OPTIMIZATION OF PROCESS PARAMETER BY USING SIMULATION- TAGUCHI APPROACH: A CASE OF HABTAMU SILA PLASTIC FACTORY IN HAWASSA CITY

MSc. THESIS

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This is to certify that the thesis entitled "Optimization of Process Parameter by using Simulation- Taguchi Approach: A Case of Habtamu Sila Plastic Factory in Hawassa city" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Industrial Engineering and Logistic Management, the Graduate Program of the Department of Industrial engineering, and has been carried out by Ademe Sisay Id. No. GPIELMR/0001/11, under my/our supervision. Therefore I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Ademe Sisay have read and evaluated his/her thesis entitled "Optimization of Process Parameter by using Simulation- Taguchi Approach: case of Habtamu Sila Plastic Factory in Hawassa city" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree

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DECLARATION

Ademe Sisay Haile, declare that this work entitled **"Optimization of Process Parameter by using Simulation- Taguchi Approach: A Case of Habtamu Sila Plastic Factory in Hawassa City"** is an outcome of my effort for partial fulfillment of the requirement for the award of the degree of masters of science with a specialization in industrial engineering and logistics management graduate program in the facility of manufacturing and has not been submitted for any degree in this University or any other Universities. All sources of materials used for the study have been duly acknowledged.

By: Ademe Sisay Haile (Writer of the Thesis)

Signature______________________________

Date__________________________________

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ABSTRACT

The control of integrated manufacturing systems is usually complex. One approach that can accommodate such complexity is modeling the manufacturing processes on a computer. The primary objective of any company is to produce products with low cost. Process parameter optimization in a cost bases optimal selection of extrusion rate, setup time, feed rate, and capacity of the loading station. Besides, the use of computer simulation have been proposed and executed to tackle the issues of manufacturing cost reduction. A simulation model is an instrument in analyzing execution. Even though next studies of the outcomes of simulation can be used for investigation of design of experiment, investigation of optimum manufacturing process parameter to reduce the cost of manufacturing. Therefore, this paper deals with the optimization of process parameters in a manufacturing system to minimize the Unit Manufacturing Cost (UMC) of Un-plasticized Poly Vinyl Chloride pipes using a combined Simulation–Taguchi approach. With the new perspectives of integrated modeling, the study contributes to the body of knowledge, which also opens a new outlook for further studies. Taguchi design of experiment is useful for managing this study and L27 orthogonal array was selected. Thus, a significant factor along with their optimum combination is using Taguchi techniques to arrive at the least manufacturing cost. The results show that these methods can be useful in reducing the number of experimental trials needed to determine the best operating parameters. The results show that key parameters for optimum performance of the system are feed rate in to the hopper and the optimization of the extruder; The predicted unit cost of manufacturing the selected pipe model is 220 Birr and thus costs decreased by 28.8%., because the utilization of the machine increased by 33%, 34.6% for the worker from the actual performance. As part of the general outcome of this study, Taguchi method was helpful for reduction of unit manufacturing cost either at the product development or at process design stage and identifying optimum control parameter combinations.

Key words: Un-plasticized Poly Vinyl Chloride pipes, Optimization of process parameters, Simulation, Taguchi approach, Minimize UMC.

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LIST OF ABBREVIATION

Abbreviation	Full name description
HSPF	Habtamu Sila Plastic Factory
EPI	Ethiopian Plastic Industry
TPS	Toyota Production System
ISO	International Standard Organization
HDPE	High Density Polyethylene
PVC	Polyvinyl Chloride
QMS	Quality Management System
LDPE	Low Density Polyethylene
DLH	Direct Labor Hour
DLCF	Direct Labor Cost Factor
FOH	Factory Overhead
DL	Direct Labor
FOHF	Factory Overhead Factor
QTY	Quantity
FOHC	Factory Overhead Cost
DLC	Direct Labor Cost
DMC	Direct Material Cost
TPI	Total Product I
RM	Raw Material
Kg	Kilo Grams
TDLC	Total Direct Labor Cost
TC	Total Cost
UMC	Unit manufacturing Cost
MIDC	Machines in Dirty Condition
UB	Unbalance
OP	Operation
ST	Stability
FBII	Feedback in Inspection
LOPM	Lack of proper Maintenance

PE	Performance
TS	Tools Set
IM	Impurities
TL	Too Long
TFS	Time for Storage
HU	Humidity
SC	Storage Condition
TE	Temperature
NQSFI	No Quality Standard for Input
WSFPFPP	Wait Semi-Finish Production from Previous Process
BNIEP	Bottleneck in each Process
WWFU	Waiting Worker for Unloading
WFURMFT	Waiting for Unload Raw Material from truck
BPBOWTROQC	Buffer Production Because of Waiting the Result of Quality Control
UWD	Unreasonable Working Distribution
NHLPFHOS	No have Layout Plant for Handling or Storing
CDNHASFRM	Company does not have any Standard for Raw Materials
AT	Available Tools
CP	Compliance Parameters
LOSOEOW	Lack of Skill or Expertise of Worker
BAW	Behavior at Work
CO	Concentration
LOPTE	Lack of Prior Training Experience
AL	Aliment
HE	Health
FA	Fatigue
WPDAN	Work Place Dirty and Noisy

CHAPTER ONE: INTRODUCTION

The introduction part gives an overview and general description of the problem area addressed and its approach. The purpose of the introduction is to present the background and problem specification of the thesis which serve as the foundation in formulating the problem statement, objectives, scopes and organization.

1.1 Background

In 1960, the world population was around 2.5 billion and 60 years later in 2020, the world population is expected more than 7.5 billion and as the people increase the need for basic needs like food, clothing, shelter, security, health, essential services and the need to quality of life increase. Consequently, resources are limited. Cost reduction and Quality improvement is one of the means to resolve this conflict (Cheah, 1999).

For a society or a nation to raise the standard of living of its population, it must strive to maximize the return from its resources or improve production operation so that the economy can grow and sustain a better quality of life. Reducing cost is very often regarded as an activity, which is going to reduce quality. This view confuses the terms used in industry concerning quality and grade. Improving the quality of products relates to the use of more expensive materials or processes to produce a product. This can raise product costs of manufacturing. Improving quality means among other things, making less faulty products with the same amount of effort or cost which usually gives a lower unit cost (Mahfouz, 2011).

Manufacturing costs, which include materials, labor and overhead, are used to calculate a company's cost of goods sold under generally accepted accounting principles. The way is to subtract cost of goods sold from revenue to arrive at gross profit. Accordingly, reducing manufacturing costs will increase gross profit. Knowing how to reduce each of those component costs can help the company to raise the profitability of the business. (Jim Woodruff, 2019).

To date, some methodologies have been proposed and implemented to solve the problems of manufacturing cost in integrated manufacturing systems, for example, Queuing Networks, Petri Net models, Structured Modelling, Computer Simulation. Since the early development of models and languages, simulation has evolved into a technique, which is extremely useful as a facility to experiment on the model rather than the real-world system, and to analyze the relationships between the parameters and output behavior. Moreover, there is flexibility in the use of simulation languages, the model can be built as close to reality as we need and taken as a decision-making support tool. Thus, it is very helpful to analyze, schedule or plan manufacturing systems using simulation instead of using complicated mathematical model equations (Tsai, 2017).

1.2 Statement of problem

Many process industries have been giving due attention to compete in the global market by delivering quality products with a minimum cost of manufacturing. The case is not exceptional for plastic industries. Today, with industry so focused on the bottom line, failing to improve the performance a big impact on profitability (Khan, 2014). In HSPF, the common failure or defects, which are normally occurring in UPVC extrusion process that reduce the performance, are due to six main causes. These are method or processing, machine, personnel, measurement, material selection, and part and mold design.

This lower performance in HSPF occurs due to poor understanding of the processing method, lack of effective capacity utilization, overall equipment effectiveness is low, use of machines is inappropriate, machine break down, and in appropriate working environments.

In HSPF, one of the main performance measures is manufacturing costs. In the production process this manufacturing costs are uncontrollable in the company and cannot be reduced through the application of lean manufacturing methods because one of the premises of lean manufacturing is continuous improvement. This means that companies continue to examine their processes and strive for improvements in efficiency. By refusing to stagnate, companies continue to innovate and move forward while providing improved value and reduced manufacturing costs for their customers. Due to this HSPF cannot working on continuous improvement on labor productivity, minimizing waste and cutting errors. From the company data the cost of manufacturing pipe model (OD= 110mm; Nominal pressure = 4 bar; Thickness = 2.2 – 2.7 mm; Length= 6m) is very high in comparison with the other models and the average cost of manufacturing reaches 309 Birr/pcs (see annex F and G).

1.3 Research question

The research questions of this research thesis were raised from how the researcher could apply computer simulation with Taguchi design of experiments to identify, quantify, and analysis manufacturing process parameters that are evident in the manufacturing system and use the result for minimizing manufacturing cost of a product in the case company.

Based on the problem statement, the following research questions were outlined in the study.

- What are the main causes of high cost of manufacturing in HSPF?
- What are the system performance measures and how should the operational parameters be directed for pipe Extrusion?
- How could the quantification result be incorporated in the future effort for minimizing cost of manufacturing?

1.4 Research objective

1.4.1 General objective

The general objective of this research is optimization of process parameter by using simulation- Taguchi approach in the case of Habtamu Sila plastic factory in Hawassa city to improve manufacturing cost.

1.4.2 Specific objectives

- ✓ To identify the main causes of high manufacturing cost in HSPF for the selected product.
- ✓ Identifying the process and performance parameters related to pipe Extrusion and conducting experiments for collecting data.
- ✓ To develop simulation model' for the effective adaption of the result for reducing the cost of UPVC product.

1.5 Significance of the research

- The primary benefit goes to Habtamu Sila pipe factory since the research work also aimed to reduce cost of a particular product produced in the factory.
- Other smaller and medium plastic Industries involved in plastic pipe production utilize as a tool to optimize their process parameter at different stages and improve their productivity.
- Different Researchers and Government office like Ministry of Industry utilize for further studying the sector.

1.6 Scope and limitation of the research

The research work with regard to minimizing cost of manufacturing is limited to only one product called UPVC pipe and to find out the main and root causes having effect on UPVC pipe high manufacturing cost. The other product like HDPE Pipes and conduit pipe and PPR (Polypropylene Risen) pipe are not included due to time limitation and lack of appropriate data for quantifications and as it was described in the scope, only one factory is considered in these study. The strategic impact of this work is to improve factors affecting manufacturing cost with a major limitation that even though some parameters are very significant the researchers ruled out to due to the economic scope of the thesis.

1.7 Organization of the study

The whole thesis work is presented as follows. Chapter one contains the introduction part dealing with the background of the study, statements of the problem, research question, research objective, significance of the research, scope and limitation of the research, beneficiaries of the research paper, and organization of the study. The second chapter discusses the literature review about the subject matter. In chapter three, the research methodologies are present. Chapter four present data analysis and presentation, data presentation and discussion. Chapter five presents the conclusions and recommendations, a list of activities, which should be performed and should be encompassed in future works in order to enhance the development of plastic and plastic product sector.

CHAPTER TWO: LITERATURE REVIEW

In previous chapter, the problem and its solution approaches were described briefly. Since proper review of literature is important to solve the problem, this chapter describes the concepts of cost and existing effort made in spite of talking related problems before. This chapter presents the knowledge of the chosen theory and ideas for achieving and accomplishing the thesis.

2.1 Meaning of cost

Underway, research, retail, and book keeping, a cost is the estimation of money that has been utilized around create something or convey a service, and henceforth is not accessible for utilize any longer. In business, the cost might be one of obtaining; in which case the measure of cash exhausted to get it is considered cost. For this situation, cash is the information that is gone keeping in mind the end goal to secure the thing. This procurement cost might be the aggregate of the cost of generation as brought about by the first maker, and further expenses of exchange as caused by the acquirer well beyond the value paid to the maker. More often than not, the cost likewise incorporates an increase for benefit over the cost of creation. More summed up in the field of financial matters, cost is a metric that is totaling up because of a procedure or as a differential for the after effect of a decision (Cheah, 1999).

2.2 Quality engineering

In the sense of quality engineering, quality is defined as the losses that a product causes to customers after shipping. These losses may include losses caused by variation in the functioning of the product, and losses due to various troubles caused by the product. Good quality requires that there be no variation in the intended function and that losses caused by product trouble as reflected in application costs be minimal (Tsuyuki, 2014). The author continued and discussed on the possible countermeasures that to solve the problem of variation, which is the root of quality problems; it is necessary to stabilize design and production technology to reduce or eliminate the potential influence of noise. For this reason, quality engineering solves quality problems by introducing a new way of thinking, design for stability, which is commonly known as parameter design. Unlike the conventional design approach, where parameters are chosen based on intended product functions and characteristic values are established which exactly match target values even if after the product is completed the problem of Variation in function (characteristic values) may occur;

the parameter design approach first conducts a parameter study to build in the function required of the product and then, for the selected design, parameter optimization is done through two stages; stabilization of function (characteristic values) and adjustment to achieve target values. As a result, stabilized target values can be secured; so that the product functions, (characteristic values) will not be impacted by noise. To sum up, the overall aim of quality engineering is to make products that are robust with respect to all noise factors and the benefits that can be gained by introducing parameter design are improvement in the quality level by reducing the variation in product function (characteristic values), cost reduction through quality enhancement, stabilization of function in the early stages of product development, and enhanced efficiency of product development.

2.2.1 Design of experiments

The outcome of a process is often influenced by many input factors. To decide at what level to set the independent variables in order to optimize the outcome is difficult and in most cases done based on previous experience, that is, what has been learned by trial and error adjustment of the independent variables in different levels. Another way of doing this is to set up a series of experiments where the input factors the independent variables are deliberately set at two or more different levels, and an experiment is run for each of the several combinations of all the independent variables while the resulting outcome is recorded (Sorensson, 2010). Typically, the problems companies face do not consist of just a single element. In most cases, several factors are involved in a complicated relationship. To begin an analysis of problems which have occurred and come up with countermeasures to prevent a recurrence, it is essential to first understand what possible causes are having an effect on the problem areas (characteristics) (Tsuyuki, 2014).

An account of the fact that several factors are involved in a complicated relationship, the number of experiments necessary to test all combinations of these factors at different levels will be very large, and the approach consequently is no longer feasible. This is where statistical methods can be applied, using design of experiments, DOE, for an experiment designed to give a maximum of information from a minimum of experiment runs: that is, at optimal cost (Sorensson, 2010).

Design of experiment is a structured, organized method for determining the relationships among factors affecting a process and its output. It has been suggested that DOE can offer returns that are four to eight times greater than the cost of running the experiments in a fraction of the time that it would take to run one-factor-at-a-time experiments. DOE, hence, is a multivariate approach to where by two or more variables are treated in a single experiment (Kumar, 2013).

In parameter design, the factors that affect the intended function of a product are controllable factors, tolerance factors and adjustable factors. Controllable factors are sometimes called design constants or design parameters and their center value or level is determined by the designer or production engineer. Apparently, tolerance factors, commonly known as noise, are a cause of variations in the intended function of a product and the adjustable factors impact the size of output related characteristic values among the controllable factors. These adjustable factors can be adjusted to bring characteristic values into alignment with target values (Tsuyuki, 2014).The typical variables in a manufacturing process need to be identified. The goal will then be to determine the process variables settings, concurrently, that yield the best product. The approach is to organize factors and level combinations in to test matrices (arrays), and perform the tests. For example, factors could be three brewing process parameters and the levels could be mixture of two and four levels. Process or product input factors A, B, C, and D vary levels (values) of these parameters Measure performance of these responses Output quality characteristics.

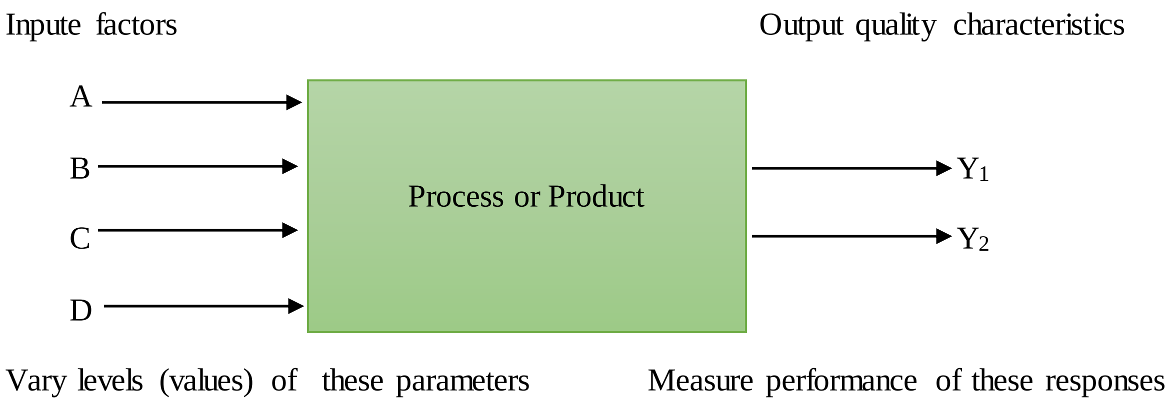

Figure 2.1 Model for designed experiment (Cartin, 2004).

The different combinations of process parameters and levels could be setup in a matrix according to a plan. Brewing would be refined, the results would indicate which combination of parameters, and their values produce the best brewing. The technique requires a greater test effort in the product development cycle, but it shortens the overall design-to-delivery cycle and minimizes the costly, typical stream of design changes to debug the new product after it starts production (Cartin, 2004).

Methodological tools of design of experiments have high utility in developing a quality product. For this kind of processes, experimentation is often the only possible way to understand the underlying mechanisms. A theoretical model with desirable predictive properties may be untenable. Statistical techniques for designing and analyzing such experiments may be very useful. A notable development in DOE was when suggested ways to change more than one factor simultaneously, in contrast to changing one factor at a time (Fisher, 1920). The approach of changing one factor at a time may take an unnecessarily large number of experimental trials and may not give clear understanding of the interactions among the factors in the experiment (Feigenbaum, 1991). DOE overcomes the information limitations of successive approximation experiments and quickly gives the kind of understanding and results that are needed. Most important, as opposed to the only certain goal of trial and error incremental improvement the underlying DOE goal of quantitatively defining cause and effect was completely in concert with the stated goals for this program. The DOE approach was therefore the obvious choice. Application of Design of Experiment, as described in Galankashi (2016) it helps companies get many benefits. Some of the benefits are it enables to gain maximum information from a minimum number of experiments, these are study effects individually by varying all operating parameters simultaneously for checking different outcomes, take account of variability in experiments on, operators, raw materials, or processes themselves, and identify interactions among process parameters, unlike with one-factor-at-a-time experiments and characterize acceptable ranges of key and critical process parameters contributing to identification of a design space, which helps to provide an "assurance of quality."

2.2.2 Types of designs

2.2.2.1 Screening designs

Screening designs are arguably the most popular designs for industrial experimentation. They examine many factors to see which have the greatest effect on the results of a process. Compared to other design methods, screening designs require fewer experimental runs, which is why they are cheap. Thus, they are attractive because they are a cheap and efficient way to begin improving a process. Often screening designs are a prelude to further experiments. It is wise to spend only about a quarter of your resource budget on an initial screening experiment. You can then use the results to guide further study. The efficiency of screening designs depends on the critical assumption of effect sparsity. Effect sparsity results because real-world processes usually have only a few driving factors; other factors are relatively unimportant (Kumar, 2013).

2.2.2.2 Response surface designs

Response surface designs are useful for modeling a curved quadratic surface to continuous factors. If a minimum or maximum response exists inside the factor region, a response surface model can pinpoint it. Three distinct values for each factor are necessary to fit a quadratic function, so the standard two-level designs cannot fit curved surfaces. The most popular response surface design is the central composite design. It combines a two-level fractional factorial and two other kinds of points: Center points, for which all the factor values are at the zero (or midrange) value and Axial (or star) points, for which all but one factor are set at zero (midrange) and that one factor is set at outer (axial) values (Kumar, 2013).

2.2.2.3 Full factorial design

A full factorial design contains all possible combinations of a set of factors. This is the most conservative design approach, but it is also the most costly in experimental resources. The full factorial designer supports both continuous factors and categorical factors with up to nine levels. In full factorial designs, you perform an experimental run at every combination of the factor levels. The sample size is the product of the numbers of levels of the factors. For example, a factorial experiment with a two-level factor, a three-level factor, and a four-level factor has 2 x 3 x 4 = 24 runs. . Unfortunately, the sample size grows exponentially in the number of factors, so full factorial designs are too expensive to run for most practical purposes (Kumar, 2013).

2.2.2.4 Mixture designs

Designs for mixture experiments are fundamentally different from those for screening. Screening experiments are orthogonal. That is, over the course of an experiment, the setting of one factor varies independently of any other factor. The interpretation of screening experiments is simple, because the effects of the factors on the response are separable. With mixtures, it is impossible to vary one factor independently of all the others. When you change the proportion of one ingredient, the proportion of one or more other ingredients must also change to compensate. This simple fact has a profound effect on every aspect of experimentation with mixtures: the factor space, the design properties, and the interpretation of the results (Kumar, 2013).

2.2.2.5 Space filling designs

Space filling designs are useful in situations where run-to-run variability is of far less concern than the form of the model. A sensitivity study of computer-simulations is one such situation. For this case, and any mechanistic or deterministic modeling problem, any variability is small enough to be ignored. For systems with no variability, randomization and blocking are irrelevant. Replication is undesirable because repeating the same run yields the same result.

2.2.2.6 Non-linear designs

Non-linear designs allow designers to generate optimal designs and optimally augment data for fitting models that are nonlinear in their parameters. Such models, when they are descriptive of the underlying process, can yield far more accurate prediction of process behavior than is possible with the standard polynomial models (Kumar, 2013).

2.2.2.7 Taguchi designs

Genichi Taguchi is a Japanese quality expert known for his work in the area of product design. He estimates that as much as 80 percent of all defective items are caused by poor product design. Taguchi stresses that companies should focus their quality efforts on the design stage, as it is much cheaper and easier to make changes during the product design stage than later during the production process. Taguchi is known for applying a concept called design of experiment to product design. This method is an engineering approach that is based on developing robust design**,** a design that results in products that can perform over a wide range of conditions. Taguchi's philosophy is based on the idea that it is easier to design a product that can perform over a wide range of environmental conditions than it is to control the environmental conditions. Taguchi has also had a large impact on today's view of the costs of quality. He pointed out that the traditional view of costs of conformance to specifications is incorrect, and proposed a different way to look at these costs. The purpose of the Taguchi method was to develop products that worked well in spite of natural variation in materials, operators, suppliers, and environmental change. This is robust engineering. The unique aspects of his approach are the use of signal and noise factors, inner and outer arrays, and signal-to-noise ratios. The goal of the Taguchi method is to find control factor settings that generate acceptable responses despite natural environmental and process variability. In each experiment, Taguchi's design approach employs two designs called the inner and outer array. The Taguchi experiment is the cross product of these two arrays. The control factors, used to tweak the process, form the inner array. The noise factors, associated with process or environmental variability, form the outer array. Taguchi's signal-to-noise ratios are functions of the observed responses over an outer array. The Taguchi designer supports all these features of the Taguchi method. You choose from inner and outer array designs, which use the traditional Taguchi Orthogonal Arrays, such as L4, L8, and L16 (Kumar, 2013).

2.2.2.8 Augmented designs

It is best to treat experimentation as an iterative process. That way, you can master the temptation to assume that one successful screening experiment has optimized your process. You can also avoid disappointment if a screening experiment leaves behind some ambiguities.

The augment designer modifies an existing design data table, supporting your iterative process. It gives the following five choices: replicate the design a specified number of times, add center points, create a fold over design, add axial points together with center points to transform a screening design to a response surface design and add runs to the design using a model that can have more terms than the original model (Kumar, 2013).

2.3 Design characteristics

As far as Natrella (1978), is concerned good experiments do not just happen; they are a result of careful planning. A good experimental plan depends on the purpose of the experiment, physical restrictions on the process of taking measurements and restrictions imposed by limitations of time, money, material, and personnel.

Natrella (1978) extends his point that the engineer in charge must explain clearly, why the experiment is being done, why the experimental treatments were selected, and how the completed experiment will accomplish the stated objectives. The experimental plan should be in writing and it should be endorsed by all key participants. The plan will include a statement of the objectives of the experiment, the experimental treatments to be applied, the size of the experiment, the period, and a brief discussion of the methods to be used to analyze the results.

Two concepts are of particular interest to the quality engineer: replication and randomization. Replication is the collection of more than one observation for the same set of experimental conditions. Replication allows the experimenter to estimate experimental error. If variation exists when all experimental conditions are held constant, the cause must be something other than the variables being controlled by the experimenter. Experimental error can be estimated without replicating the entire experiment. If a process has been in statistical control for a period, experimental error can be estimated from the control chart. Replication also serves to decrease bias due to uncontrolled factors.

Randomization is used in order to eliminate bias from the experiment and variables not specifically controlled as factors are randomized. This means that allocations of specimens to treatments should be made using some mechanical method of randomization, such as a random numbers table. Randomization also assures valid estimates of experimental error.

2.3.1 Choice of experimental design

The most important part of a DOE process, choosing an appropriate experimental design, is critical for the success of the study. The choice of experimental design depends on a number of aspects, including the nature of the problem and/or study, the factors and interactions to be studied, and available resources (Kumar, 2013).

2.3.2 Taguchi method of experimental design

The application of Design of Experiment technique on the optimization of an industrial process is being frequently used. These designs are considered as extremely useful tools in the modern industry (Kumar, 2013).

There are various ways to optimize the effect of controllable variables by using Designs of Experiments like Factorial, Central composite, Box-Behnken etc. The main drawback of all these techniques is their inability to take in to account the effect of uncontrollable factor, like environmental conditions, spindle-to-spindle variation etc. The replications used in these designs bring out the variability under similar experimental conditions and process parameters (Kumar, 2013).

For industrial processes, the number of factors and possible levels for the factors can be large. It may be infeasible to experiment for all the combinations of the levels of the factors. Taguchi has emphasized, among other things, using economical designs, using reduced number of trials, in such situations. Accordingly, in many industrial processes, interaction among the factors may be weak to consider those as negligible. It may also be possible sometimes to code or transform the factor levels and response variable values so that interactions may be considered to be of small amount. If interaction effects are weak, response variable values can be estimated with high accuracy with main effects of the factors. When there is not enough knowledge about the interactions in the process, a screening experiment may be designed, with less number of trials, to verify the strength of the interactions (Unal, 1993)

The strategy of laying out the states of examinations including various variables was first proposed by the Englishman, Sir R.A.Fisher. The technique is prevalently known as the factorial design of experiments. A full factorial design will distinguish every conceivable mix for a given arrangement of variables. Since most industrial experiments as a rule include a critical number of variables, a full factorial design brings about countless. To reduce the number of experiments to a practical level, just a little set from every one of the potential outcomes is chosen. The strategy for choosing a predetermined number of trials, which creates the most data, is known as a partial fraction experiment. In spite of the fact that this technique is notable, there are no broad rules for its application or the examination of the outcomes got by playing out the analyses. Taguchi developed an exceptional arrangement of general plan rules for factorial experiments that cover numerous applications.

Taguchi method of robust parameter design is an offline statistical quality control technique in which the level of controllable factors or input process parameters are so chosen to nullify the variation in responses due to uncontrollable or noise factors such as humidity, vibration, and environmental temperature (Montevechi, 2006). In Taguchi's, design method the input factors and noise factors are considered to have an impact on product quality. Whereas the input factors, sometimes called design parameters can be controlled by the designer, the noise factors, also known as uncontrollable factors cannot be controlled by the designer and cause the functional characteristics of a product to deviate from their target values.

2.3.3 Taguchi robustness concepts

Maintaining product or process quality involves, among other things, creating processes and products that operate close to their optimum conditions even when changes occur. More formally, robust design can be integrated into experimental design. The methods described by Genichi Taguchi are a well-known approach to integrating DOE and product and process design. While there has been much criticism of Taguchi's statistical approach, there is a broad consensus that his principles of robust parameter design are both valid and valuable contributions to engineering science.

Through proper uses and applications of quality engineering concepts, robustness of products and processes can be achieved. This can enhance their resistant to variations in production processes and enable them to with stand influences in the environments in which they are used. In this way, products and processes can attain maximum stability under limited design condition. Taguchi divides quality control efforts into two categories: on-line quality control and off-line quality control (Natrella, 1978).

On-line quality control involves diagnosis and adjusting of the process, forecasting and correction of problems, inspection and disposition of product, and follow-up on defectives shipped to the customer. Off-line quality control, whereas, involves quality and cost control activities conducted at the product and the process design stages in the product development cycle. There are three major aspects to off-line quality control:

1. System design is the process of applying scientific and engineering knowledge to produce a basic functional prototype design. The prototype model defines the initial settings of product or process design characteristics (Phadke, 1989).

2. Parameter design is an investigation conducted to identify settings that minimize (or at least reduce) the performance variation. A product or a process can perform its intended function at many settings of its design characteristics. However, variation in the performance characteristics may change with different settings. This variation increases both product manufacturing and lifetime costs. The term parameter design comes from an engineering tradition of referring to product characteristics as product parameters. An exercise to identify optimal parameter settings is therefore called parameter design (Phadke, 1989).

3. Tolerance design is a method for determining tolerances that minimize the sum of product manufacturing and lifetime costs. The final step in specifying product and process designs is to determine tolerances around the nominal settings identified by parameter design. It is still a common practice in industry to assign tolerances by convention rather than scientifically (Phadke, 1989).

Tolerances that are too narrow increase manufacturing costs and tolerances that are too wide increase performance variation and the lifetime cost of the product.

2.3.4 Taguchi's loss function

Taguchi's loss function has been extensively used for determining the engineering tolerance (Yang, 2005). The deviation of the product's functional characteristic from its desired target value contributes to some of these losses that are called losses due to functional variation (Kumar, 2013). As any quality characteristic diverges from nominal, losses grow until the point where losses are too great to deny and the specification limit is drawn. All these losses are, as W. Edwards Deming would describe them, unknown and unknowable, but Taguchi wanted to find a useful way of representing them statistically. Taguchi specified three situations: larger the better; smaller the better; and on-target, minimum-variation.

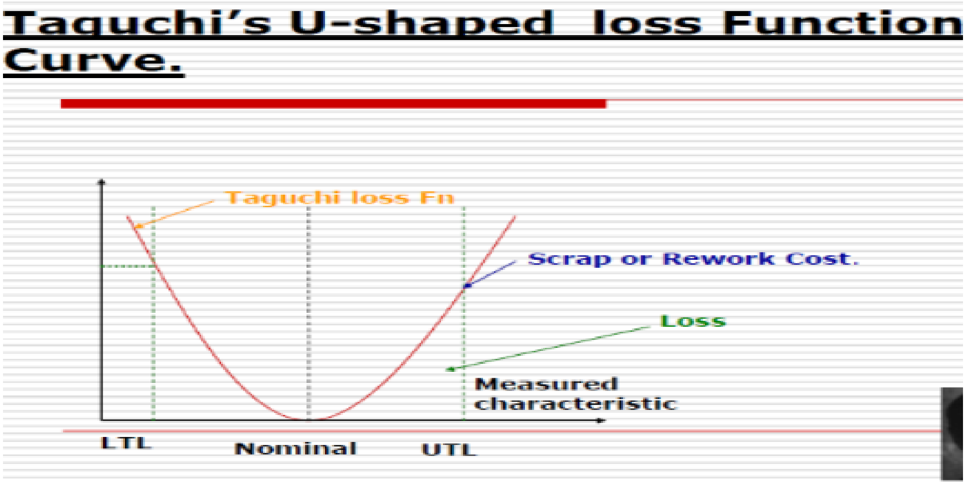

Figure 2.2 Taguchi's loss function (Lorenzo, 1990)

When a critical quality characteristic deviates from the target value, it causes a loss. In other words, variation from target is the antithesis of quality. Quality simply means no variability or very little variation from target performance (Lorenzo, 1990). An examination of the loss function shows that variability reduction or quality improvement drives cost down. Lowest cost can only be achieved at zero variability from target. Continuously pursuing variability reduction from the target value in critical quality characteristics is the key to achieve high quality and reduce cost (Unal, 1993).

2.3.5 Process optimization in Taguchi method

The Taguchi method has been explained and analyzed in detail in different published materials. According to Ikram (2013), the purpose of Taguchi's design method is to select the levels of the input factors (design parameters) and to reduce the effect of noise factors; parameter setting should be determined with the intention that product response (quality characteristic) has minimum variation while its mean is close to the desired. According to

Anurag (2016), the goal of parameter design is to identify design settings that make the product's performance less sensitive to the effects of manufacturing and environmental variations, and deterioration. In this case, the variables that affect a product's performance are classified into design parameters whose nominal settings can be specified and noise parameters that represent uncontrollable variations. Apparently, according to Phadke (1989), the main objective in the Taguchi method is to design robust systems, which are reliable under uncontrollable conditions. The method aims to adjust the design parameters (known as the control factors) to their optimal levels, so that the system response is robust; that is, the system response is insensitive to noise factors, which are hard or impossible to control. Overall, the major objective of parameter design through Taguchi method is bringing the product or process response to have the minimum variation and the mean close to target value.

Tsuyuki (2014) illustrated that Taguchi's objective was to design a system such as to maximize the S/N value while keeping the response on the target and his method for robust design was divided into two stages called parameter-design, and tolerance design. In the parameter-design stage, the designer has to determine the best setting of the control factors to minimize the quality loss. This objective is achieved by a two-step procedure.

First, set those control factors in to maximize the S/N ratios in order to minimize the sensitivity of the response to noise. Second, use the factors in to adjust the mean response to the desired target, based on the assumption that the response mean can be altered independently from the response variance due to these tuning factors. The underlying assumption at this stage is that the setting of control factors does not affect the manufacturing costs. During parameter design, Taguchi assumed a wide tolerance on the noise factors; and, under these conditions, tried to minimize the sensitivity to noise. If at the end of the parameter-design stage the quality loss has to be further reduced, which is the situation in most practical applications, the de-signer has to continue to the tolerance design stage.

In the tolerance design stage, the designer selectively reduces the tolerances of the noise factors to further minimize the quality loss. A trade-off is often considered between the reduction in the quality loss, and the costs required to reduce the tolerances of noise factors. Taguchi suggested performing the tolerance design stage only after the S/N-based optimal design has been selected in the parameter-design stage. Otherwise, it was claimed that the costly tolerance design will be somewhat wasted on a non-optimized system, leading to a higher investment in tolerance reduction to achieve the desired low quality loss. Thus, note that Taguchi's approach optimizes the system in each of the two design stages independently. It does not consider a possible situation where a non-optimal system in the parameter-design stage achieves the lowest tolerance reduction cost in the tolerance design stage. Here we aim to address such situations.

2.3.6 Taguchi application in manufacturing system

Today, with industry so focused on the bottom line, the costs of manufacturing have a big impact on profitability (Khan, 2014). Be that as it may, in many manufacturing systems, process are muddled by numerous cooperation's between these process, for example, deadlock, clash, and also vulnerabilities in the manufacturing process, for example, machine disaster, tool changes or production requirement variability. As a result, systems based on specific management goal are important to model and analyze this class of systems. Queuing Networks, Petri Net models and other structured .numerous tools and techniques have been developed for designing optimum parameter to reduce cost of manufacturing and enhance productivity of manufacturing systems (Tsai, 2017). For example, response surface methods, gradient search methods, stochastic approximation methods, heuristic search methods. These methods can find the optimum response but lack a means of evaluating the relationship of the parameters. Taguchi Methods support the methodologies for analysis and provide guidance to a selection of the optimum level.

The Taguchi strategy Feigenbaum (1991) is a capable tool for the design of great quality frameworks and is a deep-rooted method that gives an orderly and productive approach for process optimization. Taguchi approach to design of experiment is easy to adopt and apply for users with restricted knowledge of statistics, subsequently acquired wide prevalence in the engineering and scientific field (Sankaran, 2015). This is considered as one of the engineering strategy for getting product and process condition, which are modestly sensitive to the diverse cause of variation, and which create quality product with less development and cost of manufacturing Signal to noise ratio and orthogonal array are the two major devices utilized in this design. The S/N ratio characteristics can be separated into three classes when the characteristics are continuous. They are "Nominal the best", "Larger the better" and "Smaller the better". For manufacturing cost, the solution is **"**Smaller the better" (Park, 1996). Utilizing response curve, the impact of every single control variables can be defined effectively. To accomplish trusty and better outcomes without expanding the experimental cost, manufacturing process parameter designs an imperative advance in Taguchi strategy.

The following review focus on previous efforts made in spite of tackling an increase in manufacturing cost, which would help to improve productivity.

Solomon (2016) connected Taguchi robust design approach toward utilizing Taguchi Design; L27 orthogonal array to the extrusion process for creation of UPVC (Unplasticized Poly Vinyl Chloride) funnels.

Anurag (2016) connected the Cost of Quality Principle for streamlining of process setting factors for Nylon Sheathing procedure of Optical Fiber Cable production.

Ikram (2013) researched the impact and optimization of eight control factors on material evacuation/removal rate (MRR), surface harshness/hardness and kerf. In Wire Electrical Discharge Machining (WEDM) process for instrument steel D2 by use of Taguchi's L18 orthogonal array, ANOVA and signal to-noise (S/N) ratio for trial plan.

Vidal et al. (2012) endeavored to advance The Friction particle Stir welding (FSW) process which is a strong state mechanical handling innovation empowering high quality joints in materials already considered with low weldability, for example, the greater part of the aerodynamic aluminum compounds.

The Taguchi technique was utilized to locate the ideal FSW parameters for development of mechanical conduct of aluminum composite. The parameters considered were vertical, descending producing power, travel speed and stick length. An orthogonal exhibit of L9 was utilized; ANOVA examinations were done to recognize the huge components influencing ductile quality, bowing durability and hardness field tests.

Yang (2004) have contemplated optimization particle of parameter in Injection Molding utilizing Statistical Methods and IWO Algorithm statically. They attempted to persuade the impact of changing infusion shaping parameters on the shrinkage conduct of polypropylene (PP) and polystyrene (PS) plastic materials.

Narasimha (2015) introduced an efficient way to deal with discover the main drivers for the event of imperfections also, wastes and to reduce cost in plastic extrusion process. The circumstances and end results outline was executed to distinguish the main drivers of these deformities. The extrusion process parameters, for example, vacuum weight, temperature, take-off speed, screw speed of the extrusion process and crude material properties were recognized as the real underlying drivers of the wastes from the circumstances and results outline. The quality loss for the present execution variety was computed utilizing Taguchi's guideline of misfortune function and necessity for change was confirmed. In their paper, design of experiment (DOE) was connected to streamline the process parameters for the extrusion of high-thickness polyethylene (HDPE) pipe Ø 50mm what's more, plain pipe Ø 25mm. Four free process parameters including vacuum weight, take-off speed, screw speed and temperature were examined utilizing Taguchi technique. Minitab 15 programming was utilized to investigate the after effect of the trial. In view of the after effect of the examination, ideal process parameters were chosen.

Hossain (2016) directed an examination to enhance the quality level of an injection molding plastic plate item, produced using mixes plastic (75% polypropylene (PP) and 25% low thickness polyethylene (LDPE)) by upgrading the parameters utilizing the Taguchi robust design approach as an optimization technique. An orthogonal array (OA), principle impact, signal to-noise (S/N) ratio and analysis of variance (ANOVA) are utilized to break down the impact of injection forming parameters on the conduct of the plastic Tray. Their investigation demonstrates that the ideal mix of parameters that gives a sound item (Plastic Tray) are low liquefying temperature, high injection pressure, low holding pressure, long holding time and long cooling time.

Yang (2004) connected Taguchi's plan of investigation and numerical simulation particle in the improvement of an aluminum profile extrusion process. By methods for Hyper Extrude simulation programming, the extrusion process was reenacted and the impacts of process parameters on the consistency of metal stream and on the extrusion drive were explored with the signal-to-noise ratio and analysis of variance.

Hong (2006) looked into writing on utilization of different optimization methods utilized by diverse scientists for plastic extrusion process. Different systems incorporate Genetic algorithm (GA), artificial neural network (ANN), Fuzzy logic, Response surface method, Taguchi technique. Matta (2008) connected Taguchi technique with orthogonal array and signal to noise ratio to examine and improve process parameters in particular dissolving temperature, extrusion speed, and extrusion pressure and winding speed for HDPE material in Extrusion Blow Film machinery.

Galankashi (2016) connected optimization of process parameters in plastic extrusion of pipe producing utilizing signal to noise ratio, ANOVA and utilization of Taguchi loss work. Considered the imperfections in the plastic pipe, to enhance the plastic pipe fabricating process. The improvement Taguchi procedures utilized as a part of this paper. The parameters taken under contemplations were Take-off-speed and temperatures. The change all the while and loss of quality was moreover assessed in this manner evaluating the yearly-expected investment funds by the M/s Shivraj HY-Tech Drip Irrigation organization. The trial was dissected utilizing business Minitab16 programming, translation has made, and improved factor settings were picked. After expectation of result the quality misfortune was figured and it contrasted and before execution of DOE. The examination works has enhances the creation, quality and advances the procedure.

Jain (2017) recommended an approach utilizing loss of Taguchi work for assurance of ideal machine setting conditions for an Automotive Crank Shaft Supplies in view of agreement terms.

Kumar (2013) utilized the Taguchi design of experiment approach to advance the process parameters and enhance the nature of segments that fabricated. The goal of this examination was to represent the methodology received in utilizing Taguchi design of experiment approach to an extrusion blown film machinery. The orthogonal array, signal-to-noise ratio utilized to examine the execution attributes on rigidity; a more prominent S/N proportion relates to better quality qualities. Consequently, the ideal level of the procedure parameters was the level with the best S/N proportion. In this investigation, four factors to be specific liquefying temperature, expulsion speed, expulsion weight and winding pace were considered. Appropriately, a reasonable orthogonal exhibit was chosen and investigations were led. In the wake of leading the investigations, the rigidity was measured and Signal to Noise proportion was figured. With the assistance of chart and table, ideal parameter esteems were gotten.

Deroussi (2006) tended to plan and improvement of extrusion process for aluminum 6061 amalgam. They demonstrate that the extrusion temperature and load has critical on quality and cost of the expelled parts separately. Consequently, improvement of sparing process conditions found as indispensable. Forward extrusion show created to investigate the process reactions temperature, extrusion stack, extrusion proportion and clear speed for deferent process outlines. Probably the most critical plan parameters slam speed, coefficient of rubbing and bite the dust point considered. Taguchi's L9 configuration utilized to reenact the tests for each arrangement of picked expulsion factors by means of Finite Element Analysis (FEA) solver. Analysis of variance (ANOVA) received to check the centrality of the information factors on the yield reactions. At that point, the ideal process parameters are resolved utilizing Taguchi's approach.

Tsai (2017) connected the Taguchi's plan of analysis and numerical reproduction to upgrade the aluminum profile extrusion process. By methods for Hyper Extrude, the extrusion process was recreated and the impacts of process parameters on the consistency of metal stream and on the extrusion constrain were explored with the flag to clamor proportion and the investigation of difference. Through investigation, the ideal blend of process parameters for uniform stream speed appropriation was acquired, with the billet measurement of 170 mm, smash speed of 2.2 mm/s, kick the bucket temperature of 465°C, billet preheated temperature of 480°C, and compartment temperature of 425°C.Compared with the underlying process parameters, the speed relative contrast in the cross area of extruder was diminished from 2.81% to 1.39%. Similarly, the ideal procedure parameters for least required expulsion drive were picked up, with the billet distance across of 165 mm, smash speed of 0.4 mm/s, pass on temperature of 475°C, billet preheated temperature of 495°C, and compartment temperature of 445°C. A 24.7% reduction of required extrusion compel with ideal process parameters was figured it out. Through the advancement investigation in this examination, the extrusion execution has been enormously made strides. Finally, the numerical outcomes were approved by down to earth tests, and the examination demonstrated that the advancement system created in this work could give the viable direction to pragmatic generation.

Solomon (2016) took two gatherings of aluminum clear sand throwing forms for examination of first : Single aluminum clear sand throwing and second : two fold aluminum clear sand throwing aluminum clear green sand (green) throwing procedure to upgrade the procedure parameter utilizing Taguchi's hearty plan approach. By changing distinctive sittings of the throwing procedure, they endeavor to acquire ideal settings of parameters that influence the different quality attributes of the item produced using aluminum test.

Alemayehu (2015) tried to quantify waste measurement and estimate the cost of these wastes. However, the result was biased due to the author’s personal judgment. In addition, the regression technique used by the author was complex and is not helpful for UMC reduction.

2.4 System modeling and simulation

Simulation is the process of designing a model of a system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies of performance of the system (Mahfouz, 2011).

In Simulation, we use a computer to evaluate a model numerically, and data are gathered to estimate the true characteristics of the model (Law and Kelton, 2015).

- To Simulate means to imitate or mimic or to pretend (dictionary)
- Simulate is to try to duplicate the characteristics of a real system
- A simulation is the imitation of the operation of a real-world process or system over time.

According to Law and Kelton (2015), Simulation is the process of designing a mathematical or logical model of a real-system and then conducting computer-based experiments with the model to understand, describe, explain, and predict the behavior of the real system.

Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models over extended period of real time. Thus, define system simulation as a technique for solving problems by the observation of the performance, over time, of dynamic model of the system.

In other words, simulation can define as an experiment of physical scenario on the computer.

Simulation is appropriate of the reasons:

Simulation makes it possible to study an experiment with the complex internal interactions of a given system, whether it is a firm, an industry, an economy, or some subsystem of one of these. Through simulation, we can study the effect of certain informational, organizational, and environmental change on the operation of the system by making alternations in the model of the system and observing the effects of these alterations on the system's behavior. Detailed observation of the system being simulated may lead to a better understanding of the system and to suggestion for improving it, suggestions that otherwise would not be apparent and others.

The Monte Carlo method of simulation is one of the most powerful techniques of simulation and is defined as follows. Simulation can also be defined as a technique of performing sampling experiments on the model of the system. This is called stochastic simulation and is a part of simulation techniques. Because sampling from particular probability distribution involves the use of the random numbers, stochastic simulation is sometimes called as Monte Carlo simulation.

2.4.1 Applications of simulations

Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. On the one hand, a model should be a close approximation to the real system and incorporate most of its salient features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it. A good model is a judicious tradeoff between realism and simplicity. Simulation practitioners recommend increasing the complexity of a model iteratively. An important issue in modeling is model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output (Law and Kelton, 2015).

According to Law and Kelton (2015), generally a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications includes deterministic (input and output variables are fixed values) or stochastic (at least one input or output variables is probabilistic); static (time is not taken into account) or dynamic (time varying interactions among variables are taken into account). Typically, simulation models are stochastic and dynamic. A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behavior of the actual system or its subsystem can be inferred. In its broadest sense, simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time.

Simulation is used to an existing system is altered or a new system built, to reduce the chances of failure to meet specification to eliminate unforeseen bottle necks, to prevent under or over utilization of resources and to optimize system performance.

Simulation models consist of the following components: system entities, input variables, performance measures, and functional relationships. For instance in a simulation model of an M/M/1 queue, the server and the queue are system entities, arrival rate and service rate are input variables, mean wait time and maximum queue length are performance measures, and 'time in system = wait time + service time' is an example of a functional relationship. Almost all simulation software packages provide constructs to model each of the above components. Modeling is arguably the most important part of a simulation study. Indeed, a simulation study is as good as the simulation model. Simulation modeling comprises the following steps:

2.4.2 Basic steps of simulation study

According to Law and Kelton (2015), the application of simulation involves specific steps in order for the simulation study to be successful. Regardless of the type of problem and the objective of the study, the process by which the simulation is performed remains constant. The following briefly describes the basic steps in the simulation process:

1. Problem Definition

The initial step involves defining the goals of the study and determines what needs to be solved. The problem is further defined through objective observations of the process to be studied. Care should be taken to determine if simulation is the appropriate tool for the problem under investigation.

2. Project planning

The tasks for completing the project are broken down into work packages with a responsible party assigned to each package. Milestones are indicated for tracking progress. This schedule is necessary to determine if sufficient time and resources are available for completion.

3. System Definition

This step involves identifying the system components to be modeled and the performance measures to be analyzed. Often the system is very complex, thus defining the system requires an experienced simulator who can find the appropriate level of detail and flexibility.

4. Model Formulation

Understanding how the actual system behaves and determining the basic requirements of the model are necessary in developing the right model. Creating a flow chart of how the system operates facilitates the understanding of what variables are involved and how these variables interact.

5. Input Data Collection & Analysis

After formulating the model, the type of data to collect is determined. New data is collected and/or existing data is gathered. Data is fitted to theoretical distributions. For example, the arrival rate of a specific part to the manufacturing plant may follow a normal distribution curve.

6. Model Translation

The model is translated into programming language. Choices range from general purpose languages such as FORTRAN or simulation programs such as Arena.

7. Verification & Validation

Verification is the process of ensuring that the model behaves as intended, usually by debugging or through animation. Verification is necessary but not sufficient for validation that is a model may be verified but not valid. Validation ensures that no significant difference exists between the model and the real system and that the model reflects reality. Validation can be achieved through statistical analysis. Additionally, face validity may be obtained by having the model reviewed and supported by an expert.

8. Experimentation & Analysis

Experimentation involves developing the alternative model(s), executing the simulation runs, and statistically comparing the alternative(s) system performance with that of the real system.

9. Documentation & Implementation

Documentation consists of the written report and/or presentation. The results and implications of the study are discussed. The best course of action is identified, recommended, and justified.

Advanced versions of simulation software today, support the following features:

- ✓ Uniquely structured environment lets the user to quickly enter the geometry and production requirements of a model.
- ✓ Expert system technology generates details automatically while windows and pop-up menus guide the user through the modeling process.
- ✓ Changes can be made quickly and easily with far less chances of errors.
- ✓ Built in material handling templates make the user more productive, so he/she does not waste time programming.
- ✓ The user can verify and test designs, answer "what if" questions explore more alternatives and catch system glitches and 3-D animation- all before implementation.
- ✓ 3-D graphics are automatically created as the user enters data.
- ✓ Results can be communicated in real time animation.

2.4.3 Three types of simulations

According to Law and Kelton (2000), simulations generally come in three styles: live, virtual and constructive. A simulation also may be a combination of two or more styles. Within these styles, simulations can be science-based (where, for example, interactions of things are observed or measured), or involve interactions with humans.

- ➢ **Live simulations** typically involve humans and/or equipment and activity in a setting where they would operate for real. Think war games with soldiers out in the field or operating command posts. Time is continuous, as in the real world. Another example of live simulation is testing a car battery using an electrical tester.
- ➢ **Virtual simulations** typically involve humans and/or equipment in a computer-controlled setting. Time is in discrete steps, allowing users to concentrate on the important stuff, so to speak. A flight simulator falls into this category.
- ➢ **Constructive simulations** typically do not involve humans or equipment as participants. Rather than by time, they are driven more by the proper sequencing of events. The anticipated path of a hurricane might be "constructed" through application of temperatures, pressures, wind currents and other weather factors. Science-based simulations are typically constructive in nature.

2.4.4 Use of ARENA simulation software

- ❖ Identify all consequences of a planned change
- ❖ Prove an investment will work before spending
- ❖ Gain insights into why your process behaves the way it does

- Evaluate the cost saving that will come from changing your process
- Try changing your process and see the changes that make it work better for less
- In a risk-free "simulated" environment, try any idea without the cost of trying it in the real process.

2.4.5 Simulation for optimization

In the context of simulation optimization, Bettonvil et al. (2009) present a simulation-based optimization approach with multiple outputs and study the robustness of their procedure through several examples including optimization of an integrated production-inventory simulation model. Hong and Nelson propose an optimization algorithm for discrete event simulation, called COMPASS. An assemble-to-order system is studied as a numerical example. In another study, Xu et al. (2010), investigate the Industrial Strength COMPASS (ISC) as an optimization-via-simulation framework and compare it to the commercial optimization-via-simulation package OptQuest on five test problems including a production line problem. Ng et al. introduce an Internet-based platform called FACTS that integrates automatic model generation and optimization engines to facilitate model development and optimal decision-making. In the FACTS server, various optimization tools and ANN-based Meta models are made available to the user. Pichitlamken and Nelson (2003) propose an optimization-via-simulation algorithm where discrete event simulation is used to measure the performance of the system. They use the proposed approach to maximize the average output of a flow line by finding the best buffer allocation and service rates. Yang and Choud (2009) develop a multiple-attribute decision-making method to solve the multi-response simulation-optimization problem and apply the method to a case study from an integrated-circuit packaging company.

Through a case study, Mahfouz et al. (2011) integrate simulation with optimization techniques to evaluate the implementation of lean principles in small and medium enterprises (SMEs) with regards to three performance measures, namely cycle time, WIP, and work force utilization. Eklin et al. (2009) integrate simulation and optimization to develop a cost estimation model that considers limited capacity in a stochastic environment. They show the advantage of the proposed heuristic over an existing deterministic approach through an example of a manufacturing system. Melouk et al. (2013) propose a simulation optimization-based decision support system for steel manufacturing where an optimizer, OptQuest TM, sends potentially beneficial process modifications a simulation model to investigate their performance of the system. Matta (2008) presents mathematical programming representations for simulation optimization of buffer allocation in flow lines. For related studies in semiconductor and cellular manufacturing, see Pfeffer et al. (2012) and Montevechi et al. (2006) respectively. Integration of simulation with evolutionary and metaheuristic search methods for optimization purposes have been addressed in a number of papers. Piera et al (2004) describe a new approach to integrate simulation methods with search methods for optimization of complex logistic or manufacturing systems. The application of such approaches have been illustrated in case studies of an engine manufacturing line, flow shop , job shop, dedicated remanufacturing, FMS, parallel machine scheduling, and multi-constant work-in-process problem. Tsai (2017) studied the use of Taguchi's Experiment Design in simulation to solve decision-making problems in integrated manufacturing systems. In particular, the researchers use the case of a steel soaking pit/ rolling-mill plant to demonstrate how the approach works. The results reveal that this approach can take in to account the evaluation and optimization of operating conditions in complex systems simultaneously.

2.4.6 Analogy between Taguchi and simulation

The analogy between Taguchi's parameter design and the activities of simulation expressed as follows:

- In Taguchi Methods, we seek to improve or establish the design of a product or production processes using physical prototypes. In simulation approaches, we attempt to establish or improve the design or operation of a system (such as manufacturing system, service facility, etc.) using simulation models.
- In Taguchi Methods, the measures of performance are the desired functional characteristics of the product. In simulation approach the performance measures are the model performance measures for the system being designed or operated (Tsai, 2017).

2.5 Summary of review and literature gap

The use of computer simulation have been proposed and executed to tackle the issues of increasing unit-manufacturing cost in a manufacturing system. However, a simulation model just goes about as an instrument in analyzing execution. It is a trial and error strategy, and does not specifically give clarifications to watched framework practices. Apart from possession of performance characteristics, since HSPF have a multi- performance characteristics measure and need to be optimized not according to any method proposed for quality performance only but according to a method, which can particularly address the specific case (cost) with improving the quality of the product or keeping it as it, is. Solomon (2016) Connected Taguchi design approach toward utilizing Taguchi Design; L27 orthogonal array to the extrusion process for creation of UPVC (Unplasticized Poly Vinyl Chloride) funnels in Amahar pipe and plastic factory. The authors tried to prove optimization of process parameters under the host of design factor so as to improve the quality have a viable importance as most of the investigations on the Taguchi applications are on the optimization of quality performance characteristics, as the original technique was designed to optimize quality. However, the other performance characteristics (unit manufacturing cost) problems in the authors work have received no attention. On the other hand, Tesfaye (2014) used the regression technique based approach for estimating the cost of waste in Ethiopia plastic industry. However, the computational process the author used was very complex and may not be as useful as is needed for day-to-day design requirements. Unfortunately, in HSPF no method has been proposed, so far, to deal with optimization of manufacturing cost. To fill this gap, this study applied both simulation and Taguchi approach to examine and improve manufacturing process to help managers to proficiently manage their operations. The outcomes can uncover that this approach can take into account the assessment and advancement of working conditions in complex frameworks at the same time.

CHAPTER THREE: RESEARCH METHODOLOGY

In previous chapter, a related literature review on process parameter optimization using Taguchi design of experiment and computer simulation has been presented. Since proper research method is important to start scientific research, this chapter describes research process, research approach, and research strategies of the thesis. The methodology part also describes the project approach and methods for achieving the purpose and objective of the paper. Method of data collection and flow of the study is outlined to guide the readers.

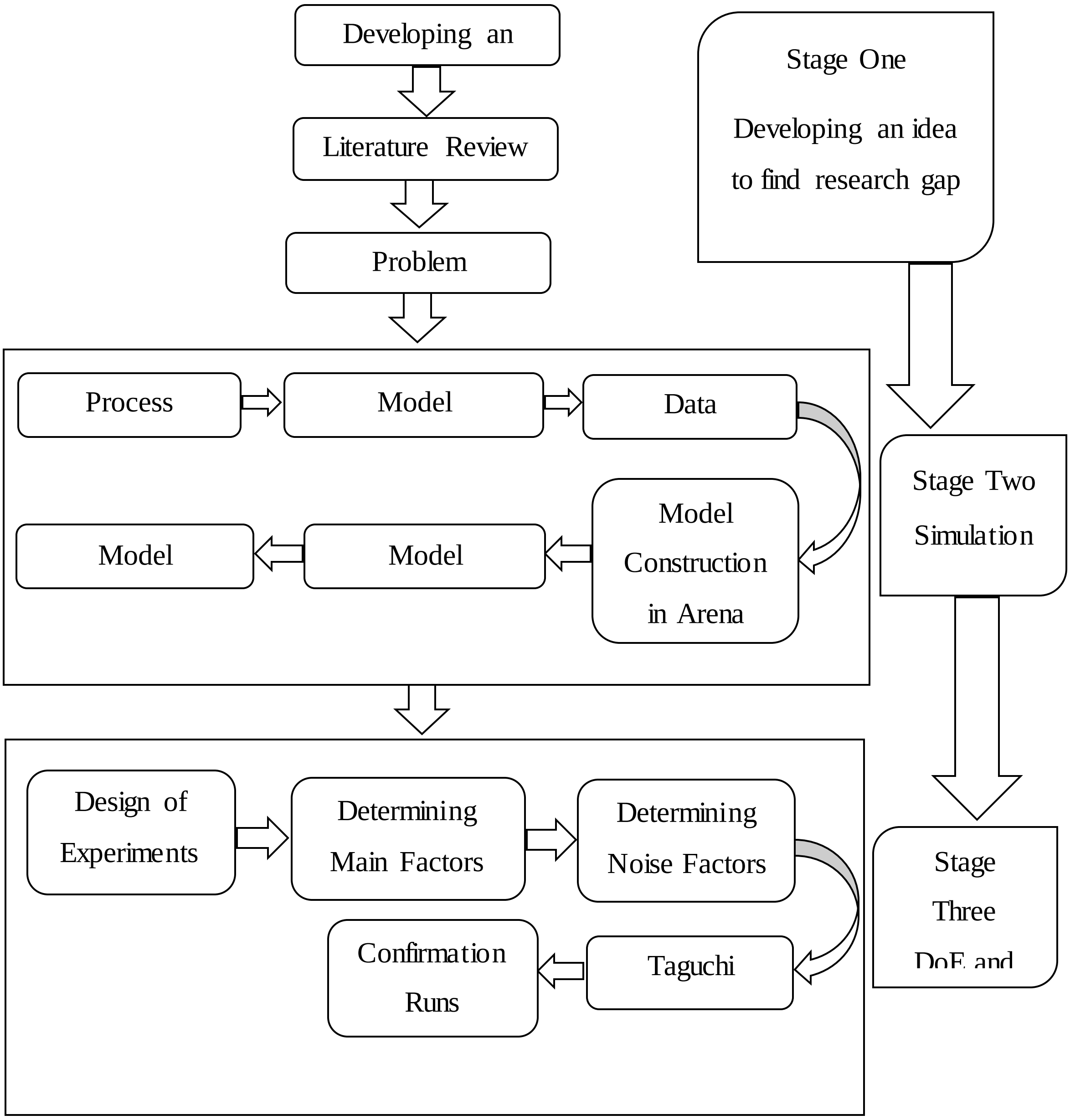

Figure 3.1 Methodology (Procedure) of the research

3.1. Research process

Although there are different methods to conduct the research, all these methods are involved in a sequence of activities that form research process with high dependency together. All activities in research process do not always follow the same order nevertheless; the relevant generic pattern can be presented. The conclusion of studies usually generates new ideas for future research. Therefore, it makes research process cyclical.

3.2. Quantitative and qualitative research approaches

Quantitative research is an inquiry into an identified problem, based on testing a theory, measured with numbers, and analyzed using statistical techniques to prove or disprove predetermined hypotheses regarding the relationships between specific variables. Qualitative research is described as the non -numerical examination and interpretation of observations, for discovering underlying meanings and patterns of relationships. It is carried out by using open-ended observations and interviews. According to the above explanation, this study is conducted using the combination of both qualitative and quantitative research approaches. The purpose to apply the qualitative research approach is an exploratory nature because it does not have a hypothesis; while the hypothesis is a predication in nature and it tries to explore not predict participant view (Creswell, 2009).

Typically, the purpose of quantitative research approach is researchers collect more than one type of data in order to get better and more holistic picture about what is going on in the field (Creswell, 2009).

The research strategy should be chosen according to the research questions in the particular situation. A number of research strategies are available for conducting a research such as literature survey, experiments, questionnaire surveys, histories, case studies, and analysis of archival information. According to the research objectives, preferable research strategies like literature survey, experiments, case studies, interviews, and archival records and documentations were selected for this research.

3.3 Research design

The research design for this study is to utilize orthogonal array as an experimental design vehicle both for the controllable and uncontrollable parameters that were used as inputs in arena simulation. Data were analyzed utilizing signal-to-noise ratio data transformation for the lower-the-better optimization criterion.

3.3.1 Survey of literatures

Complete literature was conducted regarding the concept of optimization, system modeling and simulation, design of experiment (Taguchi design approach), and manufacturing process parameter improvement strategy. These concepts were obtained from various sources.

3.3.2 Data collection methods

Following literature survey, in order to assess and find significance of factors affecting the manufacturing cost of HSPF, data collection has been carried out. Both primary and secondary data were collected by using a non-well-structured direct interviews, personal observations, and secondary data collection for case study.

Accurate data collection, recording and analysis are important as all output depends on it. Initially, data collection begins from identifying the location, entities and others. All the data that are successfully gathered were specifically identified for accurate distribution as the process go to from his experience he suggested me major product of the company that has been on the production line for the past recent years. The whole study has been conducted with respect to this pipe model (OD= 110mm; Nominal pressure = 4 bar; Thickness = 2.2 – 2.7 mm; Length= 6m).

3.3.3 Case Study: Habtamu Sila plastic factory

The researcher has gone to the case firm formally by having letter from Hawassa University Institute of Technology Faculty of Manufacturing Engineering Department of Industrial Engineering then after discussion with the production manager, who is a Manufacturing Engineering, about the title and intervention areas in the firm under the light of the title. The production manager disseminated letters for each department head that described about the researcher's authorization to get any information's. In addition, the production manager assigned one worker to work with the researcher and providing any information is that the researcher needs to gather. After having discussions amongst the production manager & production department heads, observations and through literature studies the research problem was formulated this was directed by both the aims of this research.

3.4 Selection

3.4.1 Selection of case manufacturing company

Ideally, most manufacturing plants would like to find the method for the overall minimization of cost of manufacturing strategy. To this end, to analyze productivity of production system, a case plastic pipe production system was selected from the country plastic industries, HSPF, has been selected.

- HSPF is willing for cooperation.
- HSPF is currently a private owned firm in which a relatively plentiful data required for this research purpose is available.
- Ease of accessibility for frequent data collection is attributed to the firm with respect to the researcher.

Selection of product family

HSPF is manufacturing of Pipe products. Like UPVC pipes, HDPE pipes, PPR and Conduits.

Apart from the implementation, many researches done were not successful because the researchers may not study the system very well to identify the significant factors affecting the process as well as the product. Therefore, before starting the design it should be decided what exactly wished to model. In a company with many products there may have to be some initial work done to identify which product or family group of products that should be modeled. According to the case Habtamu Sila plastic factory, UPVC pipes are selected as products to be modeled on according to the seniority of the problems they cause and by the amount of waste, it incurs in the manufacturing industry. Model formulation in modeling design the type of analysis is performed. The products that are selected are the one those most often produced. They are considered as one of the main products of HSPF in this case company. Therefore, the product selected for the case study is UPVC pipe.

The researcher selected major product of the company that has been on the production line for the past 2 years. The whole study has been conducted with respect to this pipe model (OD= 110mm; Nominal pressure = 4 bar; Thickness = 2.2 – 2.7 mm; Length= 6m). Therefore, after selecting the next step to be conducted is recording or data collection process.

During case study different data collection methods such as interview, observation, stopwatch, and secondary data collection were used. The interview questions were based on the research objectives. Its aim is to get general information about the firm's management system and selected key performance indicators such as time, flexibility, and cost.

- ✓ Discussions with the top management and manufacturing heads on the challenges the company face related to high manufacturing cost of product were made.
- ✓ Interviewing foreman's and workers for their awareness level towards minimizing cost of manufacturing without affecting the quality, minimization strategy for which it gives a clue on the effort made to improve the system

Observational evidence is often useful in providing additional information about the topic being studied. Therefore, the researcher also used this method for collecting the required data and information from the industry. It is used as a means to assess the techniques used in documentation and production processes as well as the existing facilities of the company. Important documents such as annual reports, company profile. Infrastructure and facilities of the case company have also been observed. Secondary data in relation to selling price collected from different and concerned sections of the industry. Physical visit and observation for understanding the overall activity at the shop floor and manufacturing factories to have the clear pictures of the industry and to formulate the problem. The willingness of the company to undertake the study plays a significant role in selecting a company for the case study.

The data collection includes the following parameters, which can be used in the measuring of the efficiency and effectiveness of the manufacturing process.

- ❖ Arrival frequencies of entities or time between arrivals
- ❖ Total number of tasks
- ❖ Processing times of each task
- ❖ Transfer time of WIP between stations
- ❖ Priorities between processes
- ❖ Layout of machines distance b/n machines (station)
- ❖ Conveyor length and speed

3.5 Method of data analysis

The collected data through the means of interviews, stopwatch, and direct observation and secondary data are analyzed by using tables & figures, and theoretically interpreted. The results are presented in chapters four, five and appendices.

Problems are gathered and collected based on different data collection methods then analyzed by employing different methods and industrial engineering tools. Cause and Effect Diagram was used to show the causes of high manufacturing cost and the effects clearly, is used to show the significances of factors on the response(cost) whereas DoE was used to reduce the experimentation and for easy interpretation of the results.

Chart flow and other diagrams were used where they are needed. In addition, other industrial engineering tools and software is like Arena simulation software highly applicable.

3.6 Software

There are different software's that can be used for simulation of any system whether it is a factory, bank, etc. They differ based on what they require, their flexibility, ease of use etc. simul8, witness; Arena TM, etc. are among some of the software's used to simulate any system. All software's have different version that is updated every time. In this thesis, Arena 14 version of simulation software was used to simulate the production line. The author selected this software due to its availability, flexibility, ease of use etc.

CHAPTER FOUR: RESULT AND DISCUSSION

This chapter provides an introduction and general knowledge to the case company and the order fulfilment process of the production system of UPVC pipes. The key sources of significant problems are identified. Moreover, depending on the nature of the possible key sources of the problems, the proper countermeasure that should be taken to manage the source of significant problems and ultimately reduce output cost of manufacturing is analyzed.

4.1 Company background

Habtamu Sila plastic factory is located at south nation's nationalities and people regional state (SNNPRS). It located 275 KM south of Addis Ababa via DebreZeyit, 130 East of Wolayita Sodo, and 75 KM North of Dilla. HSPF is set up in industry zone in Hawassa on a total proposed plot area of 4000 meter square on which a building with total built up area of 2500 square meter is constructed. The investigate project undertake by a well-known coffee exporting private company via Ato Habitamu Sila who founded and owned many other local company groups called ALETA LAND. The project of HSPF was begun 2010 GC or 2003 EC while construction started at 2011 GC or 2004 EC The only plastic factory over the region, and factory mainly produces Polyvinylchloride (PVC), High-density polyethylene (HDPE), and Polypropylene Resin (PPR) and conduit pipes. The total investment cost of 35 million birr.

Figure 4.1 Habtamu Sila Plastic Factory

The factory has the capacity of production of pipes are more than 12,000 meters of pipes in one day by three production lines in two shifts. For each products, for UPVC, HDPE, PPR and conduits pipes in different diameter, wall thickness and nominal pressure (PN). After a few months, the fourth line will be started. The factory is environmentally friendly compared with another factory. It uses recycling methods of waste material.

4.1.1 Major products of the factory

The major products of the factory are un-plasticized polyvinyl chloride (UPVC) pipes, high-density polyethylene (HDPE) pipes, and conduit pipe and PPR (Polypropylene Risen) pipe.

4.1.2 The Customers of the factory

Since the company is the largest plastic factory in the country, it has huge customer demands from different parts of the country. In order to maintain its market leadership and deliver the best customer service, the management of HSPF has developed a simple & compelling vision. The beloved customer includes:

- SNNPR agricultural office.
- SNNPR water works construction enterprise and SNNPR housing development and construction agency.
- Ethiopian Telecom Corporation.
- Ethiopian electric power corporation.
- Private Construction Company. In addition, factors like beer and soft drinks.
- Different nongovernmental organizations.
- Private Construction Company-Different local farmers.

4.1.3 The main suppliers of the company

Recently HSPF imports raw material from suppliers in Egypt, Middle East. United Arab Emirate, China, and India.

4.1.4 Overview of HSPF costing system /classification of costs

Productions have different costs and expenses on the industry, which must be compensated by the sold outputs. The selling price of a given output therefore includes not only the costs and expenses of the factory but also the rate of profit margin, which was designed in advance. The costs include all the production costs directly and indirectly incurred while transforming customer orders in to a valuable output, which include direct and indirect material costs, direct and indirect labor costs and utilities and facilities. Generally the cost classification in to production costs and operating expenses.

4.1.4.1 Formulation of the costing system

As it was described above the costing system of the industry can be categorized under two production costing and total costing. Production costing includes the cost parameters that have direct or indirect contributions in the transformation of raw materials into finished goods that includes direct raw material costs, direct labor costs and factory overheads. The total costing includes the listed production costing and adds up administrative expenses and sales and distribution expenses which are termed as operating expenses. In the formulation process, the researchers consider the above notion and the followings. The factory has cost centers as presented below with different direct labor and factory overhead cost factors, which play the determinant factors in estimation of costs of a product since the operating expenses were the same irrespective of cost centers.

Table 4.1 Raw materials and associated over all purchasing cost used for UPVC pipe production. (Source factory document data)

S. no.	Raw Material	Purchasing Cost (Birr/kg)
1.	PVC resin	25.34
2.	Stabilizer	46.78
3.	Calcium carbonate, $ca(co)_3$	7.36
4.	Titanium dioxide, $Ti(o)_2$	92.17
5.	Carbon black	39.62

For UPVC product data about the total frequency of products was taken and analyzed using the senior product type produced in high amount in the case company. The average cost of manufacturing a single pipe is 309 birr as calculated from the factory's data. This cost is separated to all the process using an approximate weightages value.

The customized Mathematical equation for unit cost of manufacturing pipe model (OD= 110mm; Nominal pressure = 4 bar; Thickness = 2.2 – 2.7 mm; Length= 6m) the company can be calculated as $UMC = DMC + 0.123(DL+FOH)Mi + 0.123(DL + FOH)Bi + 0.06(DL+FOH)Si + 0.258(DL + FOH)Ei + 0.148(DL+FOH)Di + 0.123(DL + FOH)Ci + 0.037(DLC+FOH)Cui + 0.06(DL + FOH)Dri + 0.037(DL + FOH)Sti$ (Source factory document data)

Where

- DMC refers to direct material cost
- DL_{Mi} refers to direct labour cost for mixing

- FOH_{Mi} refers to factory overhead cost for mixing
- DL_{Bi} refers to direct labour cost for blending
- FOH_{Bi} refers to factory overhead cost for blending
- DL_{Si} refers to direct labour cost for sucking
- FOH_{Si} refers to factory overhead cost for sucking
- DL_{Ei} refers to direct labour cost for extrusion
- FOH_{Ei} refers to factory overhead cost for extrusion
- DL_{Di} refers to direct labour cost for dyeing
- FOH_{Di} refers to factory overhead cost for dyeing
- DL_{Ci} refers to direct labour cost for cooling
- FOH_{Ci} refers to factory overhead cost for cooling
- DL_{Cui} refers to direct labour cost for cutting
- FOH_{Cui} refers to factory overhead cost for cutting
- DL_{Dri} refers to direct labour cost for deco ring
- FOH_{Dri} refers to factory overhead cost for deco ring
- DL_{Sti} refers to direct labour cost for storing
- FOH_{Sti} refers to factory overhead cost for storing

The relevant metrics for the research includes data collection related to process study, machining time and cost of every process involved in manufacturing. The major factors taken for consideration for the study are all the manufacturing process until packaging of the component and the entire process simulation. Time of operation is noted down by taking into account of uncertainties. Parameters such as cost and time are measured accurately using detailed process study. The same process was observed repeatedly to validate same time of operation. Cost parameters were enquired. Parameters such as worker wages were noted down from the company data. Operation cost involves space utilization, electricity consumption and maintenance per hour. Worker wages involves wages of permanent worker per hour. Time of operation is noted down by taking into account of uncertainties. This was decided by observing same operation to approximately five times and its values were noted. Thus, the simulation was run with the distribution type (Hong, 2006). The scheduling rule followed was First in First out (FIFO).

4.2 Tool selection

To date, some methodologies have been proposed and implemented to solve the problems cost in integrated manufacturing systems, for example, Queuing Networks, Petri Net models, Structured Modelling, Computer Simulation. One approach that can assist engineers and managers is the application of computer simulation. Since the early development of models and languages, simulation has evolved into a technique, which is extremely useful as a facility to experiment on the model rather than the real-world system, and to analyze the relationships between the parameters and output behavior. Moreover, there is flexibility in the use of simulation languages, the model can be built as close to reality as we need and taken as a decision-making support tool.

Thus, it is very helpful to analyze, schedule or plan manufacturing systems using simulation instead of using complicated mathematical model equations (Tsai, 2017).

4.2.1 Collected data's for simulation

The company has the objective of producing a quality pipes and providing to its customers. To meet this objective this factory is working with the following existing system. The factory has employed workers to increase its capacity, meet the demand and satisfy its customers. Among this workers are operators and the rest are mechanics, administrative, finance, sales and human resource office workers. Habtamu Sila Plastic factory produces pipes for different purposes. It takes up to one hour to complete the line from the mixer to belling process depending on the diameter of the pipe. Among this time for one batch raw material enter; the half an hour (30 minute) is spent in the extruder machine to melt the raw materials together.

4.2.2 Components of the system

System

Is the representation of a part of reality that is bounded in its surrounding or it's a group of independent but interrelated elements comprising unified whole

Entities: - In this study, operators that work on each machine and supervisor, Machine (extruder machine, dyeing machine, socketing machine, cutting machine, Crushing machine, Cooling machine, Melting machine, Dragging or haul off machine…etc.), Raw material (PVC resin, Caco3, Stabilizer, Tio_2 and Carbon black) and Finished product are considered as an entities of the system going to be modeled for the case study.

Attribute: In this study, type of product needed by the customers, Type of raw-material, Weight or amount, Capacity of the company are considered as an attribute of the system going to be modeled for the case study.

Resources: In this study, all machines and equipment needed for the production, all operators' required and Quality equipment are considered a Resource of the system going to be modeled for the case study.

Variables: In this study, number of WIP in the system, Number of products needed, Speed of production, Speed of delivery, Number of operators in the system, Number of suppliers in the system, Number of idle machines, Number of idle operator and Current time are considered as Variables of the system going to be modeled for the case study.

State: In this study, status of the operators, idle, busy, Status of the customers; potential or non-potential and Status of the suppliers or capacity of the supplier are considered state of the system going to be modeled for the case study. Terminating state is used in the study

Events: In this study, arrival of new part, Service time or completion and Failure of machine are considered as events of the system going to be modeled for the case study.

Activity: The followings are considered as activities in the development of the model (melting, Mixing, Shaping, Cooling, Molding, And Cutting).

4.2.3 Model conceptualization

Formulate the existing system of the factory with better modeling approach can be used to show the process clearly.

Process flow diagram

The process flow charts of the products are summarized as the following.

NO.	Description of the process	Symbol
1	Raw material store	
2	To mixer machine	
3	Mixing of raw material	
4	To extruder machine	
5	Melting of row material	
6	To die machine	
7	forming shape	
8	to meter counter	
9	Control the size of machine	
10	To vacuum tank	
11	Cooling	
12	To water spine	
13	Cooling	
14	To howl of machine	
15	Pulling of the pipe	
16	to cutter machine	
17	Cutting and chamfering	
18	To belling machine	
19	Forming socket	
20	Inspection	
21	To finished store goods	
22	Store	

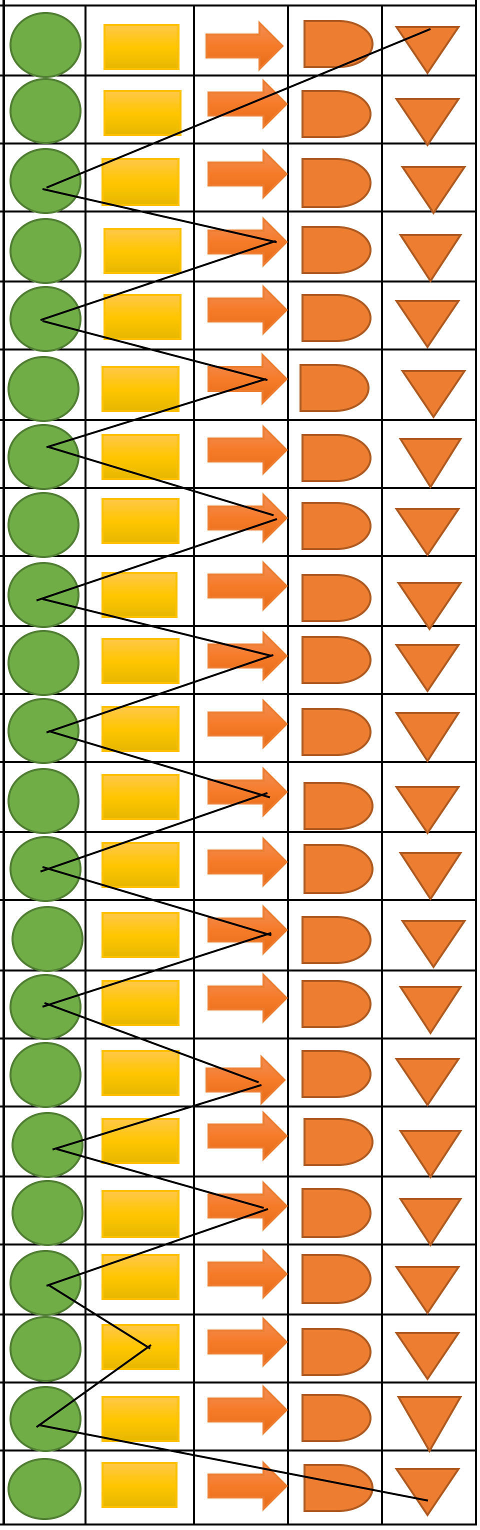

Figure 4.2 Flow process chart for UPVC product

4.2.4 Model translation

Translate all the information into modeling arena software.

Model description.

Modules used for simulation.

Basic process

- Create modules (to represent part arrival)
- Process modules (to represent operation performs)
- Dispose modules (to represent part exit)
- Decide modules (to check if the part is as per the specification)
- Batch module (to grouping the entities)
- Separate module (to multiply or split the entities)
- Assign modules
- Record modules

Advanced Transfer

- ✓ Route and station (to set the time and for animating the resource)

The manufacturer working time is 8:00 working hours per shift. Distribution is fitted to input analyzer; it evaluates the distribution's parameter and calculates a number of measures of the data.

4.2.5 Model assumption

In HSPF, there are three shifts per day. The actual working time for whole system is 8:00 working hours per day. Since it is not expected that a person will work without some interruptions, the operators may take time for their personal needs.

- Assumptions are taken for modeling the variation of workers performance at time to rest, machine failure, and power off.
- The model for one shifts are modeled and analyzed.
- In the study, only polyvinyl chloride (UPVC) pipeline is selected.

Raw material is assumed as a constant input, no interruption of operation is occurred. In order to select which type of distribution is used, the researcher has compared the square error of each distribution. The larger the square error value, the further away the fitted distribution is from the actual data (Pichitlamken, 2003).

Table 4.2 Number of observation of processing time for each operation

No.	Processes	Processing time for twenty days (Min)																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean	Standard deviation
1.	Mixing	8	8	8	7	8	9	8	7	8	9	8	8	9	8	8	8	7	8	8	8	8	3.84
2.	Melting	11	9	10	10	11	10	11	10	9	10	10	11	10	9	10	10	10	10	9	10	10	5.83
3.	Ding	3	2	4	4	4	2	4	2	2	3	3	3	3	3	4	3	3	2	3	3	3	1.39
4.	Shaping	4	2	2	3	3	4	4	2	5	4	4	2	2	2	3	3	3	3	2	3	3	1.49
5.	Cooling	3	3	3	3	3	2	2	2	4	4	4	5	4	3	5	2	2	2	2	2	3	1.56
6.	Dragging	2	2	2	2	2	1	1	2	2	2	1	1	3	1	3	3	3	4	1	2	2	2.35
7.	Cutting	2	2	3	1	3	2	2	2	2	2	2	3	2	1	2	2	2	2	2	1	2	2.27
8.	Inspection	2	2	2	2	1	1	1	2	2	2	2	2	1	1	3	2	2	2	2	1	2	2.51
9.	Socketing	8	8	8	7	7	7	7	9	9	9	9	10	10	8	8	8	7	7	7	7	8	3.93
10.	Crushing	5	5	5	4	4	6	6	6	3	7	7	4	4	4	5	5	5	5	5	5	5	1.28

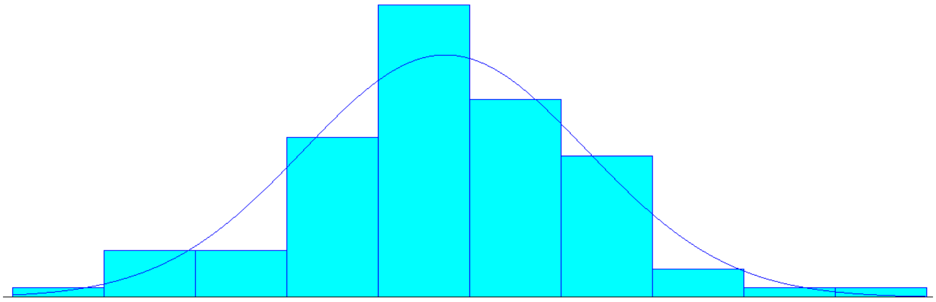

Figure 4.3 Input analyzer distribution histogram.

Table 4.3 PVC pipe process time distribution in continuous (extrusion).

Distribution Summary	
Distribution	Normal
Expression	NORM(4.99, 2.95)
Square Error	0.007157
Chi Square Test	
Number of intervals	5
Degrees of freedom	2
Test Statistic	2.18
Corresponding p-value	0.356
Kolmogorov-Smirnov Test	
Test Statistic	0.0667
Corresponding p-value	>0.15
Data Summary	
Number of Data Points	100
Min Data Value	-3.61
Max Data Value	14.9
Sample Mean	4.99
Sample Std Dev	2.96
Histogram Summary	
Histogram Range	-4 to 15
Number of Intervals	10

Arena simulation schematic representation

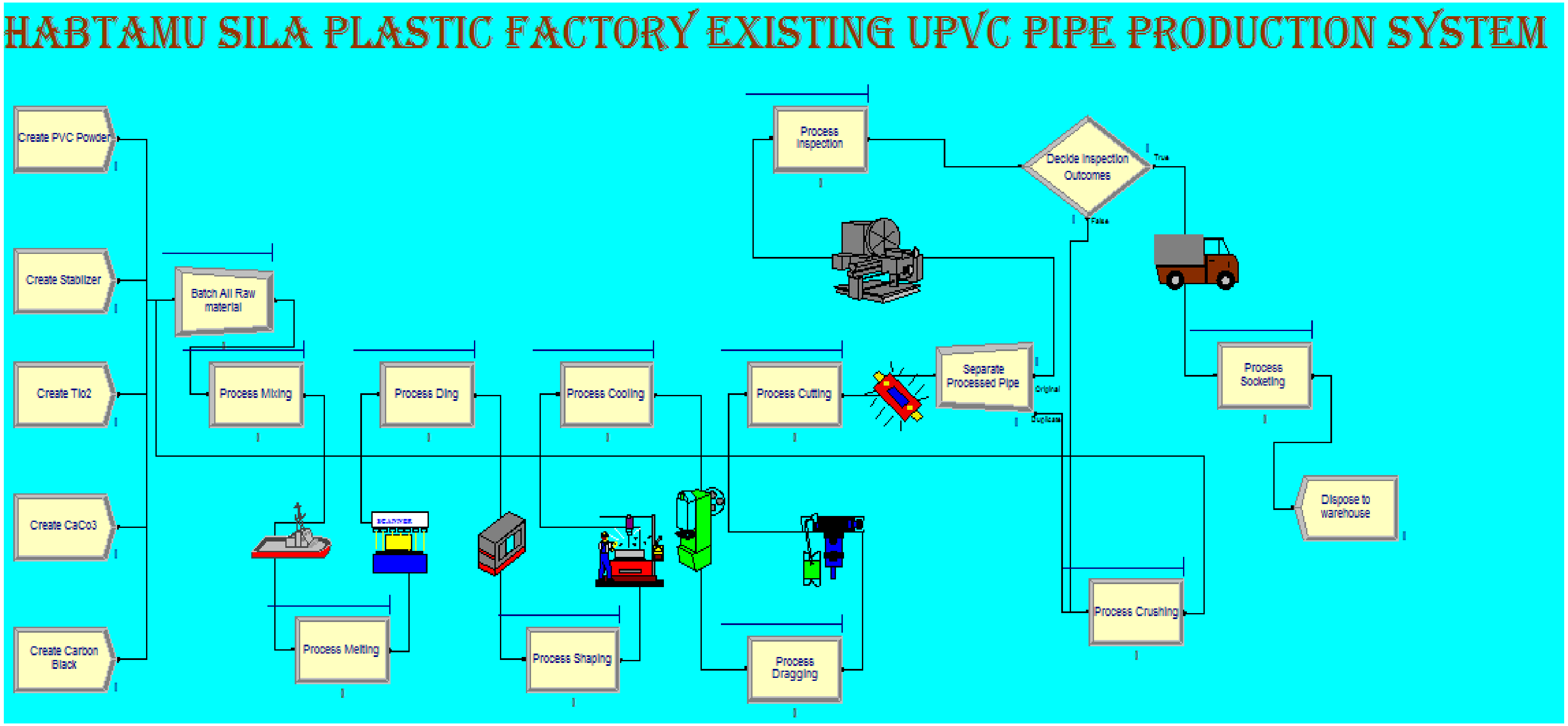

Figure 4.4 Schematic view of the simulation model using ARENA

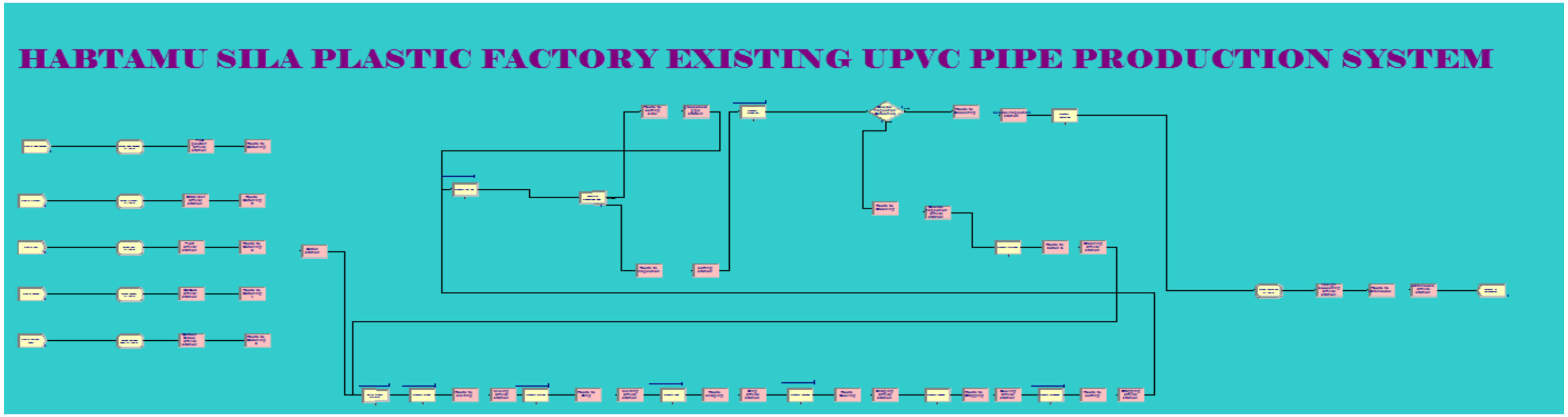

Figure 4.5 Schematic view of the simulation model using route and station in ARENA

Figure 4.6 Schematic view of the simulation model using animation in ARENA

4.2.6 Logic of flow

By using the Logic flow the researchers describes the way by which the entity acts during its journey in the simulation model. The researchers tried to observe the route the entity follows during the model building stage. Using the animation part of the Arena the authors tried to ensure that everything works as desired especially after commencing modification on the model. Many developments to the model were done before the authors reached the final model shown in figure that has the same layout of the real factory. All modifications and continuous verification were used to mimic the on-site reality and to mimic the behavior of pipe in the production line within the factory limitations. These entities pass through different inspection stations and when finished they leave the model (get disposed) at the end of the run, the snapshot of animation is shown in below table.

Table 4.4 Resource Cost data to be filled in the model (Source factory document data)

Resource - Basic Process

	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics
1	Mixer	Fixed Capacity	1	50	35	0.0		1 rows	☑
2	Die	Fixed Capacity	1	48	16	0.0		0 rows	☑
3	Vacuum Tank	Fixed Capacity	1	40	12	0.0		0 rows	☑
4	Cooler	Fixed Capacity	1	12	8	0.0		0 rows	☑
5	Haul Off	Fixed Capacity	1	40	12	0.0		0 rows	☑
6	Cutter	Fixed Capacity	1	12	4	0.0		0 rows	☑
7	Inspector	Fixed Capacity	1	20	8	0.0		0 rows	☑
8	Pulverizer	Fixed Capacity	1	20	8	0.0		0 rows	☑
9	Socket	Fixed Capacity	1	40	12	0.0		0 rows	☑
10	Extruder	Fixed Capacity	1	92	20	0.0		0 rows	☑

Double-click here to add a new row.

Table 4.5 Entity Cost data to be filled in the model (Source factory document data)

Entity - Basic Process									
	Entity Type	Initial Picture	Holding Cost / Hour	Initial VA Cost	Initial NVA Cost	Initial Waiting Cost	Initial Tran Cost	Initial Other Cost	Report Statistics
1	UPVC product rawmaterial	Picture.Van	0.25	39600	0.0	0.0	0.0	0.0	☑
	Double-click here to add a new row.								

Table 4.6 Queue type to be filled in the model (Source factory document data)

Queue - Basic Process				
	Name	Type	Shared	Report Statistics
1	Process Melting.Queue	First In First Out	☐	☑
2	Process Ding.Queue	First In First Out	☐	☑
3	Process Cooling.Queue	First In First Out	☐	☑
4	Process Dragging.Queue	First In First Out	☐	☑
5	Process Cutting.Queue	First In First Out	☐	☑
6	Process Inspection.Queue	First In First Out	☐	☑
7	Process Crushing.Queue	First In First Out	☐	☑
8	Process Socketing.Queue	First In First Out	☐	☑
9	Process Mixing.Queue	First In First Out	☐	☑
10	Process Shaping.Queue	First In First Out	☐	☑
11	Batch All Raw material.Queue	First In First Out	☐	☑
	Double-click here to add a new row.			

The busy time per hour and the idle time per hour are determined by giving an approximate weightage for each process such as extrusion, mixing, and the like. In order to reduce the effect on the quality of the product the cost of the raw materials (Initial value adding cost) are assumed constant for all the case.

4.2.7 Model verification and validation

One of the most important steps of simulation modelling is validation and verification. If the model does not reflect the real system, outputs of the model has a bad effect on the reliability and quality of the decision that will be made. Therefore, in order for this model to correctly reflect the production line behavior, it is verified and validated. The simulation software arena 14 is user friendly for testing the model in visual way and every step it helps the user to control the steps.

In terminating simulations, determining the run length is important to analyze system behavior. Run length determination can be done approximately or by trial and error and using the method described in a book (Eskandari, 2005)

4.2.7.1 Verification

Verification is the process of ensuring that the arena model behaves in a way it was intended according to the modelling assumptions made. Generally, it assesses the correctness of the model. Different methods have been applied to verify the model.

- One easy verification method is to allow only a single entity to enter the system and follow that entity to be sure that the model logic and data are correct. In this simulation model, allowing only a single entity to go through the hall system did not make any difference at all.
- Checking how the model behaves under extreme conditions. The researcher has increased and decreased parts inter arrival time. The author has tried different inter arrival times like 2, 4, 7,15,30,60 minutes to see any problems. No problems have shown up in these stressed out situation.
- Making long runs for different data's and observing the summary results for potential problems is another verification method applied.
- Code verification: when arena simulation run, it examines each option selected in the modules and the data that is supplied and then creates SIMAN MOD and EXP files. These files are used to run the simulation. Therefore, the SIMAN code for this model can be viewed using Run/SIMAN/View menu option. The author has seen this code to check if they are performing as intended.
- The author has also tried to use different process times, to see any difference. The model was allowed to run for extended periods and results from these runs were

carefully reviewed looking for huge Queues, resources not utilized etc. From these it was seen that there is no any resource that was not utilized.

4.2.7.2 Validation

- Validation is the task of ensuring that the model behaves the same as the real system. The author has tried to validate the simulation model by comparing the results of the model with the results of the real or actual system. The other validation technique that was used is inviting the existing system working staff to revise the model. Supervisors, industrial engineers, etc. have participated in this process.
- The arena simulation model is developed to find manufacturing cost of the process for a particular end item. As this analysis, deals with application of Taguchi in manufacturing, not every trial can be performed by changing those selected factors. The main limitation was that it affects production. Numerical simulation (Sankaran, 2015) helps to perform any research without actually affecting routine production. Therefore, all data required for the simulation are collected and using which analysis was performed. Analysis becomes very flexible with the software. The steps involved in ARENA simulation are studying the entire manufacturing process, developing the process flow diagram as shown in the Figure 4.10 above using ARENA, machining time and cost data entry, animating resources to facilitate simulation, running the simulation to get the manufacturing cost of UPVC pipe. The result of simulation is manufacturing cost.
- Comparing the throughput of the simulated result, and the actual production rates and the simulation mode production rates respectively, it is observed that the actual daily production rates range from 150-221 pipes/ day. The total daily production of the virtual model is 222/day. It is found that the production rate for the virtual model approximates the rates for the factory. Hence, the simulation model is validated.

Validate input – output transformation by using hypothesis testing

$$|t_0| = \left| \frac{\overline{Y}_2 - \mu_0}{s/\sqrt{n}} \right|$$

Where

t_0 - hypothesis testing, μ_0 – simulation model daily production, n – sample size (20) means twenty days observation to be taken

$\bar{Y}_2$ - Actual daily production   s- standard deviation

For the two-sided hypothesis test, if $|t_0| > t_{\alpha/2, n-1}$ hypothesis test is rejected

$|t_0| < t_{\alpha/2, n-1}$ hypothesis test is accepted

Where α – level of significance is 0.05

$$|t_0| = \left| \frac{221 - 222}{2.96/\sqrt{20}} \right| = \mathbf{1.510822}$$

$t_{\alpha/2, n-1}$ $t_{0.05/2, 20-1}$ from t – table distribution $t_{0.025, 19}$ = **2.093**

$|t_0| < t_{\alpha/2, n-1} =$ 1.5108 < 2.093 hypothesis test is accepted

4.2.8 Number of replication estimation

- In terminating simulation, it is simple to collect the appropriate data for statistical analysis. It is just to make some number n of independent replication. However, the main question is what number of replication to make. Therefore, some analysis has to be made to decide on the number of replication. First, the model must run some initial set of replication so that sample average, standard deviation and confidence interval are computed. It is obvious that the way to reduce the half width of the confidence interval on expected number out or anything for that matter is to increase the sample size n. Since it is wanted to achieve a specific half width, which is smaller than the one from the initial replication, the author tried to set h equal to the half width formula and solved.
- The difficulty with this formula is that, it is not really solved for n because the right hand side (standard deviation, degrees of freedom in t-distribution) still depends on n to get at least a rough approximation to the sample size required. The author could replace the t-distribution critical value in the formula above with the standard normal critical value since they are close for n more than about 30 and assume the current estimate of s will be about the same when computed from sample too.

UPVC production line: For UPVC pipe continuous extrusion production line based on the input analyzer the degree of freedom is 2 and the initial half width (ho) is 21.40. Assuming that the h= 0.25, taking 95% Confidence Level.

DF= n-1= 3-1 = 2

No. of replication (n) ≈ t^2n-1, 1- a/2 (s^2/h^2)

$$n \approx t^2 3\text{-}1,\ 1\text{-}\ 0.05/2\ (s^2/h^2)$$

$$n \approx t^2 2,\ 0.975\ (s^2/h^2)$$

$$n \approx \underline{\mathbf{t^2 0.975,\ 2}}\ (s^2/h^2)$$

From t- distribution table $t^2 0.975, 2$ the value is 4.303

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	**0.50**	**0.25**	**0.20**	**0.15**	**0.10**	**0.05**	**0.025**	**0.01**	**0.005**	**0.001**	**0.0005**
two-tails	**1.00**	**0.50**	**0.40**	**0.30**	**0.20**	**0.10**	**0.05**	**0.02**	**0.01**	**0.002**	**0.001**
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869

$$n \approx 4.303\ (2.96^2/0.25^2)$$

$$n \approx 4.303\ (8.7616/0.0625)$$

$$n \approx 4.303\ (140.1856)$$

No. of replication (n) ≈ **603**

By considering this equation, the number of replications of arena simulation model is 603 (Kassu Jilcha, 2015)

4.3 Identification of parameters

The division aims at reducing overall manufacturing cost of UPVC pipes without having major changes in industry. Therefore, the author tried to investigate factors affecting cost at the place of manufacture of that particular model. Thus, the primary objective was to find the significance of factors affecting the manufacturing cost of UPVC pipes in HSPF division.

4.3.1 Identifying key sources of high cost of manufacturing

Causes-and-effect diagram (CED)

This diagram, also called Ishikawa or Fishbone Diagram, is used to associate multiple possible causes with a single effect. The diagram is constructed to identify and organize the possible causes for a particular single effect. Causes in Cause and Effect Diagram are frequently arranged in four major categories. For manufacturing cases, it is Manpower, Methods, Materials and Machinery. For Administration and service sectors, it is Equipment, Policies, Procedures and People. Ishikawa advocated the CED as a tool for breaking down potential causes into more detailed categories so that they can be organized and related into factors, which help in identifying the root cause.

As per the observation from the case company the following are the main and sub causes that result in high manufacturing cost of UPVC pipe.

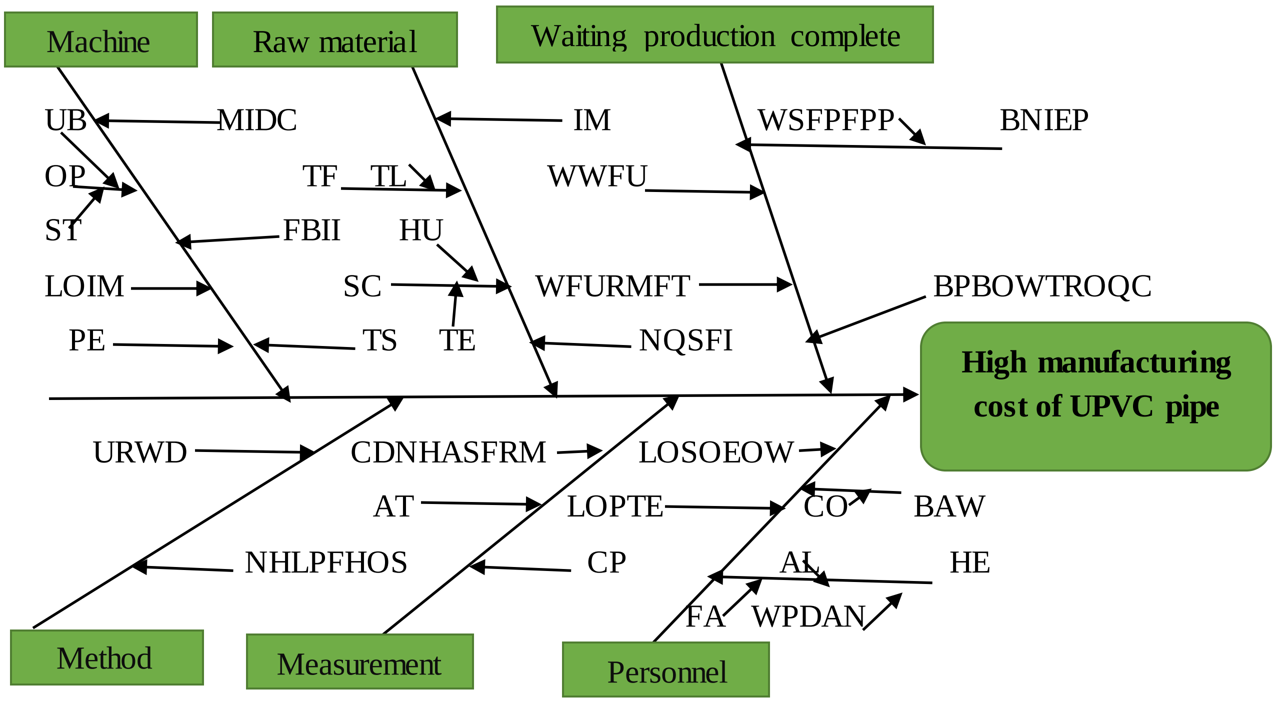

Figure 4.7 Cause Effect Diagram

High manufacturing cost of UPVC is an implication of low quality of the item (Phadke, 1989). Expanded idle hours increases the overall lead-time of the component decreasing consumer satisfaction. Expanded Average Waiting Time (AWT) and Work In Progress (WIP) prompts to lowered lead-time. Therefore, Cost of Poor Quality (COPQ) can be represented in terms of AWT and WIP in relation to lead-time, low quality (Lochner and Matar, 1990) and consumer satisfaction (Motorcu, 2010). Optimal production management aims to minimize cost and WIP. WIP requires storage space and carries inherent risk of expiration. As minimization of cost is an essential objective, COPQ on cost basis is taken as machining cost per product/item. Therefore, minimizing manufacturing cost, the authors endeavor to decrease COPQ, WIP and AWT increasing consumer satisfaction. The causes for High manufacturing cost of UPVC and low customer satisfaction are analyzed in the above cause and effect diagram.

The next phase of this thesis involves selection of suitable factors and levels for simulation and optimization. Key input parameters with their variables, in contrast, are selected based on the effect they bring on the key output factors when they are changed. The factors that directly affect the cost of manufacturing a product includes:-

- Extrusion rate
- Set-up time
- Capacity of the loading station (batch size)
- Weight of raw materials per arrival,
- Time between raw materials arrival (minutes)
- Maintenance breakdown
- Study compounding ingredients and blending procedures used;
- Dies, cooling tanks, pullers, and take-off equipment
- Transfer time to mixing inspection crashing coaling Processing time for beveling
- Batch size
- Production time

From these factors, the following parameters are selected for more investigation under the Taguchi design of experiment. The main reason of selecting these parameters is because they bring high effect on the key output factors when they are changed (Tsai, 2017).

i. Extrusion rate

ii. Set-up time

iii. Capacity of the loading station

iv. Feed Rate (entities from the hoppers to the extruder)

v. Maintenance breakdown

The significance of the above parameters was already discussed by Tsai (2017). These parameters were noted down while detailed process study.

Factors such as lead-time and queuing are indirectly analyzed using arrival parameters as they are dependent on the later. As several combinations are to be executed, simulation using ARENA® (Joseph, 2013) was chosen as a platform.

4.4 Experimental design

The authors define a system as an entity with input variables and output variables.

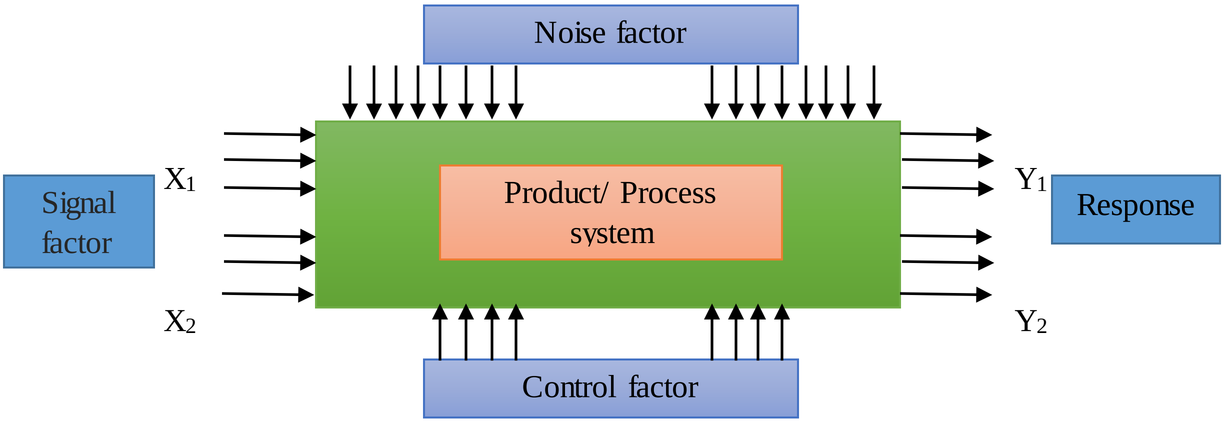

Figure 4.8 Model of the design of experiment (Yang, 2004)

4.4.1 Selection of design

A large number of experiments have to be carried out when the number of process parameters increase. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Five UPVC pipe-manufacturing parameters are considered as controlling factors. Each parameter has three levels – namely low, medium and high, denoted by 3, 2 and 1 respectively. According to the Taguchi method, if five parameters and 3 levels for each parameters L27orthogonal array should be employed for the experimentation. (Sudhakara and Prasanthi, 2014).

4.4.2 Selection of corresponding levels of control factors

Key input variables, in contrast, are selected based on the effect they bring on the key output factors when they are changed. The determined factors and their corresponding values are presented as follows:-

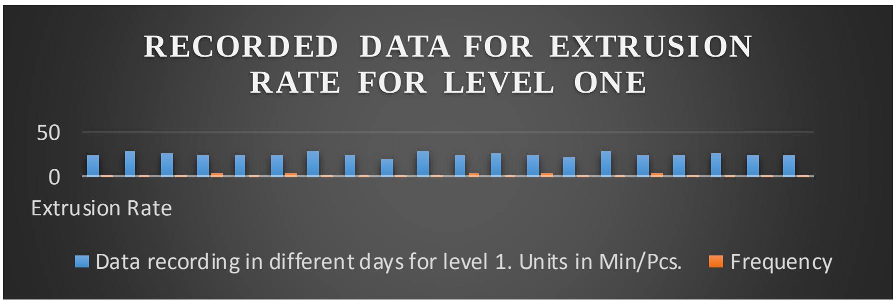

Figure 4.9 Recording data in Extrusion rate in level 1.

In order to select, the average value for the recording value of Extrusion rate for level one we have to calculate the average or mean value.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean =(46+28+26+75+50+100+28+25+38+29+75+26+75+44+28+92+25+26+48+50)/38

= 934/38

= 24.578 ≈ 25

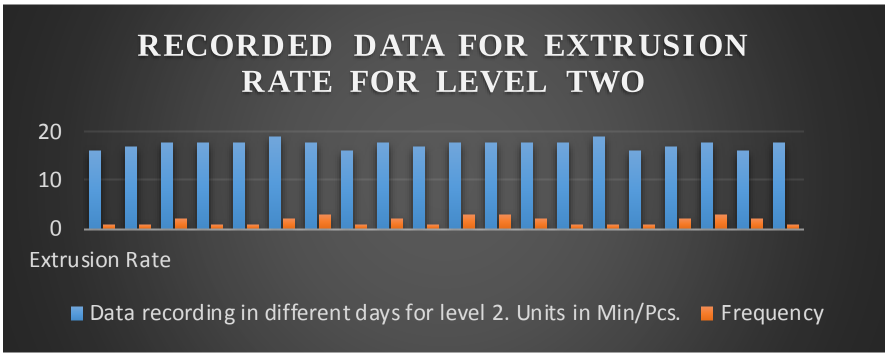

Figure 4.10 Recording data in Extrusion rate in level 2.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean = (16+17+36+18+18+38+54+16+36+34+54+54+36+18+19+16+34+54+32+18)/34

= 618/34

= 18.17 ≈ 18

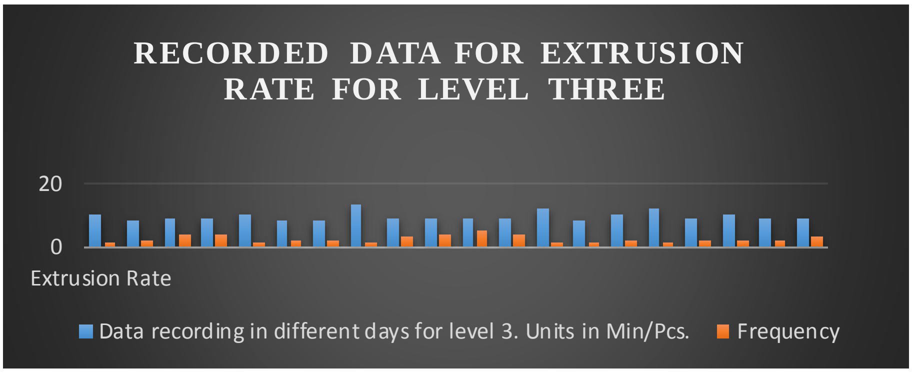

Figure 4.11 Recording data in Extrusion rate in level 3.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean = (10+16+36+36+10+16+16+13+27+36+45+36+12+8+20+12+18+20+18+27)/45

= 404/47

= 8.59 ≈ 9

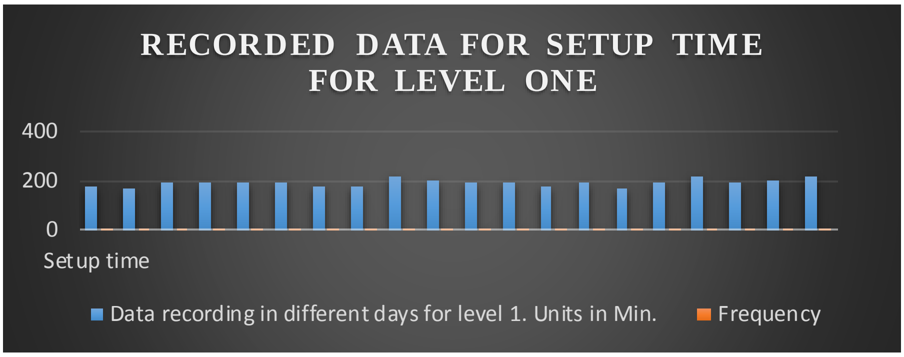

Figure 4.12 Recording data in Setup time in level 1.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean = (180+170+190+190+190+190+180+180+220+200+195+195+180+190+170+190+ 220+190+200+220)/28

= 5330/28

= 190.35 ≈ 190

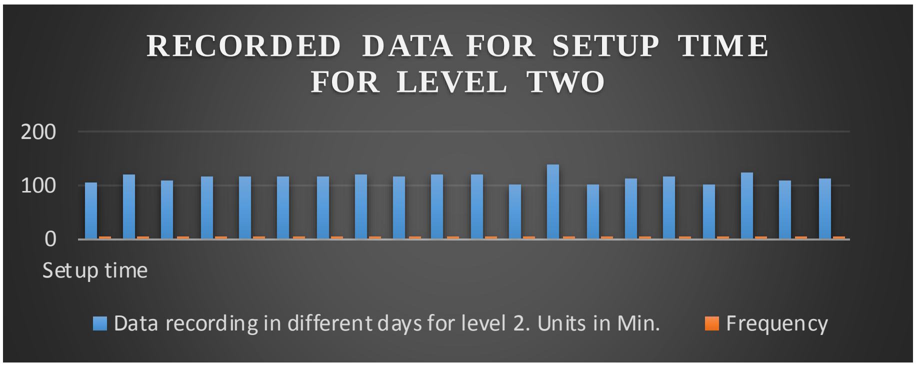

Figure 4.13 Recording data in Setup time in level 2.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(105+120+110+345+230+117+230+120+345+120+240+100+280+100+224+345+ 100+250+216+224)/38

= 3921/34

= 115.32 ≈ 115

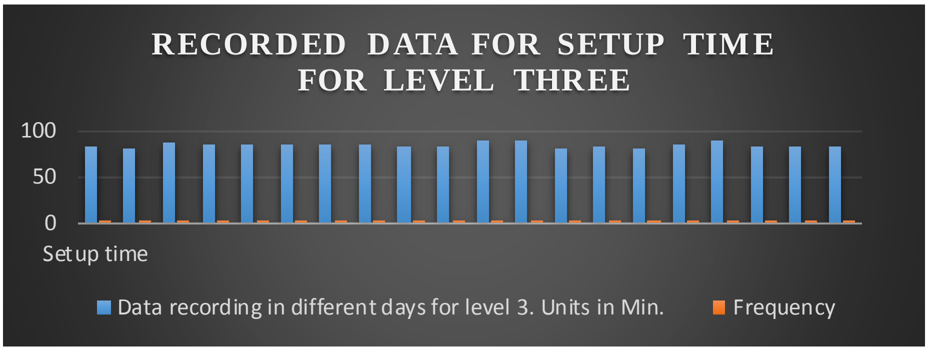

Figure 4.14 Recording data in Setup time in level 3.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(84+164+88+170+170+85+170+170+83+84+89+90+162+166+82+255+90+168+83+252)/32

= 2705/32

= 84.53 ≈ 85

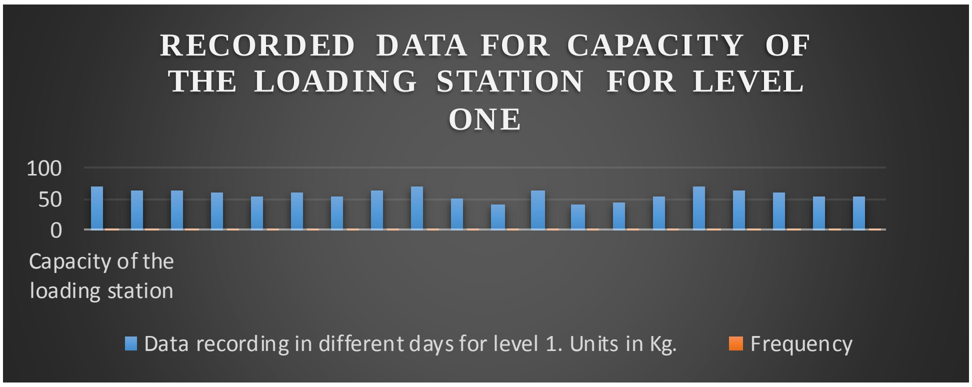

Figure 4.15Recording data in Capacity of the loading station in level 1.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(70+65+65+120+110+60+110+65+70+100+80+65+80+90+110+70+65+60+110+110)/30

= 1642/30

= 54.73 ≈ 55

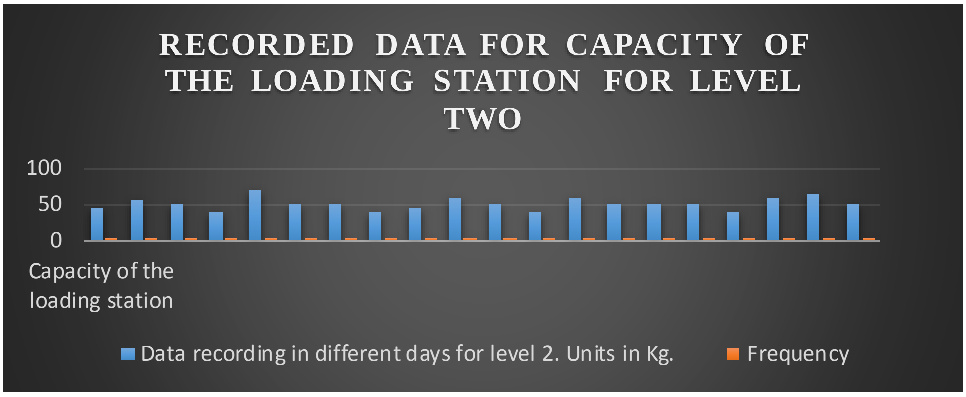

Figure 4.16 Recording data in Capacity of the loading station in level 2.

$$\bar{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(45+110+50+80+70+100+100+40+90+60+150+40+60+100+100+50+40+60+65+100)/30

= 1510/30

= 50.33 ≈ 50

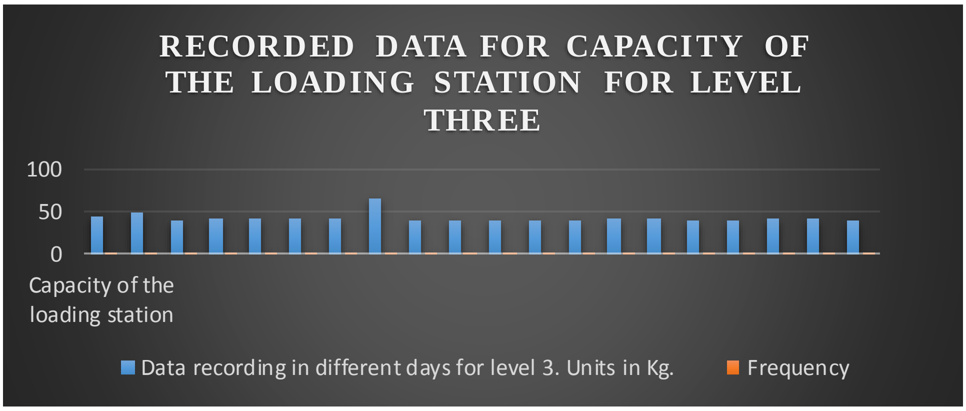

Figure 4.17 Recording data in Capacity of the loading station in level 3.

$$\bar{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(44+50+40+86+86+86+86+65+40+40+40+40+40+82+86+40+40+129+86+40)/29

= 1246/29

= 42.96 ≈ 43

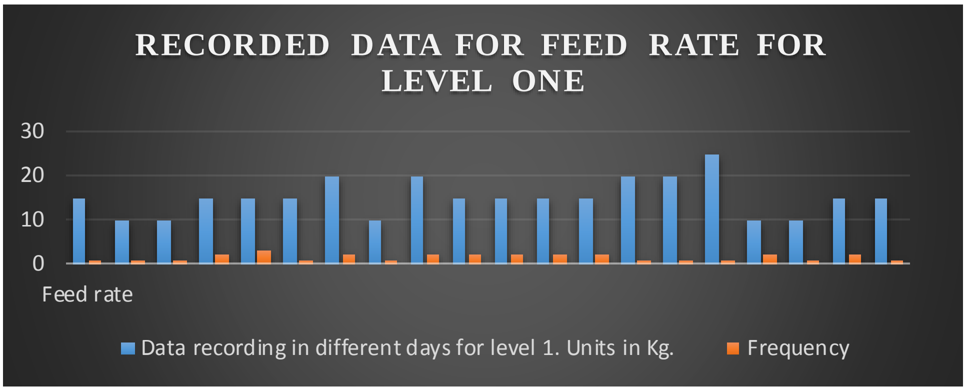

Figure 4.18 Recording data in Feed rate in level 1.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(15+10+10+30+45+15+40+10+40+30+30+30+30+20+20+25+20+10+30+15)/31

= 475/31

= 15.33 ≈ 15

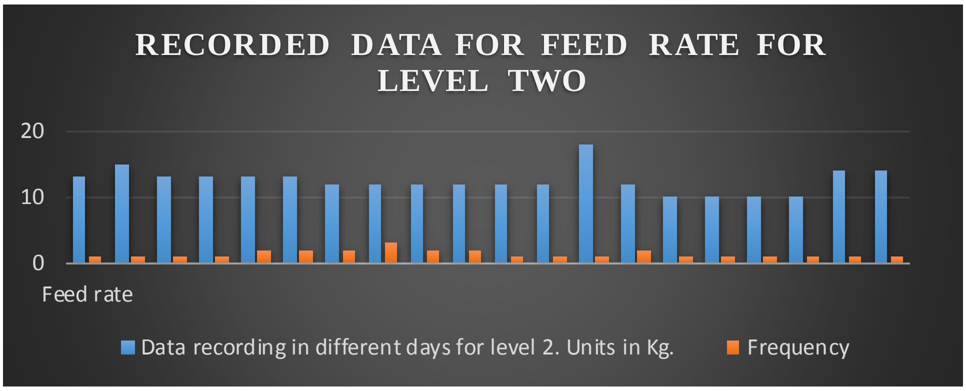

Figure 4.19 Recording data in Feed rate in level 2.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(13+15+13+13+26+26+24+36+24+24+12+12+18+24+10+10+10+10+14+14)/28

= 348/28

= 12.42 ≈ 12

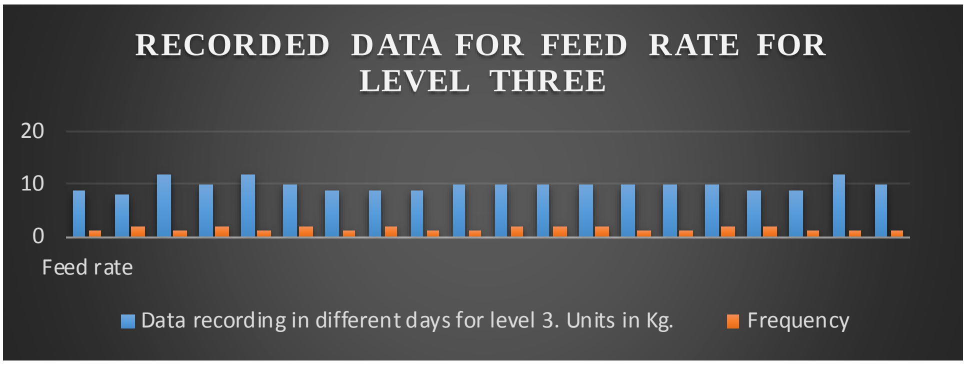

Figure 4.20 Recording data in Feed rate in level 3.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(9+16+12+20+12+20+9+18+9+10+20+20+20+10+10+20+18+9+12+10)/29

= 284/29

= 9.79 ≈ 10

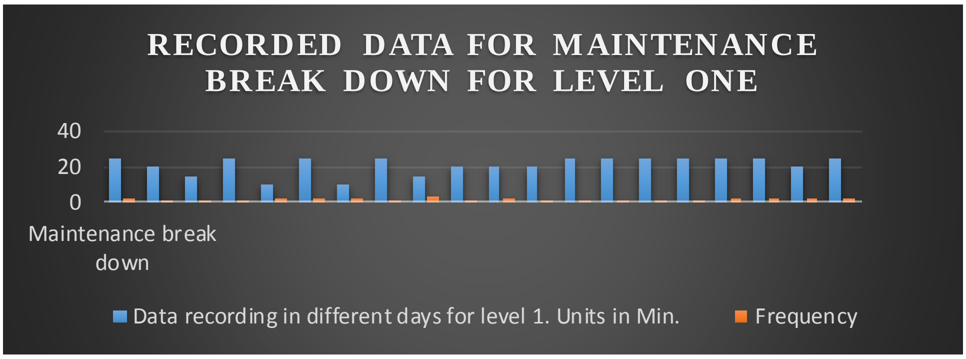

Figure 4.21 Recording data in Maintenance break down in level 1.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(25+20+30+25+20+25+20+25+30+20+20+40+25+25+25+25+25+25+60+25)/27

= 535/27

= 19.8148 ≈ 20

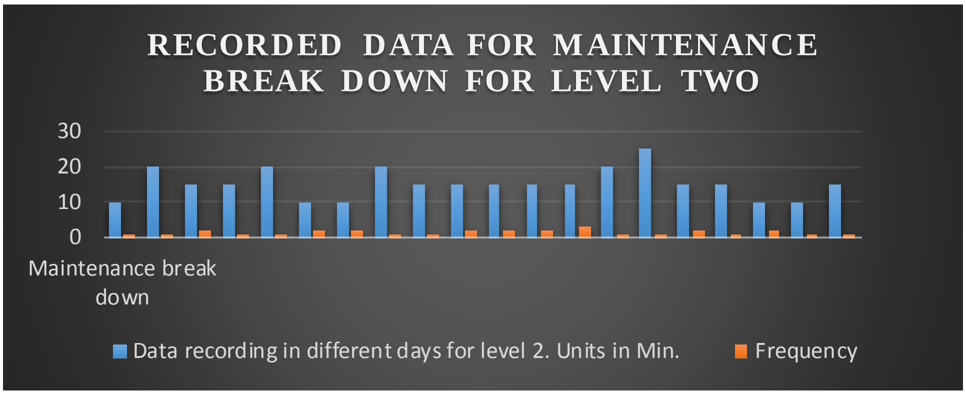

Figure 4.22 Recording data in Maintenance break down in level 2.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(10+20+30+15+20+20+20+20+15+30+30+30+45+20+25+30+15+20+10+15)/30

= 440/30

= 14.66 ≈ 15

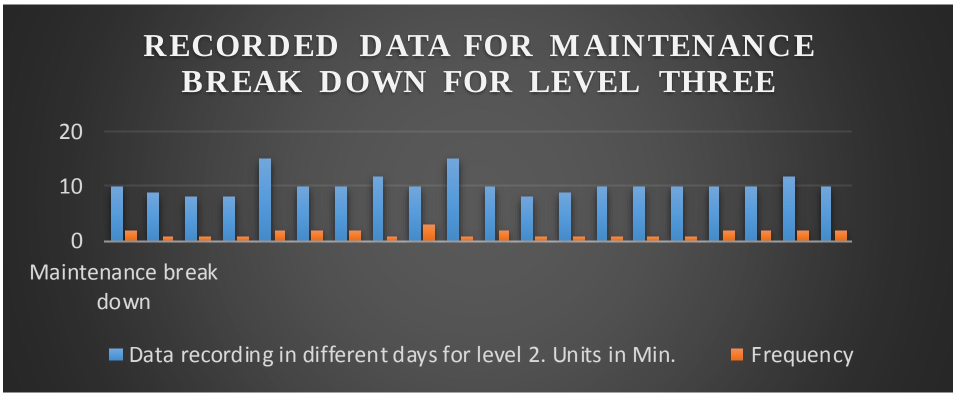

Figure 4.23 Recording data in Maintenance break down in level 3.

$$\overline{X} = \frac{\sum_{j=1}^{n} f_j X_j}{n}$$

Mean=(20+9+8+8+30+20+20+12+30+15+20+8+9+10+10+10+20+20+24+20)/31

= 323/31

= 10.41 ≈ 10

The UPVC pipe manufacturing parameters important control factors in each response and selected levels as well as their corresponding values considered for the experimentation are summarized under the following Table 4.7.

Table 4.7 Process parameters and levels

Process parameters	Units	Levels		
		Level 1	Level 2	Level 3
Extrusion rate – A	Min/pc	25	18	9
Set up time – B	Min	190	115	85
Capacity of the loading station (batch size) - C	Kg	55	50	43
Feed rate – D	Kg	15	12	10
Maintenance break down – E	Min	20	15	10
Response factor: Manufacturing cost				

Three levels or settings were selected for each parameter and the levels are taken sufficiently far apart so that a wide region can be covered by the levels. For this case, three levels were used to allow identification. The low value of the parameter variable is placed in Level 3 and the high value of the parameter variable is arranged in Level 1, while the middle value is set to Level 2. These are listed in Table above. Varying several operational parameters simultaneously may have interactive effects on the performance, which can affect the optimum solution (Unal, 1993). If the effect of one parameter on the response depends on the setting of another parameter, it is said that interaction exists in these two parameters (Phadke, 1989). For this case, four sets of two-parameter interactions that may be significant were selected to be investigated, i.e. A and C, B and C, C and D, C and E.

4.4.3 Determine degree of freedom

The degrees of freedom for a certain response under its investigation is calculated as

Df = L-1 and the degree of freedom for each factors(Df) is two and also the degree of freedom for all investigated factors (Dm) is the summation of all degree of freedom under each factors.

Table 4.8 Selected degree of freedom for each factor

Factors	Selected level	DOF for each factor (Df)	DOF for all (Dm)
Extrusion rate – A	3	2	
Set up time – B	3	2	
Capacity of the loading station (batch size) – C	3	2	10
Feed rate – D	3	2	
Maintenance break down – E	3	2	

4.4.4 Selection of orthogonal arrays

Once the degree of freedoms for each factor is selected, the corresponding appropriate Orthogonal Arrays can be determined. Selection of Orthogonal Arrays (OA) depends on the number of factors & interactions of interest and the number of levels for each factor of interest.

Table 4.9 DOF available in OA selected

		No. of factors										
		2	3	4	5	6	7	8	9	10	11	12
No. of levels	2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16
	3	L9	L9	L9	27	L18	L18	L18	L27	L27	L27	L27
	4	L16	L16	L16	L16	L32	L32	L32	L32	L32		
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50

The selected Orthogonal Arrays (OA) and the degree of freedom available in each OA selected are presented as follows:-

Table 4.10 DOF available in OA selected

No. of factors	Approximate no. of levels	Selected OA	DOF available in OA selected
5	3	L27	26

4.4.5 Confirming feasibility of selected designs

In order to select the particular orthogonal array for an experiment, the total degree of freedom available in an Orthogonal Array must be greater than or equal to the degree of freedom for the stage (Sivakumar, 2015). Satisfying the above premise ensures feasibility of the selected Orthogonal Array.

Table 4.11 Feasibility of selected OA's

Conditions	Result
OA selected	L27
D_a	26
D_m	10
$D_a > D_m$	26 > 10 Satisfied
Feasibility of selected OA	Feasible

As it can be seen from the above table, the total degree of freedom associated with the selected Orthogonal Array exceeds the degree of freedom found under investigation. Hence, the selected Orthogonal Arrays are feasible.

4.4.6 Experimental details

In this study of process optimization problem, a case study UPVC pipe (ps4) taken as an example for practical implementation.

4.5 Conduct of experiment

The designations are set according to the selected Orthogonal Arrays in each stage and are summarized in the following table.

Table 4.12 Designation of Control Factors for conducting experiments

Exp. Trial	Designation of control factors				
	Factors				
	Extrusion rate	Set-up time	Capacity of the loading station	Feed rate	Maintenance break down
1.	2	2	2	2	2
2.	2	2	2	2	3
3.	2	2	2	2	1
4.	2	3	3	3	2
5.	2	3	3	3	3
6.	2	3	3	3	1
7.	2	1	1	1	2
8.	2	1	1	1	3
9.	2	1	1	1	1
10.	3	2	3	1	2
11.	3	2	3	1	3
12.	3	2	3	1	1
13.	3	3	1	2	2
14.	3	3	1	2	3
15.	3	3	1	2	1
16.	3	1	2	3	2

17.	3	1	2	3	3
18.	3	1	2	3	1
19.	1	2	1	3	2
20.	1	2	1	3	3
21.	1	2	1	3	1
22.	1	3	3	2	2
23.	1	3	3	2	3
24.	1	3	3	2	1
25.	1	1	2	1	2
26.	1	1	2	1	3
27.	1	1	2	1	1

4.6 Analysis

The analysis is based on the steps of design of experiment by Eklin (2009). Identify parameters and their levels, select design, conduct experimental trial and analyze the result. The optimum parameters for the selected design are identified.

4.6.1 Experimental findings

Here the optimization is done by finding out the factors that help the production line to work at the least manufacturing cost. The orthogonal array selected is L27 as shown in the above table. For this reason, 27 experimental trials are run and 603 replications for each run performed to see the effects of different level combinations of the control factors on the respective outputs (response factors).

Moreover, experimental trial is conducted based on the designations of the selected control factors set. The response values observed from the experiment conducted according to the designations set in table are summarized in the following table 4.13.

Table: Experimental results found in each of the three stages

Table 4.13 Designation of Control Factors for conducting experiments

Exp. Trial	Designation of control factors					
	Factors					
	A	B	C	D	E	Average total cost (Br.)
1.	18	115	50	12	15	285
2.	18	115	50	12	10	294
3.	18	115	50	12	20	300
4.	18	85	43	10	15	340
5.	18	85	43	10	10	312
6.	18	85	43	10	20	305
7.	18	190	55	15	15	302
8.	18	190	55	15	10	285
9.	18	190	55	15	20	370
10.	9	115	43	15	15	340
11.	9	115	43	15	10	330
12.	9	115	43	15	20	289
13.	9	85	55	12	15	287
14.	9	85	55	12	10	365
15.	9	85	55	12	20	355
16.	9	190	50	10	15	350

17.	9	190	50	10	10	345
18.	9	190	50	10	20	400
19.	25	115	55	10	15	425
20.	25	115	55	10	10	405
21.	25	115	55	10	20	449
22.	25	85	43	12	15	450
23.	25	85	43	12	10	432
24.	25	85	43	12	20	321
25.	25	190	50	15	15	309
26.	25	190	50	15	10	282
27.	25	190	50	15	20	291

4.6.2 Optimization of process parameters

After investigating significance of those factors, improved combination of factors are suggested to reduce the manufacturing cost of the UPVC pipes. Hence, suggest improved combination of factors with least cost using Taguchi method.

4.6.3 Determining optimal levels of the control parameters

Main effect response determining with in the given optimal levels of the control parameters.

Table 4.14 Response table for means

Parameters	Level			Delta / sensitivity	Rank
	1	2	3		
A	373.7	310.3	340	62.8	1
B	326	346.3	351.9	25.9	4
C	360.3	317.3	346.5	43	3
D	310.9	343.2	370.1	59.2	2
E	342.2	343.1	338.9	4.2	5

The derived optimum settings of operational parameters are listed in Table below.

Table 4.15 The optimum settings of operational parameters

Operational parameters	Setting
Extrusion rate – A	9
Set up time – B	85
Capacity of the loading station (batch size) – C	43
Feed rate – D	10
Maintenance break down – E	10

Using these optimum settings to re-run simulation, the predicted system performance are listed in below.

Table 4.16 The predicted system performance

Performance measure	Value
T- Time in system	23
N_1- Queues in loading station	0
U_W- Utilization of workers	70
U_M- Utilization of machines	64
F- Number out	222
COST- Total cost/Pcs.	220

4.7 Comparison of actual and predicted system performance

Table 4.17 Comparison table

Performance measures	Average value before optimization	Average value after optimization	Difference (before and after optimization)
T- Time in system	23	23	0
N_1- Queues in loading station	0.8	0	0.8
U_W- Utilization of workers	52	70	18
U_M- Utilization of machines	48	64	16
F- Number out	221	222	1
COST- Total cost/Pcs.	309	220	89

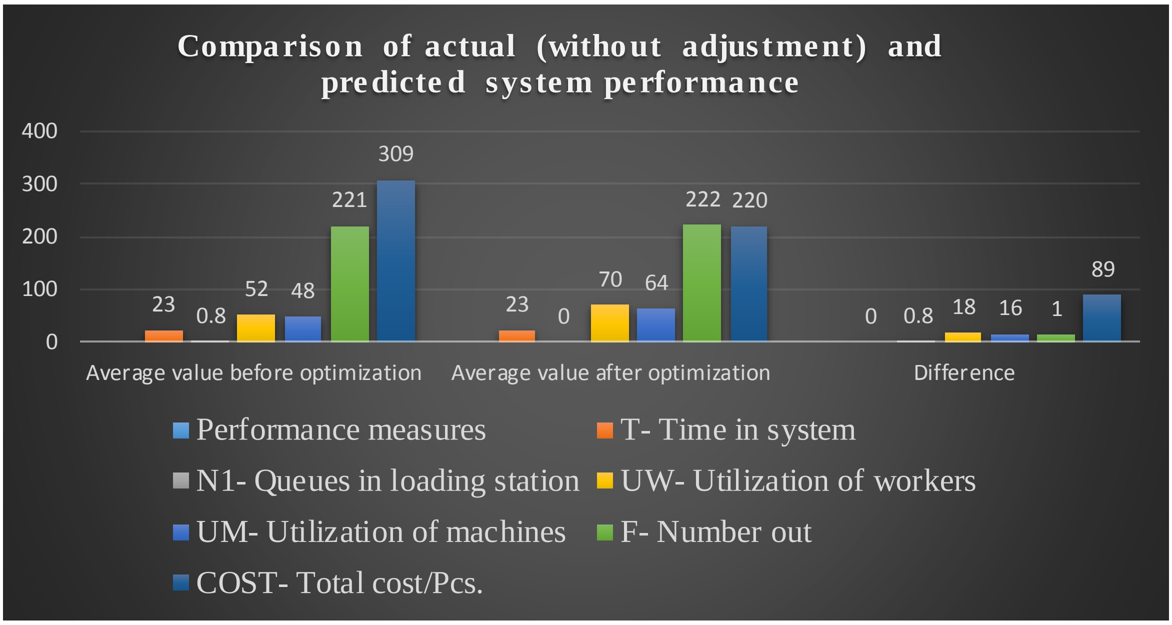

Figure 4.24 Comparison of performance

Hence, optimality verified as the result implied a significant reduction in variations of the important performance characteristics (cost) of Habtamu Sila Plastic Factory.

CHAPTER FIVE: CONCLUSION AND RECCOMENDATION

The purpose of this chapter is to summarize the study and show findings related to the changes introduced in the optimum parameter design.

5.1 Conclusion

Simulation modeling is a powerful and an interactive technique in which we can imitate the real manufacturing system to understand how it behaves if something is altered and evaluates the performance of various strategies and scenarios of manufacturing system and Taguchi design is very helpful in order to reduce the experimentation and to interpret the result of target value.

This thesis is concerned with the modeling and simulation of pipeline of plastic manufacturing process where the case study is taken on Habtamu Silla plastic factory focusing the production department. Within the production department, this thesis is mainly concerned with the modeling and simulation of the UPVC lines: For simplicity and limitation of student version Arena software, a simple pipe model is selected for the study. Collecting and analyzing all the necessary data using input analyzer of Arena, the simulation model is developed for the existing manufacturing system of this model pipe. After verifying and validating the developed simulation model, it is simulated for 24-hour working time with 603 number of replications.

After analyzing the result of the simulation run, process parameters of existing manufacturing system are identified. parameters that are identified in simulation model analysis are: Optimization of the extruder, Set-up time, Capacity of the loading station (batch size), Kg of raw materials per arrival, Time between raw materials arrival (minutes), Maintenance breakdown, studying gains with compounding ingredients and blending procedures used; dies, cooling tanks, pullers, and take-off equipment, Transfer time to mixing inspection crashing coaling Processing time for beveling, Assembly batch size, and Shift.

In this study, as the pipe factory production system comprises five main operational parameters, each at three levels, the understanding of the complete effect of each parameter and all possible interactions requires 243 (3^5) simulation runs. Hence, the use of Taguchi Methods in the simulation has been studied, and the results show that these methods can be useful in reducing the number of experimental trials (only 32-simulation replication run have been used) needed to determine the best operating parameters. The results of the work show that key parameters for optimum performance of the system are feed rate (the entities per arrival) in to the hopper and the extrusion rate, and: The predicted unit cost of manufacturing the selected pipe model is 220 birr and predicted cost of manufacturing decreased by 28.8%., because the utilization of the machine increased by 33%, 34.6% for the worker from the actual performance.

As part of the general outcome of this study, Taguchi method plays a vital role in any companies (whether engaged in manufacturing of tangible output or service rendering) to satisfy their customer needs, expectations by producing quality product or delivering services in a manner through reduction of unnecessary costs either prior to production or after the item was shipped to customers.

Taguchi method is helpful for reduction of unit manufacturing cost (UMC) and quality loss ($) respectively through incorporating ideas either at the product development or process design stage and identifying optimum control parameter combinations. (In addition, rather than directly choosing the response output, cause and effect diagram needs to be incorporated to make the study visible so as it creates worth for the company profitability.

5.2 Recommendations

This simulation tool will guide the managers to assess the day to day progress of individual work station (WIP, queue) well to have world's eye view of the whole system (output of one week, or two weeks etc.)

The Government owned 'Industrial Project Services' (IPS) has been conducting feasibility study on the diversification/expansion of the Pipe manufacturing and this thesis will be an input and helpful in their project to consider space optimization by considering better utilization of the existing machinery and equipment as well as the capacity expansion by considering the acquisition of additionally required machinery and equipment's.

The limiting factor to improve performance and utilization needs an immediate attention. In this thesis, assumptions are taken due to the non-availability of logged data. Therefore, it needs further investigation and analysis on the actual factory setting, in order to implement the suggested.

This research has introduced a combined simulation robust Taguchi approach model for existing pipe manufacturing line. The focus of the research is on solving the system bottlenecks that constrained the process and finding an optimal setting in order to improve the overall system productivity. The improvement was constrained by the data from the factory under its presents working conditions. It had some limitation to model the complex systems and therefore professional Arena software should be better option for mitigating inaccuracies.

- The usage of simulation tools can be expanded for all types of manufacturing systems and more complicated manufacturing types can be modeled in order to get specific customized solutions.
- An object-oriented program can be developed and integrated into the ARENA program in order to develop and edit the model easily. The future work may include creating templates that allow for easy modeling of a complex system.
- Further thesis works and Industrial applications should be done in areas like Capital Investment Planning, Supply Chain and Distribution Planning, Resource Planning.

The initial cost of energy-efficient extruders may be higher, but it will give rapid returns on the small extra investment. Options such as high-efficiency motors and variable-speed drives have excellent payback as both new and replacement purchases.

Whatever the age of the machine, it is essential to get the right extruder for the job and the screw diameter and design should be checked to make sure they are right for the polymer and product. Extruders run most efficiently (not only in energy terms) when operating at the design conditions for the motor and screw. The extruder should be set to run at the maximum design speed, as this is usually the most efficient setting. The screw speed should only be reduced from the maximum if there is difficulty producing good product.

- Using large extruders for small profiles wastes energy and costs money.
- Total efficiency (including energy efficiency) is best when operating at the design conditions.
- Set the extruder to run at its most efficient speed (usually the maximum design speed) and control the screw speed to give an extrusion rate as close to the maximum as possible and still produce good product.
- Size and control the electric motor to match the torque needed by the screw.

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APPENDICES

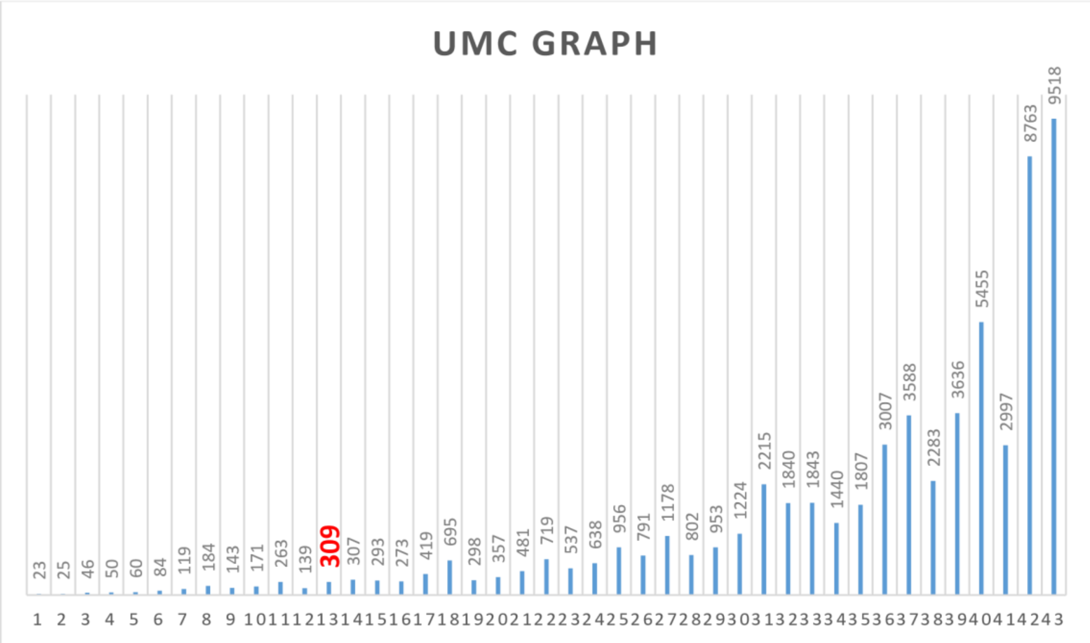
ANNEX: A. The Actual system performance (Source factory document data)

Performance measure	value
T:Time in system	23 min
Q: Queues in loading station	0.9(average number)
U1: Utilization of workers	55%
U2: Utilization of machines	41%
N:number out/production	221pcs
COST: Total cost/pcs	309birr

ANNEX: B. Unit costs

Process	Weighing factor (%)	Row material cost/entity (Br)	Operation Cost/entity (Br.)	Idle Cost/entity (Br.)	worker wages/entity (Br.)
Mixing	0.123	225	5	5	5
Blending	0.123		7	3	3
Sucking	0.06		4	1	1
Extrusion	0.285		18	5	5
Die	0.148		8	4	4
Cooling	0.123		7	3	3
Cutting	0.037		2	1	1
Deco ring	0.06		3	2	2
Storing	0.037		1	2	5

ANNEX: C. Unit manufacturing cost (Source factory document data)



ANNEX: D

(Source factory document data)

S/N	SCRIBTI	BEG.RM		2008 PURCHASE		selling to AG Pipe		TOTAL		2008 USAGE		TOTAL REMAINIG	
		QTY(KG)	COST	QTY(KG)	COST	QTY(KG)	COST	QTY(KG)	COST	QTY(KG)	COST	QTY(KG)	COST
1	LLDPE FOR	1,330,275	#######	1,551,000	53,632,513.89	4,650.00	161,918.53	2,885,925	99,388,130.34	1,202,700.00	40,776,226.81	1,526,750.00	########
2	BORSTAR 2230			1,369,500	48,996,111.57	21,550.00	748,686.00	1,391,050	49,744,797.57	91,125.00	3,102,006.17	920,625.00	########
3	BLACK MA	53,795	########	100,000	6,513,276.47	585.00	38,186.65	154,380	9,136,592.09	78,585.00	4,188,972.81	75,210.00	########
4	UV-111	5,875	895,343.04					5,875	895,343.04	5,875.00	895,343.04		
5	UV-23	4,000	617,255.10					4,000	617,255.10	4,000.00	617,255.10		
6	UV-21	24,000	########			2,825.00	504,460.02	26,825	4,790,138.21	8,875.00	1,584,808.04	14,450.00	########
TOTAL GEOM PROD.		#######	#######	#######	##########	29,610.00	#######	#######	164,572,256.35	1,391,160.00	51,164,611.97	2,537,035.00	#######
1	BARSAFE-	750,450	########	3,811,500	141,522,683.98	7,800.00	283,550.04	4,554,150	167,923,291.47	1,360,301.00	45,480,547.75	1,746,199.00	########
2	BLUE MAS	675.00	67,601.25	500	47,825.00	25.00	2,446.06	1,200	117,872.31	425.00	42,044.52	725.00	70,935.67
3	UP1000HD	13,792	631,265.68					13,792	631,265.68	10,836.90	496,009.46		
4	Red Master Bach			25.00	2,500.00			25	2,500.00	25.00	2,500.00		
OTAL HDPE PIPE PRO		#######	#######	#######	##########	7,825.00	#######	#######	168,674,929.46	1,371,587.90	46,021,101.73	1,746,924.00	#######
1	PVC-RESIN	#######	########	1,188,000	36,018,803.18	11,300.00	323,543.63	2,750,325	76,334,199.33	929,600.00	24,205,181.47	1,809,425.00	########
2	CALCIUM	720,425.0	########			1,750.00	13,381.25	722,175	5,522,059.02	166,500.00	1,273,130.60	553,925.00	########
3	PVC-STAB	352,425.0	########			400.00	17,313.19	352,825	15,271,315.33	39,250.00	1,698,856.57	313,175.00	########
4	CARBON E	14,840.0	594,460.82			17.40	697.01	14,857	595,157.83	182.60	7,314.59	14,657.40	587,146.26
5	TITANIUM	3,775.0	363,122.67			10.10	971.53	3,785	364,094.20	1,239.90	119,267.77	2,535.00	243,854.92
6	BLUE MASTER BA							0	0.00	25.00	2,446.06		
OTAL UPVC PIPE PRO		#######	#######	#######	36,018,803.18	13,477.50	#######	#######	98,086,825.71	1,136,797.50	27,306,197.06	2,693,717.40	#######
TOTAL PRODUCTION		#######	#######	#######	##########	50,912.50	#######	#######	431,334,011.52	3,899,545.40	124,491,910.76	6,977,676.40	#######

ANNEX: E. Total cost per each pipe model (Source factory document data)

UPVC PIPE IN PCS

B.1 FINISHED PRODUCTS

S/N	OD	PN	Material Consn/Kg /PCS (a)	Physical count (Ending Inventories) (b)	Raw materials used for Ending Inventories/kg c= (a*b)	WT.AVG. COST of raw materials /KG (in	WT.AVG. MOH. cost/Kg (e)	WT.AVG. D/Labor cost/Kg (f)	Cost of Ending Inventories: Raw Material g= (c*d)	Labor & others h = (c*e)	D/Labor & others i = (c*f)	Total j = (g+h+i)
1	16	16	0.69	349	240.81	24.020	7.685	2.137	5,784.32	1,850.56	514.51	8,149.40
2	20	16	0.74	609	453.10	24.020	7.685	2.137	10,883.49	3,481.93	968.08	15,333.50
3	25	16	1.36	187	253.57	24.020	7.685	2.137	6,090.87	1,948.64	541.78	8,581.29
4	32	10	1.49	84	124.99	24.020	7.685	2.137	3,002.34	960.53	267.06	4,229.93
5	32	16	2.04	120	244.80	23.993	5.578		5,873.52	1,365.54		7,239.05
6	50	6.3	2.484	1,162	2,886.41	24.020	7.685	2.137	69,332.34	22,181.30	6,167.06	97,680.70
7	50	10	3.516	521	1,831.84	24.020	7.685	2.137	44,001.22	14,077.19	3,913.88	61,992.28
8	63	10	5.43	118	640.74	24.020	7.685	2.137	15,390.76	4,923.92	1,369.00	21,683.67
9	75	4	4.224	60	253.44	24.020	7.685	2.137	6,087.70	1,947.62	541.50	8,576.82
10	75	6.3	5.046	484	2,442.26	24.020	7.685	2.137	58,663.87	18,768.17	5,218.11	82,650.15
11	75	10	7.77	279	2,167.83	24.020	7.685	2.137	52,071.89	16,659.22	4,631.76	73,362.86
12	90	4	4.12	319	1,313.00	24.020	7.685	2.137	31,538.73	10,090.10	2,805.35	44,434.17
13	90	6.3	7.69	323	2,482.58	24.020	7.685	2.137	59,632.22	19,077.97	5,304.24	84,014.44
14	90	10	10.39	103	1,070.17	23.993	5.578		25,676.72	5,969.60		31,646.31
15	110	4	7.476	378	2,825.93	24.020	7.685	2.137	67,879.59	21,716.53	6,037.84	**110,633.96**
16	110	6.3	8.076	245	1,978.62	24.020	7.685	2.137	47,527.01	15,205.19	4,227.49	66,959.69
17	110	10	12.372	328	4,058.02	24.020	7.685	2.137	97,474.69	31,184.81	8,670.30	137,329.80
18	110	16	20.55	2	41.10	24.020	7.685	2.137	987.23	315.84	87.81	1,390.89
17	125	4	9.66	1	9.66	24.54	6.29		237.07	60.80		297.87
18	125	6.3	11.58	11	127.38	24.54	6.29		3,126.05	801.78		3,927.83
21	125	10	16.25	28	455.00	23.993	5.578		10,916.87	2,538.07	-	13,454.94
22	125	16	24.3	5	121.50	23.993	5.578		2,915.16	677.75	-	3,592.91
23	160	4	15.864	83	1,316.71	24.020	7.685	2.137	31,627.79	10,118.59	2,813.27	44,559.66
24	160	6.3	18.84	1,234	23,248.56	24.020	7.685	2.137	558,436.98	178,659.20	49,672.56	786,768.74
25	160	10	28.254	466	13,166.36	24.020	7.685	2.137	316,259.78	101,180.12	28,131.07	445,570.98
26	160	10	26.74	44	1,176.56	23.993	5.578		28,229.35	6,563.06	-	34,792.40
27	160	16	39.84	1	39.84	23.993	5.578		955.89	222.23	-	1,178.12
28	200	4	23.71	215	5,096.79	24.020	7.685	2.137	122,426.34	39,167.52	10,889.73	172,483.59
29	200	6.3	28.146	580	16,324.68	24.020	7.685	2.137	392,123.42	125,450.96	34,879.09	552,453.48
30	200	10	41.4	2	82.80	23.993	5.578		1,986.63	461.87	-	2,448.50
31	200	16	65.448	43	2,814.26	24.020	7.685	2.137	67,599.42	21,626.89	6,012.92	95,239.23
32	200	16	62.22	94	5,848.68	23.993	5.578		140,328.08	32,624.97	-	172,953.05
35	225	10	54.45	18	980.10	24.020	7.685	2.137	23,542.28	7,531.82	2,094.07	33,168.16
36	250	6.3	42.558	248	10,554.38	24.020	7.685	2.137	253,519.28	81,107.72	22,550.35	357,177.36
38	280	6.3	53.4	29	1,548.60	24.020	7.685	2.137	37,197.81	11,900.59	3,308.72	52,407.12
40	280	10	88.86	146	12,973.56	24.020	7.685	2.137	311,628.58	99,698.47	27,719.13	439,046.18
41	280	16	121.32	5	606.60	23.993	5.578		14,554.23	3,383.72	-	17,937.95
42	315	6.3	67.47	204	13,763.88	24.020	7.685	2.137	330,612.29	105,771.88	29,407.72	465,791.88
43	315	10	107.43	9	966.87	24.020	7.685	2.137	23,224.49	7,430.15	2,065.80	32,720.44
44	315	16	161.19	2	322.38	24.020	7.685	2.137	7,743.66	2,477.41	688.79	10,909.86
45	355	6.3	88.56	161	14,258.16	24.020	7.685	2.137	342,485.03	109,570.29	30,463.79	482,519.11
48	400	16	258.954	4	1,035.82	24.020	7.685	2.137	24,880.59	7,959.98	2,213.11	35,053.68
53	630	6.3	281.25	7.00	1,968.75	24.020	7.685	2.137	47,289.93	15,129.34	4,206.40	66,625.67
TOTAL				#######	154,117.09	#######	308.70		3,701,745.50	1,163,839.83		5,173,967.62

ANNEX: F. (Source recorded data from factory)

Table1. Recorded data for extrusion rate for level one.

Name of Parameters	Data recording in different days for level 1. Units in Min/Pcs.	Frequency
Extrusion Rate	23	2
	28	1
	26	1
	25	3
	25	2
	25	4
	28	1
	25	1
	19	2
	29	1
	25	3
	26	1
	25	3
	22	2
	28	1
	23	4
	25	1
	26	1
	24	2
	25	2

Table 2. Recorded data for extrusion rate for level two.

Name of Parameters	Data recording in different days for level 2. Units in Min/Pcs.	Frequency
Extrusion Rate	16	1
	17	1
	18	2
	18	1
	18	1
	19	2
	18	3
	16	1
	18	2
	17	1
	18	3
	18	3
	18	2
	18	1
	19	1
	16	1
	17	2
	18	3
	16	2
	18	1

Table 3. Recorded data for extrusion rate for level three.

Name of Parameters	Data recording in different days for level 3. Units in Min/Pcs.	Frequency
Extrusion Rate	10	1
	8	2
	9	4
	9	4
	10	1
	8	2
	8	2
	13	1
	9	3
	9	4
	9	5
	9	4
	12	1
	8	1
	10	2
	12	1
	9	2
	10	2
	9	2
	9	3

Table 4. Recorded data for setup time for level one.

Name of Parameters	Data recording in different days for level 1. Units in Min.	Frequency
Setup time	180	1
	170	1
	190	2
	190	3
	190	1
	190	2
	180	1
	180	1
	220	1
	200	1
	195	1
	195	1
	180	2
	190	2
	170	2
	190	2
	220	1
	190	1
	200	1
	220	1

Table 5. Recorded data for setup time for level two.

Name of Parameters	Data recording in different days for level 2. Units in Min.	Frequency
Setup time	105	1
	120	1
	110	1
	115	3
	115	2
	117	1
	115	2
	120	1
	115	3
	120	1
	120	2
	100	1
	140	2
	100	1
	112	2
	115	3
	100	1
	125	2
	108	2
	112	2

Table 6. Recorded data for setup time for level three.

Name of Parameters	Data recording in different days for level 3. Units in Min.	Frequency
Setup time	84	1
	82	2
	88	1
	85	2
	85	2
	85	1
	85	2
	85	2
	83	1
	84	1
	89	1
	90	1
	81	2
	83	2
	82	1
	85	3
	90	1
	84	2
	83	1
	84	3

Table 7. Recorded data for capacity of the loading station for level one.

Name of Parameters	Data recording in different days for level 1. Units in Kg.	Frequency
Capacity of the loading station	70	1
	65	1
	65	1
	60	2
	55	2
	60	1
	55	2
	65	1
	70	1
	50	2
	40	2
	65	1
	40	2
	45	2
	55	2
	70	1
	65	1
	60	1
	55	2
	55	2

Table 8. Recorded data for capacity of the loading station for level two.

Name of Parameters	Data recording in different days for level 2. Units in Kg.	Frequency
Capacity of the loading station	45	1
	55	2
	50	1
	40	2
	70	1
	50	2
	50	2
	40	1
	45	2
	60	1
	50	3
	40	1
	60	1
	50	2
	50	2
	50	1
	40	1
	60	1
	65	1
	50	2

Table 9. Recorded data for capacity of the loading station for level three.

Name of Parameters	Data recording in different days for level 3. Units in Kg.	Frequency
Capacity of the loading station	44	1
	50	1
	40	1
	43	2
	43	2
	43	2
	43	2
	65	1
	40	1
	40	1
	40	1
	40	1
	40	1
	41	2
	43	2
	40	1
	40	1
	43	3
	43	2
	40	1

Table 10. Recorded data for feed rate for level one.

Name of Parameters	Data recording in different days for level 1. Units in Kg.	Frequency
Feed rate	15	1
	10	1
	10	1
	15	2
	15	3
	15	1
	20	2
	10	1
	20	2
	15	2
	15	2
	15	2
	15	2
	20	1
	20	1
	25	1
	10	2
	10	1
	15	2
	15	1

Table 11. Recorded data for feed rate for level two.

Name of Parameters	Data recording in different days for level 2. Units in Kg.	Frequency
Feed rate	13	1
	15	1
	13	1
	13	1
	13	2
	13	2
	12	2
	12	3
	12	2
	12	2
	12	1
	12	1
	18	1
	12	2
	10	1
	10	1
	10	1
	10	1
	14	1
	14	1

Table 12. Recorded data for feed rate for level three.

Name of Parameters	Data recording in different days for level 3. Units in Kg.	Frequency
Feed rate	9	1
	8	2
	12	1
	10	2
	12	1
	10	2
	9	1
	9	2
	9	1
	10	1
	10	2
	10	2
	10	2
	10	1
	10	1
	10	2
	9	2
	9	1
	12	1
	10	1

Table 13. Recorded data for maintenance break down for level one.

Name of Parameters	Data recording in different days for level 1. Units in Min.	Frequency
Maintenance break down	25	2
	20	1
	15	1
	25	1
	10	2
	25	2
	10	2
	25	1
	15	3
	20	1
	20	2
	20	1
	25	1
	25	1
	25	1
	25	1
	25	2
	25	2
	20	2
	25	2

Table 14. Recorded data for maintenance break down for level two.

Name of Parameters	Data recording in different days for level 2. Units in Min.	Frequency
Maintenance break down	10	1
	20	1
	15	2
	15	1
	20	1
	10	2
	10	2
	20	1
	15	1
	15	2
	15	2
	15	2
	15	3
	20	1
	25	1
	15	2
	15	1
	10	2
	10	1
	15	1

Table 15. Recorded data for maintenance break down for level three.

Name of Parameters	Data recording in different days for level 2. Units in Min.	Frequency
Maintenance break down	10	2
	9	1
	8	1
	8	1
	15	2
	10	2
	10	2
	12	1
	10	3
	15	1
	10	2
	8	1
	9	1
	10	1
	10	1
	10	1
	10	2
	10	2
	12	2
	10	2

ANNEX: G

Sample simulation runs

10:12:23AM **Category Overview** May 19, 2021

Values Across All Replications

Habtamu Sila Plastic Factory Production System With Arena

Replications: 603 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	222

10:12:23AM **Category Overview** May 19, 2021

Values Across All Replications

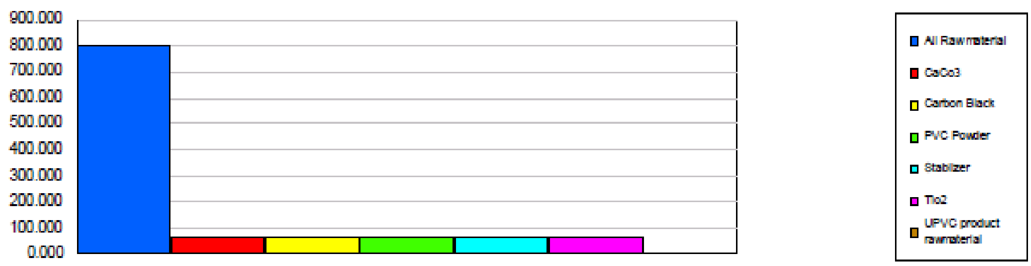
Habtamu Sila Plastic Factory Production System With Arena

Replications: 603 Time Units: Minutes

Entity

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
All Raw material	802.69	1.21	762.00	859.00
CaCo3	67.0000	0.00	67.0000	67.0000
Carbon Black	67.0000	0.00	67.0000	67.0000
PVC Powder	67.0000	0.00	67.0000	67.0000
Stablizer	67.0000	0.00	67.0000	67.0000
Tio2	67.0000	0.00	67.0000	67.0000
UPVC product rawmaterial	0.00	0.00	0.00	0.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
All Raw material	222.12	0.47	205.00	239.00
CaCo3	0.00	0.00	0.00	0.00
Carbon Black	0.00	0.00	0.00	0.00
PVC Powder	0.00	0.00	0.00	0.00
Stablizer	0.00	0.00	0.00	0.00
Tio2	0.00	0.00	0.00	0.00
UPVC product rawmaterial	0.00	0.00	0.00	0.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
All Raw material	289.50	< 0.53	273.73	315.71	0.00	639.00
CaCo3	33.6047	< 0.00	33.6047	33.6047	0.00	67.0000
Carbon Black	33.6047	< 0.00	33.6047	33.6047	0.00	67.0000
PVC Powder	33.6047	< 0.00	33.6047	33.6047	0.00	67.0000
Stablizer	33.6047	< 0.00	33.6047	33.6047	0.00	67.0000
Tio2	33.6047	< 0.00	33.6047	33.6047	0.00	67.0000
UPVC product rawmaterial	0.00	< 0.00	0.00	0.00	0.00	0.00

10:12:23AM **Category Overview** May 19, 2021

Values Across All Replications

Habtamu Sila Plastic Factory Production System With Arena

Replications: 603 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Process Cooling	3.0568	< 0.01	2.7076	3.4226	0.00	11.7921
Process Cutting	2.4595	< 0.01	1.9553	2.9491	0.00	15.0403
Process Ding	3.0606	< 0.01	2.6606	3.4387	0.00	12.6549
Process Mixing	8.0148	< 0.02	7.1586	8.7985	0.00	26.6560
Process Socketing	8.0175	< 0.02	7.2097	8.7772	0.00	26.7233

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Process Cooling	0.3737	< 0.01	0.1526	0.7321	0.00	17.4466
Process Cutting	0.3935	< 0.01	0.1247	0.8570	0.00	21.5531
Process Ding	0.3524	< 0.01	0.1338	0.7137	0.00	16.1824
Process Mixing	541.22	< 1.10	507.44	591.00	0.00	1147.66
Process Socketing	41.3599	< 1.92	7.1111	143.03	0.00	268.86

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Process Cooling	3.4305	< 0.01	2.9599	4.1184	0.00	22.6874
Process Cutting	2.8530	< 0.02	2.1327	3.7576	0.00	25.6907
Process Ding	3.4130	< 0.01	2.9520	3.9962	0.00	20.3405
Process Mixing	549.23	< 1.11	515.11	599.19	0.00	1157.87
Process Socketing	49.3774	< 1.94	14.5483	151.36	0.00	280.90

Values Across All Replications

Habtamu Sila Plastic Factory Production System With Arena

Replications: 603 Time Units: Minutes

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Cooler	236.06	0.61	216.00	264.00
Cutter	234.59	0.61	214.00	263.00
Die	237.46	0.61	216.00	266.00
Extruder	0.00	0.00	0.00	0.00
Haul Off	0.00	0.00	0.00	0.00
Inspector	0.00	0.00	0.00	0.00
Mixer	239.53	0.62	218.00	268.00
Pulverizer	0.00	0.00	0.00	0.00
Socket	224.88	0.47	209.00	241.00
Vacuum Tank	0.00	0.00	0.00	0.00