are exercised in various combinations. The functions provide a basis to for defining richly descriptive standardized work at the individual process level using parameters to distinguish the unique settings and characteristics for processing a given job. Moreover, it appears the pareto principle applies to functional sequences, and high frequency sequences can be used to establish system level production engineering issues, including facility layout, process interfacing, and cellular standard work routines that achieve flow and labor balance in a flexible manner for the majority of products. This approach is demonstrated using and industrial case study.

Advisor: Professor. Jon. Yingling

DGS: Proffessor. I.S. Jawahir

A FUNCTION-BASED APPROACH TO ESTABLISHING STANDARDIZATION AND FLEXIBLE WORK CELLS FOR HIGH-VARIETY, LOW-VOLUME MANUFACTURING

By

Yamkelani Moyo

Professor. Jon. C. Yingling
Director of Thesis

Professor. I.S Jawahair
Director of Graduate Studies

01/27/05
Date

RULES FOR THE USE OF THESES

THESIS

Yamkelani Moyo

The Graduate School

University of Kentucky

2004

A FUNCTION-BASED APPROACH TO ESTABLISHING STANDARDIZATION AND FLEXIBLE WORK CELLS FOR HIGH-VARIETY, LOW-VOLUME MANUFACTURING

THESIS

A thesis submitted in partial fulfillment of the
Requirements for the degree of Masters of Science in the
College of Engineering
At the University of Kentucky

By

Yamkelani Moyo

Lexington, Kentucky

Director: Dr. Jon Yingling Professor of
Manufacturing Systems Engineering

Lexington, Kentucky

2004

MASTER'S THESIS RELEASE

ACKNOWLEDGMENTS

Professor Jon Yingling: For his Unparralled assistance and guidance through out the course of my research, I consider myself privileged to have worked with a top caliber professor. The knowledge I have acquired under his guidance is a life's time worth.

Ray Littlefield: A strong believer and advocate of lean, who believes that lean principles are universal and can be extended to almost any field. Ray acted as my mentor and helped me find resources I need to successfully undertake my research.

Colleagues, Kristian and Ashish: Worked together on many aspects of the research and had many fruitful discussions on the best approach to handle challenges faced in conducting research.

Management and Staff at FDI: I feel deeply indebted to the management and staff at FDI, first for believing that Lean Manufacturing practices would be benefit the organization in the long term. Although, acknowledging the existences of hurdles that organizations in the high-variety, low volume manufacturing are faced with, their lean manufacturing endeavors, the support from FDI is highly appreciated.

Thesis Committee: Professors Larry Holloway and Joe Sottile: I am also grateful to my thesis committee for finding time to evaluate my work despite the tight schedules that each one of them has.

I also want the acknowledge the support my family has given me. Through the hard times and struggles my family have been a pillar of support, encouraging me all the way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION AND OBJECTIVES

Standardized work is a fundamental element in both process improvement and process control for all organizations vying for a lean status. It is imperative that the organizations engage in a continuous attempt to standardize all aspects of their operations if clear pictures of the organizations' objectives are to be created. In today's increasingly competitive world, where customers are becoming more sophisticated and more demanding regarding all aspects of the product to be produced, it is increasingly becoming important for organizations to streamline their operations if viability in the foreseeable future is desired. It is not surprising how many companies are now attempting to take steps in applying lean manufacturing principles considering the huge benefits that organizations that have successfully started lean programs have had. However, the benefits of standardized work have been limited to mostly organizations that produce high-volume, low-variety products, with only a small percentage of organizations in the high-variety, low-volume ***(HVLV)*** production enjoying similar successes.

The reluctance that the standardization of work has met in HVLV is understandable. Owing to the low repeatability of jobs released to the shop floor, motivation for creating standardized work is usually low among the work force, understandably so because of the need to constantly revise them at regular intervals of time. Neither does the hierarchical structure of the organization help alleviate the reluctance associated with standardized work implementation. The supervisor is usually overburdened with the responsibility of overseeing a large number of people in addition to the complex production control associated with such a system. Owing to this overburdening of the supervisor, it is not surprising therefore to find the supervisor too busy dealing with day-to-day issues instead of focusing more on kaizen. There is also added effort required to overcome the barrier of reluctance to change associated with people in such environments. Lack of understanding of the need to change as well as lack in confidence in new methods of working may have adverse effect on any efforts at lean and standardization.

Work standardization will also involve creating a work environment where what is supposed to happen does happen on time because of visual controls.
This is a workplace where flow of material, information and people accelerates and decelerates at will calibrated by ordinary visual controls, that tell us precisely where things are, what needs to done, by when, in what quantity, by whom and how(*Hiroyuki Hirano*).

Standardized work is established by considering the technical and process standards required to successfully manufacture a product at the desired quality and rate while providing for the complete safety of the operator. Standardization is the key to success of managing factories effectively. It should be realized that no matter how good a factory's equipment is, the factory cannot make good products without the people who have to operate the equipment and manage the factory. It is therefore imperative that managers possess the knowledge and technology as well as rules to explain how the elements (i.e. people, materials and information) work. These rules are what we refer to as standardized work.

Standards are created for people to use, and therefore it is important that these standards be acceptable and well communicate lest they become useless and all effort used to develop them go to waste. The best way to gain universal acceptability in formulating standards as well as capturing the tremdous knowledge on the shop floor is to encourage user participation at the development stage. When people are able to participate in the development of standards with standards, implementation become easier as there is greater acceptance of the process.

OBJECTIVES

The objective of this thesis is to establish generic methods for developing standardized work documentation for high-variety, low-volume (HVLV) job shop environments. Ideally these methods should exhibit the following characteristics:

- Because jobs are continuously changing, there is a need to develop rapid documentation of standardized work.

- They should be useful in the study of work methods, identifying flaws in the process and seeking remedy for the situation..
- The method should educate floor workers and seek acceptance of the standard work process, cultivate interest by encouraging a participative approach to standardization. This is accomplishing through fostering a learning environment where every individual on the shop floor is allowed to think and contribute to continuous improvement. It is therefore imperative to consider use of an appropriate suggestion system. Owing to ever changing products in HVLV manufacturing, it particularly important that the suggestion system captures ideas quickly and expediently executes them.
- They should foster long-term organizational learning, the methods should document production related procedures and catalogue them in a convenient retrievable format. This facilitates learning that occurs gradually and intermittenly over a long period of time, to be recalled and used consistently in the future. This might be achieved by recognizing and cataloguing similarities that exists between new products and previous products. This allows for knowledge about old products to be applied to new products.
- They should reduce variability in process set up and facilitate rapid change over from one job to the other.
- They should be useful in evaluating the ergonomic design of each operation, subsequently recommending improved methods that reduce the ergonomic hazard present in any job.

CHAPTER 2: STANDARDIZED WORK

2 INTRODUCTION

Standardized work is a lean manufacturing technique that can be simply stated as the documentation and application of the best practice for executing manufacturing processes. It requires continuous improvement of the process, and each improvement should be accompanied with updated documentation. Standardized work focuses more on human movements in an attempt to eliminate no-value-added tasks as well as development of procedures and controls that enable safe execution of the process and production of high quality parts.

Standardized work is implemented with an emphasis on human contribution. The best person to establish standardized work is the supervisor, who has risen from the shop floor and is competent in all processes he/she supervises. The supervisor is suited for this role because he/she has the best knowledge of the worksite conditions of any person on the shop floor and has the responsibility to ensure standardized work is followed. The supervisor would establish this documented practice by seeking input from all of the employees on the work team, effectivley constructing a consensus view of the best practice. Standardized work involves determining the most effective repetitive work pattern and documenting and training , so that all team members will perform the work accurately in the same way until a better method is established. It should be emphasized that the primary goal of standardized work is to eliminate unnecessary movements.

2.1 TOYOTA'S VIEW OF STANDARDIZED WORK

At Toyota, standardized work is viewed as a means for setting work methods for:

1. Safety
2. Building quality into the product
3. Establishing a manufacturing system
4. Eliminating burden on man or machine
5. Cost Reduction and waste elimination

6. Learning and evolving work methods to higher levels of performance

Developing and implementing standardized work may result in the following benefits:

1. The establishment of a takt time that helps cap WIP and enable work flow with minimal WIP by eliminating cycle time variability. This happens because the takt time is determined by matching the necessary production quantity with sales volume. This allows for the appropriate workload associated with takt time to be automatically determined and work to be designed with high labour utilization.
2. Aids in Quality:
   Repeatability, performing the work in the same way every time helps improve the quality of the product. Variation is reduced by the consistency of the process, since workers improve with time that they are engaged in the job and reduced variation helps them measure and confirm the effectiveness of improvements even if their effects are small.
3. Lower cost:
   The elimination of unnecessary steps helps lower the cost of production. This leads to efficient production.

2.2 WHERE IS STANDARDIZED WORK APPLIED?

The use of standardized work in the past has been popular in high-volume, low-variety industries such as car assembly plants. It is at such industries that standardized work was first used. It is only recently that benefits of standardization have been considered in low-volume, high-variety industries such as job shops. It is usually difficult to develop standardized work in such environments, as the lifespan of products is too short to warrant investment of time and money in developing detailed standardized work.

2.3 WHAT ENTAILS STANDARDIZED WORK?

Standardized work begins with method study of the process of interest. It hopes to determine the best way that a particular process is carried out. It is important to be aware of the principles that serve as guide for constructing standardized work. It is also important that ergonomics be made an integral part of any future state design.

Ergonomics can be a valuable tool to help increase customer satisfaction. Studies conducted have shown a strong correlation between employee satisfaction and customer satisfaction *(Fred E Meyers, James R Stewart*) An example of ergonomics as related to standardized work would be the removal of no value added motions that an employee makes when performing a task.

STANDARDIZED WORK FOR JOB SHOPS

Standardized work is fundamental to both process control and process improvement under the lean philosophy. The Toyota forms of standardized work documentation are suited to repetitive manufacturing situations. As we move to job shops, the products are constantly changing, and there is a need for more rapid learning and thus the need to modify and enhance both standardized work documentations and procedures. The kind of work done at ***Foam Design Incorporated (FDI)*** is of this nature. At FDI products are continuously changing and therefore requiring rapid learning on both the design and manufacturing level.

It is interesting to note that though the products at ***FDI*** have a low repeatability in production, they still possess similarities in features and in the way they are processed. Presently the only form of documentation that exists is the route sheet (***traveler***) that is released to the floor when a shop order is launched. In most cases, each job released to the floor is a complete new job, different from the previous jobs. By exploiting similarities either in features or in processing, it is envisaged that it maybe possible to develop generic standard work forms (templates) that will lessen the burden of having to create standard work forms for each and every product released to the shop floor. Such standard work forms should be amenable to the special needs of the job shop job.

One basis for developing such standardized work for such a large variety of products begins by identifying similarities in the processes used to make such products. In this thesis, a function can be defined as a sequence of operations employed to accomplish a specific change in form of a product whose occurrence is of reasonable frequency to warrant attention. At FDI , we propose that one function is the taking off a thin layer of material from the surface of a foam, for example, we call that function “skinning”. It differs from another function in both operations, sequence and purpose where the objective is to slice a layer of foam from the plank to a target thickness. If all operations on each machine can be categorized according to a functional basis and these functions are not too numerous and complicated, then the effort developing and documenting standardized work for HVLV manufacturing enviroments becomes less complicated. Most work can then be described in terms of these functions.

2.4 BACKGROUND ON FDI

Foam Design Incorporated (FDI) is a job shop manufacturing organization that is involved in the manufacture of various packaging material according to customer specification. The manufacturing process begins with a customer request for packaging material. Usually the customer sends in a sample of the item that it intends to package. The design engineering team then develops a design for the product and a prototype is built which is tested. Upon approval of the design a trial run is carried out in order to test the manufacturability of the product.

2.5 CHARACTERISTICS OF FDI MANUFACTURING SYSTEM

It is also important to establish what kind of manufacturer that you are. To accomplish this, identifying the nature of manufacturing is important. There is a need to consider two aspects to this. The first step is identifying your manufacturing style as depicted in the diagram below.

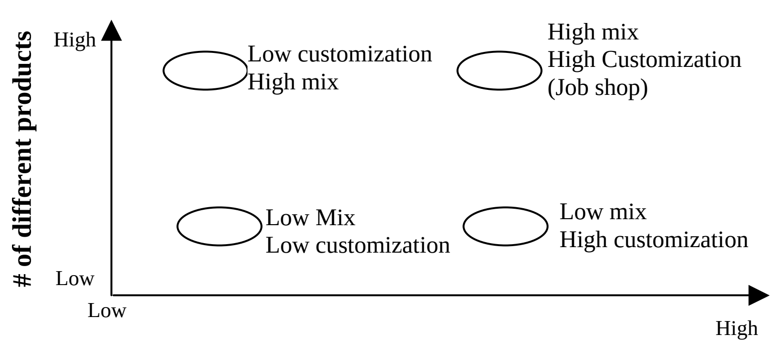


Figure 2. 1: Degree of Customization

ESTABLISH THE DEMAND PROFILE

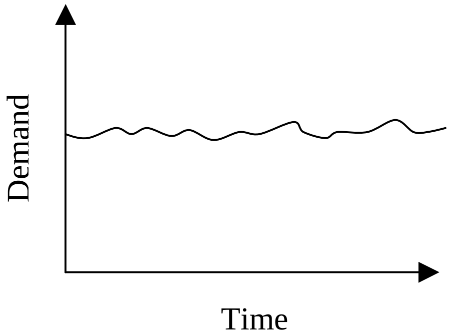


Figure 2.2

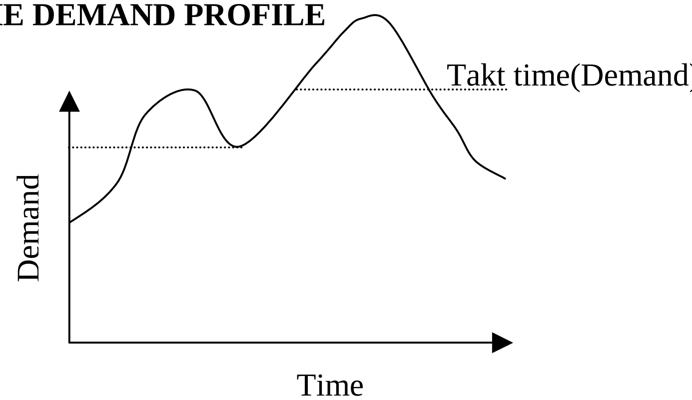


Figure 2.3

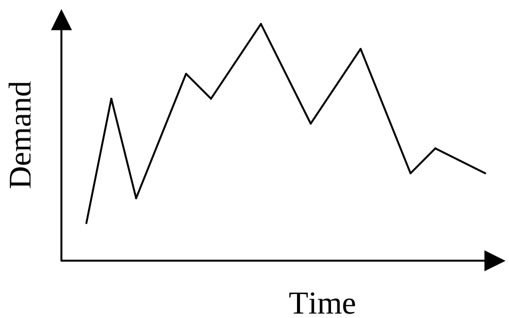


Figure 2.4

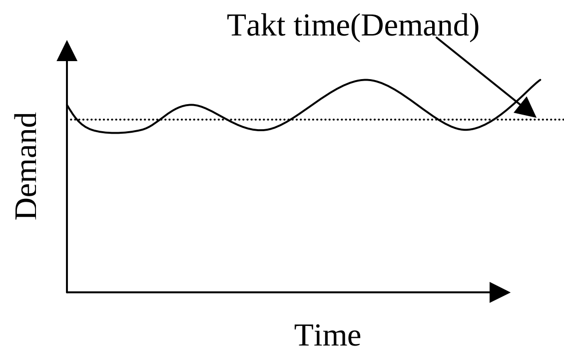


Figure 2.5

Standardized work is simpler to implement in enviroments with lower degrees of customization and lower numbers of different products. The demand profile (figures 2.2/2.3/2.4/& 2.5) is also an important consideration in determining the difficulty associated with implementing standardized work at for different manufacturing enviroments. The steadier the demand over a time interval (figure 2.2), the easier it is to implement standardized work. This is true because the rate of the process will be more consistent and the product will tend to be produced on a more continious basis. Figure 2.4 represents a situation in which implemetation of standardized work is most difficult, typical of HVLV enviroments. As illustrated in figures 2.3/2.5, a takt time can be determined and it does not vary much with time making the developing of standardized work less diffficult.

In most job shops, the situations tend to be chaotic with production being carried out intermittently with little or no standard work. This situation can only be remedied by creation of product families. Each product family can then be treated as a single product, and all production control is done for that particular product family. The concept of product family has been adopted in this project for developing standardized work for job shops. The concept of functions will be introduced later at a stage of this project.

2.6 THE IMPORTANCE OF TAKT TIME

The ability to be able to determine the takt time is always an important part of standardized work. As discussed earlier, takt time is an important componet of standardized work. The takt time determines the pace of production required to meet customer demand. The takt time can be easily determined when the demand is steady over a period. The concept of takt time is therefore easily implemented for high volume low variety manufacturing enviroments such as found in the automotive industries. This concept, though simple, has not been comprehended well and effectively emplemented in chaotic manufacturing enviroments such as job shops. It must be understood that the takt time is a dynamic quantity that can be adjusted to suit demand changes. Takt time is the heartbeat of the lean system. In low-volume, high-variety enviroments, it is important that the takt time niether be too low nor too high as such an occurrence is bound to cause problems in the operations (*Duggan, Kevin J*) . A takt time below ten seconds is likely to result in highly repetitive work leading to possible emergence of ergonomic stress injuries. At the same time work has to be designed such that takt time never exceeds five minutes as this could lead to a situation in which cycle time becomes inconsistent and inherently variability is introduced into the system. It is the intent of this project to investigate how work is designed with an appropriate takt time that eliminates both drawbacks mentioned above.

2.7 PRODUCTION CONTROL AT FDI

The production control system at FDI is inherently a push, MRP driven system. Because of so many unknown parameters and lack of standardization, the system has proved unstable. The throughput times are large, WIP is uncapped, and production is driven by urgent due dates or which certain customers have the largest voice in demanding that due dates be met. The unknown parameters are usually with regard to total work content (TWC) of a product and considering that most products are unique, little or no prior knowledge exists about them. This tends to make production chaotic and quality problems are not uncommon. At first thought it would appear that switching to a pure pull (kanban) system should be a ready solution with regards to improving throughput and quality.

However it has been noted that pure pull (kanban) systems are not always suited to all types of production enviroments. Kanban is more suited to repetitive manufacturing enviroments. In contrast, constant work in progress (CONWIP) systems, which are also pull in nature, are less complex and simpler to implement. Unlike in pure kanban systems, there is no need to determine the number of kanban cards to assign to each station in CONWIP systems. Kanban systems tend to be part specific and this makes them even more difficult for HVLV enviroments where variety explosion would result in congestion of stores on the shop floor. The flexibility afforded by adopting CONWIP systems suits the needs of FDI. CONWIP cards are line-specific meaning that parts can be released to the shop floor regardless of their part number as long as they fall within the specified route of the kanban card. Figure 2.6 shows the structure of a CONWIP based production control system that might be applied at FDI.

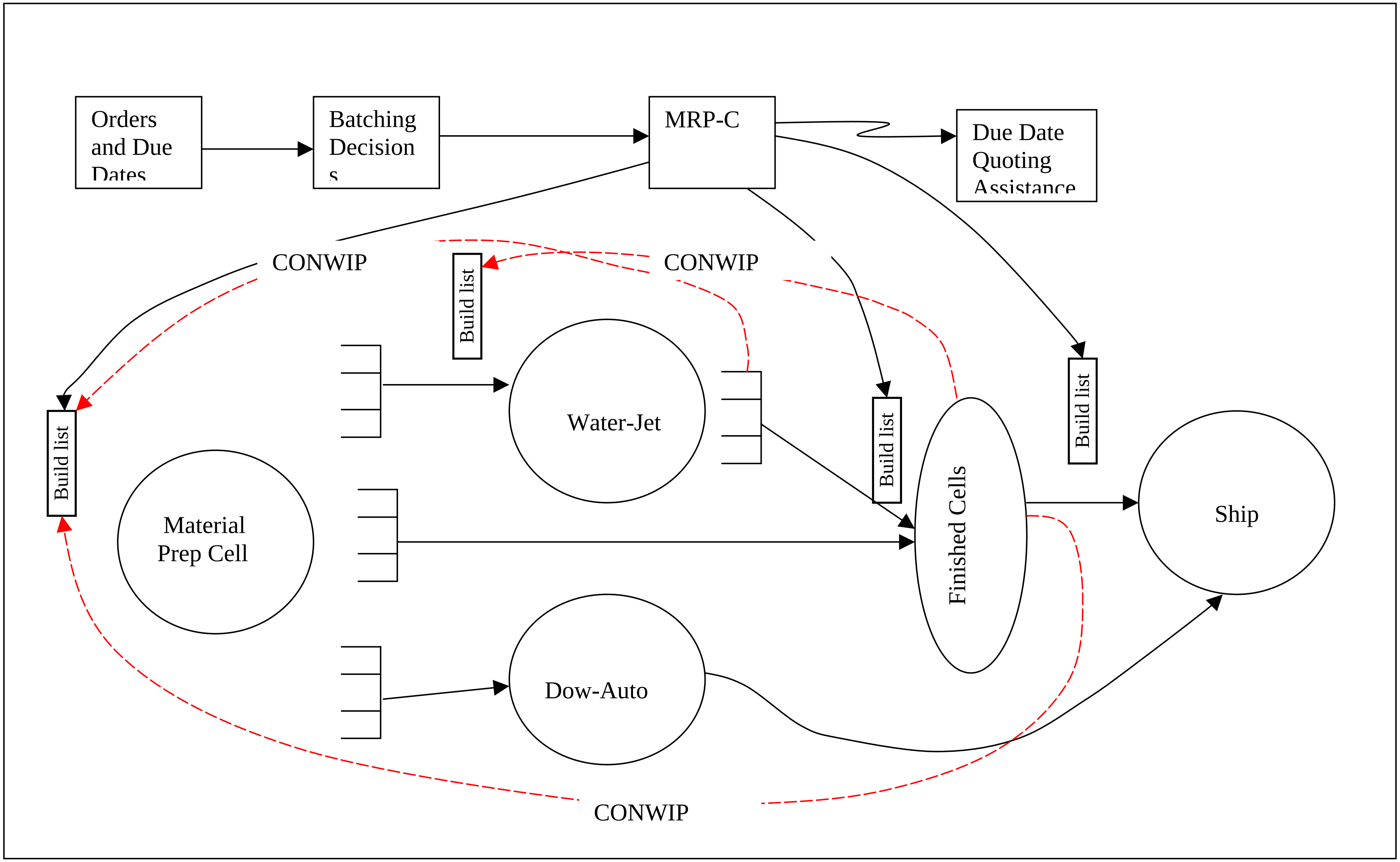


Figure 2. 6: Summary of the envisaged production control system

CHAPTER 3:

FUNCTIONAL DESIGNED STANDARDIZED WORK FOR JOB SHOP ENVIROMENTS

3. THE MATERIAL PREP CELL

Althogh the ideas of this thesis have general utility, the application focus will be on an area of the FDI plant that we will call the Material Prep Cell. Virtually all work at FDI at some point in manufacture, typically at the beginnig of production, goes through the Material Prep Cell. The word cell is used loosely, referring to three co-located machines. There is no fixed sequence of flow through the machines and generally at present, large batches of parts are simply transferred from process to process as a batch and queue operation. In Material Prep Cell, materials may be subjected to any combination of a large number of different operations from the time the material enters the cell through the point the material exits the cell. Issues to be addressed in the Material Prep Cell range from developing process-level standardized work to system-level standardized work, where the later draws attention to how the machines interface with each other. There also exists the issue of manning for each of the machines as well as set up issues. It must be emphasized that at the beginning of this project no standard work documents were in place for either set up of the machines or running of the machines. The standard work that we envisage to be developed is to be entirely on the basis of functions. This therefore makes the definition of what a function is an important step in this project.

3.1.REQUIREMENTS FOR FUNCTIONALIZING OPERATIONS

The initial determination of the functions may not be as clear-cut as we would want. There is a need to be familiar with the process and how the operator carries out the work instructions as specified and often this can only occur through a direct hands on approach. It has been observed that the initial work instruction (traveler as it is referred to at FDI) does not carry much detail. The work instruction emphasizes on the end product specifications or requirements without giving concise stepwise detail on how to accomplish the task at hand. Therefore, it is not surprising that the three processes of the Material Prep Cell require execution by experienced operators while none experienced Operators may assist in material flow but are not permitted to do any direct work on the machines. This has limited the number of people on the entire shop floor who are able to work in this area. It is because of the ambiguity associated with set up and running the machines that use of these machines has been limited to only a few individuals. Because of the absence of standard work instructions for each machine, each operator on these processes has had to rely on experience acquired while on the machine. Not only does this produce variable quality, but the process times vary according to which operator is using the machine. Setting up the machine appears to be the most variable of the operations. Take for instance, the set up of the skiver machine; its set up is so variable to the extent that the correct setting is arrived at after several trial and error adjustments cycles consequently leading to a loss of valuable production time. As can be seen, much of the knowledge of the processes is tacit, not explicit. It took a lot of hands on effort to learn the processes as well as effort to build relationship with machine operators so that their experiential knowledge could be understood and employed in this development.

3.2.FUNCTIONS DEFINED

In general terms, we define a *function* as a sequence of steps to accomplish a particular transformation of the product by the machine/process in question. Functions may have particular parameters (e.g. special steps, machine setpoints, number of cycles, etc) that form the requirement for executing that function for a particular job. Functions of operations have been defined for each of the three processes that constitute the material prep cell. The functions were defined after a careful study and observation of the operations of each of the processes that constitute the material prep cell. Function definitions were given for each process in the following manner:

3.2.1. Skiver/Slitter machine (K11)

The slitter/skiver machine is basically used for slitting of planks. This operation is performed to split the planks e.g. 6"X24"X96" block of foam into several planks of particular thickness. Two rollers pull the foam plank across a rotating horizontal blade, creating the split This is the most important process as far as the material prep cell is concerned. There are several operations that are performed on planks at this process. As far as setting up and running the machine, this process is the most complex of all the processes that constitute the material prep cell. After carefully study of how the k11 machine is used in the processing of planks, it became apparent that this machine was being used in three generic ways, which we define as functions for the process. The function definition and symbolic name for each of these processes is given below. The symbolic name is useful in the analysis of functional sequences as will be explained later.

a) Dimensional Skiving, $\mathbf{S_d}$: This entails cutting a piece of foam. into two pieces, where one piece, typically the top piece has a thickness that conforms to the exact dimensions required. The plank only passes through the machine once This function requires the operator to be knowledgeable about set up to avoid losses of material and time through trial and error adjustments of the machine.

b) Skinning, $\mathbf{S_s}$: This is probably the simplest of the functions we have defined. Skinning involves cutting off a thin layer form the surface of the plank. (this layer is often like "crust" and it is uneven and precludes effective lamination of planks). Dimension control is not employed. It is easy to set up the machine for this process since tolerances are not much of an issue.

c) Layer Cutting, $\mathbf{S_l}$: This involves cutting the material into several layers of equal thickness. The material passes through the machine multiple cycles with each cycle creating a new layer. An indexing mechanism is built into the machine to control thickness without manual adjustment on each successive layer cutting operation. Material handling is more complex for this task than it is for dimensional skiving.

3.2.2. Laminator (LM)

FDI's Laminating process uses hot air to bond two or more layers of foam. The material my be of the same composition (e.g. built up layers to obtain a target thickness of foam or varied composition e.g. multiple materials to obtain a desired structural feature) The hot air is blown in between two materials, which are subsequently pressed together between a lower moving belt conveyer and upper roller to seal the bond. Important issues that affect the success of bonding include the speed of the conveyor, the roller speed and the height of the heat bar. All the mentioned parameters have different set point values for different materials. Failure to adequately address the standardization of these set up parameters can result in serious quality problems. The functional definitions for the laminator process are given as below:

a) Single pass lamination $\mathbf{L_s}$: This involves the joining together of two pieces of material. The material to be joined may be of the same material or different materials.
b) Multi-pass Lamination $\mathbf{L_m}$: Although similar to the single pass lamination the difference here is the number of times the plank has to be recycled as it is built up with more than two layers of foam.

Band saw (B)

The bandsaw operation involves cutting a plank of foam to the desired length and width. Cutting for this operation is either unidirectional or bidirectional to obtain the desired unit material from a standard plank. A standard plank/foam size (unprocessed plank in its unaltered form) may yield any number of units according to the output specification. Because of the simple nature of this operation all bandsaw operation can be catergorised as under the bandsaw function "B".

3.3. STANDARDIZED WORK ON FUNCTIONAL BASIS

Once the functions have been defined all standard work can be defined on a functional basis. This eliminates the need to create standardized work for every job that is released to the shop floor. A parameter may also be a minor variation of the function. For example, dimensional skiving may or may not require skinning as a first step. One can simply identify the functions that pertain to processing of a job and these functions will provide a standardized work definition, subsequently one may specify the particular parameters of that function that apply to the case at hand. A *parameter* is a particular setpoint associated with the function. For Example “$\mathbf{S_d}$” would have the various machine settings necessary to obtain a desired target thickness or parameter. The defined functions are such that even if variances in work content occur, they are limited and readily defined by parameters for each defined function. The function definition can be substituted for machine groups in the product family matrix. Because in high variety manufacturing, it is essential to classify products into families and the use of functions facilitates this, since this would more precisely identify families with similar processing operations.

Standardized work can be done at both the process and system levels. Focusing on the details of functions system standardized work would address the transfer of parts between machines and appropriate machine interfacing. It would be defined for sequences of functions that occur with high frequency.

3.4. CONDITIONS FOR IMPLEMENTING STANDARDIZED WORK

3.4.1. Trouble free equipment:

If equipment trouble is frequent, then repetition will not be smooth. This means irregular movement and irregular operation sequences will interrupt the work and cause standardization to fail.

3.4.2. Good quality input resources:

If parts and materials are of insufficient quality, the processing conditions will always be changing. Since quality is built into the product in the process, every time defects occur in process due to defective input material, they will require an investigation into the cause that is beyond the scope of the process itself. This leads to unstable processes and consequently standardized work will no longer function as intended.

3.5. DOCUMENTING THE STANDARD WORK AT FDI

In a repetitive environment where the takt times are small, the standardized work is usually simply to develop and post at a place where people can readily access them. However, in a chaotic high-variety environment, with relatively long job cycle time, takt time, it is not that easy to implement standardized work. If variability is to be avoided, standardized work would still need to be implemented. In this project, process standard work was created for the material prep cell. This included the key work elements and their associated times, including safety and quality checks.

3.5.1. TYPES OF STANDARD WORK DOCUMENTS IMPORTANT FOR FDI

To avoid having to create a standardized work sheet for each product, all standard work was documented on a functional basis. The standardized work was created for the following cases:.

a) **Set up sheet:**

The absence of documented set up procedure presented the biggest problem in FDI processes. Set up involves the elements of work that take place between completion of the previous job and start of present job. This includes tear down and put away elements. No documented set up procedure and time procedure was in place to guide the operator in carrying out set up. As a result, set up method and time were hugely variable with each operator claiming his or her method to be superior to that of his/her co-worker.

b) **Operations work standard sheet:**

This chart contains the work instructions needed for the operator to perform his or her work. This is used to describe a single activity, usually one operator using only tools and equipment that are totally manually controlled. It is important to display all the knack points for the operation. Knack points are special key techniques (tricks of the trade) that enable the job to done effectively and may relate to any aspect of performance including quality, efficiency, burden and productivity. It is helpful that the chart be as visual as possible because operators do not respond positively to paragraphs of text that take time and are difficult to understand. Pictures, icons and symbols can convey operator work effectivley. The availability of digital cameras allows us to capture the product /process and incorporate needed text using available software.

c) Standard Work Chart

This chart shows the spatial arrangement of tools and equipment and tools in the cell. Also depicted in this chart are sequential positions of the operator in performing his task (dynamic layout). In addition, the takt time and the regular in-process stock are displayed on this chart. This chart is useful for improving the general working area as well as revealing irregularities in cycle time, in-process stock and abnormality in working sequence by comparing what is actually happening to the standard work chart.

d) Work Combination Chart

Once the elemental task sequence is established, a time study is done to determine how much time each task requires. Combination charts are Gant charts that show the progression of the work process over time. Work combination charts are used for both single and multi person operations that may involve more than two individuals. They are particularly helpful in that they visually show the operator time, machine time and walking time required for running a work cell. The most important information that is deduced from this chart is the cycle time, operator utilization and machine utilization and identification for the amount of time spent on none value added activities. Because of their visual nature, they enable people to see problems in conformance and thus seek improvements on the operation.

e) Preventive Maintenance Sheet (TPM)

In line with the rule of trouble free equipment that is necessary for successful implementation of standardized work, it is essential to have a preventive maintenance sheet for each piece of equipment. Operators should be able to carry out regular periodic maintenance on their equipment. Not only does this enhance their understanding of how their machines function, but creates a sense of ownership and pride in their work while reducing maintenance staffing requirements.

Process level standardized work sheets were developed for the three processes of the material prep cell: the slitter, the laminator and the band saw. For the slitter process, the available standardized work sheets were prepared for the following functions: skinning, layer cutting and dimensional skiving. Standard work documents for the laminator process include single cut lamination ($\mathbf{L_s}$) and multi-cut operation ($\mathbf{L_m}$). These make up the functional standardized work sheets for the laminator, meaning that all laminator operations can be classified as either ($\mathbf{L_s}$) or ($\mathbf{L_m}$) . Laminator functional standard work documents are shown in appendices B.

Set up sheets are an important part of the standardized work. For one to be able to set up work properly he or she must possess the knowledge about the particular process. A lot of variability can be introduced if attention to proper set up is ignored. There could be a number of factors that come into influence in the set up of the machine. These parameters need to be identified, validated and optimized. At a later stage of this project an approach for developing standardized setup procedures using experimental design will be presented for the slitter process. In a similar manner to the process standardized work, a general set up sheet for each function definition is given. The need to develop product specific parametric values to complement the general set up sheet is of equal importance. Set up values are ideally presented in table or graphic form to allow the operator to be able to determine them with minimal time.

3.5.2. DETERMINING FUNCTIONAL CYCLE TIMES

The ability to measure the functional cycle times is important if a workload balance analysis is to be carried out. The workload balance determines the amount of work that each operator is allocated in the cell. It will also show if an operator and the cell as a whole is able to meet the takt time. Obviously extremes at either end, in which case an operator’s load is far below or far above takt time, are undesirable .

Determining the cycle times for each functional definition at FDI required a time study analysis to be done. In order to successfully do the study, it was important to become familiar with the processes so that only value added elements would be timed. It is common knowledge that most operators on the shop floor view time study in bad taste. As the author has learned, it is extremely important for the time study analyst to make it known to the operator concerned that the study is been done to determine how to make the job better, not to see how fast or slow the operator is working. It is usually best not to show up with a stopwatch and immediately begin timing the operator. The best way is to get familiarized with the process, listing all the elements of the job. Observing and listing all the work elements on paper prior to the time study itself allows you to identify all the no value added tasks that may be part of the job. Such an undertaking is amenable to some form of paper kaizen. Spending some time observing and speaking to the operator is part and parcel of shop floor courtesy that not only relaxes the operator but allows him or her to open up to making suggestions about his/her process.

Determining the cycle times for the slitter functions did reveal quite a number of none value added tasks. Tasks such as walking to get material, unloading the material onto the skid, removing scrap material caught between rollers and blade, and searching for skids on which to unload material onto constituted a significant quantity of none-value-added time. While some of these tasks cannot be totally eliminated, knowledge about them can trigger an action response to minimize the negative effect. The operators at FDI have a dual role of operator and material handler. This is not recommended as it takes away the operator’s production time and creates piece-to-piece cycle time variability since these tasks are performed intermittently. Having a dedicated material handler or team leader playing this role is always recommended. Note that the lack of an officially recognized suggestion system is demoralizing to the operators who in many cases have suggestions that they wish to see implemented, but are not in a position to implement without consent of management and help from support staff. Because these suggestions are made by simple word of mouth, they quickly get drowned in the chaos and complexities dictated by production needs.

3.5.3. THE NECESSITY OF DETERMINING TIME STANDARDS

The determination of time standards in manufacturing is an important aspect of standardization. For high-variety, low-volume manufacturing environments such as Toyota, this process is less complex. However, as the production system shifts towards a low-volume, high-variety type of production, determining time standards gets more complicated Therefore, it is not surprising to find that most job shops have not attempted to standardize their operations, let alone determine time standards for their operations. This is true for FDI. There has been no attempt to determine any time standards or develop standardized work for any of the processes of the material prep cell. Although acknowledging the inherent nature of products that come from job environments makes it difficult to standardize, it is not an entirely impossible mission to accomplish. The key to standardization in job shops lies in smoothing out the variability that different products bring about, hence the introduction of the concept of functions. Functions provide a simpler route to developing standardized work in addition to standard time determination. A fucntion defines work elements common for various products and time standards can be established for the elements. It also defines elements where setting and operations may be product specific with product-to-product differences defined by parmeters of the function. The parameters form a basis for definition of time standards for these product-specific work elements.

3.5.4. METHODS AVAILABE FOR DETERMINING TIME STANDARDS

There are several methods that can be used to determine time standards with each method suited to different circumstances. The simplest and most widely used being the use of the stopwatch. We will not dwell much on the details on how this is done. The second method of determining standard time is the use of predetermined time standards. The use of the stopwatch assumes a stable operating environment meaning that the best method has been established and documented. However, for a situation in which the best method is not yet known, an estimate of the time it would take for an operator to perform an operation can only be left to the discretion of the process engineer who is responsible for developing the process plans. Only an experienced process engineer is able to estimate with a high degree of accuracy how much time it would take to perform a particular operation. As far as the operations of HVLV environments are concerned (e.g., FDI), the task of establishing cycle time for most jobs is not that simple. This is because most jobs come and go, never to be done again. Because of the low repeatability of jobs, it becomes important to be able to easily and quickly categorize the operations required for a product at each process according to the defined functions. Each function definition should have a standard time associated with it. These standard times can be catalogued and stored in a database. A code name can be assigned to each function definition. Accomplishing this means that the flow of the product through the material prep cell can be completely described on a functional basis.

3.5.5. USING STANDARD DATA

This method can be a useful method of determining time standards for jobs when characteristics of those jobs and their corresponding cycle times vary. It involves cataloging elemental time standards developed over a period of time. The database is usually organized by machine name and job description. The job description includes major parameters that explain differences in cycle time from one job to the next. Models typically in the form of look up tables or regression equations, are used to establish predicted cycle times as a fucntion of job characteristics given by these parameters. Whenever a new job needs to be done and all the machine operations are identified, the process engineer/production planner simply applies the standard time models to estimate elemental times as per the work breakdown for the given job. This can be very useful for FDI. The use of standard data can be made simpler than it usually is, for job shops given the categorizations of tasks and operations that the concept of functions has introduced and the parameters of the functions can be the parameters of the standard data model.

The benefits for use of this method at FDI are quite clear and are as follows:

- The time required to determine time standards is reduced significantly. For instance, whereas it would require 30 minutes to perform a time study for a particular job, this could be done in say 2 minutes by simple retrieving elemental standard times from the database.
- Cost of developing time standards is reduced and because we can set time standard so quickly it no longer becomes burdensome to set time standards for jobs that were previously considered too small to be covered by time standards.
- Costing of work is much simpler. In addition, the time standard is more consistent compared to standards established through other techniques.

3.6.PREDETERMINED TIME STANDARDS

A simple, fast, and inexpensive predetermined time system would be most valuable for the operations of FDI. Such a method should be help in situations where interest lies in saving time in establishing the standard at the expense of some accuracy. While stopwatch time studies require less training, it may not be appropriate considering the low volume, low repeatability jobs. The three basic processes of the material prep cell would require standard data to be developed if the work content of jobs is to be established. While we have defined functions for each of these processes, it would be inaccurate to assign a time standard to each function because these are not refined enough for an accurate measure of the work content of a job to be performed. For this purpose, several predetermined time systems (PTS) have been considered for possible role in developing time standards. A choice of a predetermined time measurement systems can be made from the following options:

1. Motion time measurement system (MTM)
2. Maynard operation sequence technique (Most)
3. Modular arrangement of predetermined time standards (Modapts)

All the above predetermined time measurement systems require a moderate to high level of training for their use. The complexity associated with the use of the method varies between the cases. However, the use of such a method in this case potentially has several advantages over the use of stopwatch time study. The accuracy of these methods is significantly high for a wide range of activities and processes. No stopwatch is needed and a major advantage of PTS in HVLV environments is its ability to be used prior to release of the job onto the shop floor. This suits the operations of FDI very well, considering that some jobs stay on the shop floor for as little as a day or less. The use of PTS in this case can be extended to the development of time standard moreover relations with employees are improved considering that no rating is needed, thus eliminating the ambiguity associated with tying a work rate to an individual's work.

3.6.1. ENVISAGED STANDARD TIME DATA FOR THE BAND SAW PROCESS

The band saw has proved to be the most challenging of the three processes of the material prep cell in developing standard work templates. This is attributed to the countless number of ways in which a plank of form can be cut. Basically the cutting of the plank is performed along its length and width in order to come up with the basic building block of the required dimensions. Each plank is cut to the required dimensions with the main objective of the cutting process being:

a. The way the cutting is done ought to generate the maximum number of units from a plank
b. The method adopted should reduce time required for cutting the plank (i.e. Minimum cutting time t_{Bc})

3.6.1.1. Constraints in the cutting process

a. Cutting speed which is related to density of foam being cut $\mathbf{v}_{bc}$

b. The depth of cutting, which in this case is the stacking height ***h*** of the planks

3.6.1.2. Band saw elemental tasks

The operator performs a number of tasks on the band saw which are repeated an appropriate number of times in order to obtain the required dimensions. The basic operator elemental tasks on the band saw are as follows:

a. Pick up plank from pallet *(*a function of plank density and size*)*

b. Load plank on band saw table

c. Adjust /set blade guide to desired measured value

d. Cut to length (a function of the speed of cutting)

e. Index blade guide

f. Remove scrap

g. Rotate planks

h. Perform quality check

The desired process operations for any product at the band saw can be arrived at by combining the above given elemental tasks in any number of ways. For instance, one product could have elemental task ***f*** appearing three times while another product would only require one occurrence of a task ***f.*** The cycle time for the product at the band saw for a particular product can be arrived at by computing the frequency of occurrence of each elemental task. It is important to be able to identify tasks whose elemental times are constant and those that are variable. It is envisaged that the elemental times for these tasks can be determined by using a predetermined time measurement method. The elemental times can be easily catalogued for easy and fast retrieval. To arrive at a cycle time for a particular cutting operation on the band saw, the process engineer would retrieve the constituent elemental task from a database. Summing up the constituent elements would thus result in the process cycle time for that particular product. It should be possible to computerize this process so that the process engineer only needs to respond to a computer prompt for input with the output being cycle time for that particular product.

3.7.SYSTEM STANDARDIZED WORK

By system-standardized work; we are referring to how the machines that make up the Material Prep Cell might interface. Pontentially it might be possible to change operations fom batch and queue to cellular operations where small batches (ideally single piece) are transferred from process to process. How such a cell might function as a unit is the main question. For the Material prep, such a cell would require considerable flexibity because processing requirements differ dramatically from job to job. Our functional definition, however, provides a basis for characterising the needed flexibility. In particular we can take a random sample of jobs, define the *functional sequence* for each, and perform a pareto analysis to identify which sequences are not common. The high frequencies can then be a focus for defining appropriate interfacing issues. Cell layout is also an important aspect. To improve on the current layout, we performed a FROM/TO analysis using the functional sequences.

Table 3.1: Functional sequence frequency

Seq #	Functional Seq	Freq
1	B	30
2	S_D	12
3	S_L-B	10
4	S_D-B	6
5	S_L	5
6	S_S-B	4
7	L_S-S_L	2
8	B-L_S-S_L	2
9	S_D-L_S-S_L	2
10	B-S_L-L_M-B	2
11	B-S_D	1

Seq #	Functional Seq	Freq
12	B-S_L	1
13	B-S_L-L_M-S_D	1
14	L_S-S_D-B	1
15	L_S-S_D	1
16	S_D-B-L_S-S_D	1
17	S_D-L_M-S_D	1
18	S_D-L_S-S_D-B	1
19	S_L-L_S-S_D	1
20	S_L-L_S-S_S-B	1
21	S_S-L_S-S_D	1
22	S_S-L_S-S_L-B	1

Table 3.2: From/To analysis according to function

FROM/TO	B	S_S	S_D	S_L	L_S	L_M	From	Ends	Sum
B			1	4	3		8	56	64
S_S	5				2		7	0	7
S_D	9				3	1	13	19	32
S_L	11				2	3	16	12	28
L_S		1	6	7			14	0	14
L_M	2		2				4	0	4
Into	27	1	9	11	10	4	-	87	149
Start	37	6	23	17	4	0	87	-	-
Sum	64	7	32	28	14	4	149	-	-

To prepare the From/To chart, travelers (route cards) were obtained for a substantial number of products. The work instructions on the travelers were then classified according to function definition. Table 3.1 shows the functional sequence frequency chart. The frequency chart is used in constructing the *from/to* table shown in table 3.2. To verify the accuracy of the Functional sequence chart (Table 3.1) and From/To table (Table 3.2), the total jobs entering that function from all other functions plus the total number of jobs that start with that function should equal the total number of job from the same function to any othere functions and any jobs that end at that function. This check is illustrated in *from/to* table (Table 3.2). For instance, the number of jobs entering the bandsaw function (27) plus the total number of jobs that start at the bandsaw(37) is 64. To verify if this is accurate, the total number of jobs coming out of bandsaw function to any other functions (8) plus the total number of jobs that end at the bandsaw function (56) is 64, confirming the accuracy of the analysis.

Using the Chart and and functional sequences, Figure 3.1 was created which shows the current layout and flow of jobs between the material prep machines. From the just concluded analysis it is apparent that:

- The majority of flow into the band saw terminates there, with few jobs flowing from the band saw to other processes. The bandsaw is a naturally a batch process and it seems best to operate it that way processing work from any required earlier operations at the laminator and skiver “K11”.

- Most flow occurs between the laminator and Skive/Slitter machine. Since each machine can operate single piece and flow between them is not interrupted by the batch bandsaw process this should make these two machines single piece flow compatible or alternatively operate with small batches for improved flow.
- .The laminator is light and mobile, and this should allow for a reconfigurable cell depending on the product been processed.

The recommended layout change resulting from the *from/to* analysis is shown in Figure 3.2.

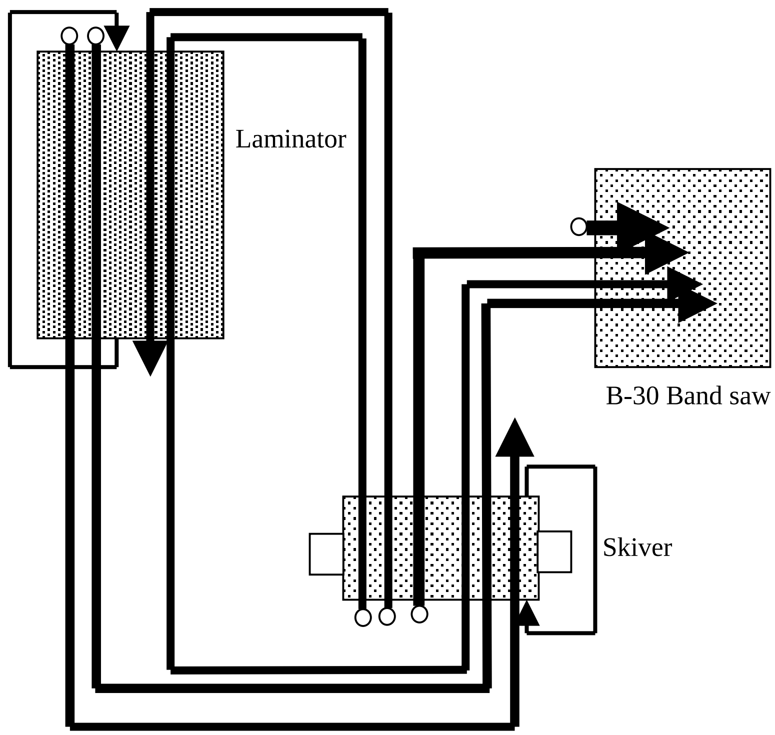


Figure 3.1: Current Layout and flows

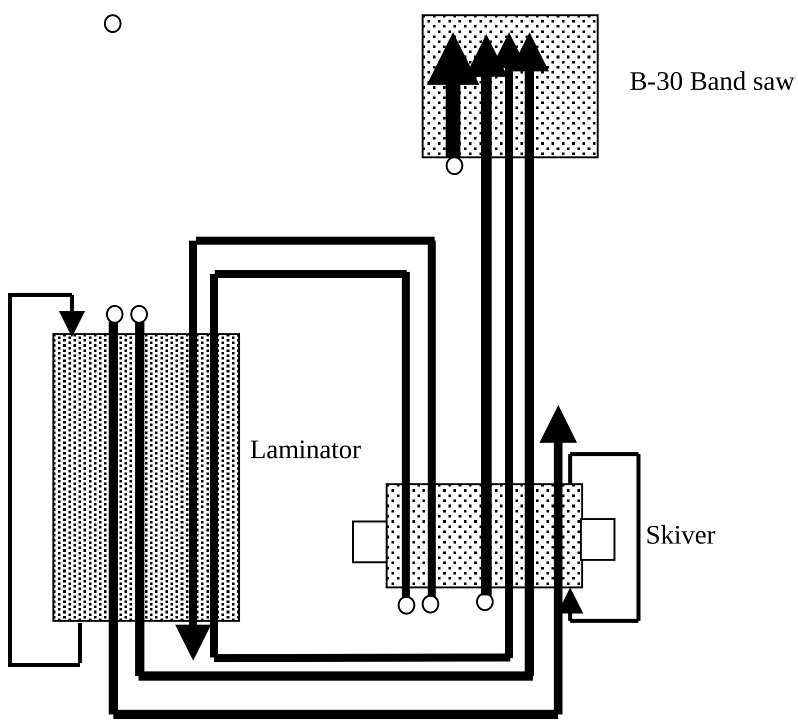
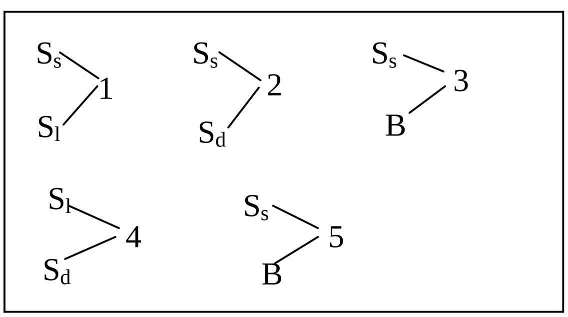


Figure 3.2: Revised floor layout

Considering that most flow occurs between the skiver/slitter machine and the laminator, it helps considering functional sequences that involve these two machines and thus develop system standardized work tables that depict running these common functional sequences in the most efficient way. Table 3.3 shows the functional sequence frequency chart that takes into consideration flow between Skiver/Slitter and the Laminator machines. The objective of this analysis is to determine which sequences occur with high frequency to deserve focusing attention in developing standardized work templates. A cumulative frequency graph for the functional sequences allows us to select all the sequences that fall within 80% of the cumulative frequency total. Figure 3.4 shows the cumulative frequency graph and it is apparent from the illustration that the functional sequences (a, b, c…..i) are of relative importance compared to the rest of sequences that are beyond i.

Table 3.3: Functional sequence frequency, skiver-laminator interfacing

Func Seq number	Functional Seq	Freq	ΣFreq
A	2-L_s-S_d	6	**6**
B	1-L_m-S_d	5	**11**
C	2-L_m-S_d	4	**15**
D	2-L_s-S_l	4	**19**
E	S_d-Lm-S_d	4	**23**
F	S_d-L_m-S_d	3	**26**
G	S_l-L_S-B	3	**29**
H	4-L_m-S_d	2	**31**
I	5-L_m-S_d	2	**33**
J	5-L_s--S_d	2	**35**
K	1-L_s-S_l	1	**36**
L	4-L_m-S_d	1	**37**
M	L_m	1	**38**
O	L_m-S_d	1	**39**
P	L_s-S_d	1	**40**
Q	$S_{.}L_{m-}S_d$	1	**41**
R	S_d-L_s-S_l	1	**42**
S	S_l-L_s	1	**43**
	Total	**43**	



S_d: Dimensional Skiving
S_l: layer cutting on skiver
S_S: Skinning
L_s: Single pass laminating
L_m: multi pass laminating
B: Band saw

Figure 3.1.1: function sequences prior to

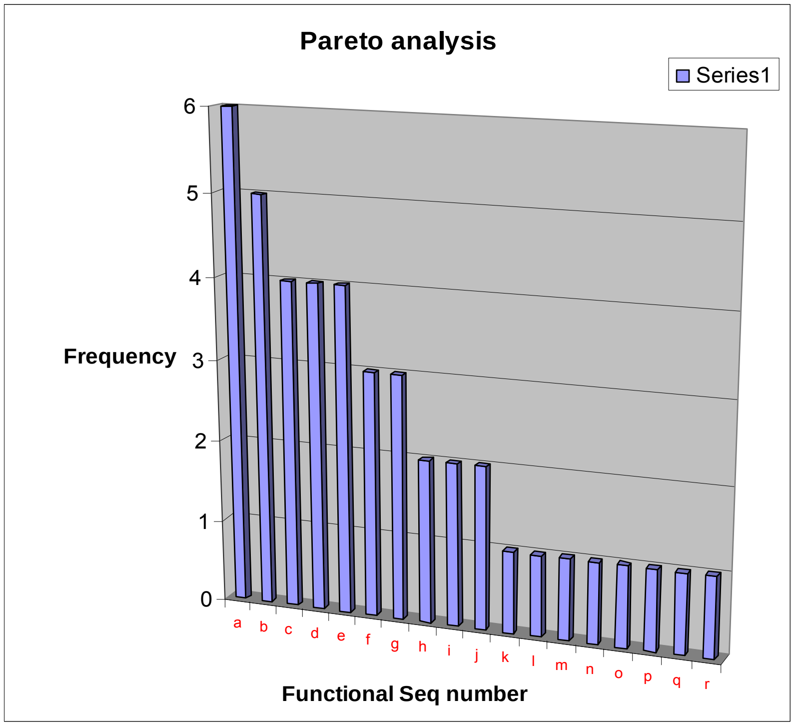


Figure 3.3: Functional sequence frequency histogram

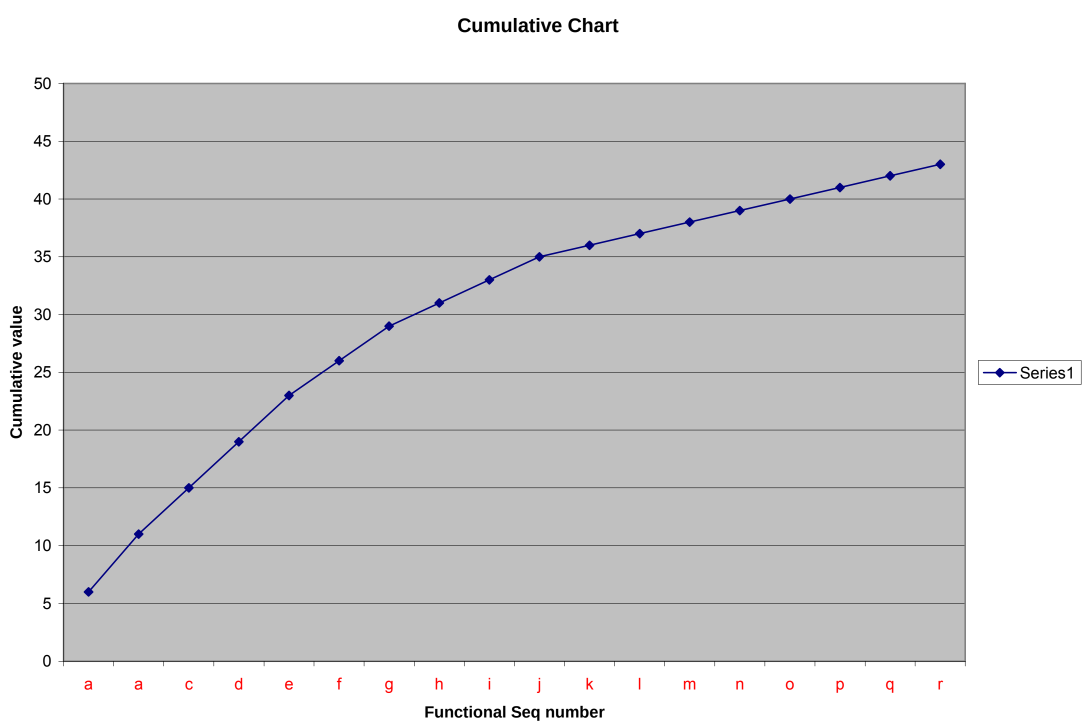


Figure 3.4: Functional sequence cumulative chart

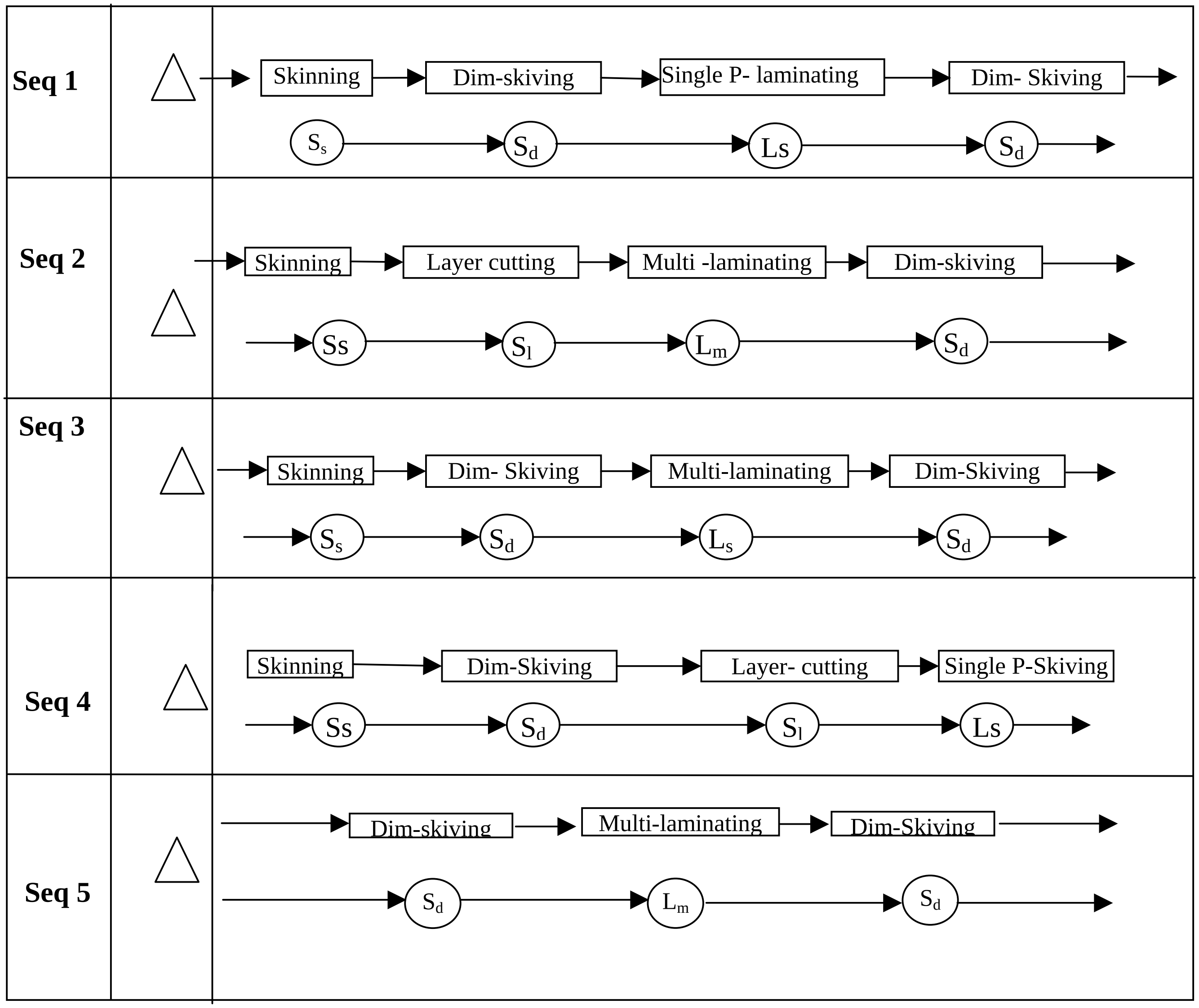


Figure 3.5: Common functional sequences, skiver-laminator interfacing

For the the above high frequency functional seqeunces we can build work combination charts to represent how the cell can function as a unit. Although the material prep cell may be considered machine constrained, manning levels do affect the cycle times to some extent. As part of the lean innitiative it is an important goal that minimum manning levels be sought by incorporating kaizen improvements to lessen the burden on the operator. Some of the kaizen ideas that should improve the process cycle time as well as lowering the manning levels will be discussed at later stage in this project.

MATERIAL PREP CELL CONFIGURATION

As noted previously Figure 3.1 shows the current layout while Figure 3.2 shows the recommended layout. The recommended layout demonstrates the desirability to maintain a close proximity between slitter machine and laminator. The cell design should be such that minimal walking takes place. Walking in such an analysis is considered waste and is subject to exclusion in determining cycle times for each process. It is also desirable to introduce flexible interfacing through consideration of an appropriate material conveyance system. The thicknesses of the flow lines are in direct proportion to the volume of material moving in each given route. A particularly desirable property in a high-variety low-volume job shop would be the ability of the machine to be mobile and thus be able to conform to a desired cell layout within a short space of time. The mobility of the laminator is therefore a desirable property in this context. Another important consideration in system-standardized work is the material conveyance system. Presently skids are used for transporting material between the two machines. The design of the presently used skids is ergonomically unsound. The wheels are too small, thus requiring a bigger force to move the skid especially when fully loaded. Movement of the skid is achieved by pulling a rope attached to it. In moving any object pushing is usually the preferred method of force application. The base of the skid is fixed at a level almost close to the floor. This too contributes to a bad design. Ideally all work should be carried out at elbow height. This therefore calls for a revised skid design, which would be height adjustable.

The work at the slitter and laminator was done in big batches independent of each other. The slitter operator would work on a huge batch of material until completed. The completed material would then be transported to the laminator area where it would lie until adequate capacity to process it would be available. In some cases the amount of material processed at the slitter was so huge that the buffer zone at the laminator was inadequate, meaning that alternative temporary storage space had to be found on the shop floor. Allowing such irregular build up of inventory is contradictory to lean approaches. Not only did large batch production result in storage problems, but it also resulted in quality problems since in many cases it came to notice that either the planks were oversized or undersized. The consequences of excess inventory are bad, considering the decreased throughput, extra handling, as well as lost time should a quality problem surface that would require reworking the entire batch.

The solution to this problem would be to consider production in the material cell at a system level and to document standard work at the system level. Small batch production is encouraged and for this project a batch of 5 and 10 was considered for the system standardized work. One unit of material is considered to be a standard sized plank.

Table 3.4: Batch processing times

				Time to process a batch											
	Function	Symb		5		10		15		20		25		30	
				1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope
k11	Skinning	Ss		280	200	560	400	840	600	1120	800	1400	1000	1680	1200
	Dimsension cut	Sd		280	200	560	400	840	600	1120	800	1400	1000	1680	1200
	Layer cuting	Sl	3	840	600	1680	1200	2520	1800	3360	2400	4200	3000	5040	3600
			4	1120	800	2240	1600	3360	2400	4480	3200	5600	4000	6720	4800
			5	1400	1000	2800	2000	4200	3000	5600	4000	7000	5000	8400	6000
			6	1680	1200	3360	2400	5040	3600	6720	4800	8400	6000	10080	7200
Laminator	Single Pass	Ls		325	250	650	500	975	750	1300	1000	1625	1250	1950	1500
	Multipass Lamin	Lm	3	975	750	1950	1500	2925	2250	3900	3000	4875	3750	5850	4500
			4	1300	1000	2600	2000	3900	3000	5200	4000	6500	5000	7800	6000
			5	1625	1250	3250	2500	4875	3750	6500	5000	8125	6250	9750	7500

nb: The following times ignore effecto of setup

Table 3.5: Function cycle times

			Cycle times for Functions Def				
			Ss	**Sd**	**Sl**	**Ls**	**Lm**
K11	**LM**	**1 Ope**	56	56	56	65	65
		2 Ope	40	40	40	50	50

Stanadardized Work Combination Table: System (07/15/02)
2-Ls-Sd

R & D	Prod

Seq uence	Operation	Time: Auto	Manul	Walk
	Operator 1			
1	SKIN BOTH SIDES	9.3		0.16
2	DIMENSION CUT	4.6		0.3
3	SKIN BOTH SIDES	9.3		0.16
4	DIMENSION CUT	4.6		0.3
5	DIMENSION CUT	4.6		0.16
6	SKIN BOTH SIDES	9.3		0.16
7	DIMENSION CUT	4.6		0.3
8	DIMENSION CUT	4.6		0.16
9	SKIN BOTH SIDES	9.3		0.16
10	DIMENSION CUT	4.6		0.3
11	DIMENSION CUT	4.6		0.16
12	SKIN BOTH SIDES	9.3		0.16
13	DIMENSION CUT	4.6		0.3
8	MULTI-PASS LM	16.25		0.3
9	MULTI-PASS LM	16.25		0.3
	MULTI-PASS LM	16.25		0.3
	MULTI-PASS LM	16.25		0.3

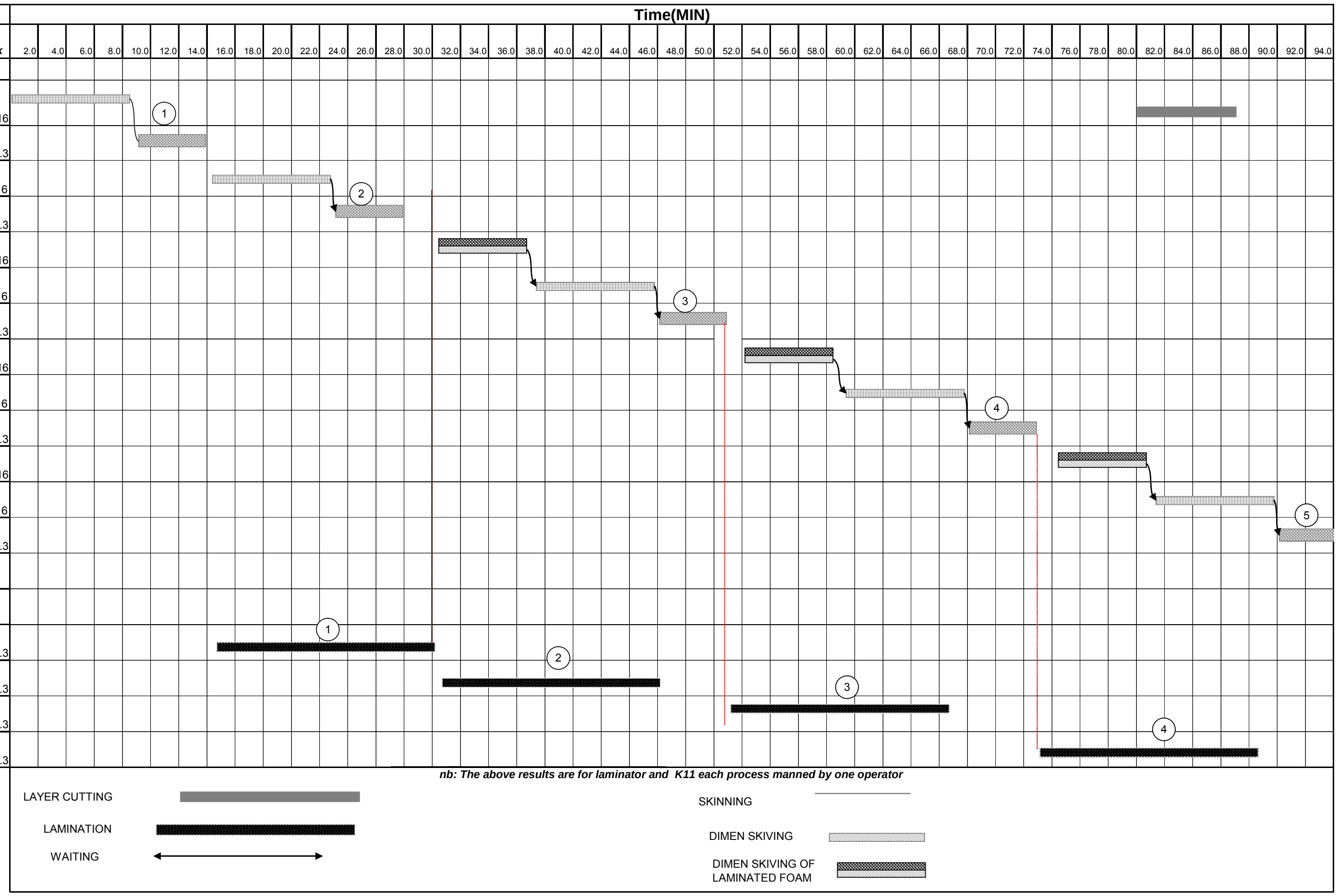


Figure 3.6:Combination for a Function

3.7.1. THE 2-L_S-S_D HIGH FREQUENCY COMBINATION CHART

As an example of system level standardized work Figure3.6 shows the combination chart for the high frequency functional sequences **2-L_S-S_D** . As defined, the number **2** in the **2-L_S-S_D** functional sequence representation *(*See Figure 3.1.1) represents the initial functions of skinning followed by dimension skiving. The material is processed in batches of 5. After the skiver/slitter operation, the material is then moved to the Laminator process for the single pass lamination function (i.e. **L_S**) to be carried out. After the lamination process, the material is brought back again to the skiver/slitter machine so that the function of dimension skiving (**S_D**) is done. This completes the flow of the functional sequence (**2-L_S-S_D)**. It should be noted that each function has associated with it, a set up procedure.

The combination chart (Figure 3.6) represents timing of this sequence of operations. The encircled numbers represent the cycle during which the function is being processed. The combination chart assumes that the work begins at the skiver/slitter machine. After the first 2 cycles of the skiver/slitter functional sequence, it is apparent from the combination chart that the function occurrence falls into a regular pattern. This is an indication of a steady state system operation. From this pattern, the analyst is able to deduce the system cycle time by reading the chart. This regular pattern represents flow at its best, and although it is apparent that some degree of idle time will be present at the laminator process, the advantages of improved flow outweigh the drawbacks. It should be noted that the combination chart has been created with an assumption that the set up time is minimal because of the presence of standardized set up procedures. Failure to address set up problems prior to this may result in a distorted picture, far from the idealized situation as illustrated in the combination chart. Addressing process level issues is therefore a vital component in achieving high system standardized work goals.
The combination chart shown (Figure 3.6) is for the high frequency functional sequence

(2-Ls-$S_{d)}$. It serves as a good illustration of how the three processes of the material prep interface. In a similar manner, system standardized work documentation can be applied to other high frequency functional sequences (and these are givrn in Appendix C2-C5). This is very helpful because it indicates the production time needed to run a particular functional sequence, and consequently shop floor control is made much easier. It is also important to note that manning in this cell can be varied according to the desired rate of production.

3.8.PROCESS LEVEL STANDARDIZED WORK AT FDI

At the process level, each machine has detailed standardized work documents associated with the work done at that machine. Included among the standardized work documents are the set up sheet, which indicates how to set up and run a job, the operations chart, which shows the work procedures and all the knack points associated with the job. The standard work chart is also presented, detailing man/machine interfacing. The work combination chart is the last standardized work document created for each process. All process standard work documents produced during this project are presented in the appendices A and B . It should be noted that although generic standardized work sheets have been prepared according to their functional basis, the set up of a particular process might require knowledge of specific parametric values associated with specific material types. There are quite a number of different types of foam material used at FDI, each of which possesses distinct mechanical and chemical properties. As such, each material behaves differently when processed at a particular machine, and thus material-specific set up parametric values need be found and tabulated for each material type. While the functional standardized work is generic and applicable to all materials, the need to complement the standardized work with further standardized documents that furnish material specific parametric values, presented in an appropriate graphical format, is an important aspect in HVLV product environments. These parametric values can be determined in either of two ways, experimentally or based on information given by an experienced operator. Experimental determination is favored to the latter, which may be prone to error.

Experimental determination of K-11 slitter setting " Top roller settting"

R & D	Prod

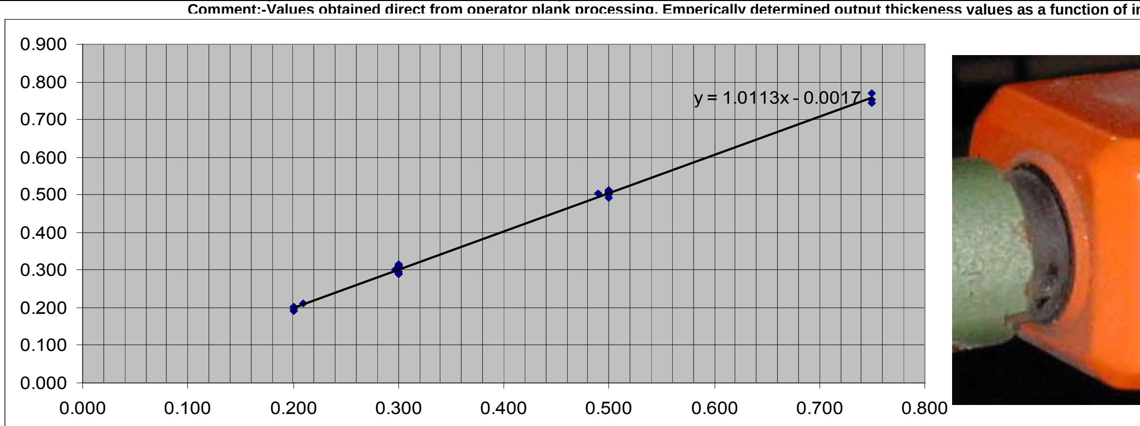
Updated: 8/5/2002

1

2

Desired thickness		T0p setting	Desired thickness		Top setting	Desired thickness		Top Setting	Desired thickness		Top Setting	Desired thickness		Top Setting
1/32	0.031	0.030	11/16	0.694	0.694	1-11/32	1.344	1.357	2	2.000	2.021	3-3/8	3.375	3.411
1/16	0.063	0.062	23/32	0.725	0.725	1-3/8	1.375	1.389	2-1/16	2.063	2.084	3-7/16	3.438	3.475
3/32	0.094	0.093	3/4	0.757	0.757	1-13/32	1.406	1.420	2-1/8	2.125	2.147	3-1/2	3.500	3.538
1/8	0.125	0.125	25/32	0.788	0.788	1-7/16	1.438	1.452	2-3/16	2.188	2.211	3-9/16	3.563	3.601
5/32	0.156	0.156	13/16	0.820	0.820	1-15/32	1.469	1.484	2-1/4	2.250	2.274	3-5/8	3.625	3.664
3/16	0.188	0.188	27/32	0.852	0.852	1-1/2	1.500	1.515	2-5/16	2.313	2.337	3-11/16	3.688	3.727
7/32	0.219	0.220	7/8	0.883	0.883	1-17/32	1.531	1.547	2-3/8	2.375	2.400	3-3/4	3.750	3.791
1/4	0.250	0.251	29/32	0.915	0.915	1-9/16	1.563	1.578	7/16	2.438	2.463	3-13/16	3.813	3.854
9/32	0.281	0.283	15/16	0.946	0.946	1-19/32	1.594	1.610	2-1/2	2.500	2.527	3-7/8	3.875	3.917
5/16	0.313	0.314	31/32	0.978	0.978	1-5/8	1.625	1.642	2-9/16	2.563	2.590	3-15/16	3.938	3.980
11/32	0.344	0.346	1	1.010	1.010	1-21/32	1.656	1.673	2-5/8	2.625	2.653	4	4.000	
3/8	0.375	0.378	1-1/32	1.041	1.041	1-11/16	1.688	1.705	2-11/16	2.688	2.716			
13/32	0.406	0.409	1-1/16	1.073	1.073	1-23/32	1.719	1.736	2-3/4	2.750	2.779			
7/16	0.438	0.441	1-3/32	1.104	1.104	1-3/4	1.750	1.768	2-13/16	2.813	2.843			
15/32	0.469	0.472	1-1/8	1.136	1.136	1-25/32	1.781	1.800	2-7/8	2.875	2.906			
1/2	0.500	0.504	1-5/32	1.168	1.168	1-13/16	1.813	1.831	2-15/16	2.938	2.969			
17/32	0.531	0.536	1-3/16	1.199	1.199	1-27/32	1.844	1.863	3	3.000	3.032			
9/16	0.563	0.567	1-7/32	1.231	1.231	1-7/8	1.875	1.894	3-1/16	3.063	3.095			
19/32	0.594	0.599	1-1/4	1.262	1.262	1-29/32	1.906	1.926	3-1/8	3.125	3.159			
5/8	0.625	0.630	1-9/32	1.294	1.294	1-15/16	1.938	1.958	3-3/16	3.188	3.222			
21/32	0.656	0.662	1-5/16	1.326	1.326	1-31/32	1.969	1.989	3-1/4	3.250	3.285			
									3-5/16	3.3125	3.348			

Comment:-Values obtained direct from operator plank processing. Emperically determined output thickeness values as a function of input thickness.



Top Roller setting

Figure 3.7: Skiver machine quick set up chart

Figure 3.7 illustrates the results of experimental study carried out to establish set up values for the upper roller of the slitter machine. The two columns shown, that fall under the *desired thickness* heading, give the value of the desired thickness in fraction and decimal formats respectively. To illustrate how this table works, suppose that an operator needs to cut material to a thickness of 5/16 inches off the top roller. The operator would need to refer to the general set up sheet to be able to follow the set up instructions as specified (standard set up). At a particular stage of the setting up, the operator will be prompted to input a value of the set up parameter. This particular value is not given in the set up sheet since it is product specific in nature while the set up sheet is generic (appendices A). To obtain the product specific value, the operator makes reference to the product specific set up table (Figure 3.7). Using the table, the operator locates 5/16 Inches under the desired thickness column. The value lying in the same row under the top setting column thus gives the actual value that the operator needs to set on the machine

Equally important is the ability to be able to carry out set up of the laminator in the minimum amount time. Standardizing the set up procedure for this process is a worthwhile effort that can be richly rewarding in the long run. The ability to come up with standard set up values that can be relied on for now and in future production can be accomplished both experimentally and through systemic data acquisition and documentation of the knowledge of an experienced operator. Although designing and running experiments is probably the better method, in certain cases cases the second option is appropriate when there is a lack of expertise to carry out experiments and the reluctance management shows in its commitment to afford adequate resources for experimental purposes. It is important to realize that less than fully accurate standards are better than none at all, because it gives you a starting point in. In light of this, the situation at FDI favored using set up standards as determined by an experienced operator. It has to be understood that the education of shop floor staff is important for such purposes since it is the shop floor personnel that have to embrace the program for it to be successful.

The purpose and usefulness of implementing set up standards was explained to all relevant shop floor employees. A user friendly data sheet was created that would be used to capture data whenever the laminator was being set for a particular job. All process related data would be captured and a comment section was included so that any quality problems would be included as well. Because only a limited number of experienced operators possessed adequate knowledge to successfully set up the laminator, this meant that the data in this sheet would capture the data of an experienced operator. Over a period of time this data could accumulate to include a wide variety of laminator material combinations. At a later stage it would then be possible to consolidate this data to create product specific set up sheets as well as providing a stepping stone for set up improvements. Observing the operator as he performs his work presents the opportunity to observe all the knack points associated with the job, all of which are important for standardized work. The standardized set up values as determined by the operator is illustrated in table 3.6 shown below.

Table 3.6: Laminator machine quick set up table

foam design

Laminator Set Up Sheet

R&D	Prod

	material 1 Density	material 2 Density	Belt Speed	Roller speed	height of heat bar
1	1.7	1.7	1.2	67	0.5
2	1.7	2	1	65	0.5
3	1.7	4	0.8	65	0.5
4	1.7	6	0.8	63	0.5
5	1.7	9	0.7	60	0.5
6	2	2	1.4	65	0.5
7	2	4	0.8	65	0.5
8	2	6	0.8	65	0.5
9	2	9	0.6	60	0.5
10	4	4	0.6	65	0.5
11	4	6	0.6	67.5	0.5
12	4	6	0.6	67.5	0.5
13	9	9	0.3	67.5	0.5

nb: The following are only guidelines that have not been confirmed experimentally
these readings are based on experiencence of the workforce and are assumed for all materials.

The above set up values were determined for etha-foam. Table 3.6 shows three set up parameters (belt speed, roller speed and height of heat bar) that need to be determined before running a job on the laminator. Table 3.6 is amenable to a feed and speeds table with the exception that the values have been determined empirically through the knowledge of an experienced operator. Without such a table it is always difficult to assign an inexperienced operator for such a task. Operator flexibility is an inherent desired quality for improved flow on the shop floor. It has to be understood that a complete set of values will include a multitude tables consisting of materials of different types and densities. This takes time, effort and commitment, but the results are worthwhile. The set up sheet and other related laminator standard work documents can be viewed in Appendix B.

3.9.KAIZEN: GENERAL BACKGROUND AND ISSUE IN HVLV PLANTS

What is the single most important resource in an organization? Most would agree is not the facilities, or equipment or even the technology. It is the people. In many cases organizations are guilty of not tapping the full potential of their employees. They are guilty of underutilizing the intelligience of their workforce. How then can organizations like FDI, manufacturing HVLV Without a formal suggestion system, begin realizing the full potential of their employees? The most important thing is empowering them. In many organizations there exists a brain line between top management and work force. This is illustrated in figure below.(*Robin E. McDermott*)

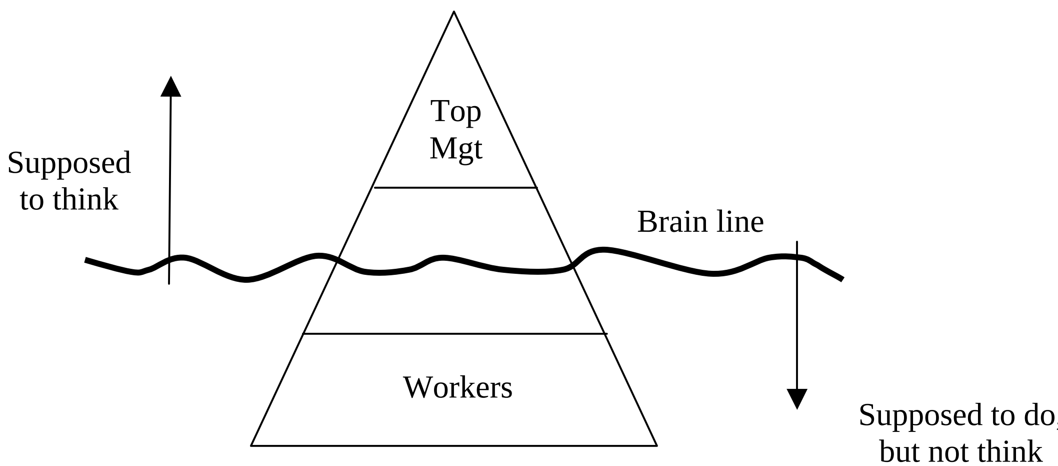


Figure 3.8: A Brain line

The first step towards employee empowerment is for management to acknowledge the undesirable presence of a brain line. Only then can management be in a position to act to erase it, thus empowering the employee. The existence of this brain line in many organizations is largely evident when management does not provide employees with the proper training in the use of continuous improvement (CI) tools. An important step in this process is the creation of an environment in which employees feel comfortable suggesting ideas. The creation of a formal suggestion system is a key to a successful kaizen program. A suggestion system will ensure that employees get their ideas for improvement heard and assure them that their suggestions will be acted on. Organizations can implement any one of a number of different models of suggestion systems. Employee driven suggestion systems (EDSS*)*, would appear to be the most effective and appropriate suggestion systems for organizations vying for a lean status. In an EDSS the workforce is empowered to drive their ideas to completion without having to go through a bureaucratic chain of command. Establishing an EDSS is a big project that must involve a representative from each area of the organization. It is also important that input from front line employees, for whom the system is being created, be sought as early as the development phase. The development team may consist of not more than ten members. Any more can make it difficult to act quickly.

In the traditional suggestion system employees submit their ideas for improvement. The idea is then assigned elsewhere in the organization, typically the engineering department, maintenance department etc. When this is done, usually it is found that the person responsible for implementing the idea harbors some level of resentment towards the person making the suggestion, who is viewed as causing more work for the implementor. In a similar fashion, the suggestor is often found to be resentful of the implementer who is seen as taking ownership of the idea and in some cases the implementation does not resemble the original idea. It is therefore important to have the idea generator become fully involved in its implementation. A typical EDSS may require just the idea generator and approval of the supervisor for implementation. It should be remembered that good ideas come from people close to the work as opposed to general kaizen that can be practiced by anyone. All ideas coming from the shop floor should be treated equally, and no idea should be discriminated against. Employees usually know that their ideas aren't valued when their supervisors:

1. procrastinate in responding to their idea
2. write their idea on a piece of paper and misplace it
3. tell them idea is too costly to put into practice
4. say their idea has been thought of before and it never worked

Given this background, it is imperative for any HVLV job environment to put in place an effective formalized suggestion system that is able to respond in the quickest possible time to the input of its shop floor employees. Standardized work should be used as the starting point of kaizen activities. It has been said that there can be no kaizen where there are no standards. Without standards it is difficult to locate problems or points that require kaizen. The desire for shorter lead times, higher quality, reduced in process stock, increased production capacity, and reduced manning levels; ultimately leading to corporate profits should be motivators for a strong kaizen program. All kaizen work requires initial understanding of how the process works and an analysis of the present situation is required.

3.9.1. KAIZEN FOR THE MATERIAL PREP CELL

A number of kaizen ideas that could improve the operation of the processes were identified during the course of developing functionally based standardized work for the Material Prep Cell. Although some of the ideas could be considered as not having much of an impact, implementing them does make a difference. The concept of continuous improvement emphasizes making baby step improvements rapidly accumulates to big gains in performance. Starting off with the skiver/slitter process each of the ideas will be discussed.

3.9.1.1. Kaizen idea 1:

When performing the slitting process, two rollers draw a plank and force it against a moving blade. The plank is split into two by the blade. This action is illustrated in figure15 shown below. Both split planks are ejected on the opposite side of the machine. This operation is usually flawless if the thickness of the upper plank is large enough. However, when the thickness of the material coming off the top becomes very thin and light in weight, there is a tendency of this material to conform to shape of the roller and get entangled within the roller. This problem is largely associated with the skinning function. When this happens, contact between the roller and incoming foam is affected and subsequent material that is drawn through is not cut accordingly, leading to quality problems. Because of this problem this operation has had to be carried out with two operators, with one operator positioned on the output side of the machine. The job of the second operator is merely to get hold of the material coming off the top of the blade to avoid the material being drawn back by the roller.

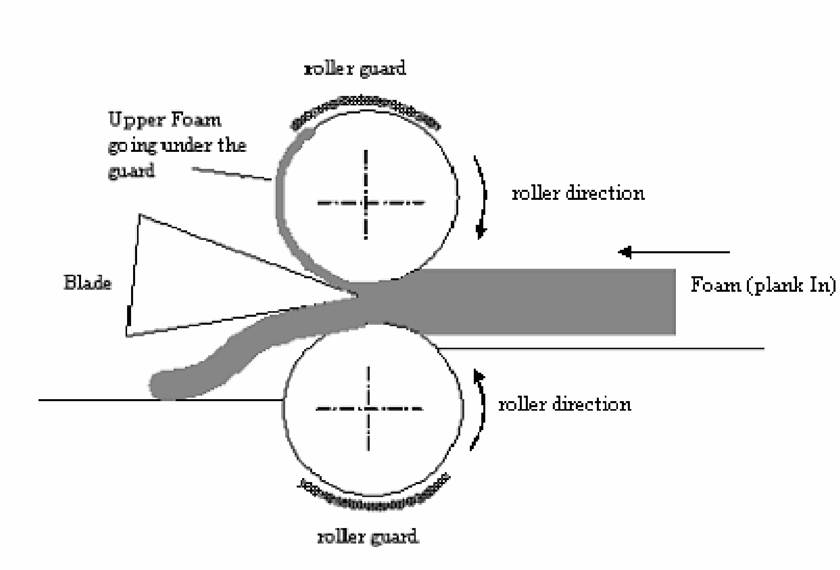


Figure 3.9: slitting process illustrated

SUGGESTION FOR PROBLEMS:l

3.9.1.2. Suggestion 1:

The first suggestion involves using compressed air to blow off the thin layer of foam coming off the top roller. This air can be introduced through a pipe laid parallel to the roller and having several nozzles to let out high-pressured air. A simple illustration of such a set up is shown in Figure 3.10.

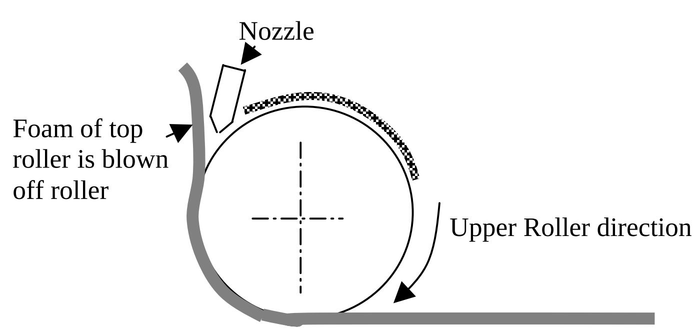


Figure 3.10: kaizen suggestion 1

3.9.1.3. **Suggestion 2:**

The second suggestion uses the same concept, but instead of the nozzle a flexible material such as polypropylene bristles used for the end of bro oms can be made come into contact with the roller when ever thin material is been skived. This arrangement is illustrated in figure 3.11 below. This action prevents the foam from being drawn back by the roller.

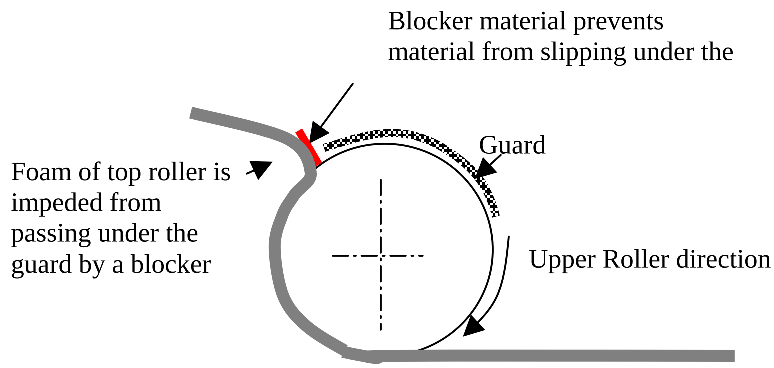


Figure 3.11: improvement illustrated

The two solutions mentioned above should not be too difficult to implement given the availability of skilled maintenance personnel. Eliminating this problem should result in a significant reduction in the cycle time, since the time taken to walk to the output side as well as spent removing foam that is caught between rollers is eliminated.

3.9.1.4. Suggestion 3:

From observing and talking to the operator while at work at the input side of the slitter machine it is apparent that there is potential for ergonomic improvement at this particular work station. The main concern with the material loading aspect of the work is that there are no mechanical assists to aide this operation despite the excessive loads and awkward postures the operator has to deal with. Because of energy expended during work, recovery time becomes an important issue. A situation in which the recovery time exceeds the task time becomes of major concern and deserves redesign of the work. For practical cases such situations do prevail when products exceed 16kg and vertical movements are involved or when the object is over 8kg and is moved more than 0.75

meters. Loading of the skiver/slitter machine falls in this category, thus becoming cause for concern considering that loads as heavy as 50kg may have to be repeatedly lifted off a floor level skid onto the machine without any mechanical assist. This puts a strain on the worker and leaves him or her susceptible injury. Remedying this situation may involve use of adjustable lift tables available from various material handling vendors to elevate the material to the table height of the skiver enabling it to be slid into position with little or no lifting. Alternatively the maintenance department may be able to custom build their own table. The main objective is to alleviate the ergonomic risks associated with posture and excessive lifting.

KAIZEN ILLUSTRATED FOR SKIVER MACHINE

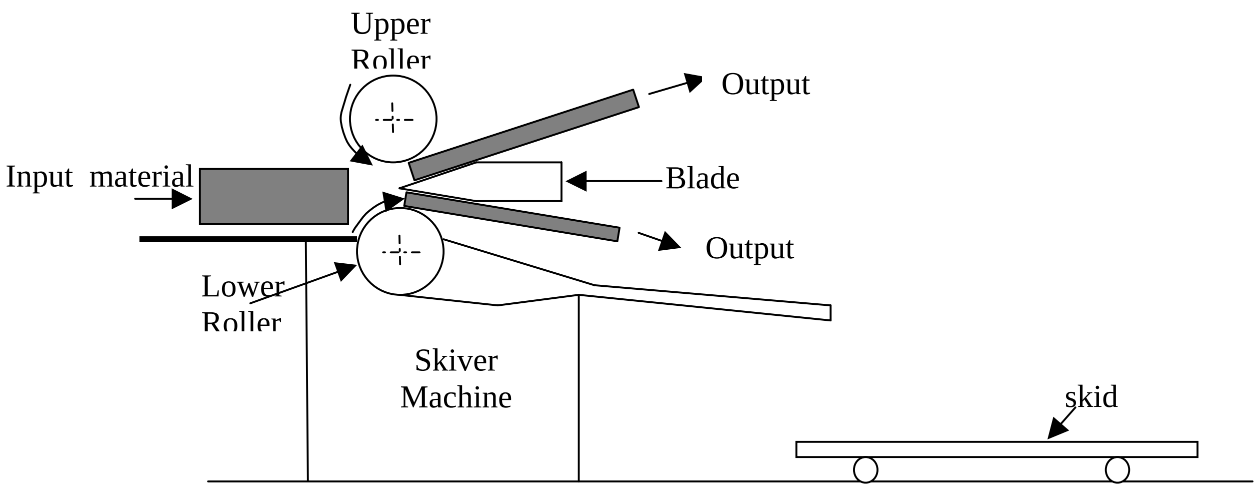


Figure 3.12: Skiver machine before Improvement

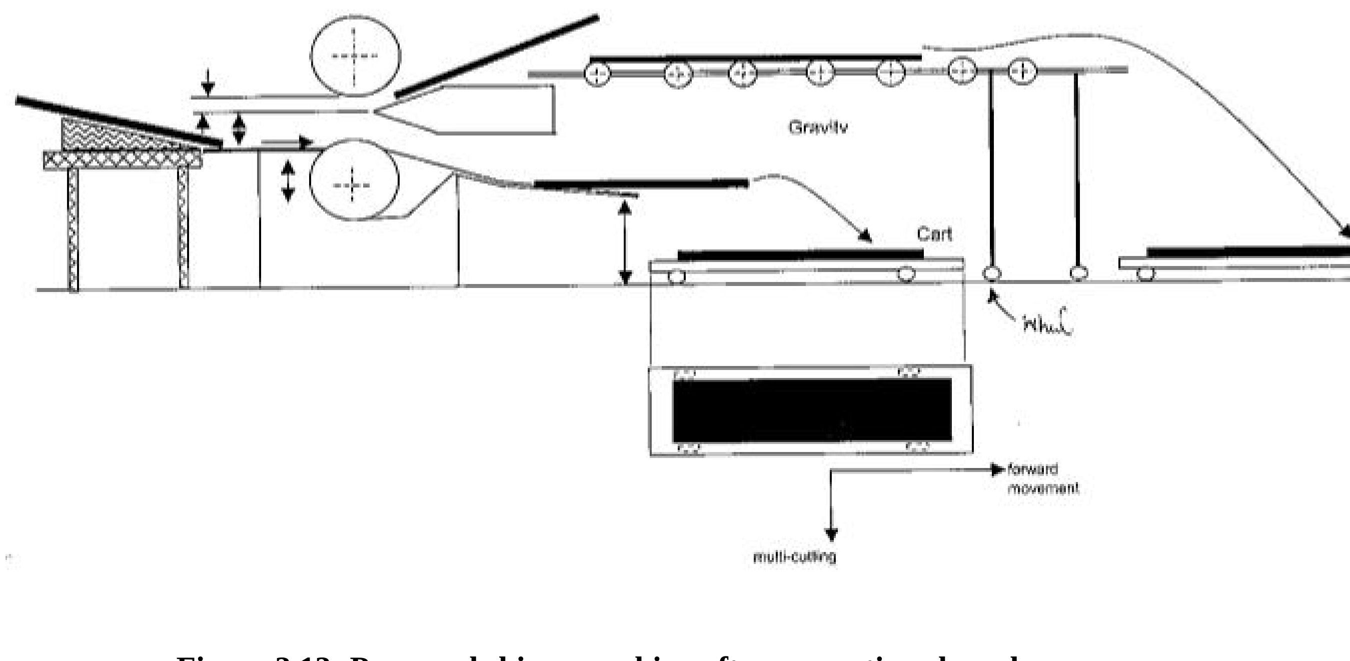


Figure 3.13: Proposed skiver machine after suggestions have been implemented

3.9.1.5. SUGGESTION 4

Associated with any machine processing are knack points, which are work procedures that need to be adhered to if a quality product is to be obtained. These knack points should be shown on the operations standard work chart To achieve a quality cut, it is necessary to know the knack points for the particular process. The knack points can only be identified by observing and talking to the operator while processing the material. (Figure 3.12 shows the skiver machine prior to the proposed kaizen implementation). One of the knack points associated with the skiving operation involves the operator holding the plank at an inclined position, with the lagging end of plank elevated above the leading end. This ensures that the plank is drawn in through rollers at an angle. The angle has to be maintained until the whole plank is drawn through. As a result, the operator is forced to remain fixed at that position, ensuring the right angle is maintained for the entire machining cycle. In general there is a need to separate man's work from machine's work and this principle has led to a suggestion of introducing a table with an inclined surface at the input side. Such a development should then free up the operator to do other things, e.g. preparing for the next loading cycle.

3.9.1.6. SUGGESTION 5

Another kaizen idea at the Slitter hopes to achieve some degree of automatic ejection of material at the output side of the machine, rather than have the operator walk to the output side to unload the material for each plank that is drawn through. Automatic ejection may eliminate the need to do this. Separating the material coming off the top and bottom rollers is challenge to be met and the proposed method for accomplishing this objective is illustrated in Figure 3.13.

CHAPTER 4

4. SET UP REDUCTION FOR MATERIAL PREP PROCESSES

Set up reduction methods appear to be necessary for material prep processes, in particular for the skiver/slitter machine (K11). Setting up this particular process is not only complex but time consuming as well. Reducing the time for set up would therefore reduce the cycle time significantly and enable operation of the skiver and laminator as a cell with small transfer batch operation and small production batches. Set up reduction on the skiver/slitter (K11) would entail the creation of set up tables as will be explained below. This in turn requires extensive experimentation with each foam combination that is processed at the laminator. This then brings us to the need to design experiments.

4.1.DESIGN OF EXPERIMNENTS

Design of experiments (DOE) is carried out to gain the maximum amount of information with minimum usage of resources, materials, time and equipment. DOE is a statistical technique used to study the effects of multiple variables simultaneously. The DOE technique can be used to scientifically solve problems whose solutions lie in specifying the proper combination of ingredients or factors. It is a useful technique, which has the effect of improving process control and performance. There have been several methods used in DOE, each exhibiting its advantage relative to the others. R.A Fisher pioneered the use of Design of experiments. However, because of the complex nature of his approach to DOE, his work was only limited to the agricultural and chemical industry. Genishi Tagushi came out with a simplified form of DOE, which ensured consistency of results even if different individuals conducted experiments. Tagushi's DOE has been widely applied in manufacturing.

4.1.1. AREAS WHERE DOE IS APPLICABLE

Wherever there are products and processes, DOE can be applied. DOE can be used effectively in areas such as research, product development, manufacturing and production processes, e.g., machining, heat treatment, casting and molding. The main use of DOE is in problem solving for processes that are affected by many factors.

4.1.2. APPROACHES TO DOE

According to Keki R Bhote there are three basic approaches or techniques to Design of experiments. The three documented techniques in the DOE field are as follows:

- Classical DOE (R.A Fisher)
- Tagushi DOE technique
- Shainin

The Tagushi technique for DOE is a modification of the Fisher's classical approach. Shainin's approach is a collection of powerful techniques invented by Dorian (USA). Although Shainin's approach has not received much publicity, quality experts have claimed that Shainin's approach is the most powerful of the three DOE. Use of these techniques helped Motorola achieve a one thousand fold improvement in quality over a period of ten years. All the three DOE approaches to DOE, Classical, Tagushi, and Shainin, are more powerful than the traditional approach that used to vary one factor at a time with the other variables held constant.

4.1.3. COMPARISON OF THE THREE TECHNIQUES

Shainin DOE is considered more successful than either classical or Tagushi DOE approaches. In the case of classical and Tagushi approaches repeating of the experiments may be necessary if failure to produce the intended results occurs. Not only is this costly but it also results in prolonged disruption to production while on the other hand Shainin's approach is economical in the number of trial runs required and production is not disrupted. Analysis of variance is required for both classical and Tagushi DOE while this is not a requirement for Shainin. As for ease of use Shainin is superior to the other approaches such that even operators are comfortable with its use. The opposite is true for classical and Tagushi methods as analysis of variance is complicated such that even engineers shy away from it.

4.1.4. WHAT IS ANALYSIS OF VARIANCE?

Analysis of variance is necessary if we are to learn about factor influences and how sensitive results are to different factors. The main objective here is to extract from results how much variation each factor causes relative to the total variation. This is to say the variation of an individual factor can be expressed as a percentage of the total variation. By performing an analysis of variance study we are able to determine which factors need control and which do not. ANOVA serves as a way to quantitatively determine the interactions that exist between factors.

4.1.5. BENEFITS DERIVED FORM CARRYING OUT TAGUSHI DOE

- Establishes the best or optimum condition for a product or process
- Estimates the contributions of individual factors
- Estimate the response under optimum conditions

The optimum conditions are determined by studying the main effects of each factor.

4.1.6. THE QUALITY CHARACTERISTIC

Every product is designed to perform some particular function. The quality characteristic of a product is that measurable output feature of the product that can be related to how well the product has been processed. A single criterion or multi-criteria could be used for such a measure. Usually the measure will possess one of the following three characteristics:

- Bigger is better
- Smaller is better
- Nominal is best

The idea in DOE is to combine factors at an appropriate level, each within respective acceptable limits to produce the best result and yet exhibit minimum variation.

4.1.7. MAJOR STEPS IN TAGUSHI AND CLASSICAL DOE

- Brainstorm the quality characteristics and design parameters important to the product or process
- Design and conduct experiments
- Analyze the results to determine the optimum conditions
- Run confirmatory tests using the optimum conditions

The DOE should begin with careful detailed planning. It should also be emphasized that this particular stage requires participation of a group. Ideally the group is made up of a combination of staff from different functional backgrounds within the organization. All involved should at least have first hand knowledge about the process or product of concern. The planning session ideally is led by a facilitator who should not be directly involved with the experiments. However, it is important for the facilitator to be knowledgeable about DOE methodology. The DOE project can be either for process optimization or problem resolution. Background data gathering is therefore important. Familiarity with processes and products is also prerequisite.

4.1.8. THE PROJECT LEADER

The project leader owns and is responsible for the whole project. He initiates the project, schedules meetings and does everything to ensure that everyone is involved.

4.1.9. THE PLANING SESSION

Issues to be addressed during the planning session include the following:

- Project Objectives
- Factors
- Levels
- Interactions

What it is that we are really after? How many objectives do we want to satisfy? How are we to measure them? These are some of the questions that need to be addressed. The quality characteristic should emerge at this stage of planning. It is important that all decisions reached be on consensus in the setting of objectives. A decision on what factors are to be included in the study should immediately follow the setting of objectives. At this level of planning group members should be allowed to express their opinion as they wish without any discrimination against any of the suggested factors. In the event of too many factors emerging, screening of the factors follows, and unfortunately there is no science to this and the screening will rely on consensus of group members.

4.1.10. DECIDING THE LEVELS TO ASSIGN TO EACH FACTOR

The higher the level assigned to each factor the better the experiment is. However, the higher the levels assigned to each factor are, the bigger the experiment becomes and more costly it is to conduct. Economics therefore determine a smaller number of levels assigned to each factor.

4.1.11. ACCOMODATING EXPERIMENTAL ERROR

Repeating experiment trial runs is always recommended provided it is not too costly to do so. Repetition is particularly recommended if strong noise factors are present. By repeating the experiments the original data points can be confirmed. If the noise factors vary during the day, then repeating the trial runs may reveal their influence. Repetition also offers the opportunity to analyze for variance around the target value. Repetition allows for determination of a variance signal called the Signal to Noise ratio (S/N). The greater this value, the smaller the variance around the target value.

The factors in DOE can be classified as either controllable or uncontrollable. The controllable factors are all those known to us which we have direct control of. On the other hand the uncontrollable factors (noise factors) are all those that affect the process or product but which we have no power over. Examples may include such things as humidity or room temperature at which a process is run.

4.1.12. THE ORDER IN WHICH THE EXPERIMENTS ARE RUN

It is important that the trial conditions should be run in a random manner. This is done to prevent influence of experiment set up affecting the outcome of the experiments.

4.1.13. PITFALLS IN THE USE OF TAGUSHI AND CLASSICAL DOE

The central weakness with Tagushi and classical DOE is their inability to fully separate the main effects from the interaction effects when the number of experiments is limited. In classical and Tagushi DOE, engineers and team members guess the possible cause of problems. They use brainstorming and vote on which factors are the most likely causes of the problem. If the guesses are wrong the experiments may fail to reveal a clear picture of effects. Classical and Tagushi require analysis of variance. The complexity associated with ANOVA discourages its use by engineers.

4.2. SLITTER EXPERIMNETAL DESIGN

4.2.1. BACKGROUND INFOFRMATION ON SLITTER PROCESS

The skiver/slitter machine (K11) is one of the three machines that are part of the material prep cell. This particular process is important in that it largely influences how smoothly the cell runs. Among the three machines of the material prep cell, the K11 is the most difficult machine to operate. The set up time for this machine is large and variable and opportunities for reducing this exist. Correct set up of this machine is usually achieved after the operator has gone through a number of trial runs. At times it would take one, two or even three trials before the operator could arrive at the desired setting. As a result, the more experienced the operator, the fewer trials he would need before determining the correct settings. Since no standard set up documentation exists to guide the set up process it is very difficult for any operator to set up and run the machine within the allowable set up time. The differences in the way different materials behave when being processed further exacerbate the problem of standardizing set up. This means that the same set up values on the machine will not necessarily yield the same output results. For different materials setting up the skiver was a gray area that needed to be studied and findings documented to help reduce set up variability in the future. In a bid to satisfy the lean philosophy of rapid and ease of set up, the challenge was to develop a set up procedure that not only reduces set up time but also eliminates the variation presently associated with current set up procedure.

4.2.2. THE SLITTER PROCESS

The K11 process is a cutting process. It involves cutting foam material (plank) into two separate materials. This is accomplished by means of a blade that is positioned in between two adjustable rollers. The rollers, termed upper and lower, are able to adjust in a vertical direction, with the effect of altering the blade position relative to material thickness. Appropriate adjustments of these rollers allow the desired material thickness to be cut. Another important process parameter is the amount of pressure that needs be applied to material to permit it to be run through the slitter. Operators refer to this as the “mash” setting. Each particular material will behave differently, and therefore there is a need to determine the mash required for each material.

4.2.3. PLANNING TO CARRY OUT THE EXPERIMENT

Because of the presence of variation in the product it was decided to carry out an experimental study for the K11. This required that the operational details of the process be studied in full and all possible causes of variation noted. A significant amount of time was spent at the process observing operational set up. Observation led to the determination of factors for the experiment. A brainstorming session was held to discuss the experimentation process and its requirements. In all the planning session had 5 participants, which included a facilitator, Dr Yingling and the author as the project leader.

4.2.4. THE OBJECTIVE TO THE EXPERIMENTAL DESIGN

- Establish among all factors determined, which factor has the largest influences on process. In accomplishing this objective we are in a position to decide which factors need tight control and which do not.

4.2.5. DECIDING THE FACTORS

The factors were decided by means of a brainstorming session. The three most important factors decided upon were as follows:

- Roller setting
- The amount of mash given to the material
- The speed of the rollers

4.2.6. THE QUALITY CHARACTERISTICS

The thickness of the foam at the output side of the slitter is the quality characteristic. To measure the quality characteristic a tape measure is used to measure the thickness of the edge of each plank. However, it was noticed that variation in the thickness of foam does exist along the length of the foam. Six readings of the foam thickness were taken at different positions along the length of the foam and the average thickness was computed. From the six readings for each trial the standard deviation was computed. The standard deviation was used as a second quality characteristic for the DOE.

4.2.7. CONDUCTING THE EXPERIMENT

Since the number of factors decided upon were a manageable figure, it was decided that a full factorial experiment be done rather than conduct a fractionated experiment. Eight trial runs were to be done with trials run in randomized manner so as to reduce the chance of experimental error. It is recommendable to replicate trial runs. In this experiment, each trial run was to be done twice and this was to be randomized as well.

4.2.8. THE MATERIAL TO BE USED FOR THE EXPERIMENT

The experiments were to be run for different materials pending availability. It was also decided that the focus of the experiments would be on materials that were commonly used. A Pareto analysis was carried out.

4.3. CARRYING OUT THE EXPERIMENTS

Table 4.1: Data set for full factorial experiment

	Factors		
Trial #	Mash	Speed	Top Setting
1	H	H	H
2	H	H	L
3	H	L	H
4	H	L	L
5	L	H	H
6	L	H	L
7	L	L	H
8	L	L	L

The table above shows the trial conditions for the experiment. Each factor was assigned to two levels, High (H) and Low (L). The factors in use for this experiment are as follows:

- mash = X_2/X_1 (ratio of output thickness to input thickness as shown Figure 4.1) n.b. the smaller the ratio, the higher the mash value.

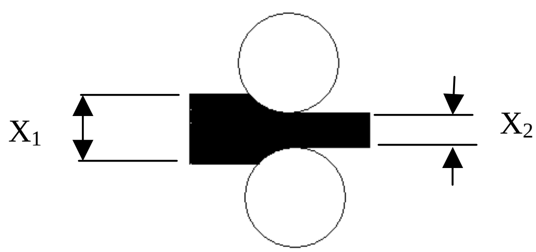


Figure 4.1: Mash ratio determination illustrated

- speed
- top setting

Table 4.2: Factor levels defined

	high	Low
mash(%)	90	96
speed	80	30
top setting	1"	0.2

M=Mash S= Speed T= Top Setting

The experiments were conducted for the combinations of factor levels shown in the table above. A high mash means that the material is deformed to 90% of the original thickness. Speed is considered high at 80 and low at 30. The experiment was also conducted for very thin material considered to be a top setting of 0.2”and thicker material considered to be a top setting of 1”.

4.4.CONDUCTING THE EXPERIMENT

In conducting the experiment, an attempt was made to simulate the real working conditions on the skiver. The material used in the experiment was no less than 50% of the original size of the material used in the real process.

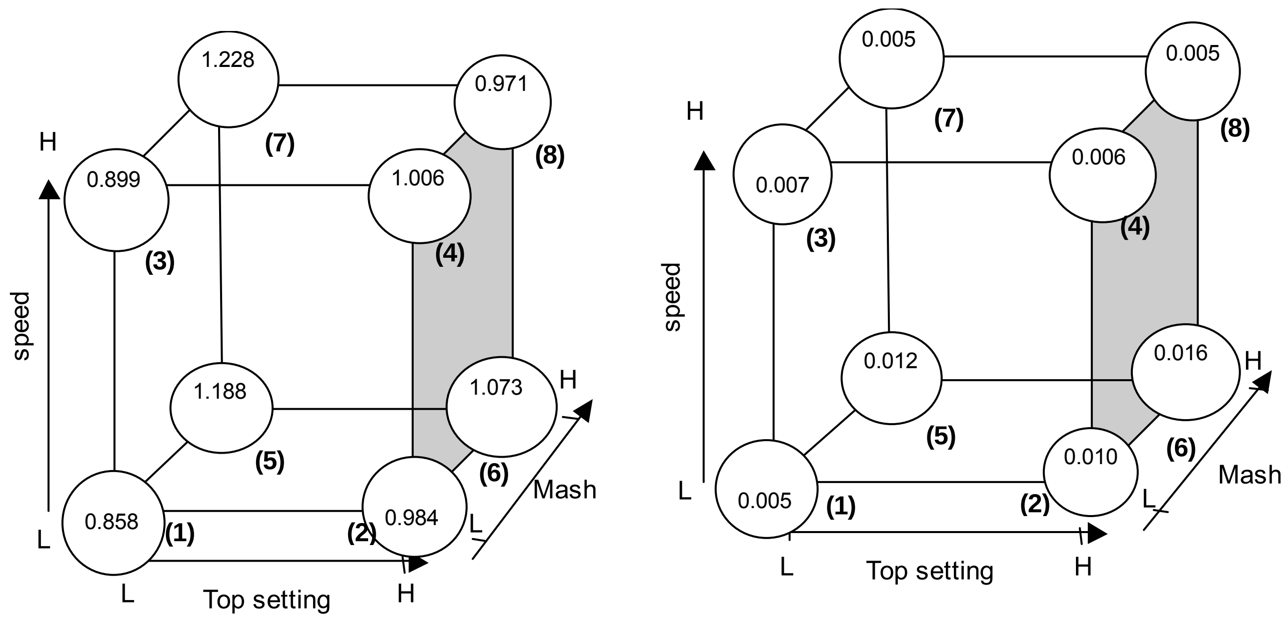
Table 4.3 : Full factorial experimental

		Factors			Thickness (Z) at positions Run1 Run2						Performance mesures				
y	Sequence Randomiztion	Mash	Speed	Top setting	1	2	3	4	5	6	Ave			ratio Ave/Top	Std dev
1	6	H	H	L	0.250	0.250	0.250	0.240	0.241	0.252	0.247	0.005			
					0.265	0.259	0.258	0.267	0.264	0.268	0.264	0.004	0.255	1.228	0.005
2	3	L	L	H	0.986	0.985	0.997	0.975	0.997	0.997	0.990	0.009			
					1.000	0.996	0.980	0.995	1.004	1.010	0.998	0.010	0.994	0.984	0.010
3	8	H	L	L	0.235	0.232	0.237	0.242	0.244	0.246	0.239	0.006	0.238	1.188	0.012
4	4	L	L	L	0.170	0.168	0.173	0.168	0.170	0.180	0.172	0.005	0.172	0.858	0.005
5	5	H	H	H	1.081	1.082	1.077	1.069	1.083	1.076	1.078	0.005	1.078	0.971	0.005
6	2	L	H	L	0.192	0.181	0.181	0.174	0.176	0.175	0.180	0.007	0.180	0.899	0.007
7	1	L	H	H	1.012	1.010	1.022	1.021	1.022	1.011	1.016	0.006	1.016	1.006	0.006
8	7	H	L	H	1.100	1.100	1.080	1.080	1.088	1.056	1.084	0.016	1.084	1.073	0.016

4.4.1. ANALYZING THE RESULTS OF THE EXPERIMENTS

The results of the experiment were analyzed using two output measures. The first measure used was the ratio of output thickness to the top setting value, while the second output measure used was the standard deviation of the individual readings within each trial. Of particular interest to this analysis were any significant interactions between factors as well as the main effects of the individual factors.

The cubes shown below are graphical representation of the sample space for the three factor full factorial experiment. The corners of the cube represent the outcome of the eight runs carried out for the experiment.



A: Output thickness to Top Setting ratio B: Standard Deviation of thicknes

Figure 4.2: Cube plots of the Outcomes(Quality characteristic)

4.4.2. CALCULATION OF AVERAGE PERFORMANCE

M_H= (1.228+1.188+0.971+1.073)/4=1.1150………….. :High level mash

M_L= (0.984+0.858+0.899+1.006)/4=0.9707. …………: Low level mash

S_L= (0.984+ 1.188+0.858+1.073)/4=1.0258 …………..:Low level speed

S_H= (1.228+0.971+0.899+1.006+)/4=1.0260…..………:High level speed

T_L= (1.228+1.188+0.858+0.899/4=1.0583…… ……….:Low level top setting

T_H= (0.984+0.971+1.006+1.073)/4=1.0085……………:High level top setting

The average performance for each factor shown above is computed from the table of results (table 4.3). The average performance effect for a particular level of a factor is obtained by summing all output for which that particular factor appears at the level, (table 4.3) and then averaging the result.

4.4.3. CALCULATING THE MAIN EFFECTS

The main effect for a factor is the difference between the average performance effect for that factor at a high level and at a low level. The main effect gives a relative measure of the influence that particular factor has on the performance of the process as a whole. The main effects for the three factors are given below.

4.4.4. MAIN EFFECTS WITH (OUTPUT/TOP SETTING) AS QUALITY CHARACHERISTIC

mash=M_H-M_L=1.1150-0.9707=0.1443

speed=S_H-S_L=1.0260-1.0258=0.0002

top setting=T_H-T_L=1.0085-1.0583=-0.1773

4.4.5. INTERACTION EFFECTS

Interaction effects are computed to determine how much two factors influence the outcome of the process when they act together. This is similar to the situation where high temperature alone makes it uncomfortable, but high temperature and high humidity make us extremely uncomfortable. Because interaction effect involving heat and humidity on the level of comfort. Likewise we desire to find if any strong interaction effects do exist for the given factors.

Table 4.4: mash - speed interaction results

		Mash	
		H	L
Speed	L	1.1306	0.9206
	H	1.0994	0.9527

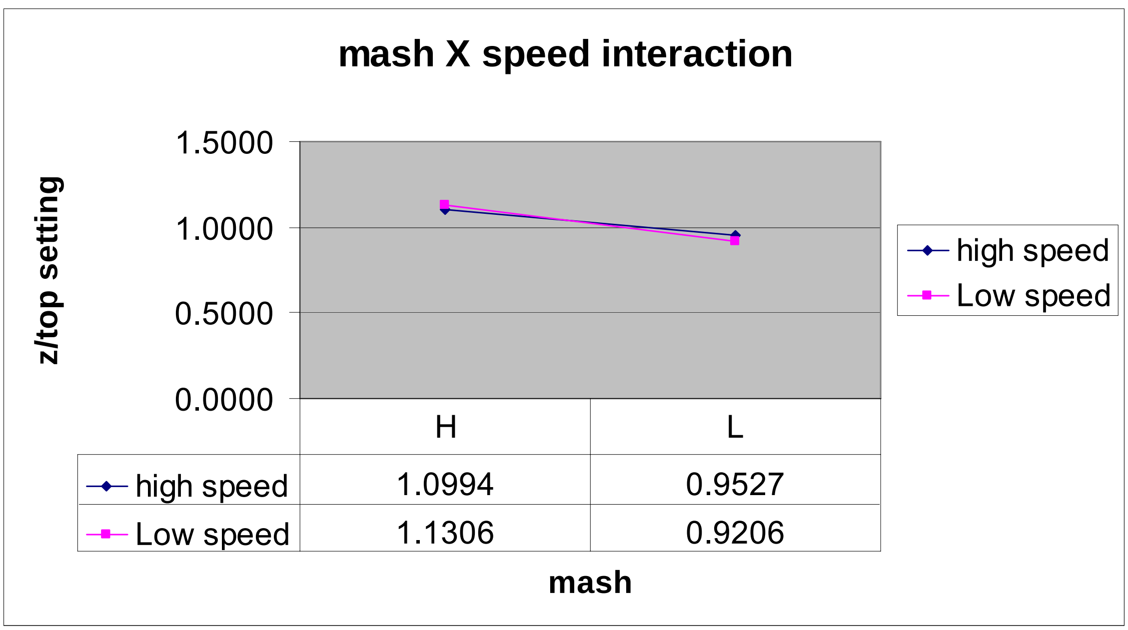


Figure 4.3: mash -speed interaction graph

Figure 4.3 shows a weak interaction effect between mash and speed since the lines are similar in shape. The implication is that the effect of altering the speed of the roller with fixed magnitude at low mash will have the same effect as lowering speed at a higher mash value.

TOP SETTING Vs SPEED INTERACTION

Table 4.5: Top setting –speed interaction results

		Speed	
		L	H
Top-Setting	L	1.0227	1.0634
	H	1.0285	0.9887

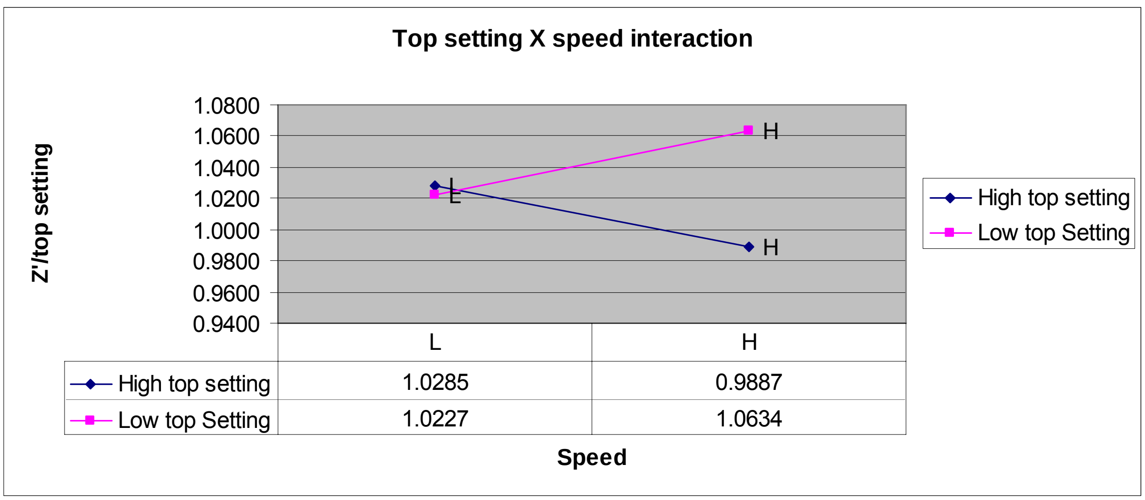


Figure 4.4: top setting –speed interation graph

A reasonably strong interaction effect may exist between top setting and speed. The high top setting line is of a lesser slope indicating that change of speed does not significantly alter the output.

TOP SETTING VS MASH INTERACTION

Table 4.6: top setting-mash interaction results

		mash	
		L	H
Top- Setting	L	1.1306	0.9143
	H	1.0222	0.8763

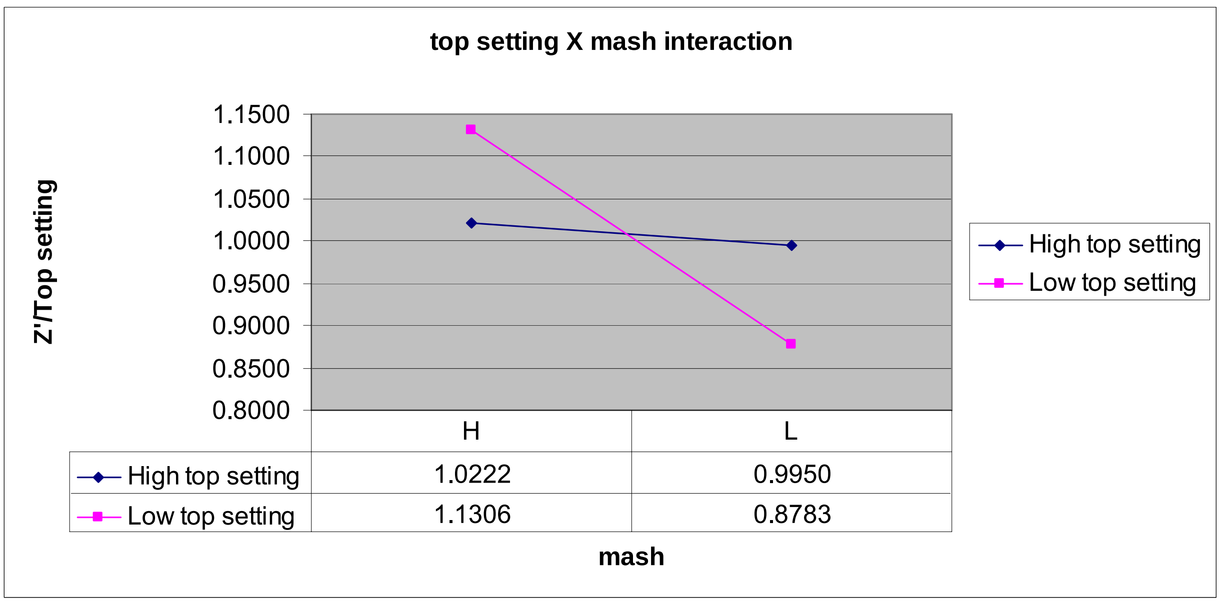


Figure 4.5: top setting-mash interaction graph

Some interaction exists between top setting and amount of mash as indicated by the two unparallel lines in the figure above. For low top setting (thinner material) there is a bigger change in the output characteristic in moving from high to low mash. The amount of mash applied appears not have a significant effect when material is much thicker, making it easier to work with thicker material and more difficult for thin material.

STANDARD DEVIATION INTERACTION EFFECTS

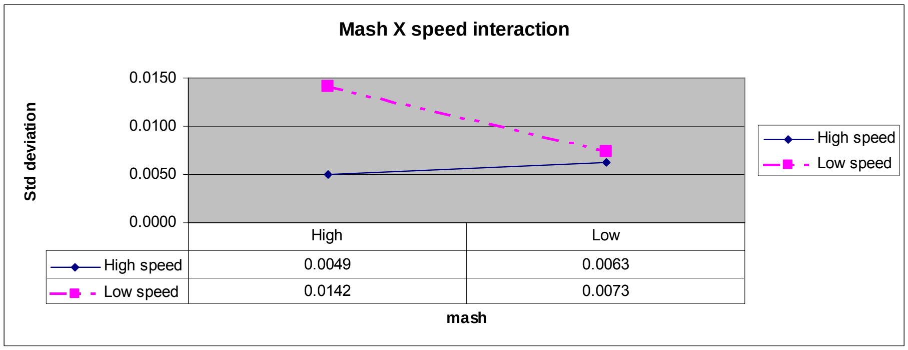


Figure 4.6: mash, speed interaction

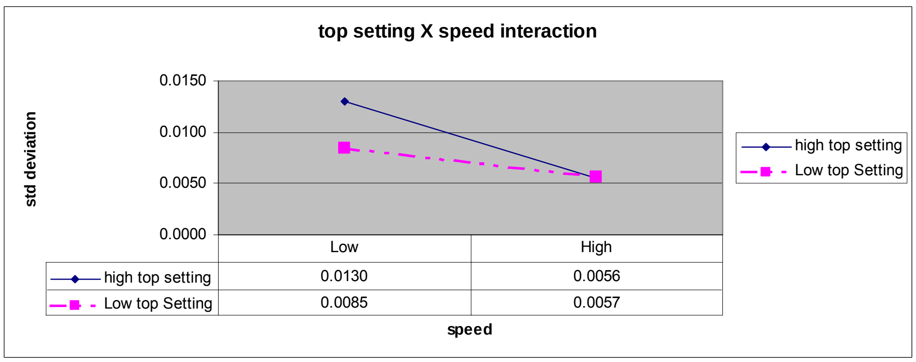


Figure 4.7: Top setting, speed interaction

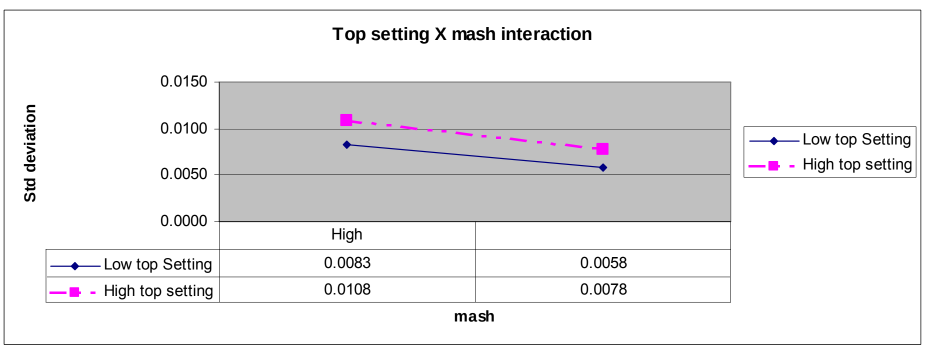


Figure 4.8: Top setting, mash interation

INTERPRETATION OF STANDARD DEVIATION INTERACTION EFFECTS

Because variations in thickness along the length of the foam are often occurring during processing of material, it was imperative to establish its causes. Using similar factors to the earlier experiment, interaction effects were investigated using standard deviation as our quality characteristic. Results suggest the following:

1. A significant interaction effect exists between mash and speed factors as shown by the unparrallel lines in Figure 4.6.
2. A slight interaction effect does exist between top setting and speed factors (Figure 4.7). There appears to be a reduction in the standard deviation when high speed is used. This occurs for both thin and thicker material. This suggests the desirability for processing to be carried out at a higher speed, at least higher than the minimum speed of 30.
3. No interactions effects seem to occur between mash and top setting (Figure 4.8). This is apparent from the parallel lines in the interaction graph. The standard deviation gets smaller the lower the level of mash used. This suggests that, for each material type, using the minimum amount of mash that allows material passage is desirable.

DETERMING THE OPTIMUM CUTTING CONDITIONS

The optimum cutting parameters can be derived from the table of results as well as observing the interaction graphs. The sought after value for our quality characteristic is the ratio given (output thicknes/topsetting). The closer this value is to one, the closer uuuuuthe associated parameters are to optimum. Therefore, looking at our table of results we attempt to pick any value of the quality characteristic closest to one and note the conditions for that particular trial condition.

From the table of results (Table 4.3) trial 7 and trial 2 have values closest to one. Examining the levels of the factors for both trials, the following can be deducted.

Table 4.7: Optimum cutting parameter

	Mash	**Speed**	**Top setting**
Trail 7	L	H	H
Trial 2	L	L	H

Results of both trials 7 and 2 suggest that low mash on High topsetting lead to better quality cut. Determining this minimal pressure (low mash) for each material type is therefore a challenge that has to be overcome. Results also suggest that for thicker materials, higher speeds can be used without undue loss of quality. However, it appears that when cutting thinner materials, slower speeds are recommendable.

4.5.ANALYSIS OF VARIANCE

The complete DOE Technique cannot be complete without the analysis of variance study. This helps us learn more about the relative contribution of each factor towards the overall variance. For purposes of this study we are to define some variables as follows:

V=mean squares	***F***= variance ratio
S=Sum of squares	***f***=Degrees of freedom
e=experimental error	***P***=Percent contribution
T=total of all results	***N***=Number of experiments
CF=Correction Factor	***n***=Total degrees of freedom

The variance for each factor is determined by the sum of the squares of each trial result involving the factor, divided by the degrees of freedom for that factor. For instance, the variance factor for mash, speed, and top setting factors are respectively represented as follows:

$V_M=S_M/f_M$ $V_S=S_S/f_S$ $V_T=S_T/f_T$

The degrees of freedom for each factor equal one less than the levels for each factor.

$CF= T^2/N$

4.5.1. SLITTER (K11) ANALYSIS OF VARIANCE STUDY

Making reference to the table of results for the DOE study (table 9 p60), the following computations were made:

The total for each level for a particular factor is computed from table 9 as follows:

M_L=3.743 M_H =4.46

S_L=4.103 S_H=4.104

T_L=4.173 T_H=4.034

$C_f=8.207^2/8=8.419$

The total variance for each factor is calculated using the following formulae $S_A=A_1^2+A_2^2$-CF where factor S_A is the variance for factor A. A_1^2 and A_2^2 are the squares of sum of factor A at level 1 and 2 respectively.

Therefore values of S_M, S_S, and S_T are computed as shown below:

$\boldsymbol{S_M}=M_L^2/N_{ML}+M_H^2/N_{MH}-C_f$

$=3.743/4 + 4.46^2/4-8.419$

$=\mathbf{0.0564}$

$\boldsymbol{S_S}=S_L^2/N_{SL}+S_H^2/N_{SH}-CF$

$=4.103^2/4+4.104^2/4-8.419$

$\mathbf{=0.000356}$

$\boldsymbol{S_T}=T_L^2/N_{TL}+T_H^2/N_{TH}-CF$

$\mathbf{=}4.173^2/4+4.034^2/4-8.419$

$=\mathbf{0.00277}$

4.5.2. DEGREES OF FREEDOM FOR EACH FACTOR

F_M=Number of levels of M – 1=1

F_S= Number of levels of S – 1=1

F_T=Number of levels of C-1=1

4.5.3. VARIANCE FOR EACH FACTOR

$V_M = S_M/F_M$ **$V_S = S_S/F_S$** **$V_T = S_T/F_T$**

=0.0564 **=0.000356** **=0.00277**

Table 4.8: ANOVA TABLE

Factor	DOF (f)	Sum of sqrs (S)	Variance (V)	Percent (P)
M	1	0.0564	0.0564	94%
S	1	0.000356	0.000356	0.6%
T	1	0.00277	0.00277	4.6%
		0.059526	0.059526	

From the ANOVA table (table 4.8) it is apparent that speed as factor does not have a significant effect on the variation of the process. The table also reveals that the mash has the most significant contribution to the variation of the process. The implication here is that the mash is the most important factor that deserves to be controlled followed by top setting while speed is of relatively less importance.

4.5.4. PROBLEMS ENCOUNTERED IN CARRYING OUT EXPERIMENTS

The low availability of expensive material allowed replications for only two trials while other trial runs only had one run each. Although measurement equipment used were vernier and tape measure, there are doubts with regards to the appropriateness of either method. It is recommended that for consistencies's sake, one method be used as opposed to choosing between the two according to operator preference. An awareness of systematic errors in the use of equipment should be promoted. For instance the consistency of results obtained using vernier calipers was questionable. The use of this equipment appeared in some way to distort the shape of material, consequently leading to different results for repeat measurement of the same spot. Whether this distortion is significant in relation to the allowable tolerance is a question that has to be answered.

CHAPTER 5 : CONCLUSION

The biggest challenge in applying lean standardized work principles in a HVLV lies in developing and educating people to embrace and accept the core values of lean standardized work. Success in implementing lean standardized work in HVLV environments lies in the active participation of an integrated cross section of people from all functional areas of the organization. If there is a way of getting people excited about lean standardization and its core principles, this would be a big boost in achieving a lean status. It is the belief of this author that focus should be shifted more to developing programs that have the ability to encourage the worker to develop interest and actively participate in any form of lean initiatives. From a consultant standpoint, there is lot that can be done to improve the performance of HVLV environments as far as reducing the chaos that is associated with them. It will be noted that operators in HVLV environments may fall into three different categories: the skilled, semi skilled and general personnel. It is the opinion of this author that erasing or reducing the separation of skill level can go a long way in accelerating the progress of lean initiatives in the organization. It was noted that where separation of skill exists, workers on the shop floor exhibit strong ownership of processes and this tends to impact negatively on the rest of the workforce whose interest in the particular processes is diminished. Consequently opportunities of obtaining a greater pool of suggestions are forfeited. Improving flow and reducing variation should be secondary goals in an HVLV environment. Important aspects of achieving success in secondary goals include the provision of training in the use of continuous improvement tools by all personnel. The ability to classify and group products according to functional basis as discussed in this project has a huge potential in achieving assembly-like forms of standardized work. Carrying out this project was a worthwhile experience from a learning point of view, and it has revealed opportunities that can be explored to achieve better performance for HVLV environments.

APPENDICES

Material Prep standardized work documents

Appendices A: Skiver/Slitter standardized work documents

1. Appendix A1: skiver/slitter set up sheet- skinning
2. Appendix A2: skiver/slitter- skinning and dimensional skiving
3. Appendix A3: Skiver/slitter- Layer cutting
4. Appendix A4: skiver/Slitter operations work standard sheet-skinning
5. Appendix A5: skiver/slitter operations work standard sheet-dimensional skiving
6. Appendix A6: skiver/slitter operations work sheet-layer cutting
7. Appendix A7: skiver/slitter standard work chart
8. Appendix A8: skiver/slitter standard work combination table

Appendices B: Laminator standard work combination table

1. Appendix B1: Laminator set up sheet
2. Appendix B2: Laminator set up table
3. Appendix B3: Standard work chart-Laminator
4. Appendix B4: standard work combination table-single pass lamination

Appendix C: System standardized work documents

2. Appendix C2: Combination chart for functional sequence- 1-Lm-B
3. Appendix C3: Combination chart for functional sequence- Sd-Ls-Sd
4. Appendix C4: Combination chart for functional sequence- 2-Lm-Sd
5. Appendix C5: Combination chart for functional sequence- 2-Ls-B

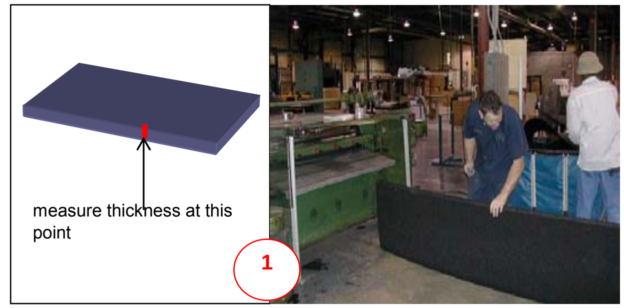
Appendix A1

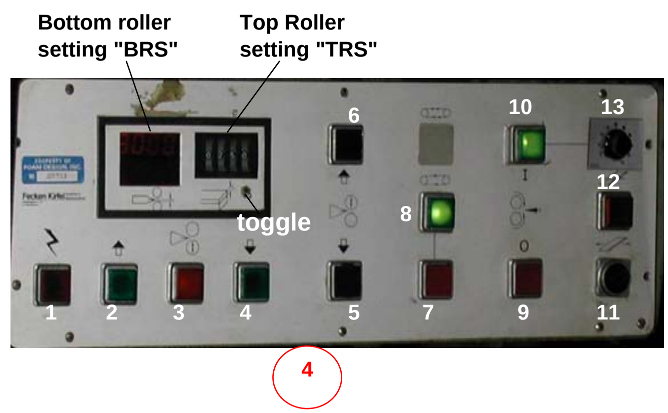
Set Up Sheet Process: K11 Slitter Layer Cutting

R & D	Prod

Updated: 11/1/2002

No	Operation Element	Symbol	Key point
1	**Measure First plank at position shown**		Use tape measure at the center of the plank
2	**Set Top roller setting (*TRS*)**		***TRS=desired thicknes - 1/16"*** Use buttons ***5 & 6*** to adjust position of top roller
3	**Flip toggle to "On" position**		Switch ensures indexing of table for subsequent cuts.
4	**Set bottom roller setting *(BRS)***		***BRS=desired thickness - /16"*** Use buttons ***2 & 4*** to adjust lower roller position.
5	**Turn Blade on**		Use button ***8*** to turn blade on and button ***7*** for turning the blade off
6	**Set Roller Speed.**		For Material Thickness<0.2" ***Set speed <= 30*** Thicknesses>0.2" ***Set speed = 30 - 60*** Use speed dial **"13"** to set speed as shown in 4





Other Considerations

Inspection

V visual quality

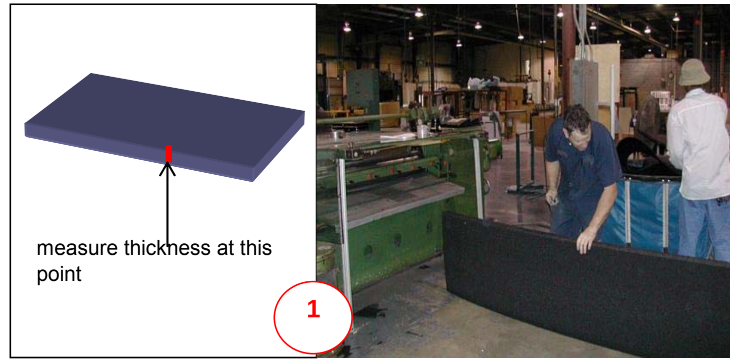
Safety

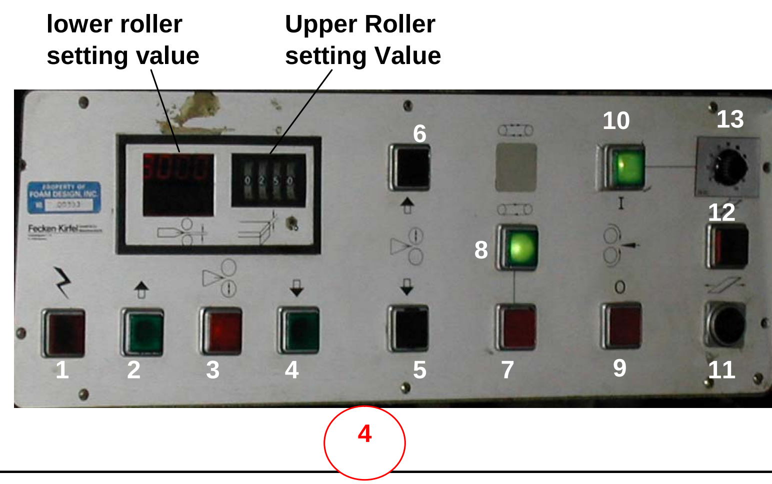
Set Up sheet   Process: K11 Slitter
Skinning & Dimensional cutting

R & D	Prod

Updated: 5/8/2002

No	Operation Element	Symbol	Key point
1	**Measure First plank at position shown**		Use tape measure at the center of the plank
2	**Set Top roller setting (*TRS)***		***TRS=desired thicknes - /16"*** Use buttons ***5 & 6*** to adjust position of upper roller
3	**Set Bottom Roller Setting *(BRS)***		***BRS=desired thickness - /16"*** Use buttons ***2 & 4*** to adjust lower roller position.
4	**Turn Blade On**		Use button ***8*** to turn blade on and button ***7*** for turning the blade off
5	**Set Roller Speed.**		For material thickness<0.2" Set speed=30 Thicknesses>0.2" Set speed = 30 - 60





Other Considerations

nb: ensure blade sharpness by grinding on hourly basis when machine is in use. Sharpen blade only while blade is rotating

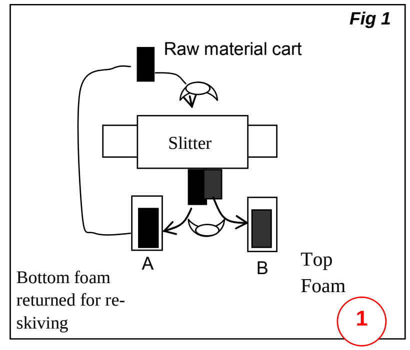
Inspection   V visual quality   Safety

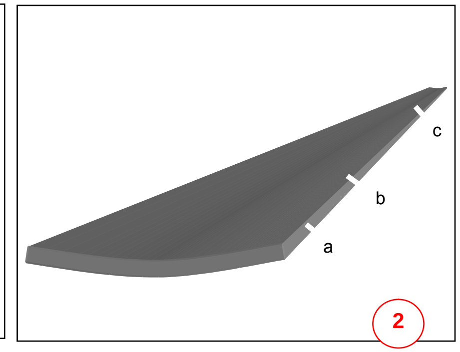
Appendix A3

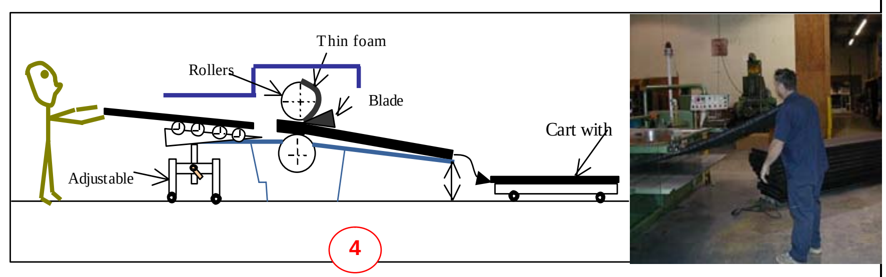
Operations Work Standard Sheet   Process: K11 Skinning

R&D	Prod
Updated:	5/8/2002

No	Operation Element	Symbol	Key point
1	**Position carts**		Position carts as shown
2	**Measure First plank at position shown**		measure the thickness of foam at positions **a, b & c** as shown. Use calipers for measurement
3	**Set Up Process for side 1**		Set upper roller to 0.114" Ensure no foam entangles with the upper roller
			Lower roller setting=Actual plank thickness + 1/16" -(Desired top thickness)
4	**Feed plank through skiver**		maintain inclined position of plank as you feed it through skiver
5	**Separate skived material**		throw the skinned material into trash box as shown in 1 stack bottom foam with skinned surface facing down
6	**Transfer**		Tranfer skid stacked with skinned foam to input side of K11 for 2nd skinning operation Repeat steps 1-step 4 to skin other side of plank







Other Considerations

Inspection   visual Check   Safety

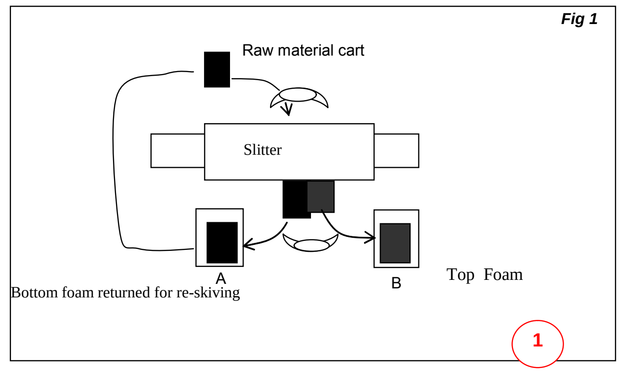
Appendix A4

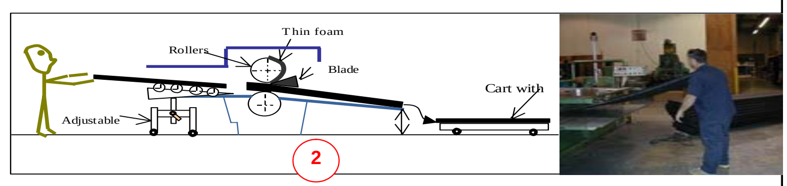
Operations Work Standard sheet — Process: K11 Dimensional skiving

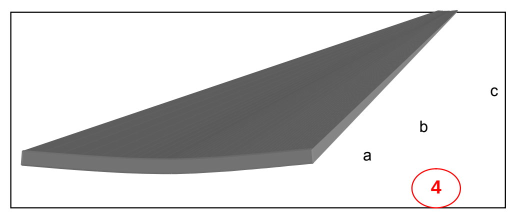
R&D	Prod

Updated: 11//01/02

No	Operation Element	Symbol	Key point
1	Position carts		Position carts as shown
2	Measure the thickness of first plank		measure the thickness of foam at positions **a, b & c** as shown. Use calipers for measurement
3	Skive Material		maintain inclined position of plank as you feed it through skiver
			If slipping occurs between roller and plank, reduce lower roller height by 0.002"
4	Separate top plank from bottom plank		Place top and Bottom plank on separate skids as shown in (1)
5	Verify thickness	◆	using veneer caliper measure thickness of planks at positions shown in (2) Check for any unskived areas and ensure that consistency of thickness through length of plank.







Other Considerations

◆ **Quality** ◇ **visual quality** ✚ **Safety**

Appendix A5

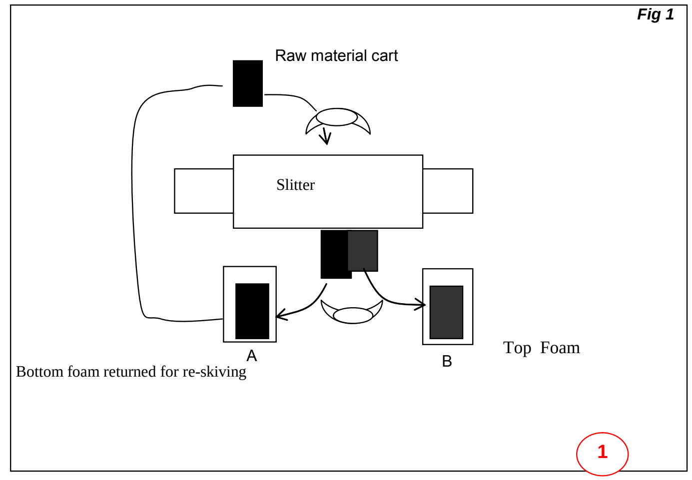
Operations Work Standard Sheet **Process: K11 Layer Cutting**

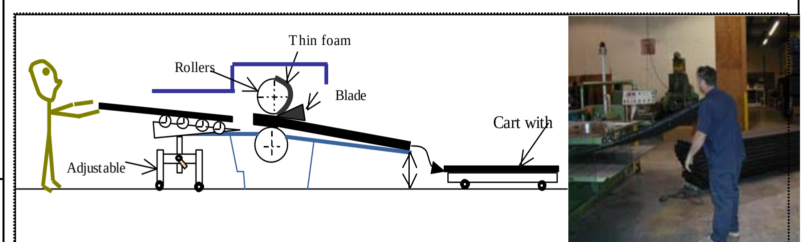
R&D	Prod

Updated: 5/8/2002

No	Operation Element	Symbol	Key point
1	**Position carts**		Position carts as shown
2	**Skive Material**		Maintain inclined position of plank as you feed it through skiver
3	**Separate top plank from bottom plank**		Place bottom and top plank on skid as shown in (1) foam on skid B and bottom foam on skid A
4	**Transfer skid A to input side of K11**		Index table as indicated in setup sheet and run material through K11 once again, maintain incline of material as it feeds through.
5	**Repeat steps 1-4 for successive layer cuts**		Repeat steps 1-5 until thickness of bottom foam < desired thickness of top foam

Fig 1





2

Other Considerations

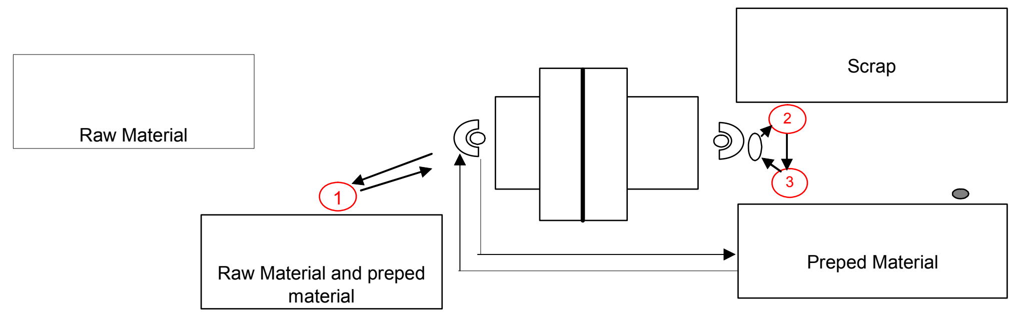
Quality **visual quality** **Safety**

Appendix A6

Standardized Work Chart Process: K11 Slitter

R&D	Prod

Seq No	Operation Name	Operation Time
1	Pick Plank from buffer	7
2	Move to Skiver	5
3	Position and skive plank	16
4	Move to Output side	10
5	Separate Planks	8
6	Move to input side of K11	10



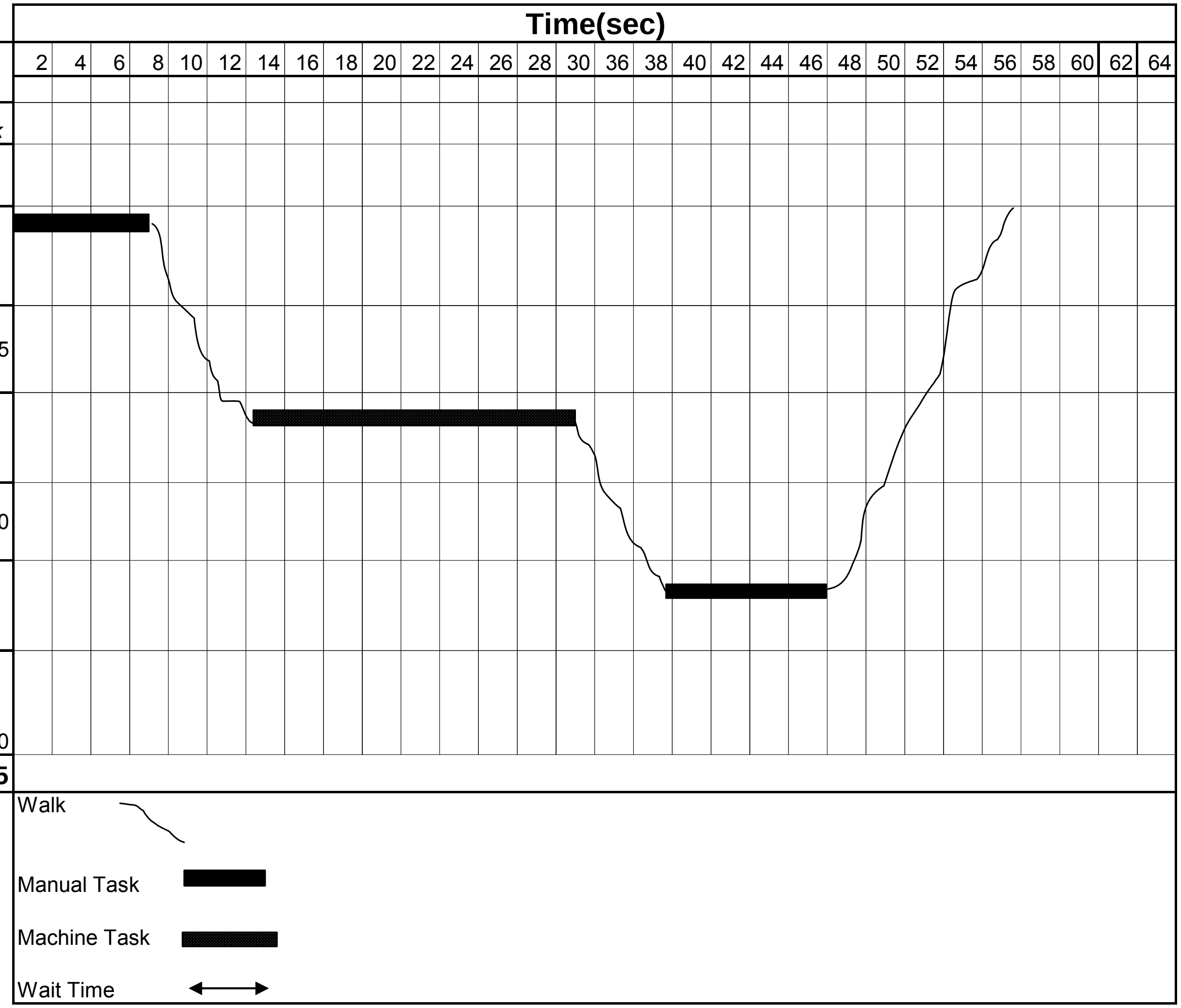
Quality Check	Safety Check	Standard In-process Stock		Cycle Time	Process Number	
		Symbol	Number			
				56sec		

Appendix A7

Stanadardized Work Combination Table for K-11 Slitter (07/15/02)

R&D	Prod

Seq No	*Operation decription*	Time		
		Auto	*Manul*	*Walk*
1	Pick foam		7	
2	Move to skiver			5
3	Position & Skive Plank	16		
4	Move to Output side			10
5	Separate the skin from the plank		8	
6	Move to input side of K11			10
	Total	**16**	**15**	**25**



Appendix B1

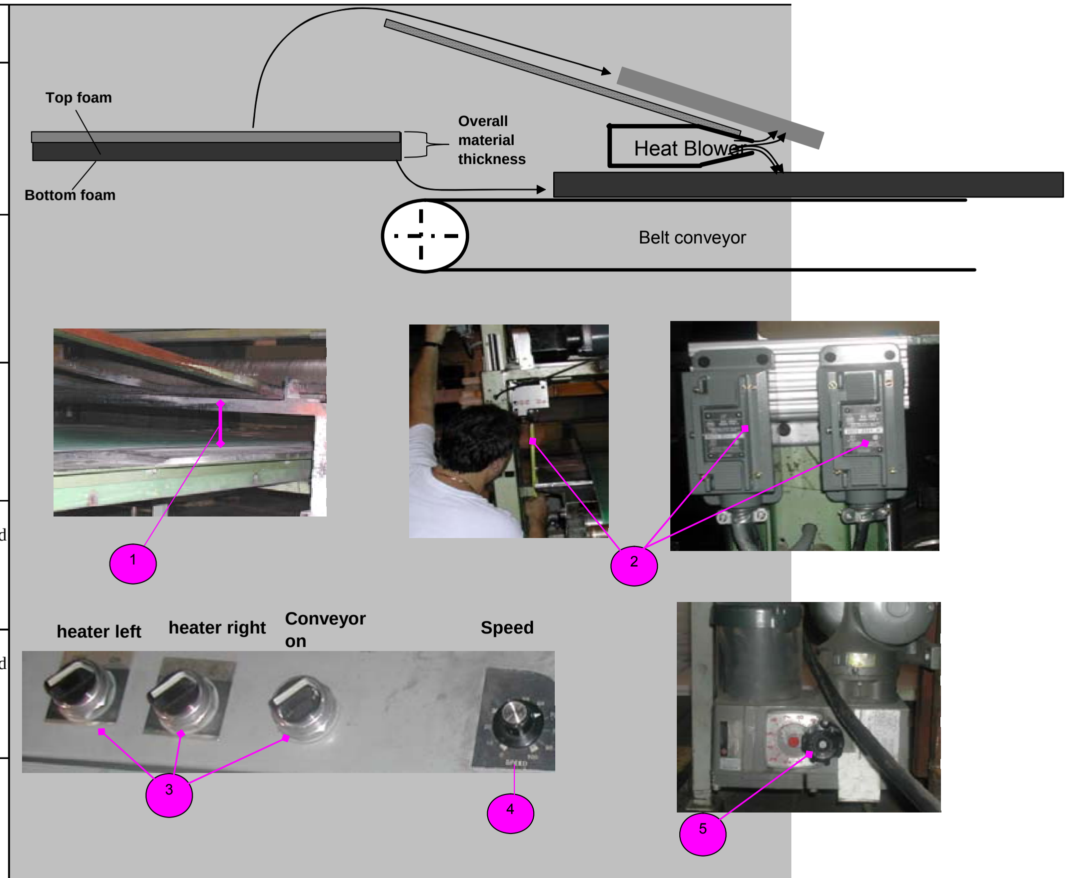
Operations Set-Up sheet

Process: TL Setup

FDI P/N: All Dow Parts

R & D

Seq No	Operation Element	Symbol	Key point
1	**Adjust heat bar Height (*HBH*)**		***HBH=Overall material thickness (Top + Lower) + 0.5"*** Using a tape measure to adjust height of heat bar .
2	**Roller height (*RH*) adjustment**		***RH=Overall material thickness - 1/16"***
3	**Turn on the heat bar**		Turn the heat for the right and left side of the heat bar, Turn the motor power on.
4	**Adjust speed of roller**		See part specific table of material combinations provided for roller speed
5	**Adjust speed of belt**		See part specific table of material combinations provided for belt speed
6	**Begin lamination 15 minutes after turning on the heat**	◆	This ensures enough time for heat build up in the heat bar



REMARKS

◆ Quality

Safe

Appendix B2

Appendix 8

Laminator Set Up Sheet

R&D	Prod

	material 1 Density	material 2 Density	Belt Speed	Roller speed	height of heat bar
1	1.7	1.7	1.2	67	0.5
2	1.7	2	1	65	0.5
3	1.7	4	0.8	65	0.5
4	1.7	6	0.8	63	0.5
5	1.7	9	0.7	60	0.5
6	2	2	1.4	65	0.5
7	2	4	0.8	65	0.5
8	2	6	0.8	65	0.5
9	2	9	0.6	60	0.5
10	4	4	0.6	65	0.5
11	4	6	0.6	67.5	0.5
12	4	6	0.6	67.5	0.5
13	9	9	0.3	67.5	0.5

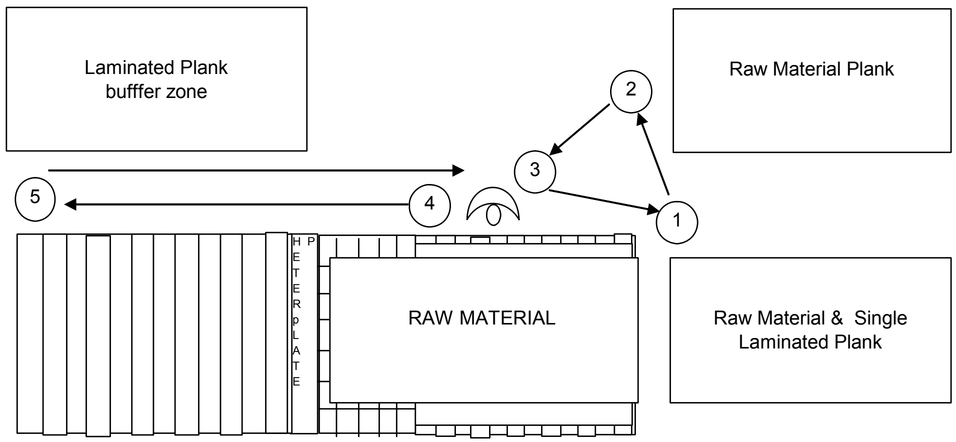
nb: The following are only guidelines that have not been confirmed experimentally these readings are based on experiencence of the workforce and are assumed for all materials.

Appendix B3

Standardized Work Chart Process: Laminator

R&D	Prod

Seq	Operation	Operat
1	Pick Plank & position on conveyor	7
2	Pick &Position top foam	9
3	Laminate the two planks	16
4	Unload the laminated plank and place in buffer zone	10
5	Walk back for restart	14



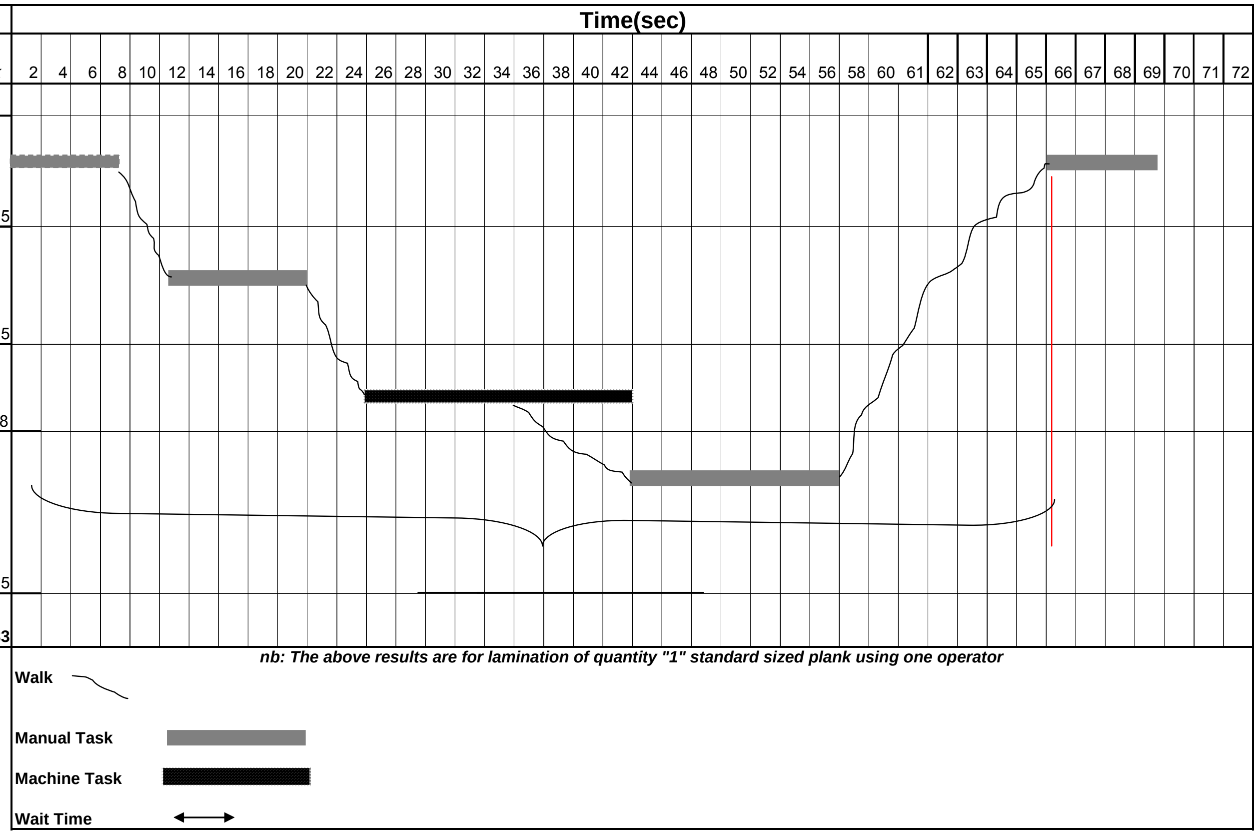
Quality Check	Safety Check	Standard In-process Stock		Takt Time	Cycle Time	Process Number
		Symbol	Number			
					65 sec	

Appendix B4

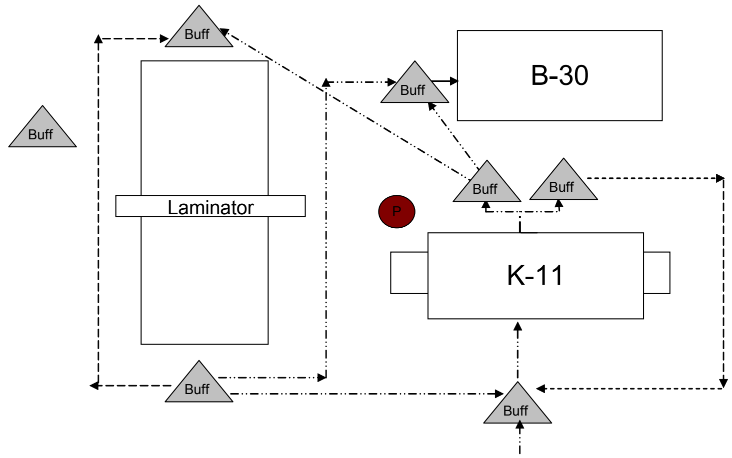
Stanadardized Work Combination Table K-11 Lminator (07/15/02)
Single Pass "one operator"

R & D	Prod

Seq uence	Operation	Time: *Auto*	*Manul*	*Walk*
1	***Operator 1***			
2	Pick and position Botton foam on conveyor		7	5
3	Pick and position top foam for lamininating		9	5
4	Laminate the two planks	16		8
5	Unload laminated plank and stack in buffer area		10	15
	Total	**16**	**26**	**33**



Appendix B5: MATERIAL PREP CELL LAYOUT AND SYSTEM STANDARD DATA



	Function	Symb		Time to process a batch											
				5		10		15		20		25		30	
				1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope	1 Ope	2 Ope
k11	Skinning	Ss		280	200	560	400	840	600	1120	800	1400	1000	1680	1200
	Dimsension cut	Sd		280	200	560	400	840	600	1120	800	1400	1000	1680	1200
	Layer cuting	Sl	3	840	600	1680	1200	2520	1800	3360	2400	4200	3000	5040	3600
			4	1120	800	2240	1600	3360	2400	4480	3200	5600	4000	6720	4800
			5	1400	1000	2800	2000	4200	3000	5600	4000	7000	5000	8400	6000
			6	1680	1200	3360	2400	5040	3600	6720	4800	8400	6000	10080	7200
Laminator	Single Pass	Ls		325	250	650	500	975	750	1300	1000	1625	1250	1950	1500
	Multipass Lamin	Lm	3	975	750	1950	1500	2925	2250	3900	3000	4875	3750	5850	4500
			4	1300	1000	2600	2000	3900	3000	5200	4000	6500	5000	7800	6000
			5	1625	1250	3250	2500	4875	3750	6500	5000	8125	6250	9750	7500

nb: The following times ignore effecto of setup

			Cycle times for Functions Def				
			Ss	**Sd**	**Sl**	**Ls**	**Lm**
K11	**LM**	**one Ope**	56	56	56	65	65
		2 Ope	40	40	40	50	50

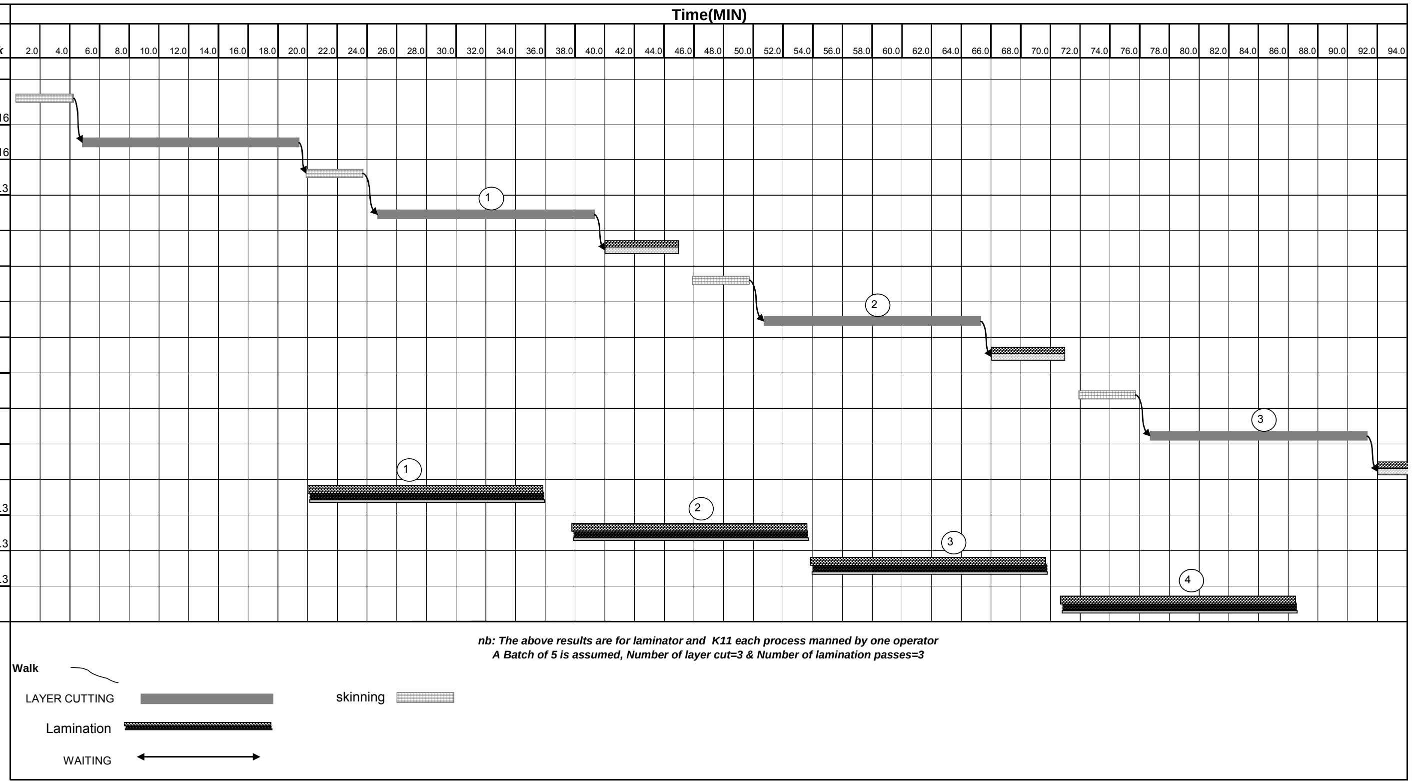
Ss: Skinning Sd: dimensional skiving Sl: Layer cutting Ls: single Pass Lamination Lm: Multipass Lamination

Appendix C 2

Stanadardized Work Combination Table: System (07/15/02)
1-Lm-Sd

R & D	Prod

Seq uence	Operation	Auto	Manul	Walk
	Operator 1			
1	SKINNING (1 side)	4.67		0.16
2	LAYER CUTTING (3 passes)	14		0.16
3	SKINNING (1 side)	16		0.3
4	LAYER CUTTING (3 passes)			
5	DIMENSION CUT			
1	MULTI-LM (3 passes)	16		0.3
2	MULTI-LM (3 passes)	16		0.3
3	MULTI-LM (3 passes)	16		0.3

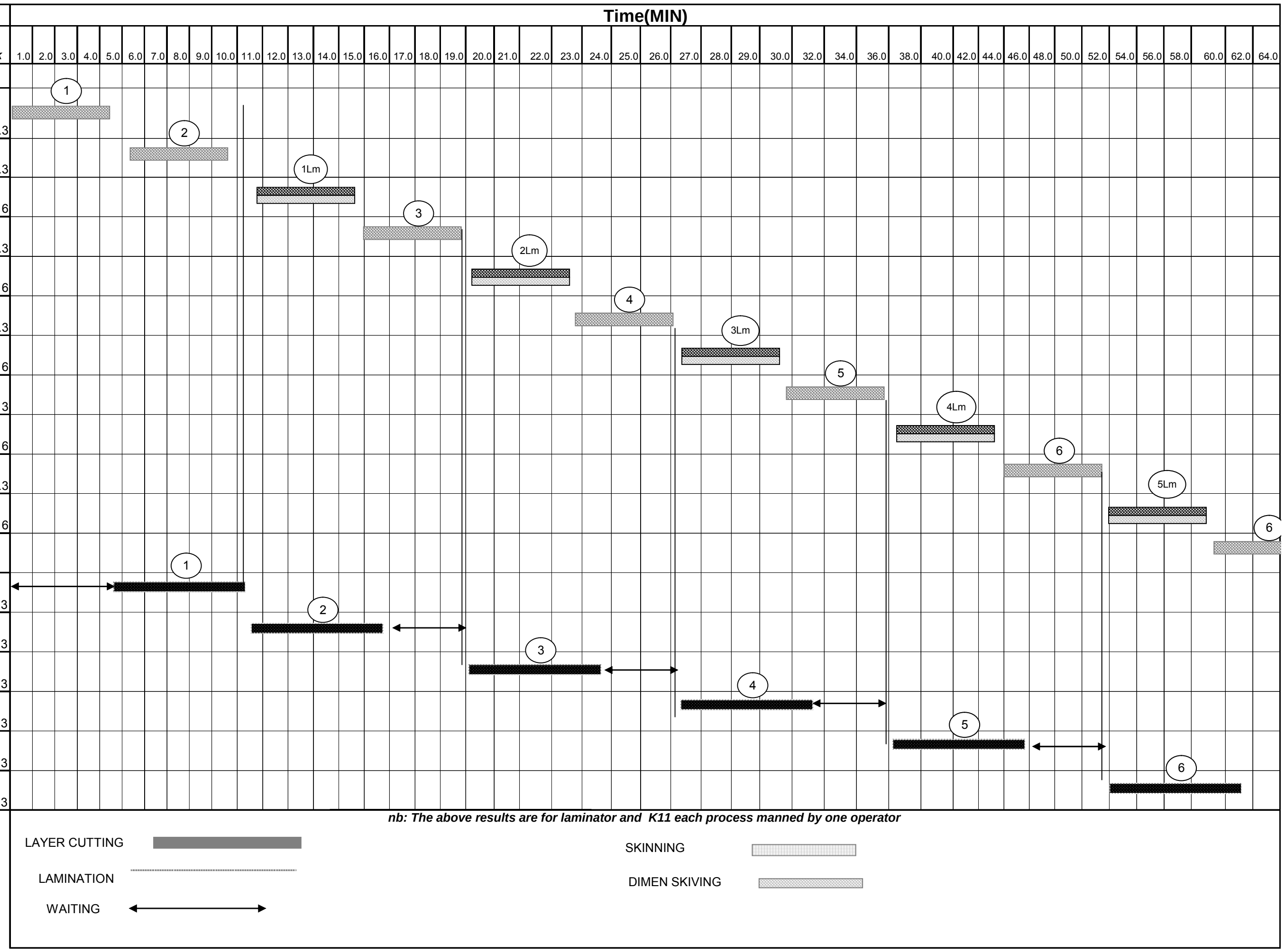


Appendix C 3

Stanadardized Work Combination Table: System (07/15/02)
Sd-Ls-Sd

R & D	Prod

Sequence	Operation	Time: Auto	Time: Manul	Time: Walk
	Operator 1			
1	DIMENSION CUT	4.6		0.3
2	DIMENSION CUT	4.6		0.3
3	DIMENSION CUT	4.6		0.16
4	DIMENSION CUT	4.6		0.3
5	DIMENSION CUT	4.6		0.16
6	DIMENSION CUT	4.6		0.3
7	DIMENSION CUT	4.6		0.16
8	DIMENSION CUT	4.6		0.13
9	DIMENSION CUT	4.6		0.16
10	DIMENSION CUT	4.6		0.3
11	DIMENSION CUT	4.6		0.16
1	SINGLE-PASS LM	5.4		0.3
2	SINGLE-PASS LM	5.4		0.3
3	SINGLE-PASS LM	5.4		0.3
4	SINGLE-PASS LM	5.4		0.3
5	SINGLE-PASS LM	5.4		0.3
6	SINGLE-PASS LM	5.4		0.3



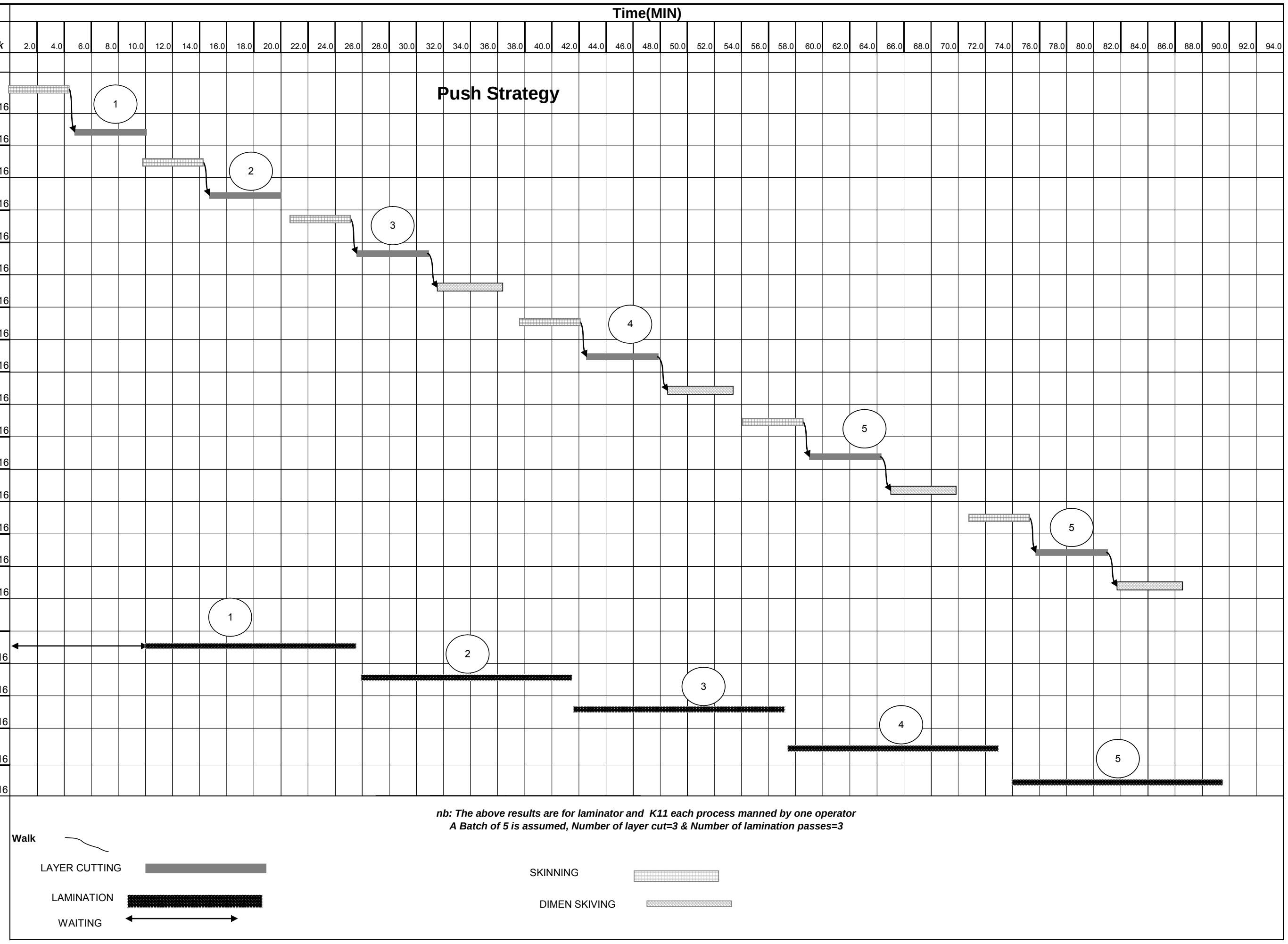
nb: The above results are for laminator and K11 each process manned by one operator

Appendix C 4

Stanadardized Work Combination Table: System (07/15/02)
2-Lm-Sd

R & D	Prod

Seq uence	Operation	Auto	Manul	Walk
	Operator 1			
1	SKIN BOTH SIDES (1 side)	4.6		0.16
2	DIMENSION CUT	4.6		0.16
3	SKIN BOTH SIDES (1 side)	4.6		0.16
4	DIMENSION CUT	4.6		0.16
5	SKIN BOTH SIDES (1 side)	4.6		0.16
6	DIMENSION CUT	4.6		0.16
7	DIMENSION CUT	4.6		0.16
8	SKIN BOTH SIDES (1 side)	4.6		0.16
9	DIMENSION CUT	4.6		0.16
10	DIMENSION CUT	4.6		0.16
11	SKIN BOTH SIDES (1 side)	4.6		0.16
12	DIMENSION CUT	4.6		0.16
13	DIMENSION CUT	4.6		0.16
14	SKIN BOTH SIDES (1 side)	4.6		0.16
15	DIMENSION CUT	4.6		0.16
16	DIMENSION CUT	4.6		0.16
1	MULTI-LM (3 passes)	16		0.16
2	MULTI-LM (3 passes)	16		0.16
3	MULTI-LM (3 passes)	16		0.16
4	MULTI-LM (3 passes)	16		0.16
5	MULTI-LM (3 passes)	16		0.16



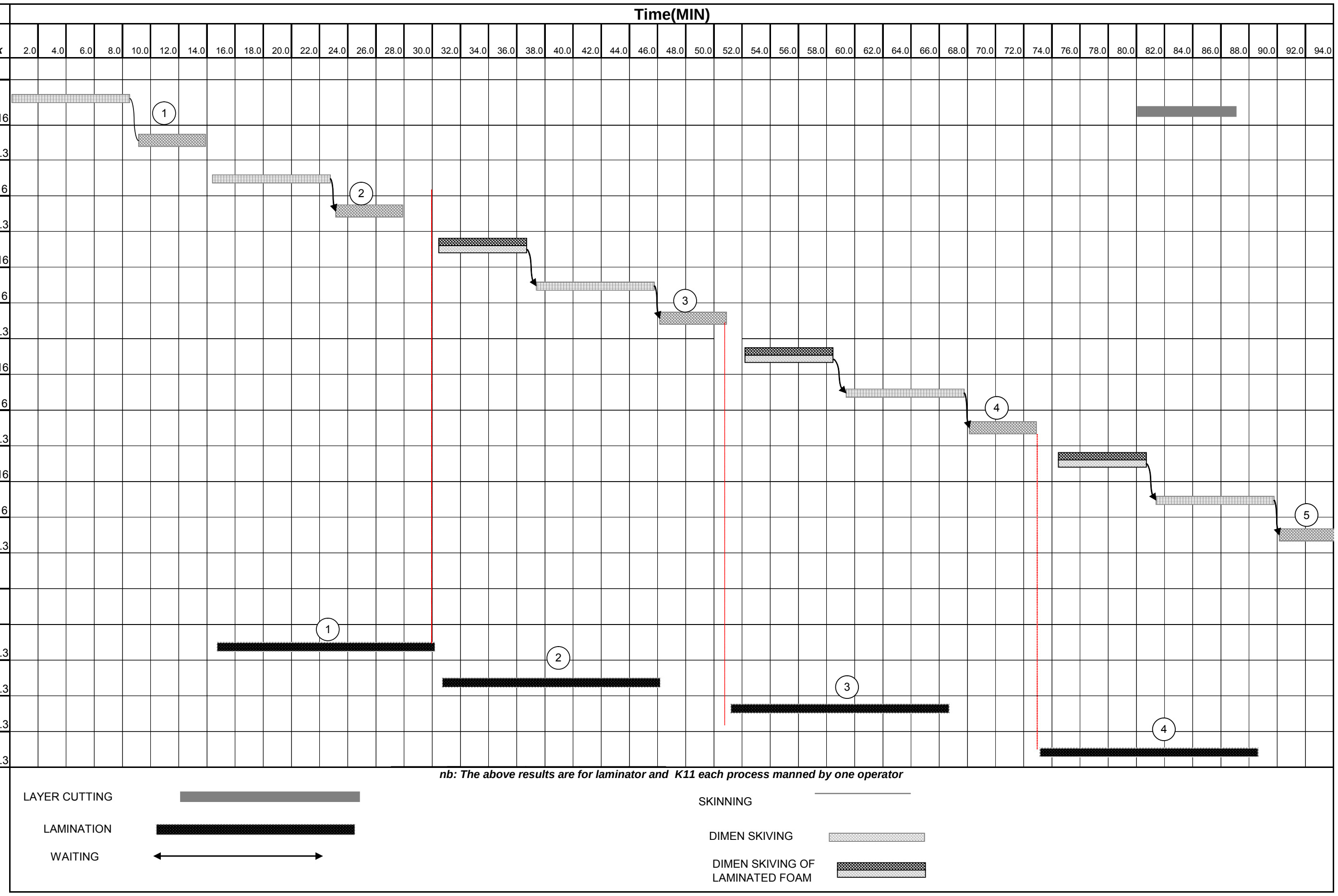
nb: The above results are for laminator and K11 each process manned by one operator
A Batch of 5 is assumed, Number of layer cut=3 & Number of lamination passes=3

Appendix C 5

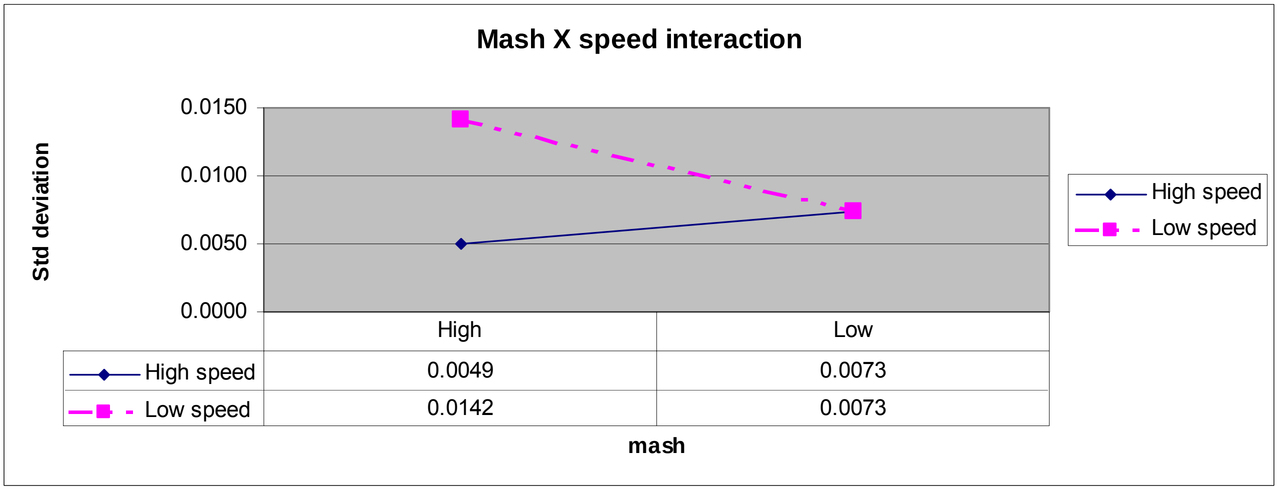
Stanadardized Work Combination Table: System (07/15/02)
2-Ls-Sd

R & D	Prod

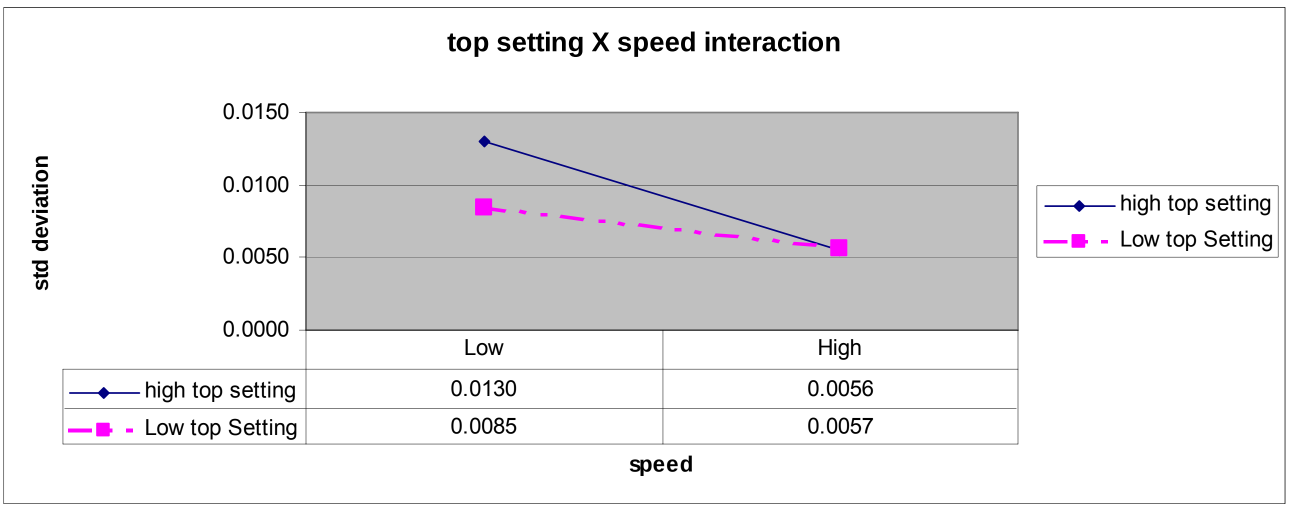
Sequence	Operation	Time: Auto	Time: Manul	Time: Walk
	Operator 1			
1	SKIN BOTH SIDES	9.3		0.16
2	DIMENSION CUT	4.6		0.3
3	SKIN BOTH SIDES	9.3		0.16
4	DIMENSION CUT	4.6		0.3
5	DIMENSION CUT	4.6		0.16
6	SKIN BOTH SIDES	9.3		0.16
7	DIMENSION CUT	4.6		0.3
8	DIMENSION CUT	4.6		0.16
9	SKIN BOTH SIDES	9.3		0.16
10	DIMENSION CUT	4.6		0.3
11	DIMENSION CUT	4.6		0.16
12	SKIN BOTH SIDES	9.3		0.16
13	DIMENSION CUT	4.6		0.3
8	MULTI-PASS LM	16.25		0.3
9	MULTI-PASS LM	16.25		0.3
	MULTI-PASS LM	16.25		0.3
	MULTI-PASS LM	16.25		0.3



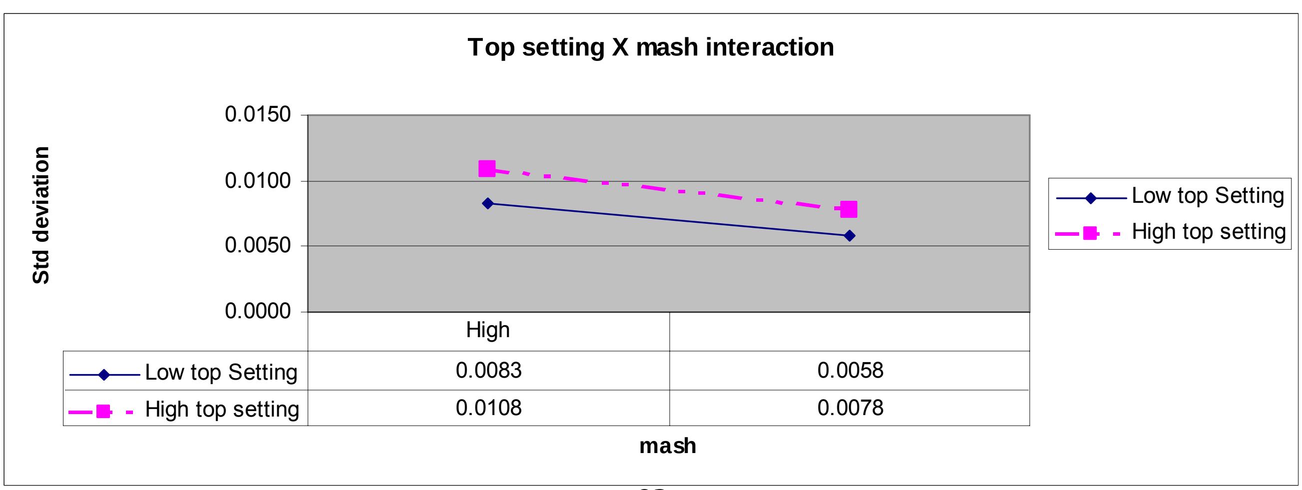
Appendix C6



	High	Low
High speed	0.0049	0.0073
Low speed	0.0142	0.0073



	Low	High
high top setting	0.0130	0.0056
Low top Setting	0.0085	0.0057



	High	
Low top Setting	0.0083	0.0058
High top setting	0.0108	0.0078

BIBLIOGRAPHY

1. (Fred E. Meyers & James R Stewart), Motion and time study for Lean manufacturing
2. (Niebel Benjamin), Methods, standards and work design
3. (Duggan, Kevin J), Creating mixed model value streams
4. (Hiroyuki Hirano), 5S for operators
5. (Ishighiro, Nakamara), The new standardization, keystone to continuous improvement in manufacturing
6. (Wallace J, Hopp & Mark L Spearman), Factory physics
7. (Keki R bhote) World Class Quality, Design of Experiments Made Easier, More Cost effective Than SPC
8. (Ranjit K Roy), Design of experiments using the Tagushi approach: sixteen steps to product and process improvement
9. (Jiju Antony, Tzu-Yao Chou and Sid Ghosh), Training for design of experiments. Work study, volume 52 number 7 2003
10. (Japan Human relations Association), Kaizen teian2: Guiding continuous improvement through employee suggestiongs
11. (Robin E McDermot, Raymond J. Mukulack, Michael R Beauregard), Employee Driven Quality: Releasing the creative spirit of your organization through suggestions systems
12. (Mike Rother and Rick Harris), Creating continuous flow: An Action Guide for Managers, Engineers and Production Associates
13. (Roy, Ranjit K), A primer on Tagushi methods
14. (Benjamin Niebel and Andris Freivalds), Methods, Standards and work design
15. (Philip J. Ross), Tagushi techniques for quality engineering
16. (James R Stewart), MODAPTS: A safeguard for worker safety and quality of life
17. (Pam whitehouse), Going with the flow. Manufacturing Engineer, April 2003
18. (James Bently), Manufacturing success stories. Manufacturing Engineer, April 2003
19. (Jon C Yingling), Applying Lean in high variety, low volume manufacturing. Lean manufacturing conference, May 2002

VITA

Date of birth: 23 September 1976

Place of Birth: Bulawayo, Zimbabwe

Education:

1. Bachelor of Engineering in Industrial engineering (National University of Science and Technology, Bulawayo, Zimbabwe, May 2000)

Advisor: Professor. Jon. Yingling

DGS: Proffessor. I.S. Jawahir