CHAPTER ONE

INTRODUCTION

1.1 Overview/background

Although the technological achievements of the last 50 years can hardly be disputed, there is one weakness in all devices that is the possibility of failure. What person has not experienced the frustration of an automobile that fails to start or a malfunction of a household appliance? The introduction of every new device must be accompanied by provision for maintenance, repair of parts, and protection against failure. This is certainly apparent to the military, where the life-cycle maintenance costs of systems far exceed the original purchase costs. The problem pervades modern society, from the homeowner who faces the annoyances of appliance failures, to electric utility companies faced with the potentially disastrous consequences of nuclear reactor failures. The insurance industry would not exist without the possibility of one type of failure or another (Blischke and Murthy, 2000). A subject that is so important to many decisions could hardly escape quantitative analysis. The name reliability is given to the field of study that attempts to assign numbers to the propensity of systems to fail. In a more restrictive sense, the term reliability is defined as the probability that a system performs its mission successfully. Because the mission is often specified in terms of time, reliability is often defined as the probability that a system will operate satisfactorily for a given period of time. Thus reliability may be a function of time. Estimating reliability is essentially a problem in probability modeling. A system consists of a number of components. In the simplest case, each component has two states, operating or failed. When the set of operating components and the set of failed components is specified, it is possible to discern the status of the system. The problem is to compute the probability that the system is operating its reliability. The concepts and methods of probability theory are used to compute the reliability of a complex system. In addition, bounds are provided on the probability of success that are often much easier to compute than the exact reliability. System reliability can be defined as the probability that a system will perform its intended function for a specified period of time under stated conditions (Ahmadi and Soderholm, 2008). It is important because a company's reputation, customer satisfaction and system design costs can be directly related to the failures experienced by the system (Ansell and Phillip, 1994). It is also challenging since current estimation techniques require a high level of background in system reliability analysis, and thus familiarity with the system. Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products which vary greatly in their size, complexity, and application are manufactured using injection moulds. The injection molding process requires the use of an injection molding machine, raw plastic material, and a mold

(Besseris, 2008). In the last three decades, engineering analysis methods have advanced to improve reliability of engineering systems while considering system input uncertainties. Reliability represents safety level in industrial practice and may vary due to time-variant operation condition and components deterioration throughout a product life-cycle (Billinton and Allan, 2008). Reliability remains a product quality indicator of paramount importance in competitive manufacturing operations. Offering novel ideas in enhancing product reliability levels is a subject of continuous research.

Society depends on services provided by critical infrastructures, and hence it is important that the infrastructures are reliable and robust. Estimating system reliability is an important and challenging problem for system engineers (Branke, 2008).

The concepts and methods of probability theory are used to compute the reliability of a complex system. In addition, we provide bounds on the probability of success that are often much easier to compute than the exact reliability (Ansell and Phillips, 1994).Watson (1998) discussed how this vision of the future might unfold. Technological advances have created a global economy in which a lot of information is available to virtually anyone at any time. Combined with the expansion of business partnerships and regional economic pacts, access to information will create a world in which competitors can spring up anywhere, without much warning. The competitive advantage afforded by being first to market will not last as long as in times past. Traditional challenges, such as achieving design quality and controlling manufacturing processes will continue to be vital, requiring more use of sophisticated methods. Services rendered to the customer will become a more prominent way to gain competitive advantage. Companies will need to use new, more advanced statistical techniques, better management methods, and appropriate digital technologies.

Analysis of reliability of production systems using Monte Carlo Simulation (MCS) method provides very accurate values. Consequently, the method looks promising since its convergent speed is independent of mathematical problems dimension and estimation is statistical. It gives a true good confidence level including the solution with a given probability distribution models (Ebisike, 2014). According to Barringer (2004), analysis of reliability of production systems begins with management and how they communicate the need for a failure free environment to mobilize actions to preserve production systems and processes. The need for reliability considers cost of alternatives to prevent or mitigate failures, which require knowledge about times to failure, and failure modes which are found by reliability technology. Justification for reliability improvements require knowing: (1) when things fail, (2) how things fail, and (3) conversion of failures into time and money.

Barringer (2004), explained reliability growths plots, as a powerful tool for predicting future failures for mixed failure modes. Weibull probability plots are powerful single failure mode tools for predicting the type of failure mode which guides reliability centered maintenance strategies and forecasting future failures for each failure mode (Jiang and Murthy, 1999). Both analytical tools are minimum requirements for every reliability engineer's tool box. Real data examples are shown to illustrate the value for acquiring engineering/maintenance data and unemotional voice is a rational for decisions and for corrective action. Examples and illustrations describe the basics of each tool.

Daniela et al (2003) used a Monte – Carlo simulation via excel spreadsheet to determine the reliability of a geothermal power plant. This simulation technique utilizes the powerful mathematical and statistical capabilities of excel. Simulation time is dependent on the complexity of the system, computer speed and accuracy desired, so a simulation may range from a few minutes to a few hours. Kshamta and Shedom (2005) worked on the reliability analysis of an antilock braking system using stochastic Petri nets. The work attempted to model the anti – lock braking sub – system of a vehicle system using stochastic Petri nets. The reliability analysis was undertaken with particular focus on coincident failure of components.

Jiang (2012) developed a methodology to evaluate and determine the necessary level of reliability for process equipment such as larger centrifugal compressors and turbines in a refinery environment using mean time between failure (MTBF) and Weibill analysis. According to Bruce (2004), total assessment of reliability requires the quantitative estimate of three distinct and separate classes of failure: that is early life, event – related and wear out. The early life, also known as infant mortality, is a result of or relatively severe defects introduced during any level of manufacture of assembly, and typically results in decreasing failure rates as defective parts fail and are replaced. Event – related failure mechanisms occur randomly and are a result of undetected defects that fail due to external and internal stresses. Wear out failure mechanisms occur as a result of prolonged exposure to environmental and operating stresses and will occur in the entire population of items if they are long enough in service.

Khalili and Amiri (2012) presented a statistical analysis of failure date of an automated pizza production line, covering a period of four years. The analysis includes the computation of descriptive statistics of the failure data, the identification of the most important failure, the computation of the parameters of the theoretical distribution that best fit the failure data, and the investigation of the existence of autocorrelations and cross correlations in the failure data.

The analysis is meant to guide food product machine manufactures and bread and bakery products manufactures to improve the design and operation of their production lines. It can also be valuable to reliability analysis and manufacturing systems analysts, who wish to model and analyze real production systems.

Enhancing reliability satisfies customers with on-time delivery of products through increased production equipment reliability and reduced warranty problems from products that failed early. Higher reliability reduces the cost for equipment failures that decreases production and limits gross profits from plants operating at maximum capacity as with commodity products and high demand proprietary products. Reliability is spoken, but failure measured. Failures demonstrate evidence of lack of reliability. Reliability problems are failure, and failures cost money in an economic enterprise. Failures in most continuous process industries are measured in terms of downtime for the process. Similarly, cutbacks in output are also failure to achieve the desired economic results from the process or equipment downtime (Barringer, 2004). Fewer people can define when a cutback in output grows into a demonstrated failure. Definition of failure, which leads to a need for reliability improvements, is a vital factor in analyzing the reliability of a system. Failures galvanize organizations into action for making improvements.

Funding for reliability improvements must come from the cost of unreliability. At the heart of reliability improvements is the need to find affordable business solutions. Good reliability engineering work for business is the never ending search for affordable improvement resulting in large profits by cleverly solving nagging problems. Good reliability engineering is not the search for perfection but rather a search for effective business solutions to failure problems. Reliability numbers (a value between zero and one) lack a motivation for making business improvements. However, reliability numbers spring to life when converted into monetary values expressing the cost of unreliability. Annualizing losses by means of the cost of unreliability immediately identifies for everyone the amount of money that can be spent to correct reliability problems. Clever solutions minimizing expenditures for correct solutions are the basis for hero awards in the industry. Throwing money at reliability for correction is the basis for hero awards in the industry.

Reliability values are not fixed and immutable, but change with business conditions. Different business conditions require use of different reliability engineering tools for solving their problems. You do not need an improvement over your fiercest competitor so your business is the low cost provider. Motivations for reliability improvements are driven by the cost of unreliability and how unreliability affects the bottom line of the business (Barringer, 2003).

This dissertation examines the issues related to incorporating aging effects in reliability analysis of injection mould system in details and introduces some methods using Monte Carlos simulation.

Reliability techniques have been in development for a number of years. These methods first appeared in a mathematical form in the 1920's (Meeker and Escobar, 2010). Practical usage of these methods was not developed until the late 1960's with the development of a second-moment reliability index (Montgomery, 2004). Cassenti (2008) furthered deterministic methods by developing the probabilistic static failure analysis procedure of unidirectional laminated composite structures. Yang (2004) presented a reliability analysis of laminated plates based on the last-ply-failure analysis concept. Thomas (1991) developed an analysis result for a single continuous lamina and laminated plate based on weakest link theory and furthered this work by presenting a more precise reliability estimation subjected to multi-axial loads. Kam (1999) predicted the reliability of simply supported angle-ply and cantilever symmetric laminated plates.

Reliability of a system depends on its maintenance policy. The increasing competition in the market creates an urgent need to search for new ways in which manufacturing companies can differentiate themselves and gain better competitive position. By examining the debate on markets and resources one could realise the existence of two opposing perspectives, i.e. the inside-out perspective and the outside-in perspective. A significant amount of the annual operational costs are attributed to maintenance costs. An effective and efficient maintenance policy would operate a system to achieve operational objectives successfully, considering that the systems are getting complex with the advancement of technology. When systems required during emergency or which are required perennially are considered, for example, aircraft carriers, airplanes, printing presses and many other systems, maintenance policies determine the steady availability of the system. Additionally, it may not be in the interest of management to invest in redundant capacity or in excessive maintenance efforts. For example, one of the biggest operational challenges faced by a plant manager is to reduce maintenance costs, capital investment in maintenance resources and redundant capacity without reducing system reliability. In the United States, the estimated cost of maintenance increased from $200 billion in 1979 to $600 billion in 1989. Maintenance activities account for, on an average, 28% of the total cost of finished goods (Blanchard, 2000). In short, maintenance costs are important and need to be considered in the early phase of the product life-cycle, i.e., during design or procurement. This would help reduce maintenance costs substantially during the service life of the system. A large system is a conglomerate of several small subsystems. The interaction between these numerous subsystems leads to a very dynamic and complex system. In a dynamic technological environment, it is imperative to consider the effect of future technological changes, as much as possible, on all the subsystems not only before the system construction but also during the lifetime of the system. The technological changes will have impact on the procurement and operational costs of the system. Furthermore, the initial investment can affect the operation, i.e., the number of breakdowns of the system during its service life (Drew, 1998).

Machine downtime, whether planned or unplanned, is intuitively costly to manufacturing organisations, but is often very difficult to quantify. The available literature showed that costing processes are rarely undertaken within manufacturing organisations. Where cost analyses have been undertaken, they generally have only valued a small proportion of the affected costs, leading to an overly conservative estimate (Smith, 1981). Maintenance and change of strategy in repairable system occupied a very important position in the reliability mathematics. The expected benefits and expected cost of the long-run operation of the system have been widely studied as the aim functions.

Reliability of system precedes its products quality. In the current world of continually increasing global competition it is imperative for all manufacturing and service organizations to improve the quality of their products. Quality has been defined in many ways (Evans and Lindsay, 1992). The American Society for Quality Control (1978) defined quality as the totality of features and characteristics of a product or service that bears on its ability to satisfy given needs. The quality of a product has always been of interest to the provider and customer. Quality is as old as industry itself. In the period before the industrial revolution, good craftsmen and artisans learned quickly through intimate contact with their customers that quality products meant satisfied customer, and satisfied customer meant continued business. However, with the industrial revolution, came the mass production by people who rarely interacted with customers. As a result, although cost decreased, the emphasis on quality also decreased. In addition, as the product manufactured and the service provided became more complex, the need for a formal system to ensure their quality and all their components became increasingly important. From the technical perspective, true progress toward improving and monitoring quality on a mass scale did not begin until the advent of statistical quality control SPC. SPC refers to the statistical techniques used to control or improve the quality of the output of some production or service processes. Shewhart Control Chart is a graphical device for monitoring a measurable characteristic of a process, showing whether the process is operating within its limits of expectation (Sim, 2000). Most products, even very simple ones, have many correlated characteristics or dimensions that affect their quality, for example, a nail is defined by its length, diameter, hardness etc. Quality control can be considered from two orientations. For example the product or process perspective. Taking a product orientation, the focus is on the parts or units after manufacture. Considering a single quality dimension at a time, the quality of a part is defined based on the target value and specification limits for that quality dimension. Specification limits, usually determined by engineering considerations, specify the range of quality dimensions within which it is acceptable to maintain the parts quality dimension. The target value is the most desirable quality dimension value, and is often centered between the specification limits. A non-conforming unit is usually defined as apart, whose quality characteristics of interest lies outside the engineering limits, whereas if a part's quality dimension falls within specification it is called a conforming unit (Taguchi, 1979).

1.2 Problem statement.

Innoson Plastic Industries, Enugu, state, has at present seven (7) damaged injection moulding systems that did not last up to 15years of usage and with excessive down time and low performance output of 40% before they packed up. This has hindered the industry from achieving it's targets: such as provision of employment, diversification of national economy and low cost product for the consumers.

1.3 Aim and objectives of the study

The aim of this work is to enhance the performance of Innoson injection moulding system.

The objectives of the study are:

(a) To evaluate the reliability of Innoson injection moulding system.

(b) To model the maintenance of Innoson injection moulding system.

(c) To cost injection moulding system down times.

(d) To evaluate the quality of productions of Innoson injection moulding system.

1.4 Scope and limitations

Collecting consistent field data for reliability, failure rates, machine downtimes and quantity of defective product, was the major difficulty encountered during the first phase of this research work. The general indices used in reliability analysis, the importance of reliability, system components failure rates and the use of Monte Carlo reliability models to develop a universal software for analyzing reliability for maintenance using failure data were considered. Reliability and failure rates data for ten (10) years were considered using series of past data to analyze reliability.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews some applicable literature associated with reliability, maintenance, system downtimes and quality of product; applications as well as the statistical tools used to analyze them.

2.1 Theoretical background

The aircraft Industry began the search for reliability of systems since technologically they came on board before others. After World war I, as air traffic and air crashes increased, reliability criteria and necessary safely levels for aircraft performance emerged. Comparison of single and multi-engine aircraft from the point of view of successful flights were made and requirements in terms of accidents rates per hours of flying time were developed. By 1960, for instance, it had been deduced that fatal accidents occurred in approximately one out of one million landings (Lewis, 1987).

World war II brought about the development of mathematical reliability equations. Robert Lusser, a mathematician, was called in as a consultant. He formulated the product law of series components, which says that reliability of a serial system is equal to the product of the reliabilities of the components

$R_s = R_1 R_2 R_3 \ldots R_N$. Thus in a serial system, the reliability of the individual components must be much higher than the system reliability for satisfactory system performance (Lewis, 1987).

The American department of defense which tried to improve the reliability of its equipment during the Korean war in the 1940's, found that an unreliable equipment has a lot of down time and required a lot of maintenance. It found that the cost of Arms services was $2 per year to maintain every dollar worth of electronic component. For instance, for an equipment life of ten years, it cost 20million dollars to maintain every million of purchase value equipment. It was thereby, demonstrated to the government that it was wiser to design for reliability rather than to wait and repair equipment after failure.

The 1960s saw the emergence of new reliability techniques and a wider variety of specialized applications. Starting from the earlier focus on the ways that components behaved, whether mechanical, electrical, or hydraulic, the emphasis broadened to studies of the effect component failures had on the system which they were parts of (Lewis and Yang, 1998).

The era of Intercontinental Ballistic Missiles and subsequent man-rated rocket developments such as mercury and Gemini programmes accelerated the demands-for-success. This was prompted by the one-shot requirements, culminating to the countdown of the rocket engines and system on the lunch pad (Upchurch and Willard, 1993).

Considerable effort was applied to both component and system functional testing during the aerospace years. Records were kept of each failure, its analysis, and the inspection records of deficiencies that turned up in the investigations. Each component mode of failure, mechanisms and cause, its failure effect on the system was evaluated for application of corrective action to preclude recurrence. With the increased complexity, more sophisticated block diagrams, and other models were required. In 1961, the concept of Fault tree Analysis was originated as a plan to evaluate the safety of minuteman launch control system. Later, the Boeing Company introduced the concept of computer utilization (Phillips and Harbor, 1996).

2.2 Overview of study

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2.3 Necessities of reliability analysis

Enhancing reliability satisfies customers with on-time delivery of products through increased production equipment reliability and reduced warranty problems from products that fail early. Higher reliability reduces the cost of equipment failures which decreases production and limits gross profits from plants operating at maximum capacity as compared with commodity products and high demand proprietary products. Reliability is spoken of, but failure is measured. Failures demonstrate evidence of lack of reliability. Reliability problems are failure, and failures cost money in an economic enterprise. Failures in most continuous process industries are measured in terms of downtime for the process. Similarly, cutbacks in output are also failure to achieve the desired economic results from the process or equipment downtime. Fewer people can define when a cutback in output grows into a demonstrated failure. Definition of failure, which leads to a need for reliability improvements, is a vital factor in analyzing the reliability of a system. Failures galvanize organizations into action for making improvements (Barringer, 2004).

2.4 Over view of injection moulding machine

Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products which vary greatly in their size, complexity, and application are manufactured using injection molding. The injection molding process requires the use of an injection molding system, raw plastic material, and a mold. The plastic is melted in the injection molding machine and then injected into the mold, where it cools and solidifies into the final part. Injection molding is used to produce thin-walled plastic parts for a wide variety of applications, one of the most common being plastic housings. A plastic housing is a thin-walled enclosure, often requiring many ribs and bosses on the interior. These housings are used in a variety of products including household appliances, consumer electronics, power tools, and as automotive dashboards. Other common thin-walled products include different types of open containers, such as buckets. Injection molding is also used to produce several everyday items such as toothbrushes or small plastic toys. Many medical devices, including valves and syringes, are manufactured using injection molding as well (Phillips and Harbour, 1996).

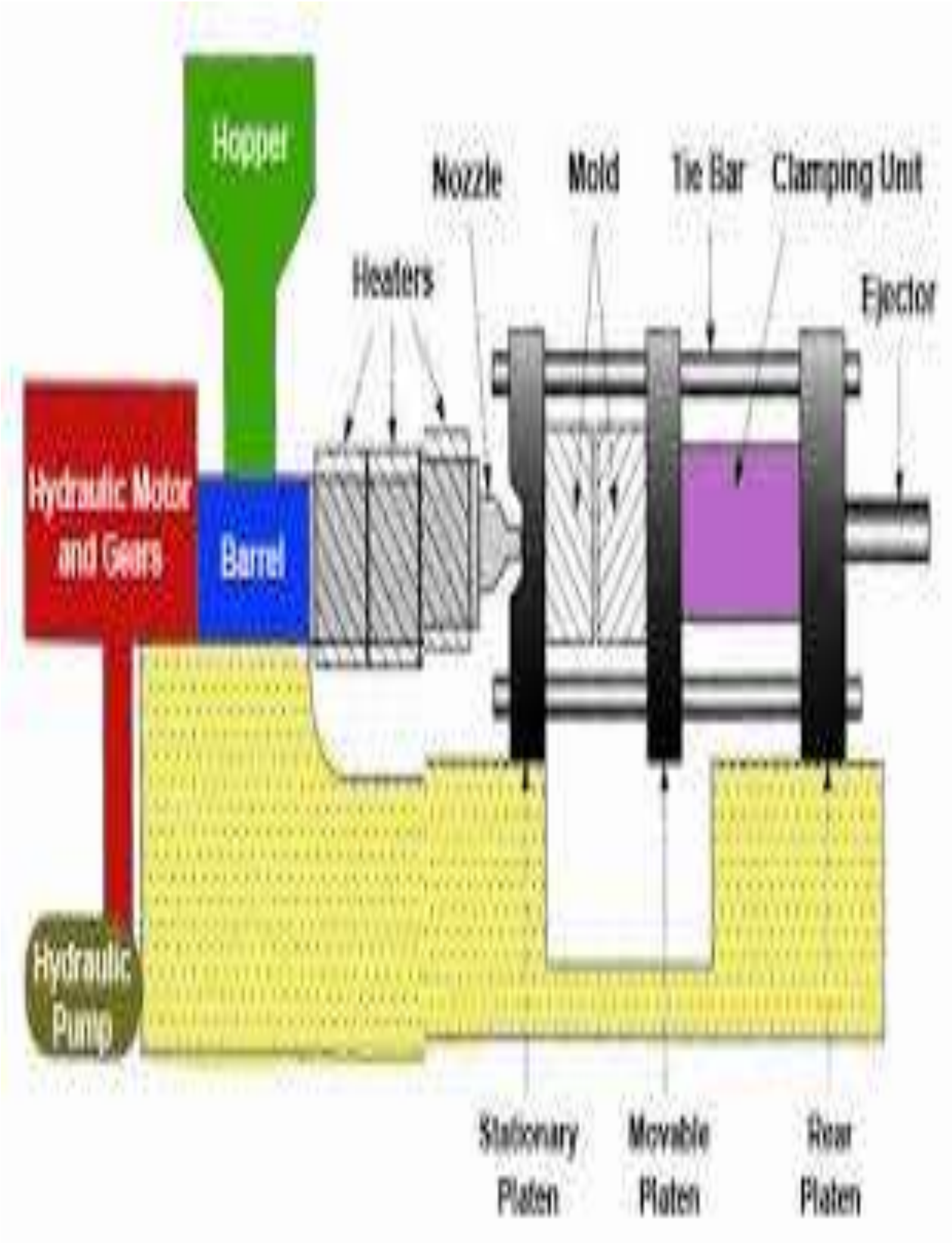

FIG 2a: Injection moulding system

2.4.1 Injection moulding machine process cycle

The process cycle for injection molding is very short, typically between 2 seconds and 2 minutes, and consists of the following four stages:

1. ***Clamping*** - Prior to the injection of the material into the mold, the two halves of the mold must first be securely closed using clamping unit. Each half of the mold is attached to the injection molding system but one half is allowed to slide. The hydraulically powered clamping unit pushes the mold halves together and exerts sufficient force to keep the mold securely closed while the material is injected. The time required to close and clamp the mold is dependent upon the machine - larger machines (those with greater clamping forces) will require more time. This time can be estimated from the dry cycle time of the machine (Zhang, 2011).

2. ***Injection*** - The raw plastic material, usually in the form of pellets, is fed into the injection molding system, is moved towards the mold by the injection unit. During this process, the material is melted by heat and pressure, the molten plastic is then injected into the mold very quickly while the buildup of pressure packs and holds the material. The amount of material that is injected is referred to as the shot. The injection time is difficult to calculate accurately due to the complex and changing flow of the molten plastic into

the mold. However, the injection time can be estimated by the shot volume, injection pressure, and injection power.

3. ***Cooling*** - The molten plastic that is inside the mold begins to cool as soon as it makes contact with the interior mold surfaces. As the plastic cools, it solidifies into the shape of the mould. However, during cooling some shrinkage of the part may occur. The packing of material in the injection stage allows additional material to flow into the mold and reduce the amount of visible shrinkage. The mold cannot be opened until the required cooling time has elapsed. The cooling time can be estimated from several thermodynamic properties of the plastic and the maximum wall thickness of the part.

4. ***Ejection*** - After sufficient time has passed, the cooled part may be ejected from the mold by the ejection system, which is attached to the rear half of the mold. When the mold is opened, a mechanism is used to push the part out of the mold. Force must be applied to eject the part because during cooling the part shrinks and adheres to the mold. In order to facilitate the ejection of the part, a mold release agent can be sprayed onto the surfaces of the mold cavity prior to injection of the material (Zio, 2009). The time that is required to open the mold and eject the part can be estimated from the dry cycle time of the machine and should include time for the part to fall free of

the mold. Once the part is ejected, the mold can be clamped shut for the next shot to be injected.

After the injection molding cycle, some post processing is typically required. During cooling, the material in the channels of the mold will solidify attached to the part. This excess material, along with any flash that has occurred, must be trimmed from the part, typically by using cutters. For some types of material, such as thermoplastics, the scrap material that results from this trimming can be recycled by being placed into a plastic grinder, also called regrind machines or granulators, which regrinds the scrap material into pellets. Due to some degradation of the material properties, the regrind must be mixed with raw material in the proper regrind ratio to be reused in the injection molding process.

2.4.2 Injection moulding equipment

Injection molding machines have many components and are available in different configurations, including a horizontal configuration and a vertical configuration. However, regardless of their design, all injection molding machines utilize a power source, injection unit, mold assembly, and clamping unit to perform the four stages of the process cycle (Zie et al, 2002).

2.4.2a Injection unit

The injection unit is responsible for both heating and injecting the material into the mold. The first part of this unit is the hopper, a large container into which the raw plastic is poured. The hopper has an open bottom, which allows the material to feed into the barrel. The barrel contains the mechanism for heating and injecting the material into the mold. This mechanism is usually a ram injector or a reciprocating screw. A ram injector forces the material forward through a heated section with a ram or plunger that is usually hydraulically powered. Today, the more common technique is the use of a reciprocating screw. A reciprocating screw moves the material forward by both rotating and sliding axially, being powered by either a hydraulic or electric motor. The material enters the grooves of the screw from the hopper and is advanced towards the mold as the screw rotates. While it is advanced, the material is melted by pressure, friction, and additional heaters that surround the reciprocating screw. The molten plastic is then injected very quickly into the mold through the nozzle at the end of the barrel by the buildup of pressure and the forward action of the screw (Zhang, 2011). This increasing pressure allows the material to be packed and forcibly held in the mold. Once the material has solidified inside the mold, the screw can retract and fill with more material for the next shot.

2.4.2b Clamping unit

Prior to the injection of the molten plastic into the mold, the two halves of the mold must first be securely closed by the clamping unit. When the mold is attached to the injection molding machine, each half is fixed to a large plate, called a platen. The front half of the mold, called the mold cavity, is mounted to a stationary platen and aligned with the nozzle of the injection unit. The rear half of the mold, called the mold core, is mounted to a movable platen, which slides along the tie bars. The hydraulically powered clamping motor actuates clamping bars that push the moveable platen towards the stationary platen and exert sufficient force to keep the mold securely closed while the material is injected and subsequently cools. After the required cooling time, the mold is then opened by the clamping motor. An ejection system, which is attached to the rear half of the mold, is actuated by the ejector bar and it pushes the solidified part out of the open cavity (Zio, 2009).

2.4.2c Machine specifications

Injection molding machines are typically characterized by the tonnage of the clamp force they provide. The required clamp force is determined by the projected area of the parts in the mold and the pressure with which the material is injected. Therefore, a larger part will require a larger clamping force. Also, certain materials that require high injection pressures may require higher tonnage machines. The size of the part must also comply with other machine specifications, such as shot capacity, clamp stroke, minimum mold thickness, and platen size.

Injection molded parts can vary greatly in size and therefore require the above mention measures to cover a very large range (Zie et al, 2002). As a result, injection molding system are designed to accommodate a small range of this larger spectrum of values. Sample specifications are shown in Table 2a for three different models (Babyplast, Powerline, and Maxima) of injection molding machine that are manufactured by Cincinnati Milacron.

Table 2a: Injection moulding system specification

	BABYPLAST	**POWERLINE**	**MAXIMA**
Clamp force (ton)	6.6	330	4400
Shot capacity (oz.)	0.13 - 0.50	8 – 34	413 – 1054
Clamp stroke (in.)	4.33	23.6	133.8
Min. mold thickness (in.)	1.18	7.9	31.5
Platen size (in.)	2.95 x 2.95	40.55 x 40.55	122.0 x 106.3

2.4.2d Tooling

The injection molding process uses molds, typically made of steel or aluminum, as the custom tooling. The mold has many components, but can be split into two halves. Each half is attached inside the injection molding machine and the rear half is allowed to slide so that the mold can be opened and closed along the mold's parting line. The two main components of the mold are the mold core and the mold cavity. When the mold is closed, the space between the mold core and the mold cavity forms the part cavity, that will be filled with molten plastic to create the desired part. Multiple-cavity molds are sometimes used, in which the two mold halves form several identical part cavities. Some of them are as follows;

0. **Mold base**

The mold core and mold cavity are each mounted to the mold base, which is then fixed to the platens inside the injection molding machine. The front half of the mold base includes a support plate, to which the mold cavity is attached, the sprue bushing, into which the material will flow from the nozzle, and a locating ring, in order to align the mold base with the nozzle. The rear half of the mold base includes the ejection system, to which the mold core is attached, and a support plate. When the clamping unit separates the mold halves, the ejector bar actuates the ejection system (Zhang, 2011). The ejector bar pushes the ejector plate forward inside the ejector box, which in turn pushes the ejector pins into the molded part. The ejector pins push the solidified part out of the open mold cavity.

1. Mold channels

In order for the molten plastic to flow into the mold cavities, several channels are integrated into the mold design. First, the molten plastic enters the mold through the sprue. Additional channels, called runners, carry the molten plastic from the sprue to all of the cavities that must be filled. At the end of each runner, the molten plastic enters the cavity through a gate which directs the flow. The molten plastic that solidifies inside these runners is attached to the part and must be separated after the part has been ejected from the mold. However, sometimes hot runner systems are used which independently heat the channels, allowing the contained material to be melted and detached from the part. Another type of channel that is built into the mold is cooling channels (Zio, 2009). These channels allow water to flow through the mold walls, adjacent to the cavity, and cool the molten plastic.

2. Mold design

In addition to runners and gates, there are many other design issues that must be considered in the design of the molds. Firstly, the mold must allow the molten plastic to flow easily into all the cavities. Equally important is the removal of the solidified part from the mold, so a draft angle must be applied to the mold walls. The design of the mold must also accommodate any complex features on the part, such as undercutsor threads, which will require additional mold pieces. Most of these devices slide into the part cavity through the side of the mold, and are therefore known as slides, or side-actions. The most common type of side-action is a side-core which enables an external undercut to be molded. Other devices enter through the end of the mold along the parting direction, such as internal core lifters, which can form an internal undercut. To mold threads into the part, an unscrewing device is needed, which can rotate out of the mold after the threads have been formed (Xie et al,2002).

2.4.3 Materials

There are many types of materials that may be used in the injection molding process. Most polymers may be used, including all thermoplastics, some thermosets, and some elastomers. When these materials are used in the injection molding process, their raw form is usually small pellets or a fine powder. Also, colorants may be added in the process to impact the color of the part. The selection of a material for creating injection molded parts is not solely based upon the desired characteristics of the final part. While each material has different properties that will affect the strength and function of the final part, the properties also dictate the parameters used in processing the materials. Each material requires a different set of processing parameters in the injection molding process, including the injection temperature, injection pressure, mold temperature, ejection temperature, and cycle time. A comparison of some commonly used materials is shown in Table 2b;

Table 2b: Material description

Type of material	**Properties**	**Applications**
Acetal	Strong, rigid, excellent fatigue resistance, excellent creep resistance, chemical resistance, moisture resistance, naturally opaque white, low/medium cost	Bearings, cams, gears, handles, plumbing components, rollers, rotors, slide guides, valves
Cellulose Acetate	Tough, transparent, high cost	Handles, eyeglass frames
Polycarbonate	Very tough, temperature resistance, dimensional stability, transparent, high cost	Automotive (panels, lenses, consoles), bottles, containers, housings, light covers, reflectors, safety helmets and shields
Polypropylene	Lightweight, heat resistance, high chemical resistance, scratch resistance, natural waxy appearance, tough and stiff, low cost.	Automotive (bumpers, covers, trim), bottles, caps, crates, handles, housings
Polystyrene - General purpose	Brittle, transparent, low cost	Cosmetics packaging, pens
Thermoplastic Elastomer/Rubber	Tough, flexible, high cost	Bushings, electrical components, seals, washers

2.4.4 Injection moulding cost drivers

Injection moulding machines have mainly three cost drivers as follows:

2.4.4aMaterial cost

The material cost is determined by the weight of material that is required and the unit price of that material. The weight of material is clearly a result of the part volume and material density; however, the part's maximum wall thickness also plays a role. The weight of material that is required includes the material that fills the channels of the mold. The size of those channels, and hence the amount of material, is largely determined by the thickness of the part.

2.4.4bProduction cost

The production cost is primarily calculated from the hourly rate and the cycle time. The hourly rate is proportional to the size of the injection molding system in use so it is important to understand how the part design affects machine selection. Injection molding machines are typically referred to by the tonnage of the clamping force they provide. The required clamping force is determined by the projected area of the part and the pressure with which the material is injected (Zhang, 2011). Therefore, a larger part will require a larger clamping force, and hence a more expensive machine. Also, certain materials that require high injection pressures may require higher tonnage machines. The cycle time can be broken down into the injection time, cooling time, and resetting time. By reducing any of these times, the production cost will be lowered. The injection time can be decreased by reducing the maximum wall thickness of the part and the part volume. The cooling time can also be decreased for lower wall thicknesses, as they require less time to cool all the way through. Several thermodynamic properties of the material also affect the cooling time. Lastly, the resetting time depends on the machine size and the part size. A larger part will require larger motions from the machine to open, close, and eject the part, and a larger machine will require more time to perform these operations.

2.4.4c Tooling cost

The tooling cost has two main components - the mold base and the machining of the cavities. The cost of the mold base is primarily controlled by the size of the part's envelope (Zio, 2009). A larger part requires a larger, more expensive, mold base. The cost of machining the cavities is affected by nearly every aspect of the part's geometry. The primary cost driver is the size of the cavity that must be machined, measured by the projected area of the cavity (equal to the projected area of the part and projected holes) and its depth. The quantity of parts also impacts the tooling cost. A larger production quantity will require a higher class mold that will not wear as quickly. The stronger mold material results in a higher mold base cost and more machining time.

One final consideration is the number of side-action directions, which can indirectly affect the cost. The additional cost for side-cores is determined by how many are used. However, the number of directions can restrict the number of cavities that can be included in the mold. For example, the mold for a part which requires 3 side-action directions can only contain 2 cavities. There is no direct cost added, but it is possible that the use of more cavities could provide further savings.

2.5 Causes of failure and unreliability

The causes of failure of components and equipment in a system can be many. Some are known and others are unknown due to the complexity of the system and its environment. A few of the causes are: poor design (component or system), wrong manufacturing techniques, incompetence and experience, complexity of equipment, organizational rigidity and human errors (Xie et al, 2002).

2.5.1Poor design, production uses

Poor design and incorrect manufacturing techniques are obvious reasons of low reliability. Some manufactures hesitate to invest more money on an improved design and modern techniques of manufacturing and testing. Improper selection of materials is also part of poor design.

Components and equipment do not operate in the same manner in all conditions. A complete knowledge will avoid their misuse and minimize failures.

2.5.2 System simplification

In many cases, complex and sophisticated production systems are used to accomplish a task, which could have been done by other simple system. The implications of complexity are costly. Firstly, it employs more components hereby decreasing overall reliability of the system. Secondly, a complex production system presents problems of understanding and maintenance. Even an experienced designer will take time to comprehend all the processes and interactions and is likely to commit mistakes during the design and development state. On the other hand, simplicity costs less, causes fewer problems, and has more reliability (Zhang, 2011). A basic rule of reliability with respect to complexity is keep the system as simple as compatible with the performance requirements.

2.5.3 Human reliability

In spite of increased application of automation in industries and organizations, it is impossible to completely eliminate human involvement in the operation and maintenance of production systems. The contribution of human errors to unreliability may be at various stages of the product cycle. Failure due to human error can be due to: lack of understanding of the equipment, carelessness, forgetfulness, and poor judgmental skill, absence of correct operating procedures and instructions, and physical inability. However, its life time can increase if it can be repaired and put into operation again. In many cases preventive measures are possible and a judiciously designed preventive – maintenance policy can help eliminate failure to a large extent. The adage "prevention is better than cure" applies to products as well as to equipment.

2.5.4 Communication and coordination

Reliability is a concern of almost all department of an organization. It is essentially a birth – to – death problem involving such areas as: raw materials and parts, conceptual, and detailed engineering design, installation, operation and maintenance (Zio, 2009). A well – organized management with an efficient system of communication is required to share information and experience about

components. Although, it is not possible to eliminate all human errors, it is possible to minimize some of them by proper selection and training of personnel, standardization of procedures, simplification of control schemes, and other incentive measurers. The designer should ensure that the operation of the equipment is as simple as possible with practically minimum probability for error. The operator should be comfortable in his work and should be free from unnecessary stresses (Akmar and Aminmaji, 2006).

2.5.5 Reliability engineering tools

Many concepts and practical engineering tools are available for making reliability decisions. Knowing about reliability tools is one thing, but using reliability tools for reducing the high cost of unreliability is what counts for improving plants and businesses. A few reliability engineering tools are described below to illustrate the breadth of techniques now available (Patterson, 1993).

2.5.6 Acquiring reliability data

According to Barringer (1996), accurate failure data is required for making good reliability decisions. Many factories, chemical plant, and refiners have recorded and stored 10 – 20 years of failure data in maintenance information system. Most industries are sitting on the equivalent of a gold mine of data without analyzing them. Industry must educate and train engineers to mine the data gold and recognize value in the data banks for making reliability improvements. Often failure data is viewed as having little value. Engineers have not been trained to handle suspensions in the data (i.e., no failure or failures from different failure modes currently under investigation) and failure data often cannot be plotted using conventional X – Y plots. Using system data for quantifying failure characteristic is important because it reflects actual results of procurement practices, maintenance practices, operating practices, and life cycle actions in real world conditions. For these reasons, system failure data is extremely valuable for projecting paradigm shifts using new criteria for improvements. Fresh data is acquired accurately and rigorously when organizations observe that failure data is actually used for decisions. Failure reporting and corrective actives systems (FRACAS) are considered early and important elements for initiating improvements by acquiring reliability data correctly and using them in a closed loop system for improvements (Mourbray, 1979).

2.5.7 Reliability indices

Reliability data can be converted into uncomplicated, figure – of – merit, performance indices. Consider these indices as yardsticks and not as micrometers. One simple, arithmetic concept, is very useful for "getting a grip" on reliability by using mean time to failure or mean time between failures derived from the summation of ages of failure divided by the number of failure, this is a simple, gross indicator of reliability (Law and Kelton, 1991).

Reliability is observed when mean time to failure (MTTF) for non –repairable items or mean time between failure (MTBF) for repairable items is long compared to the mission time. Likewise, small values for mean time indices, compared to the mission time, reflect unreliability. Reciprocals of MTBF or MTTF provide failure rates which are commonly displayed in tables for reliability data. Mean times indices are understandable to engineers but failure rates are usually better for calculations (Law and Kelton, 1991).

Accuracy of these simple indices are improved when large number of data is screened using well know statistical tools like F-test, chi-square. When only a small volume of data is available the data is best analyzed using Weibull analysis techniques to arrive at MTBE or MTTF values (Barringer, 2004).

Reliability models realistically assess system conditions when both actual failure rates and predominate failure modes are included in the calculation process by use of fault tree analysis. When combined with costs, repair times, and chance events of Monte Carlo simulations, models are very helpful for demonstrating near actual operating conditions experienced in a plant. Good simulations models help determined maintenance strategies and turnaround timing for equipment renewal.

Monte Carlo computer simulation models are usually based on simple heuristic rules. Heuristic rules are based on observed behaviour of components or systems. Heuristic rules are easy to construct using knowledge based computer systems although they cannot anticipant all potential failure events. The purpose of reliability models is to stimulate creative ideas for solving costly problems and to prevent replication of the same old problems. Reliability models offer a scientific method for studying actions, responses, and costs in the virtual laboratory of the computer using actual failure data from existing plants. Models provide a way to search for lowest cost operating conditions by predicting the outcome of conditions, events equipment (Metropolis and Stanislaw, 1949).

2.5.8 Lubricant – related failure

Proper lubrication is essential in any gearing system. Lubrication has two principal functions; to minimize rubbing friction and to carry off heat. If the lubricating film thickness is adequate and the lubricant is clean, wear will be minimized. The lubricant must sometimes provide protection against corrosion. If the lubricant fails, its internal chemical compound can break down with time, with heat or by unforeseen reactions with chemicals from its ambience. Several types of gear failure can be traced back to lubricant failure (Alan, 1991).

2.6 Maintenance

Machines, buildings and other service facilities are subject to deterioration due to use and exposure to environmental conditions. If the process of deterioration is not checked, it may render the facilities unserviceable. It is, therefore, necessary to repair and recondition them from time to time so as to enhance their life span. The important period in the life of a product or a system is the operating period. Since no product is perfect, it is for people concerned to identify the causes of failure and carry out proper maintenance. However, in some organizations, rigidity of rules and procedures prohibits the creative – thinking and implementation of proper maintenance policies.

Maintenance aspect is more important in machines due to their non-uniform pattern of wear and tear which depends on a large number of factors. Therefore, concentration will be on machine maintenance in this section.

Every machine is thoroughly tested and inspected by the manufacturers before delivery and the purchaser before it is accepted. When in use, however it will be subjected to wear and tear hence proper attention should be given to protect the machine and its components from undue wear and failure. A proper attention means lubrication, cleaning, timely inspection and systematic maintenance. Maintenance of a machine means efforts directed towards the up-keep and the repair of that machine(Wang, Liu and Chen, 2010)**.**

Every machine will require repairs even if it is best designed, hence the repair must be done at such a time when it may have least disruption, that is machine may be repaired when it is not used or its use may be postponed without affecting the production of the goods. Therefore, checking the machine is generally done when it is not in operation, so that the defect, if any, can be immediately and easily rectified without causing extensive damage.

In this way, we say that maintenance is responsible for the smooth and efficient working of equipment and helps in improving its productivity. It also helps in keeping the machine in a state of maximum efficiency at needed times with economy.

Success of any organization largely depends on proper selection of personnel for the operations. Production depends largely on the maintenance of plant and equipment. Hence, the organization of the maintenance wing should be such that a proper maintenance and overhauls, can be done economically and effectively. Maintenance wing is generally given an important position in the organization. Maintenance functions performed with their input, and accepted results as output. These outputs are controlled through different parameters and based on feedback of these parameters further controls can be applied till desired maintenance results are obtained (Tan and Raghavan, 2010).

2.6.1Evaluating maintenance performance

The following parameters should be considered while evaluating maintenance performance:

i. **Labour productivity:** Actual utilization of maintenance crew is compared with that of norms decided for the purpose.

ii. **Equipment Availability:** Considering that machine is not idle,

$$\text{Availability}=\frac{\text{Operation Time}}{\text{Operation Time} + \text{Maintenance Time}}$$

iii. **Time** spent on preventive maintenance v/s repair time

iv. **Cost Parameter.** It compares the cost of wages and material on (1) preventive maintenance, and (b) breakdown maintenance.

v. **Number of job** card (requisition for maintenance) in hand v/s job cards completed, along with the number of effective man – hours involved

vi. **Overtime analysis:** This is the ratio of overtime hours to the total maintenance hours.

vii. **Condition of equipment:** To be identified by level of maintenance like M.T.B.F., level of noise, tolerance, vibrations etc.

viii. Comparing Budgeted expenditure and actual expenditure.

ix. Percentage of maintenance cost of the value of products output.

2.6.2 Involving other department for maintenance

Maintenance is carried out to retain an item in, or restore it to, an acceptable standard of performance. The function of the maintenance department is to keep the facilities of the organization in an optimum operating condition so that the intended functions are performed satisfactorily (Zio, 2009). The aim of maintenance is to reduce the frequency and severity of failure so as to ensure the availability and efficiency of the existing plant, equipment and buildings at an optimum level. In order to make the maintenance function more effective, other departments such as design, engineering, purchasing, finance, research and development, and production should be involved. This concept of involving other departments for maintenance is termed “terotechnology”. It is concerned with the specifications and design for reliability and maintainability of plant, equipment, building with their installation and commissioning, modification and replacement, along with the feedback of information on all these aspects (Wagner, Shamir and Marks, 1987).

2.6.3 Objectives of maintenance

The main objectives of maintenance are as follows:

a. To maximize the availability of plant, equipment for productive utilization.
b. To extend the lifespan of plant/equipment by minimizing their wear and tear and deterioration.
c. To reduce the cost of loss in production due to break down.
d. To ensure safely of personnel.
e. To provide information on the cost and effectiveness of maintenance (Tam and Raghavan, 2010).

2.6.4 Overall systems performance

The overall performance of a production system is determined by the qualitative properties of the system. These properties are found in all the different components of the system in designing, the most difficult task is the balancing of the properties and costs of each of the components in order to achieve a system, which can be operated at optimal production during the calculated life time of the system.

Terms used in the above model are explained here below in brief.

1. **Overall systems performance**: This is total production and economic results over the life time of the system.
2. **Capability performance**: This is the average production per unit time.
3. **Availability performance:** This is the part of total calendar time the equipment is in such condition that it can be used for production. When the equipment is waiting for maintenance or under maintenance, it is not available for production.
4. **Operation performance.** This is the ability of the operation system to utilize the equipment capacity and availability (Xie et al 2002). Production planning and control, the personnel, safety, motivation, payment etc. have influence on the operation performance.
5. **Capacity performance.** This is the ability of equipment to produce at the rated capacity with specified product quality.
6. **Reliability performance.** This is the ability of the equipment to perform the required function when operated. If it does not meet the specification, the equipment have failured and needs maintenance. Reliability

performance is generally measured in probability of function or in mean time to failure (MTTF) or failure rate.

7. **Maintainability performance.** This is the property that determines the time for the system to be repair, and is measured in mean time to repair (MTTR) which mainly depends on the designer of the equipment.
8. **Support performance:** This is the ability of the logistic support system, or maintenance system, to provide support to the equipment when maintenance is requested. It depends on the organization of maintenance and resources e.g. personnel, tools, spare parts, instruction etc. This is measured in Mean Waiting Time (MWT) or Mean Logistics Down Time (MLDT) (Tan and Raghavan, 2008).

2.6.5 Maintenance system

Both the maintenance system and operation system are the subsystems of production system, and work with production equipment. When equipment is used, its different components are subjected to stress, resulting to wear and deterioration. This affects the condition and functioning of the component and after some time undermines the functioning and the component requires repair or replacement, so as to restore to the acceptable condition.

At the stage when the component function is no longer acceptable, the equipment is said to have failed. It is then out of operation, and maintenance activity is performed to restore the functions to an acceptable level.

Therefore the term maintenance can be defined as:

"All activities necessary to keep equipment in or restore it to a specified condition" (Zhang, 2011).

2.6.6 Failure and failure development

A component can fail in various ways, the knowledge of which is of great importance for the decision on actions i.e. either to prevent the failure to diagnose it, or to measure it. This knowledge of different failure modes play an important role in the planning of maintenance and of special tools.

2.6.7 Types of maintenance

Generally maintenance can be done in the following two ways:

- Breakdown maintenance
- Preventive maintenance

In the first case of maintenance, repair is done after the breakdown occurs, while in the second case, maintenance is done on the basis of prediction or on the basis of periodical checking.

2.6.7a Breakdown maintenance

Breakdown of a machine can occur due to the following two reasons:

(i) Due to unpredictable failure of components which cannot be prevented;

(ii) Due to gradual wear and tear of the parts, which can be eliminated to a large extent by regular inspections known as preventive maintenance. From experience, it can be decided, when a part should be replaced, so that breakdown can be avoided.

In breakdown maintenance, defects are rectified only when a machine cannot perform its function any longer, and the production department is compelled to call on the maintenance engineer for the repairs. After repairing the defect, the maintenance engineers do not attend to the machine again until another failure occurs(Salazar, Rocco and Galvan, 2006).

In this types of maintenance, repair shall have tobe done on failure, thus it disrupts the whole production. This method is much more expensive also due to increase of depreciation cost, payment to idle operations, overtime to the maintenance staff for doing the emergency repairs, and idling of matching equipment.

2.6.7b Preventive maintenance

Preventive maintenance is sometimes termed “planned maintenance,” “scheduled maintenance” or “systematic plant maintenance” (Papakos et al, 2010). It is an extremely important function for the reduction of maintenance cost and to keep good operational conditions of equipment and hence to increase the reliability. Preventive maintenance aims to locate the sources of trouble and to remove them before the breakdown occurs. Thus, it is based on the idea “preventive is better than cure.” Scheduled maintenance is always more economical than unscheduled maintenance.

The best safeguard against costly breakdown is to inspect, lubricate and checkup the equipment as frequently as possible. To make use of equipment and to maintain it in reliable condition, necessary measures should be taken to prevent overloading, dampness, negligence and misuse of machines. Frequency of inspection should be decided on the basis of the importance of the machine, wear and tear of the machine and its delicacy. The periodic inspection or checking helps to identify the reasons leading to breakdown and to rectify them, when they are at minor stages. Thus, the repair can be done when it results to, least effect on the production schedule (McEntire, 2010). Further preventive repair takes lesser time as compared to breakdown repair and thus down time is reduced.

2.6.8 Corrective maintenance

Although this is broadly a preventive maintenance but this term is gaining importance. While carrying out repair on a machine, either some minor modification work is done so that it may work little better them it was working before break-down, or some remedial action is introduced in such a way that it does not happen again, such works fall under corrective maintenance.

Whereas preventive maintenance is responsible for cleaning the equipment, lubricating to prevent wear, programmed replacement and also indirectly dealing with condition monitoring, failure statistics, and adjustments so as to limit wear. Corrective maintenance deals with normal repairs, programmed replacements, modifications to reduce requirements of maintenance and overhauls in addition to break-down repairs (Zhang, 2011).

2.6.9 Predictive or condition based maintenance

This is also used along with preventive maintenance. In this system, health of the equipment is regularly monitored and recorded in the form of mechanical vibrations, noise, acoustic, thermal emissions; changes in chemical compositions, smell, pressure, relative displacement and so on. This helps in diagnosis and detection of faults, if any. Vibrations and noise are most valuable signals. Condition monitoring can be applied in the following three ways:

(a) Qualitative checks by measuring some parameters regularly e.g failures

(b) Condition checking by measuring some parameters regularly e.g vibration.

(c) Trend monitoring by making measurements and plotting them in order to detect gradual departure from a norm (Zhang, 2011).

2.6.10 Objectives of preventive maintenance

Preventive maintenance has the following main objectives:

- To obtain maximum availability of the equipment by avoiding breakdowns and by reducing the shutdown periods to a minimum.
- To keep the machine in proper condition so as to maintain the quality of the product.
- By minimizing the wear and tear, to preserve the value of the equipment
- To ensure the safety of the workers.
- To keep the plant at maximum production efficiency.
- To achieve all the above objectives with most economical combination.

2.6.11 Functions/ elements of preventive maintenance

The following are some of the important functions of the preventive maintenance programmes:

- Inspective or check ups
- Serving including cleaning, cooling and lubrication

- Planning and scheduling
- Records and analysis
- Training of maintenance staff
- Storage of spare parts.

2.7 Analysis of various engineering reliability distribution models

In addition to the techniques discussed, here are the summaries of various engineering tools used for reliability analysis. There are different types of statistical models used in analyzing any engineering data. The accuracy of analysis depends on whether the chosen model is appropriate: choice of wrong model can lead to serious errors. Some of these statistical engineering models are:

2.7.1 Reliability analysis using Weibull distribution model

The weibull distribution model is one of the most flexible failure distributions which are widely used because it can adequately describe the reliability behaviour during the life and time of present day systems. It is used to model systems that are non repairable (Xie, Tang and Goh, 2002).

2.7.2 Reliability analysis using Weibull probability density model

The weibull probability density for failure is given as:

$$\mathbf{f(t) = \alpha\beta t^{\beta-1} e^{-\alpha\beta t}.} \qquad \textbf{When } t \geq o \qquad (2.1)$$

$f(t) = 0$ **when $t < 0$** (2.2)

When α is the scale parameter,

β is the shape parameter and

t is the length of time.

For density function, the cumulative functions is given as

$$\mathbf{F(t) = \int_{\Theta}^{t} \alpha\beta\Theta^{\beta\text{-}1e\text{-}\alpha\Theta\beta} d\Theta} \quad (2.3)$$

$$\mathbf{F(t) = 1 - {}^{e\text{-}\alpha\beta\Theta}, \text{ when } t \geq 0} \quad (2.4)$$

The reliability function is given as;

$$\mathbf{R(t) = 1 - F(t)} \quad (2.5)$$

$$\mathbf{R(t) = e\text{-}^{\alpha\Theta\beta\text{-}1}. \text{ When } t \geq 0} \quad (2.6)$$

$$\mathbf{H(t) = F(t) / R(t)}$$

$$\mathbf{H(t) = \alpha\beta t^{\beta-1}} \quad (2.7)$$

2.7.3 Reliability analysis using log normal distribution model

The log-normal distribution model is a flexible model generally used to model failure caused by degradation processes (such as wear, corrosion and mechanical fatigue), failures of electronic units. The model has been used to model stress failure mechanism, such as failure caused by rapture. The weibull distribution model may not work as effectively for systems failures that are caused by chemical reaction or a degradation process like corrosion (Harrison, 1992). Typically, these types of situations are usually modeled using the lognormal distribution model.

The probability function of lognormal function is given as:

$$\mathbf{F(t) = 1/ d2\pi \ .exp (½ (pu)^2) 1/t} \qquad \mathbf{(2.8)}$$

Where d is the standard deviation,

m is the mean value parameter

e and π are mathematical constants, equal to 2.7183 and 3.1416 respectively.

Expressing the probability function in terms of standard units. For this model, time to fail is usually associated with large uncertainty, it describe fatigue and other phenomenon that are caused by ageing or wear.

2.7.4 Reliability analysis using Chi-square distribution Model

Chi – Squared Accelerated Reliability Growth (CARG) Model has been developed as a new method for single and multi – stress level reliability growth life data analysis. The chi – squared distribution model has been as a traditional method of identifying reliability confidence bounds for the exponential failure lifetime behaviour of components assemblies, and systems and is often extended to accelerated life test data analysis. The Chi Square test (X^2) is a measure of discrepancy existing between the observed failure and the expected failures frequencies (Harrison, 1992).

The symbol $X^2$is the Greek letter Chi – square

The test was first used by Karl Pearson in the 1990. It is defined as:

$$\mathbf{X^2} = \frac{\Sigma\,(E-0)2}{E} \qquad (2.9)$$

Where O refers to the observed failure,

E is expected failures frequencies, and is given as;

The expected failure frequencies are calculated as:

$$\mathbf{E_{ij}} = \frac{RT \text{ x } CT}{N} \qquad (2.10)$$

Where E = Expected failure frequency

R_T = The total number of row containing in the cell

C_T = The total number of column containing the cell

N = The total number of observations.

2.7.5 Reliability analysis using Fisher test (variance ratio test)

The variance Ratio test is used to evaluate the impact of condition monitoring on machine component. The text is named in honor of the great statistician R.A Fisher (Jim, 2006). The objective is to find out whether two independent machines/ component systems of variance differ significant, or whether two independent machines/component systems of variance differ significant, or whether the two samples may be regarded as drawn from the normal population having the same variance (Jim, 2006).

In carrying out the test of significance, the ratio of F is calculated as:

$$F = \frac{\text{Mean square between components samples}}{\text{Mean square within components samples}} \quad (2.11a)$$

$$F = \frac{Msb}{Msw} \quad (2.11b)$$

Where, sb is the variance of components between samples

$$\mathbf{S_b = n\sum (xj - xi)^2} \quad (2.12)$$

And, sw is the variance of components within samples

$$\mathbf{S_w = (xj - xi)^2} \quad (2.13)$$

Where, Xj is the samples grand mean value

Xi is the sample means value

(k-l) is the degree of freedom between the component samples

K(n-l) is the degree of free within the component samples

2.7.6 Reliability analysis of Bayesian networks model

Based on it prior probabilities, the CPT that belong to a dependent node, such as X_3, can be calculated using Bayes theorem as;

$$P(X_3/X_1X_2) = \frac{P(X1X2/X3)P(X3)}{P(X1,X2)} \quad (2.14)$$

Equation (2.14) shows that the probability for the node X_3 is independent of nodes other than X_1 and X_2 in the system. As a result of this property the total number of computations done for calculating this probabilityisreducedfrom2n (where n is the number of nodes in the network) to 2m, where m is the number of parents for a node(and m5n). Similar to prior probability, conditional probability table CPT canal so be computed by using historical data of the system behavior. It advantage is that it does not require the assistant of human expert; it uses historical data about the system to be modeled and constructs the Bayesian Network model without need for human intervention (Gran and Helminen, 2001).Alternatively, the Bayesian method is becoming more accepted in reliability engineering. Numerous articles have discussed the reliability assessment with different data types and reliability information, which form the foundation of life cycle reliability assessment (Antonio and Hoffbauer, 2007). Ardakan and Hamadani(2014) have proposed specific methodologies to deal with subjective information in reliability assessment. Antony et al. (2005) developed hierarchical Bayesian methods for assessing system reliability with multilevel binomial data. Arvidsson and Gremyr(2008) have presented models and approaches for reliability assessment with lifetime data for different system structures subjected to various reliability information situations. Furthermore, Azaron, Katagiri, Kato and Sakawa (2005) developed a framework for estimating time-varying reliabilities with condition-state data sets. Whiteside, Pinho and Robinson (2012) presented a Bayesian updating mechanism to deal with reliability assessment with evolving, insufficient, and subjective data sets. Wang, Liu and Chen (2010) described Bayesian approaches for reliability assessment of complex systems by combining multilevel hetero-generous binomial data, lifetime data, and degradation data.

2.7.7 Reliability analysis of Bathtub curve for finite support model

Advantages for fitting a given dataset that is considered to have a bathtub failure rate estimates the reliability indices by simulating the actual process and random behavior of the system in a computer model in order to create a realistic lifetime scenario of the system.

$$\mathbf{r(t) = \beta/t + \eta + 1/\gamma - t} \qquad (2.15)$$

Failures can be distinguished as to whether they are initial (Debugging Phase), sudden (chance failure), or wear (wear – out phase), according to their "m" (shape parameter) obtained through Weibull analysis as shown below (Abernethy, 1996).In general, equipment has three patterns over time, shown by Figure 1. The graph is called bathtub curve because of its looks. In the first stage, which is called infant mortality or burn in, failure rate is decreasing over time. So up times tend to become greater, i.e., reliability growth. In the second stage which is called useful life, failure rate is constant. There is no trend, indicating a renewal process. In the final stage, which is called wear out, failure rate is increasing. So time between failures becomes smaller, showing aging trend.

Bathtub curve diagram

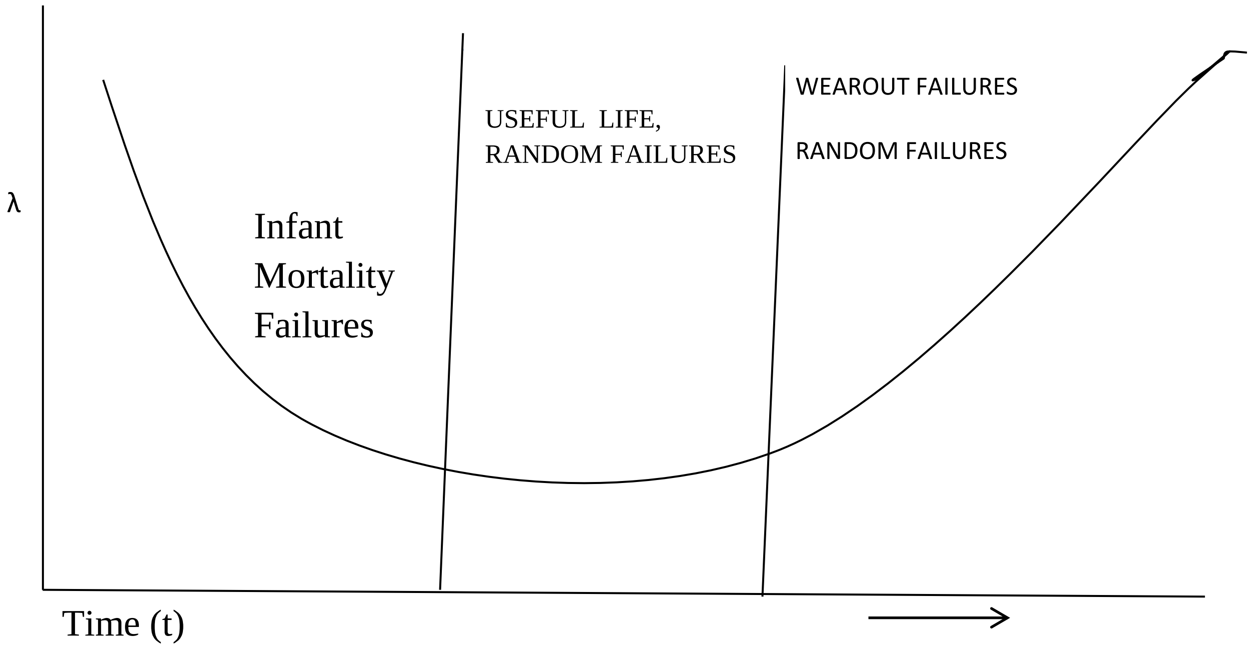

Fig 2a : Typical failure characteristics of a complex system (not to scale)

The first phase is the debugging period. The presence of marginal and short life parts at original operation is characterized by a decreasing rate of failure per time period. The next phase is characterized by a relatively constant chance failure rate period, which is the effective life of the system. While the last phase, a period of increasing failure rate which indicates the beginning of wear – out failure in the system.

The shape factor m, determines the failure rates behaviour:

i. If failure rate determines over time, then m is less than 1
ii. If failure rate is constant over time, then m is equal to 1
iii. But is failure rate increase over time, then m is greater than 1.

Also, an understanding of failure rate may provide insight as to what probably causes the failure. If m is less than 1, the distribution exhibits a degree failure rate, and the units will appear to become more reliable as they age. Hence this suggest “INFANT MORTALITY” that is defective items fails early and the failure rate decreases over time as they fallout of the population. This is a failure rate decrease over time as they fallout of the population. This is a characteristic of either manufacturing or installing faults. Constant failure rates suggest that items are failing from random events. While an increasing failure rate depicts WEAR OUT or AGE. Parts are more likely to fail as time approaches the shelf life. The reliability models for these three phases are commonly referred to as the DFR, CFR, and IFR models respectively (Allen, 2001).

2.7.8 Reliability analysis of Weibull distribution model

It is basically used for reliability of systems that got to do with wear-out phase. Summarizing, it may be beneficial when performing design of experiment studies to maximize concurrently and independently the scale and shape parameters in order to improve reliability.

$$\mathbf{R_{(t)} = \exp [(- t/n)^{B}]} \qquad (2.16)$$

2.7.9 Reliability analysis of exponential distribution model:

The exponential distribution model provides a good model for a systems that is just likely to fail any time, regardless of whether it is brand new, a year old, or several years old. For this reasons, the exponential model is used to model components that typical do not wear out until long after the expected life of the expected to show fatigue, corrosion, or wear before the expected life of the system is complete, such as ball bearing or certain laser or filament devices (Akmar andAminmaji, 2006). It is widely used in reliability it best practices are in non repairable MTTF systems. A constant failure rate model for continuously operating system lead to an exponential distribution.

The probability that is will survives to time t is given by:

$$\mathbf{R\ (t) = 1\text{-}F\ (t)} \qquad (2.17)$$

If failure rate is constant during the period of useful life of the system, denoting the constant rate by α.

The probability exponential of the system is given by:

$$\mathbf{F\ (t) = \alpha e^{-\alpha t} \qquad when\ t > 0} \qquad (2.18)$$

From equation (2.10), the reliability exponential of the system is given by:

$$\mathbf{R\ (t) = 1 - F(t)}$$

We obtain; $\mathbf{R(t) = 1 - F\ (t)}$

$$\mathbf{R\ (t) = e^{-\alpha t}} \qquad (2.19)$$

2.7.10 Reliability analysis of normal distribution model

The normal distribution, also known as the Gaussian distribution, is the most widely-used general purpose distribution. It is for this reason that it is included among the lifetime distributions commonly used for reliability and life data analysis. There are some who argue that the normal distribution is inappropriate for modeling lifetime data because the left-hand limit of the distribution extends to negative infinity. This could conceivably result in modeling negative times-to-failure. It is used in many engineering situation to represent measurement of a physical characteristic. Thus if an observation can be thought of as arising from cumulative effect of a large number of factors then the normal distribution may be appropriate. For example in machining operation the width of a groove represents the cumulative effect if a large number of small effects such as sharpness of the cutter, hardness of the materials, or temperature of a coolant. Insuch a case the use of normal distribution yields a good approximation to the determination of the groove width (Meyer, 1975).

Equation for normal reliability function is;

$$\boldsymbol{R}\,(\boldsymbol{T}) = \int_{T}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-0.5(t-\mu/\sigma\,)dt} \qquad (2.20)$$

2.7.11 Reliability analysis of extreme value distribution model

When the random variable of interest represents the occurrence of an extreme, the extreme value distribution is used. For example, the time to failure of a parallel connected circuit made of many redundant components will occur when the last of the items fails. Thus, the random variable representing the maximum time to failure of the component will describe the reliability of the circuit. On the other hand, the time of failure of a large series – connected circuit will correspond to time at which the first component fails; therefore, the random variable representing the Maximum time of failure of the component will describe the reliability of the circuit (Meyer, 1975). Extreme value equation formular is given as;

$$F(x) = 1 - \exp[-e^{x-\mu/\beta}], \ -\infty < x < \infty, \beta > 0 \quad (2.21)$$

2.7.12 Reliability analysis of gamma distribution model

This model handles system whose failure distribution is exponential. While not as frequently used for modeling life data as the previous distributions, the generalized gamma distribution does have the ability to mimic the attributes of other distributions such as the Weibull or lognormal, based on the values of the distribution's parameters. While the generalized gamma distribution is not often used to model life data by itself (Mostly due to its mathematical complexity and its requirement of large sample sizes (>30) for convergence), its ability to behave like other more commonly-used life distributions is sometimes used to determine which of those life distributions should be used to model a particular set of data.

2.7.13 Generalized gamma failure rate function

Gamma statistical background for failure rate function is given by:

$$\lambda(t) = \frac{f(t)}{R(t)} \quad (2.22)$$

2.7.14 Generalized gamma reliability function

The reliability function for the generalized gamma distribution is given by:

$$R(t) = \begin{cases} 1 - \Gamma_I\left(\frac{e^{\lambda\left(\frac{\ln(t)-\mu}{\sigma}\right)}}{\lambda^2}; \frac{1}{\lambda^2}\right) & \text{if } \lambda > 0 \\ 1 - \Phi\left(\frac{\ln(t)-\mu}{\sigma}\right) & \text{if } \lambda = 0 \\ \Gamma_I\left(\frac{e^{\lambda\left(\frac{\ln(t)-\mu}{\sigma}\right)}}{\lambda^2}; \frac{1}{\lambda^2}\right) & \text{if } \lambda < 0 \end{cases} \qquad (2.23)$$

However, for the purpose of this study, the Monte Carlo normal distribution and multi regression model are used for reliability analysis.

2.8Analysis of various engineering maintenance distribution models

2.8.1Gamma distribution for preventive maintenance.

When accurate data is not available, a Gamma distribute on is considered to be useful since it only requires estimates of average and most likely (or mode) lifetimes of a component to describe the specific failure distribution. Also in case of the gamma distribution, it captures increasing failure rates, which has been observed to be the case with most components.

The gamma function may be represented as:

$$\mathbf{f(t) = z/\Gamma(\alpha). (zt)^{\alpha -1} e^{-zt}} \qquad (2.24)$$

where t = age of unit ≥ 0

z = scale parameter = 1/ (mean - mode)

α = shape parameter = z * mean ≥ 1 This model has no economic value if mean/ mode ≥ cf/cp (Drew, 2000), where the average cost of scheduled preventive maintenance is denoted by cp and the average cost of breakdowns (including costs of downtime and possible lost sales, idle direct and indirect labor, delays in dependent processes, increased scrap and cost of repairs) is denoted by cf. The expected cost of maintenance per unit time (with preventive maintenance at age T),

C_T = Expected cost per maintenance/ expected inter-maintenance time (2.25)

= Expected cost per maintenance * expected maintenance frequency (2.26)

2.8.2 Various other models

Various other models have been developed using techniques like linear programming, non-linear programming, dynamic programming, mixed integer programming, decision theory, search techniques and heuristic approaches. The following models are briefly described in this section to explain other techniques used for maintenance modeling. Hariga (1996) has developed a general model to determine a periodic inspection schedule as part of a preventive maintenance policy for a single machine subject to random failure. The problem has been formulated as a profit maximization model with a general failure time distribution. A heuristic approach has been developed to obtain an approximate inspection schedule, when the failure times are exponentially distributed. Menipaz (1990) introduced the concept of a discounting factor to bring all future cash expenses to time, $t = 0$. The objective function considered is the expected cost per cycle when some or all cost components are variables and a discount rate is assumed. The objective function is solved using a differentiation method and a dynamic programming approach. Zuckerman (2000) developed a stochastic model to determine the optimal maintenance schedule under the following criteria: long run average cost and total expected discounted cost over an infinite horizon. The system is subject to shocks causing a random amount of damage to the system components. The research methodology uses the average opportunity loss as a driver to determine the maintenance policy. Inozu and Karabakal (1994) have formulated a model that is marine industry specific. According to the authors, the maintenance schedule in the marine industry is very complicated owing to conflicting objectives. Here a new approach to perform group (multi-item) replacement has been proposed under budget constraints (capital rationing). It considers all replacement decisions of an entire ship fleet (or all component replacements for a single ship) simultaneously. The problem has been formulated as an integer linear program. A Lagrangian methodology for the replacement problem is also presented. This has been introduced to find the dual of one of the constraints, namely, the 31 capital rationing constraints, and incorporate it into the objective function in order to solve the integer program easily. Sim and Endrenyi (2000) have developed a minimal preventive maintenance model for repairable, continuously- operating devices whose conditions deteriorate with time in service. This model is useful for devices like coal pulverizers, circuit breakers, and transformers. The preventive maintenance times are assumed to have an Erlang distribution while the failures are Poisson distributed. Deterioration failures have been considered in the model. The objective function used by the model is to minimize the unavailability of the system. Sherif (2000) developed an optimal maintenance model for life-cycle costing analysis that determines a schedule that minimizes the system's future total expected maintenance cost. This may be added to other costs like acquisition, salvage, operation costs to obtain the life-cycle cost. The equations for optimal maintenance schedule and minimum expected future cost of the system, developed in the model, are solved recursively using dynamic programming principles.

2.8.3 The Delphi approach

There are three conditions under which subjective opinion can be useful as opposed to formal forecasting methods. They are: the non-availability of historical data, the impact of external factors that are different than the factors that governed the previous development of the technology and ethical and social factors that dominate the economic and technical considerations related to the development of the technology (Sim, 2000). The Delphi process, originally developed by the Rand Corporation, consists of extracting the opinions from a group of experts, making a consolidated list of opinions, circulating the consolidated opinion among all the group members to get a revised opinion list and continue the iteration with controlled feedback. Controlled feedback helps avoid repetitive questioning on issues where consensus already exists or it helps delete controversial comments. The group is then analyzed statistically, using regression methods, graphs and other techniques to obtain the mean and deviation of opinions (Sim, 2000).

2.8.4Technology-only models

Technology-only models assume the technology to be "autonomous" or "out-of-control", that is the effect of external factors are reflected in factors internal to the technology producing system. The two growth curves known are: (i) The growth of scientific knowledge: This model explains that the growth of scientific knowledge or information on the basis of factors within the science and technology. It explains that the rate of increase of scientific knowledge is a function of information already known, the maximum that can be known in that field, the number of people working in the field, and the interaction between the researchers.

The equation is: **It = L - (L-I0) exp(-KmfN2 t/2L)** (2.27)

Where It = information available at time 't'

I0 = information available at time '0'

L = Maximum amount of information possible

N = number of researchers involved

K = constant of proportionality m = average relative productivity resulting from a transfer of knowledge as compared to a researcher working alone, that is, the average increase in knowledge of a researcher during interaction with another researcher in the same area.

f = fraction of the possible information-transferring transactions per unit time that actually take place. There are certain terms used in this model that are very subjective in nature. (ii) A universal growth curve: This model attempts to explain growth toward an upper limit on the basis of effort made by researchers.

The equation obtained is

$$\mathbf{P(f,t) = 1 - exp - [-ln(2) (c_1t + c_2)/ (ln(Y-1) + Y + c_2)]} \quad (2.28)$$

$$\mathbf{Y = (F\text{-}fc)/(F\text{-}f)} \tag{2.29}$$

where P(f,t) = probability of achieving level 'f' by time 't'.

F = upper limit of 'f'.

fc = functional capability of the competitive technology. c_1, c_2 = constants

2.8.5 The dynamic model

The dynamic model developed is as follows:

Purchased quantity at time 't',

$$\mathbf{Qt = f\,(rt, Yt, Pt, St, Tt)\ Qt = rt + b_1Yt + b_2Pt + b_3St + b_4Tt} \tag{2.30}$$

$$\mathbf{Qt = Qt\text{-}1 + rt + b_1Yt + b_2Pt + b_3\,St + b_4Tt} \tag{2.31}$$

where St = stock level at time 't'

Tt = tastes or preferences at time 't'

This is the level equation for Qt.

Similarly, the level equation for stock level has been developed.

$$\mathbf{St = St\text{-}1 + Qt - d\ EQj,\ where\ 1£\ j£\ n} \tag{2.32}$$

where d = mean value of depreciation over time in existing stocks for the same product.

n = the number of years.

2.9 Analysis of various engineering downtimes distribution models

Four machine reliability - downtimes models are Exponential, Weibull, Gamma and Log-normal. In the continuous time case, each machine is denoted as;

[f_{tup}(t),f_{tdown}(t)], where[f_{tup}(t),f_{tdown}(t)] are the pdf"s of up- and downtime, respectively. The expected value and coefficient of variation of up- and downtime, T_{up}, T_{down}, $CV_{up}$and CV_{down}, respectively.

2.9.1Exponential reliability-downtimes model

Exponential reliability model (exp), Consider a machine, which is a continuous time analogue of the geometric machine. Namely, if it is up (respectively, down) at time t, it goes down (respectively, up) during an infinitesimal time ∂t with probability λ∂t (respectively, μ∂t). The parameters λ and μ are called the breakdown and repair rates respectively. The pdf's of the up- and downtime of the machine, denoted as t_{up} and t_{down}, are as follows;

$$f_{tup} = \lambda e^{-\lambda t}, \quad t \geq 0 \tag{2.33}$$

$$f_{tdown} = \mu e^{-\mu t}, \quad t \geq 0 \tag{2.34}$$

Clearly, t_{up} and t_{down} are exponential random variables and we refer to a machine an exponential machine, i.e., obeying the exponential reliability model. In addition, it is In addition, it is easy to show that for an exponential machine

$$T_{up} = \frac{1}{\lambda} \quad , \quad T_{down} = \frac{1}{\mu} \tag{2.35}$$

$$CV_{up} = 1, \quad CV_{down} = 1 \tag{2.36}$$

$$\mathbf{e} = \frac{\mu}{\lambda+\mu} \tag{2.37}$$

2.9.2 Weibull reliability-downtimes model

Weibull reliability down model (W): Weibull distribution is widely used in Reliability Theory. For a machine obeying Weibull reliability model, its up- and downtime pdf‟s are given by:

$$f_{tup}(t) = \lambda^{\Lambda} e^{-(\lambda t)^{\Lambda}} \Lambda t^{\Lambda-1}, \ t \geq 0 \tag{2.38}$$

$$f_{tdown}(t) = \mu^{M} e^{-(\mu t)^{M}} M t^{M-1}, \ t \geq 0 \tag{2.39}$$

Where and are positive numbers. It can be calculated that for a Weibull machine.

$$CV_{UP} = \frac{\sqrt{\Gamma(1+\frac{2}{\Lambda}) - \Gamma 2(1+\frac{1}{\Lambda})}}{\Gamma(1+\frac{1}{\Lambda})} \tag{2.40}$$

$$\mathbf{CV_{down}} = \frac{\sqrt{\Gamma(1+\frac{2}{M}) - \Gamma^2(1+\frac{1}{M})}}{\Gamma(1+\frac{1}{M})} \tag{2.41}$$

2.9.3 Gamma reliability-downtimes model

Gamma reliability-downtimes model (ga): For a machine obeying the gamma reliability model, its up- and downtime pdf"s are given by gamma distribution,

$$\mathbf{f_{tup}(t) = \lambda e^{-\lambda t}\frac{(\lambda t)^{\Lambda-1}}{\Gamma(\Lambda)},} \qquad \mathbf{t \geq 0,} \tag{2.42}$$

$$\mathbf{f_{tdown}(t) = \mu e^{-\mu t}\frac{(\mu t)^{\Lambda-1}}{\Gamma(M)},} \qquad \mathbf{t \geq 0,} \tag{2.43}$$

Where,

$$\mathbf{\Gamma(x) = \int_0^{\infty} sx - 1e - sds,} \tag{2.44}$$

and ʌ and M are positive numbers. In addition, it can be calculated that for a gamma machine

$$\mathbf{T_{up} = \frac{\Lambda}{\lambda}} \tag{2.45}$$

$$\mathbf{T_{down} = \frac{M}{\mu}} \tag{2.46}$$

$$\mathbf{CV_{up} = \frac{1}{\sqrt{\Lambda}}} \tag{2.47}$$

$$\mathbf{CV_{down}} = \frac{1}{\sqrt{M}} \qquad (2.48)$$

2.9.4Log-Normal reliability-downtime model

Log-Normal reliability-down model (LN): For a machine obeying the log-normal reliability model, its up- and downtime pdf's are given by;

$$\mathbf{f_{tup}\,(t)} = \frac{1}{\sqrt{2\pi\wedge t}}\ \mathbf{e}\text{-}\frac{(in\,t-\lambda)2}{2\wedge 2}, \qquad t \geq 0, \qquad (2.49)$$

$$\mathbf{f_{tdown}\,(t)} = \frac{1}{\sqrt{2\pi M t}}\ \mathbf{e}\text{-}\frac{(in\,t-\mu)2}{2\wedge 2}, \qquad t \geq 0, \qquad (2.50)$$

Where, f_{tup} and f_{tdown} are positive numbers. In addition, it can be calculated that for a lognormal machine

2.10Analysis of various engineering quality distribution model

2.10.1 Normal and Weibull distributions

Normal distribution is the standard is standard choice for most quality control applications. The well known normal probability density fuction (p.d.f), $f_N(y)$, and cumulative density function (c.d.f), $F_N(y)$, are given below. The variable y represents measurement of the quality characteristic of interest e.g. the length of a nail.

$$\mathbf{f_N(y)} = \frac{1}{\sqrt{2\pi\sigma}}\mathbf{exp(}\text{-}\frac{(y-\mu)2}{2\sigma} \qquad (2.51)$$

$$f_N(y) \quad \int_{-\infty}^{y} f\aleph(S)ds \tag{2.52}$$

The two parameter Weibull is also considered. The Weibull has probability density function $f_W(y)$ and cumulative density function $F_W(y)$ given by:

$$f_W(y) = \frac{a}{b}y^{a-1}\exp(-[\frac{y}{b}]^a \tag{2.53}$$

$$F_W(y) = Pr(0 \geq Y \geq y) = 1 - \exp\{-[\frac{y}{b}]^a\} \tag{2.54}$$

Where the parameters aand b are called the shape and scale parameters respectively. The mean μ_W and variance σ^2_W of the Weibull are given by:

$$\mu_w = b\Gamma(1 + \frac{1}{a}) \tag{2.55}$$

$$\sigma^2_W = b2\ \{\Gamma[1 + \frac{2}{a}] - \Gamma^2(1 + \frac{1}{a})\} \tag{2.56}$$

where Γ(x) is the Gamma Function (Abramowitz and Stegun, 1980). The two-parameter Wiebull is a very flexible distribution although it is only defined for

y> 0. In most quality control applications the measurements are positive valued dimensions. For time to failure applications the parameter have a special interpretation. Namely, if a > 1, the failure rate increases with time; whereas if

a = 1, the Weibull distribution is an exponential distribution, and the failure rate decreases with time.

2.10.2 Grouped data

Define the grouping criterion as follows. Let the K interval endpoints of the step-gauge be denoted by X_j, j = 1, 2, ………K; then the probability that an observation is classified as belonging to the group j is given by

$$\boldsymbol{\pi i} = \int_{-\infty}^{\boldsymbol{x1}} \emptyset\,(\boldsymbol{y})\boldsymbol{dy} \qquad (2.57)$$

$$\boldsymbol{\pi j} = \int_{\boldsymbol{j-1}}^{\boldsymbol{x}} \emptyset\,(\boldsymbol{y})\boldsymbol{dy} \qquad \textbf{j = 2,…..,k} \qquad (2.58)$$

$$\boldsymbol{\pi\, k+1} = \int_{\boldsymbol{xk}}^{\infty} \emptyset\,(\boldsymbol{y})\boldsymbol{dy} \qquad (2.59)$$

Where Ø(y) represents the probability density function of the observations.

2.10.3 Likelihood and log-likelihood ratios

Let Q be a (k+1) column vector whose j[th] element Q_j denotes the total number of observations in a sample of size n that are classified into the jth group. Then, defining Θ as the parameter(s) of interest, the likelihood of any hypothesis about Θ, given the sample Q (Edwards, 2000):

$$\mathbf{L\,(\Theta/Q)} = \mathbf{c}\sum_{\boldsymbol{j=1}}^{\boldsymbol{k=1}} \boldsymbol{\pi\theta}\,\textbf{where}\sum_{\boldsymbol{j=1}}^{\boldsymbol{k=1}} \boldsymbol{Q} = \boldsymbol{n} \qquad (2.60)$$

c is the constant of proportionality, and $\pi\theta$ is the group propabilty that depends on the underlying distribution.

2.10.4 Weibull quality parameter

The maximum likelihood estimates for the Weibull distribution is:

$$\boldsymbol{\frac{\partial}{\partial a}\sum_{J=1}^{k+1} Q\ ln\left\langle exp\left|-\right|\frac{x-1}{b}\right\rangle - exp\left\langle -\left|\frac{x}{b}\right|a\right\rangle \quad = \quad 0} \qquad (2.61)$$

$$\boldsymbol{\frac{\partial}{\partial a}\sum_{J=1}^{k+1} Q\ ln\left\langle exp\left|-\right|\frac{x-1}{b}\right\rangle - exp\left\langle -\left|\frac{x}{b}\right|a\right\rangle \quad = \quad 0} \qquad (2.62)$$

Hwaseop and Youngju (2012) proposed a smart injection molding system framework based on real-time manufacturing data considering the characteristics of injection molding systems. Sasa and Milutinovi (2015) analyzed errors, their causes and effects by Failure modes and effects analysis in determining reliability of injection moulding system. FMEA introduces steps for their correction in case of injection molding for manufacturing numerical simulation based on Finite Element Method (FEM) performed for the early identification of the process design errors. Marco and David (2015) investigated reliability centered maintenance (RCM) methodology based on equipment reliability, which is estimated assuming that all failure modes are independent. Shivakuma (2014) used FMEA for identifying and prioritizing the probable risk associated with failures or defects in injection moulding system. Rahul (2013) analysed areas where stress can affect the failure of tie bar due to heavy weight of stationary platen the deflection or misalignment with movable platen in injection moulding system using finite element analysis and optimization.

Hao and Guoqun (2013) presented a new core-back chemical foam injection molding (CFIM) method different from the conventional method. Ercan and Ayse (2014) utilized Bees Algorithm for single-resource, multi-mode, resource-constrained mold project scheduling in order to generate a systematic approach to solve problems in injection moulding systems. Junji and Guoqun (2012)proposed a novel gas-assisted microcellular injection molding (GAMIM) method by combining the gas-assisted injection molding (GAIM) with the microcellular injection molding (MIM). Muhammad and Faiz (2013)presented previous research conducted in the field of corrosion resistance and mechanical properties of bio implants made of 316L stainless steel (SS) powder using the powder injection molding process. While Behzad and Mohammad (2014) studied injection molding process of ultrahigh molecular weight polyethylene (UHMWPE) reinforced with nano-hydroxyapatite (nHA) simulated and optimized through minimizing the shrinkage and war page of the hip liners as an essential part of a hip prosthesis. For analyzing the performance of an anode-supported solid oxide fuel cell produced using high-pressure injection molding, Jakub and Ryszard (2014) studied cell with a total thickness of 550 mm was produced in the Ceramic Department (CEREL) of the Institute of Power Engineering in Poland and experimentally analyzed in the Energy Department(DENERG) of Politecnico di Torino in Italy. Quiles and Duart (2013)reported the effect of acrylated epoxidized soybean oil (AESO) addition on the mechanical, thermal, andthermomechanical properties of polylactide (PLA) parts obtained by injection molding. Joon-Phil and Jin-Soo (2015) investigated the design of the trimodal powder feedstock and its feasibility for micro powder injection molding (μ-PIM). A novel ductility enhancing method for injection molded plastic parts was developed by Xiaofei and Hrishikesh (2015). By applying microcellular injection molding to polymer blends of proper morphology, the ductility and toughness of the molded parts was significantly improved while using less material. Fei, Yang and Cheng-Bing

(2013), reported for the first time the effects of phenol formaldehyde (PF) resin sizing modification of shortcarbon fiber (SCF) on the mechanical properties of injection molded PF-treated SCF reinforced polyethersulphone (PES) composites. Jing and Xianhu (2015) inspired by the bamboo-like structure, an efficient and simple melt sequential injection molding was proposed to fabricate a controllable skin core structure of iPP samples with self-reinforcement and toughness. Andrew and Paul (2016) investigated fabrication methods for titanium substrates exhibiting continuous micro and nano scale arrays in injection moulding system, with increasing feature heights over the length of the array are reported. Enhancing the joining strength of injection-molded polymer-metal hybrids by rapid heating and cooling, Xiping and Liu (2015) designed a variotherm injection mold and the corresponding temperature control system for metal-polymer joining. Foaming is an effective method to save material,reduce weight, and tune mechanical properties, and thus to broaden the applications of PEBA. Flexibility and scalable strategy to fabricate low-density PEBA foams via mold-opening foam injection molding was reported by Guilong and Guoqun (2016).

Pina-Estany and García-Granada (2015) investigated injection moulding system as a promising manufacturing process for obtaining cost-effective plastic parts with nanostructured surfaces. Kyung-Ran and Duck-Kyu (2016) prepared a disc-shaped porous stainless steel (PSS) support for hydrogen separation membrane via metal injection molding (MIM) method to facilitate the mass production of porous substrates. Xavier and Alex (2016) confirmed ultrasonic injection moulding as an efficient processing technique for manufacturing ultra-high molecular weight polyethylene (UHMWPE)/graphite composites. Taguchi method was applied to achieve the optimal level of ultrasonic moulding parameters and to maximize the tensile strength of the composites. Cremaa and Sorgatoa (2016) analysed the effect of Rapid Heat Cycle Molding RHCM on both microstructure and ultimate tensile strength of polypropylene reinforced with 30 wt% long glass fibers in injection molded fiber composites as an important shell-core structure. Juan, Jauregui-Beckera and Tosellob (2016) presented a software tool for automating the design of cooling systems for injection moulding and a validation of its performance. Injection moulding process simulations based on the finite element method were performed to assess the quality of the moulded parts depending on the employed cooling system design. Hopmann and Fischer (2016)describes the design, development and commissioning of an alternative plasticising unit for micro injection moulding. The magnetic field induced an anisotropic structural reinforcement that imparted to composite samples a magneto strictive feature, namely the capability to sense the magnetic field and to react with a shape change under the application of the magnetic field. Valentina and Marco (2015) investigated the combination of magneto-sensitive elastomers concept to the injection molding process. To this aim, a special mold has been designed and a preliminary rheological study has been made in order to choose the elastomer suitable for the purpose. Ana, Gemma and Angel (2015) investigated the production of smart materials such as those with magneto elastic properties such as field-dependent elastic modulus, which was estimated by subjecting the specimens to free longitudinal vibration while they remained within different magnetic fields from0 to 2000Oe by injection moulding system. Xuan-Phuong (2013) studied plastic injection molding widely used for manufacturing a variety of parts. The work reviews the state-of-the-art of the process parameter optimization approaches such as response surface model, Kriging model, artificial neural network, genetic algorithms, and hybrid approaches were used for plastic injection molding. In demonstration of pharmaceutical tablet coating process by injection molding technology, Vibha and David (2014) demonstrated the coating of tablets using an injection molding (IM) process that has advantage of being solvent free and can provide precision coat features. Focusing on injection molding processes with partial actuator failures, a new design of infinite horizon linear quadratic control was introduced by Ridong and Furong (2015). A new state space process model throughinput–output process data of injection moulding system. Furthermore, an improved infinite horizon linear quadratic control scheme, whereby the process state variables and tracking error could both be regulated separately, was proposed to show enhanced control performance against partial actuator failures and unknown disturbances. Zhang (2013) proposed a general infinite horizon linear quadratic control (LQ) design on a process with time delay in injection velocity. On the other hand, robustness issues are provided for controller designs to ensure a robust stable control system.

According to Marco and Giovanni (2014) applied artificial intelligence (AI) to replicate thermoplastic components with adequate dimensional accuracy, especially in the case of geometries with high aspect ratios in injection moulding system. Scott (2016) investigated polymer processing such as plastic injection molding, the mold cavity temperature (MCT) profile directly relates to part quality and part reject rates for optimizing the mold cooling process using real time control of MCT as it directly affect part quality. Teste Yu and Kai-Min (2015) designed cooling channels for the thermoplastic injection process by generating spiral channels for conformal cooling. Kristian and Lars (2013) studied sensors fabrication on the surface of insertion on a bridge tool for injection moulding of a component using Direct Write Thermal Spray.

Xundao and Yun (2015) focused on a dynamic control method of quality stability for turbines based on the online monitoring of variation in melt properties. Dialynas and Zafiropoulos (2005) studied failure modes, effects and criticality analysis (FMECA) of electronics system using fuzzy logic. Deeptesh and Amit (2015) represented the generic process of failure Mode Effect and Performance Enhancement for centrifugal pump failures after implementation of optimum strategies of maintenance. Cheng et al (2013) analysed the reliability of Metro Door System Based on FMECA. Atikpakpa et al (2016) evaluated failure and reliability of turbines used in Nigerian thermal plant. Faria and Azevedo (2013) evaluated the reliability of failure delayed in injection moulding systems, they handled stochastic models containing multiple processes with generalized distributions.

Ćatić (2011) carried out performance analysis of the elements of the light commercial vehicle steering tie-rod joint. Kang et al (2016) undertook engineering performance analysis on an offshore structure using the first-and second-order reliability method. Chang and He (2016) studied the failure mode, effect and Performance Analysis in Applied Electronics (AE). Marhaug et al (2016) carried out performance analysis for maintenance purposes of platform supply vessels in remote areas, their method considers functional redundancy and the consequences of loss of function as criticality criteria at the main and sub-function levels. Shivakumar(2015) implemented FMEA in Injection Moulding Process. Pancholi and Bhatt (2016) conducted multicriteria FMECA based decision-making for aluminium wire process rolling mill through COPRAS-G. Gurwinder, S. G. and Atul G. (2016) carried out multi-state component criticality analysis for reliability improvement of process plant. Lu et al (2013) carried out failure mode effects and criticality analysis (FMECA) of circular tool magazine and ATC. Ibrahim and El-Nafaty (2016) assessed the reliability of fractionator column of the kaduna refinery using Failure Modes Effects and Criticality Analysis (FMECA). Belu et al (2013) implemented Failure Mode, Effects and Performance Analysis in the production of automotive parts, this method provides improved quality and product reliability by identifying solutions and corrective actions to eliminate the failure mode or to damp the adverse effects.

Obviously, reliability is an important feature in the design and maintenance of a large-scale injection mould system, recent research has implemented various models of reliability for different process equipments, but little research has considered variance ration of failure between system components under preventive maintenance and those outside preventive maintenance. Studies that have examined reliability problems in industries have focused almost exclusively on comprehensive design for reliability measures. However, the current study specifically considered performance enhancement of an indigenous company in Nigeria utilising Monte Carlo Normal distribution to analyse the reliability and failure rate of the entire system.

2.11 Summary of literature and knowledge gap

The literatures reviewed as highlighted above on injection moulding systems indicates the lack of studies on maintenance schedules for moulding systems. The earlier injection moulding system performance enhancement may not be directly applicable in supporting scheduling maintenance for moulding systems. The challenge is in determining the appropriate set of maintenance schedules through reliability analysis. Preventive maintenance threshold was established for injection moulding systems scheduling. Monte Carlo simulation interacted with multi regression model to establish a threshold for preventive maintenance of Innoson injection moulding system. Through this reliability based threshold, appropriate maintenance of the system is guaranteed, to prevent unavailability of systems and poor quality of production thereby increasing throughput and profitability. The subsequent chapters elaborate on each of these key components.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

System reliability can be defined as the probability that a system will perform its intended function for a specified period of time under stated conditions (Jiang, 2012). This chapter describes the research methodology and reliability analysis that were implemented to assess Innoson Plastic Industries Injection Moulding System to rectify defects and discrepancies.

The research methodology used in this study is based on mixed research model, which is a combination of quantitative and qualitative approaches. The qualitative technique involves an in quiry process based on a complex structure, holistic picture, formed words and the natural setting of the industry in which the research was conducted, while the quantitative approach is an inquiry based on testing, measurement, and reliability techniques for determining the predictive relationships. This model is considered a relatively new paradigm since no work have been done before now, on the reliability of injection moulding system. It was chosen in order to achieve full potential, including benefits of mixed methodology that incorporate mechanisms to produce a holistic and detailed analysis and to provide a comprehensive investigation of the research questions (Wu and Hamada , 2012).

These benefits include the following:

- The ability to engage in both inductive and deductive reasoning.
- Allows qualitative approach to complement the result of the quantitative approach.
- Maximizes the advantages of quantitative methodologies and minimizes the demerits.
- Applies both objective and subjective points of view.
- Mixed model is pragmatic and more realistic and serves as the middle ground for positivist and constructivist theories.

The quantitative portion of this research study involved a data capture and analytical tool approach. Monte Carlo Normal Distribution model analyses were used to establish relationships among the relevant study variables pertaining to reliability of injection moulding system, while the multi regression model was developed to checkmate on points of failure and reliability. The qualitative portion of this research study utilities content analysis based on open-ended questions which involved techniques for making inferences by objectively and observation.

As shown in Figure 3a, linear process is chosen for this projects which was proposed by Baxter et al (1996). It began with the topic of the research and was able to address all the important facts of the research before terminating at the writing stage, after examining all the other means of gathering data and information as well as the research design and data analysis.

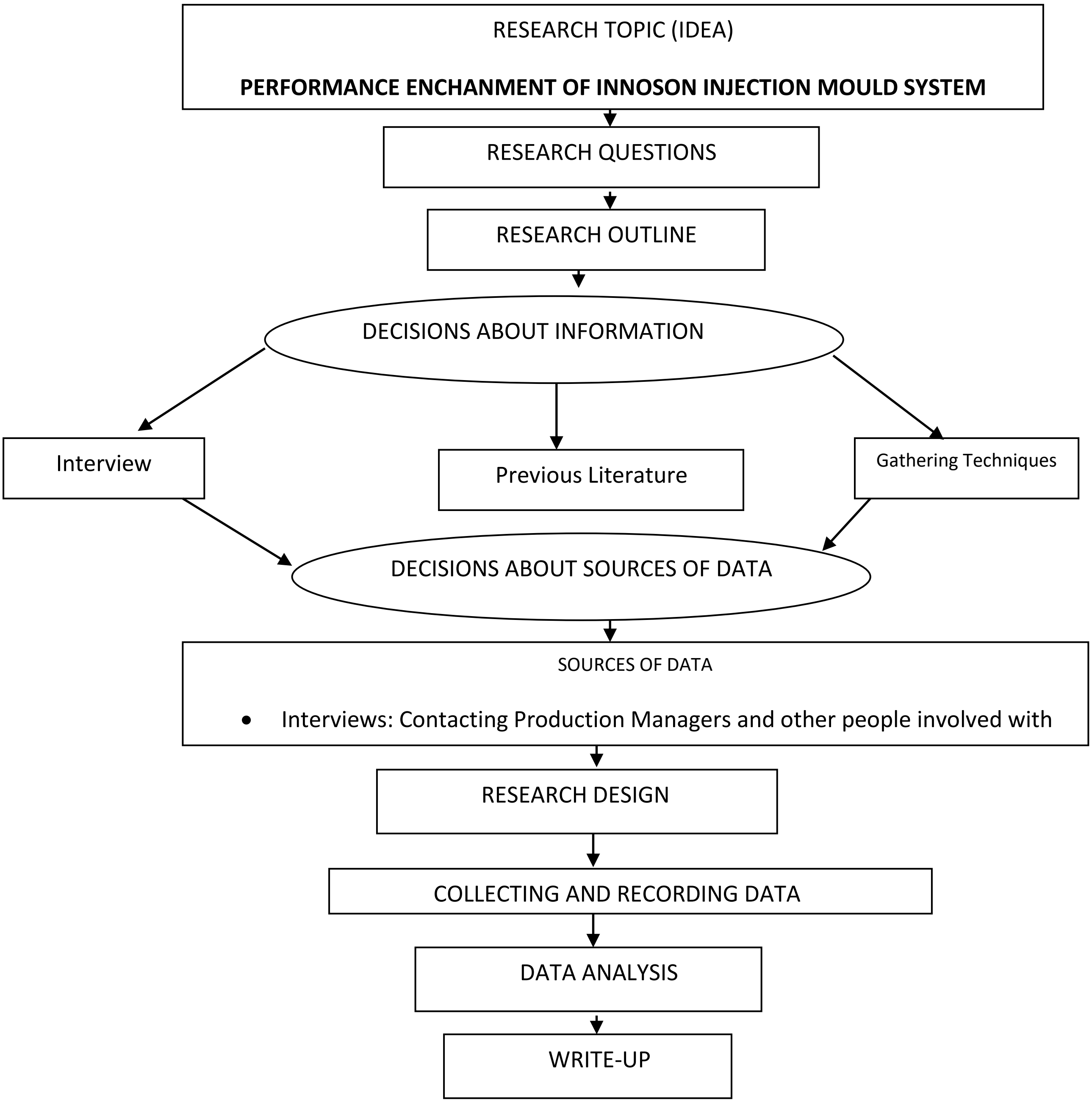

Figure 3a: The linear research process for the project. (Source: Balaxter et al 1996)

Guauri and Cronhaug (2002) stated that research is sometimes considered to be a process as it involves different types of activities which unfold over a period of time. As could be observed from Figure 3b selecting a topic of interest. The figure also shows that research requires constant updating as it progresses in order to achieve its objectives.

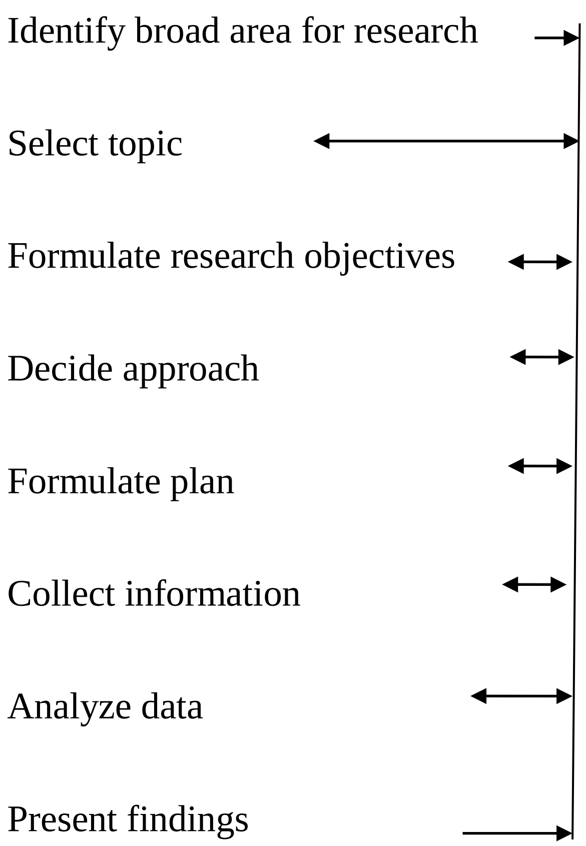

Figure 3b: The research process (Source: Gray 2004)

As embarking on a research is time consuming and always requires a lot of efforts, it is very pertinent that while choosing a research topic, efforts should always be made to select a good topic which is very interesting to the researcher, in order to avoid boredom and loss of interest during the exercise.

The broad area for this research is improved production after which it was narrowed down to the topic which is Performance Enhancement of Innoson Injection Moulding System. The topic apart from being of great interest to the author, also offers the benefit of utilizing its findings to increase personal development. The adoption of Monte Carlo Normal distribution, multi regression condition based software, Shewhart control and PASW 18 have proved to be very successful strategies, as they offer lots of advantages over traditional manufacturing method.

Furthermore, research problem where the research objectives are deduced from is not the same as the research topic, as research topic is quite more encompassing and broader. According to Ghauri and Gronhaug (2002) a distinctive question is answered when we go from more widespread research topics to a research problem, as research problem is more of a question which drives a research.

The two approaches to research are inductive and deductive. In inductive approach the researcher embarks on data collection which is properly analyzed and subsequently used to develop a theory due to little or no available literature on the topic. The second type is deductive approach which is used for this project, as a basic plan or strategy of the research, and the logic behind it, which will make possible and valid to draw more general conclusions from its. The quality of every research depends greatly on its design, an effective research design was adopted for this work which will result in acquiring the needed information, thereby answering the research questions. The set of research activities adopted for this project is shown in figure 3c.

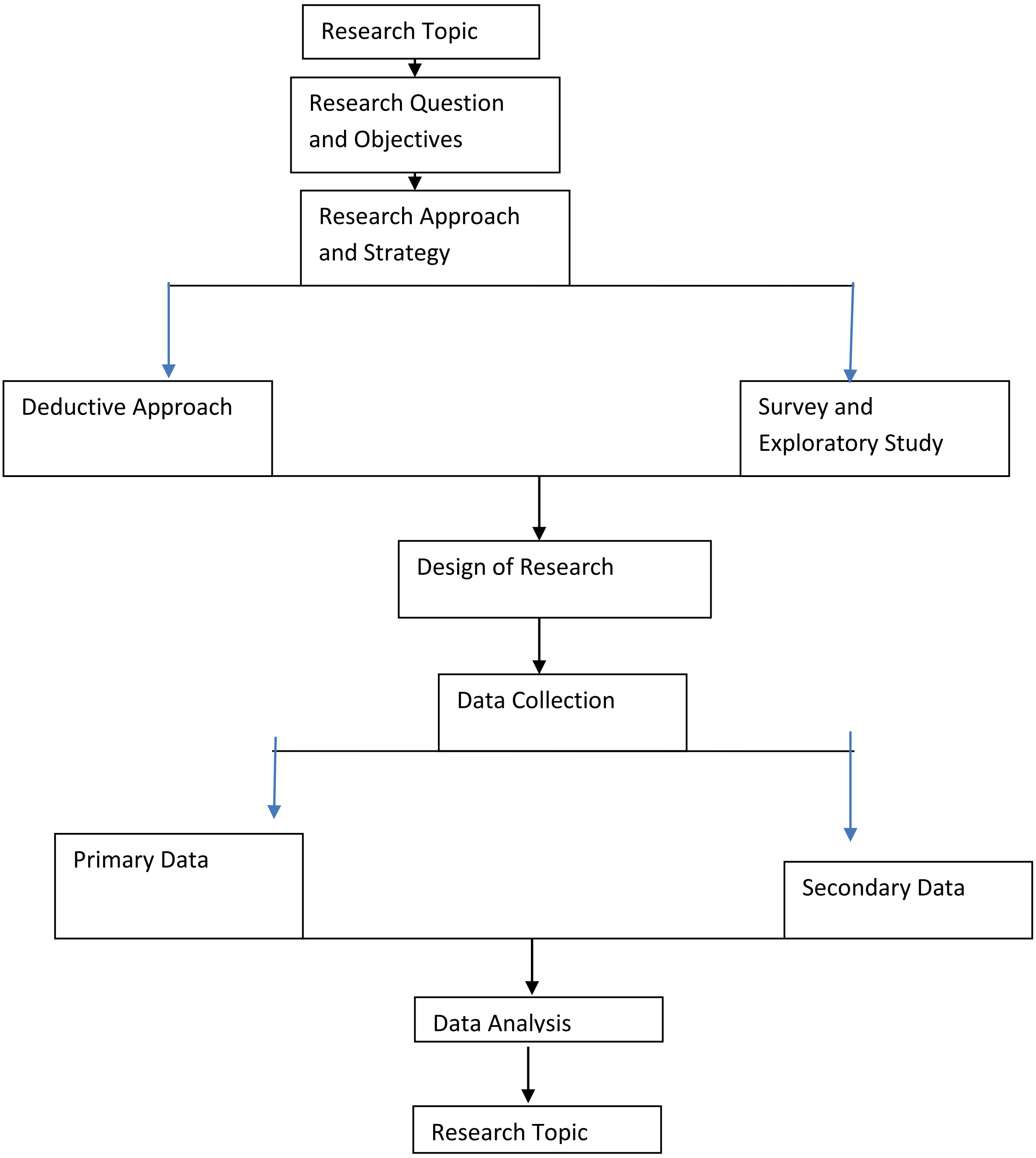

Figure 3c: The research design.

(Source: Saunders, Lewis and Thornhill, 2003)

3.2 Research methods/strategies

According to Rose and Peterson (1965) to obtain data and facts involves the use of methods/Strategies, as facts cannot be seen everywhere waiting to be picked up. Furthermore they have to be chiseled out of the unbroken web reality, observed and analyzed within a stipulated pool of information, and their size must be related to other important facts.

Saunders, Lewis and Thornhill (2003) observed that research strategy involves the process of obtaining answers to the research questions.

However, Bryman and Bell (2003) explained that research method is the act of data collection which entails the use of questionnaire, interview or the monitoring of events and activities by the researcher in order to obtain the required information. Research method/strategy can therefore be defined as the systematic data collection which is aimed at sourcing of information that will result in the answering of the research question. Due to their similarity as shown above, many authors argue that research method and strategy should be used interchangeably as they have the same objectives.

The three research methods as compared in Table 3a are quantitative qualitative and mixed methods research procedures.

Table 3a: Quantitative, quantitative and mixed research method' procedures (Source: Creswell, 2003)

Quantitative research methods	Qualitative research methods	Mixed research method
Predetermined instrument based questions	Emerging methods	Both predetermined and emerging methods
Performance data,	Open ended questions	Both open and close
Attitude data	Interview data	Ended questions
Observational data and	Observation data	Multiple forms of data
Census data	Document data, and audiovisual data	Drawing on all possibilities
Statistical analysis	Text and image analysis	Statistical and text analysis

3.2.1 Quantitative research method

The quantitative method of research develops knowledge through the adoption of post positivist claims; it involves the use of observation, experimentation and measurement to arrive at data in statistical forms. In a recent study, Grix (2004) pointed out that quantitative research method used "techniques that apply more to numeric data. Researcher develops concept or variable which can be measured, and converts it into specific data-collection techniques". He stated that the techniques "produce precise numerical information which can be understood as the empirical representation of the abstract concept."

The quantitative research method can be said to a more scientific approach as it involves systematic deductions, logical reasoning, as well as an overall analysis to obtain a data. The approach is generally used for scientific researches that require the quantification of data.

3.2.2. Qualitative research method

According to Grix (2004) qualitative research investigates in-depth knowledge through the participating of the researcher who adopts interviewing and observation techniques, the study of ethnography or documentary analysis. He explained that this method involves, but does not solely rely on numerical measurements.

The qualitative method of research is based on the skills and intuition of the researcher who has to employ his or her knowledge to explain and describe the chosen research topic through the sequential flow of information.

3.2.3 The research method for the project

The generally agreed two research methods are the quantitative and qualitative research approaches. However, in a recent study, Creswell (2003) argued that mixed research method is the third approach to research, he stated that it "employs strategies of inquiry that involve collecting data either simultaneously or sequential to best understand research problems. He pointed out that the data collection "also involves gathering both numeric information as well as text information so that the final database represents both quantitative and qualitative information."

To obtain a well balanced result, mixed methods research procedure was adopted for this work in order to achieve a well-balanced research as it involves both text and statistical analysis. While utilizing the mixed methodology in the overall research of the study, the method adopted in the context of reliability of production system is modeling and simulation based on discrete event systems. A model is the body of information about a system gathered for the purpose of studying the system. The information gathered in this work were mainly reliability, failure rate, downtime cost and default production parameters. Hence the method of modeling and simulation was used which is based on Monte Carlo Normal distribution model that interacted with multi regression model. These models combine the advantages of a practical approach with the rigor of a formal method, in which one consistently uses models throughout the reliability and failure rate cycle.

3.3 Method of data collection and analysis

There are various methods of data collection, but for this work, data were obtained for injection moulding system for a period of ten (10) years from the production and maintenance manager in Innoson Plastic Industries, Enugu, Enugu State. Reliable data are needed to build strong reliability, and injection moulding system is no exception. In analyzing the reliability and maintenance of injection moulding system, Monte Carlo Normal Distribution Simulator and multi regression model were used in this research. These softwares, employ the use of tables, graphs, standard formulae and models as an exploratory method intended to discover what the data seemed to be saying by using simple arithmetic to summarize the data. The data were extracted from the written records of failure kept by the maintenance personnel during each day. The records included the failures that occurred during the day, the action taken, the downtime, but the exact time of failure, that is the accuracy of computing the mean time between failures (MTBF) of a particular system is in order of 8 – hours shift. The data selected have relationship with the reliability of injection moulding system. These relationships are explained more fully later in the dissertation.

3.4 Data analysis of reliabilityand preventive maintenance parameters

Monte Carlo Simulator, Monte Carlo Normal Distribution model and multi regression models were used to evaluate the assumptions of each component, and evaluating the reliability and failure rates of the individual components to get the entire system reliability and failure rate of the injection moulding system. Baumgarterner (2012) in condensed matter physics used Monte Carlo, Family and Landau (2012) in kinetics of aggregation and gelation maintenance and Landau and Binder (2014) in a guide to Monte Carlo simulations in statistical physic, used Monte Carlo simulation due to its vast advantages.

3.5 The number of failure

The number of failure for the various systems were determined by going through the maintenance record book. These failures were based on the corrective maintenance records for the period under ten years consideration as in the maintenance records, the mean time between failure (MTBF).

3.6 The Mean Time Between Failure (MTBF)

The MTBF was computed from the available data. It is the study interval hour divided by the number of failure for a particular system. This is done for each component of the system.

$$\text{MTBF} = \frac{\text{Study Interval}}{\text{Number of failure}} \quad (3.1)$$

In some cases, it is the ratio of the operating time of the restorable system component to the number of failures during this time.

$$\text{MTBF} = \frac{\text{Operating Time}}{\text{Number of failure}} \quad (3.2)$$

3.7 Determination of Failure Rate (FR)

There are two methods of determining failure rate. In the first method, failure data for a comparable system or component already are used. This method assumes that the system in use is comparable to the new system and that the principles of transferability applies – this principle states that failure data from one system can be used to predict the reliability of a comparable system. The second method is through testing or examining the actual operating data of the system or its component. Both methods were used in the analysis. The failure rate is the inverse of the MTBF.

$$\text{Failure rate} = (\text{MTBF})^{-1} \quad (3.3)$$

$$\text{Failure rate} = \frac{\text{Number of failures}}{\text{Operating time}} \quad (3.4)$$

3.8 Equipment availability

Availability is the probability of the system being in the state of operation except when operation is not expected. Is the degree to which the system is ready to work or being in the working condition when required. It is also defined as the proportion of time during which equipment is available for use.

3.9 System reliability

The reliability of the equipment is the negative power of the natural – log of the value of the number of failure per year. The number of failure per year is obtained by dividing the number of failure for the entire years by the number of years under consideration.

3.10 Monte Carlo normal distribution model

A MonteCarlosimulationmethodhasbeenchosenfor the prediction ofthereliabilityofcompositesasthistechnique will allow theabilitytoeasilymakechangestothemodelsandtoallow systems reliabilityandcovariancetobeaddedin future models. The Monte Carlo method has three main steps:

- Generate a randomly distributed set of input variables.
- Perform calculations based on these to find out variables.
- Determine probability from a large number of repetitions.

A number of simulations were run for each set of statistical distributions resulting to a given reliability for that component and the system technique used. The number of simulations is calculated from the Monte Carlo Simulation that models increasing failure rates with the system age.

The Monte Carlo simulation generates random reliability and failure rates that fall within the normal distribution range from the historical 10 years data.

3.10.1 Reliability calculation for individual component

$$\boldsymbol{\psi}(\text{ʁ}) = \frac{\boldsymbol{\psi}\mathbf{1} + \boldsymbol{\psi}\mathbf{2} + \boldsymbol{\psi}\mathbf{3}\ldots\ldots\ldots\ldots\ldots\ldots\boldsymbol{\psi}\text{ʁ}}{\text{ƛȣ}} \qquad (3.5)$$

$$\boldsymbol{\psi}(\text{ʁ}) = \frac{\text{ƛȣ}\ \boldsymbol{\psi}\text{ʁ}}{\text{ƛȣ}} \qquad (3.6)$$

Where $\boldsymbol{\psi}(\text{ʁ})$ is reliability for individual components.

ƛȣ issum of all reliability rate, generated in simulation based on number of iterations ran. That is the sum of all reliability generated in simulation (20,000) randomly generated reliability within distribution based on the 10 years time series.

For example, calculate the Monte Carlo simulation generated reliability rate for each component based on the example of 5 iterations, given as follows:

Reliability generated 0.761, 0.663, 0.747, 0.975, 0.920

ƛȣ= 0.761 + 0.663 + 0.747 + 0.975 + 0.920 = 3.797

N = 5 iterations

$\boldsymbol{\psi}$(ʁ)= 3.797/5 = 0.809

The system failure rate likewise is the sum of the components failure rates.

3.10.2Reliability calculation for DT series system

DR_T = Hydraulic P(u) * Injection P(u) * Control P(u) * Mold P(u) * Clamping P(u)   (3.7)

$$\sum_{i=1}^{m} cf(j) = c\sum_{i=1}^{m} f(j)\sum_{i=1}^{m} f(j) + g(1) = \sum_{i=1}^{m} cf\ (j) = \sum_{i=1}^{m} g(j) \tag{3.8}$$

$$\sum_{i=1}^{m} 1 = 1 + 1 + 1 + \cdots + 1 + m\sum_{i=k}^{m} 1 + m - k + 1 \tag{3.9}$$

$$\sum_{i=1}^{m} i = 1 + 2 + 3 + \ \ldots + m \ = m(m + 1) = 2m + 0(m) \tag{3.10}$$

$$\sum_{i=1}^{m} i2 == 1 + 2 + 3 + \cdots + m = m(m + 1)(2m + 1) = m3 + m2 \tag{3.11}$$

Where DR_T is total reliability of all the individual components for the series system.

Also, reliability for Hydraulic is $R_{1,}$ that of Injection is $R_{2,}$Control is $R_{3,}$ Mould is $R_{4,}$ and Clamping is R_5

Therefore, total reliability of all the individual components for the series system is;

$$\mathbf{y_r = a_0 + a_1x_{i1} + a_2x_{i2} + a_3x_{i3} + \ldots\ldots + a_px_{ipi} = 1,2,\ldots.5} \quad (3.12)$$

where yr denote reliability rate in unit per month of the injection mould system.

x_{i1}, x_{i2}, x_{i3}, x_{i4} and x_{i5}denote the input component variables of the system.

a_0, a_2, a_3, a_4 and a_5 are the fixed but unknown estimators of the independent variables or the constant coefficient estimators.

x_{i1}= Hydraulic unit/Month

x_{i2} = Injection unit/Month

x_{i3}= Control unit/Month

x_{i4}=Mould unit/Month

x_{i5}= Clamping unit/Month

3.10.3 Monte Carlo simulation model for individual component (effective improvement tool)

The model software MCS, uses models of this form:

$$ {}_1^nYr = \partial\lambda ʒ\left\lfloor \frac{dy}{dx}\nabla x1 - \frac{dy}{dx}\nabla xn \right\rfloor + \frac{dy}{dx}\nabla xnr \quad (3.13)$$

Where ${}_1^nYr$ is the Reliability of the individual components in the injection moulding system.

$\partial\lambda ʒ\left\lfloor \frac{dy}{dx}\nabla x1 - \frac{dy}{dx}\nabla xn \right\rfloor + \frac{dy}{dx}\nabla xnr$ is random selection of the historical data for reliability of the system, within the 20,000 runs of the simulator.

$$ {}_1^nYf = \partial\lambda ʒ\left\lfloor \frac{dy}{dx}\nabla x1 - \frac{dy}{dx}\nabla xn \right\rfloor + \frac{dy}{dx}\nabla xnf \quad (3.14)$$

Where ${}_1^nYf$ is the failure of the individual components in the injection moulding system.

$\partial\lambda ʒ\left\lfloor \frac{dy}{dx}\nabla x1 - \frac{dy}{dx}\nabla xn \right\rfloor + \frac{dy}{dx}\nabla xnf$ is random selection of the historical data for failure rate of the system, within the 20,000 runs of the simulator

3.10.4.System failure calculation for individual components

$$\Phi_{(ʃ)} = \frac{\phi\, 1 + \phi\, 2 + \phi\, 3 \,\ldots\ldots\ldots\, \phi ʃ}{ʧ} \quad (3.15)$$

$\phi_{(f)} \quad = \quad \text{ff}\phi_{f} / \text{ff}$ (3.16)

3.10.5 Sequential models

$$\coprod_{i=1}^{HR_t} k = \nabla p_1 \nabla p_2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \nabla pn = e^{-i\omega t} \quad (3.17)$$

$$\coprod_{i=1}^{IR_t} k = \nabla p_1 \nabla p_2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \nabla pn = e^{-i\omega t2} \quad (3.18)$$

$$\coprod_{i=1}^{CR_t} k = \nabla p_1 \nabla p_2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \nabla pn = e^{-i\omega t3} \quad (3.19)$$

$$\coprod_{i=1}^{MR_t} k = \nabla p_1 \nabla p_2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \nabla pn = e^{-i\omega t4} \quad (3.20)$$

$$\coprod_{i=1}^{MR_t} k = \nabla p_1 \nabla p_2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \nabla pn = e^{-i\omega t4} \quad (3.21)$$

3.10.6 Series system non linear models

$Y_{iR} = f(x, a_0, a_1, \ldots\ldots\ldots\ldots am) + e_{iR}$ (3.22)

Y_{iR} = Dependent variable

$f(x, a_0, a_1, \ldots\ldots\ldots\ldots am)$ = Independent variable

e_{iR} = a random error for every reliability iteration

$Y_{if} = f(x, a_0, a_1, \ldots\ldots\ldots\ldots am) + e_{if}$ (3.23)

Y_{if} = Dependent variable

$f(x, a_0, a_1, \ldots\ldots\ldots\ldots am)$ = Independent variable

e_{if} = a random error for every failure rate iteration.

3.11 Multi regression model

Multi regression model schedule maintenance for reliability and failure rates:

$\varphi ɤ = \alpha 0 + \alpha 1 \beta ɤ 1 + \alpha 2 \beta ɤ 2 + \alpha 3 \beta ɤ_3 + \ldots <= 0.3$ (3.24)

Forecast model for reliability is;

$\varphi ɤ = \alpha 0 + 0.0001 \beta ɤ 1 + 0.0003 \beta ɤ 2 + 0.0002 \beta ɤ_3 + 0.0001 \beta ɤ 4 + 0.01 \beta ɤ 5 + \ldots\ldots <= 0.3$

(3.24) $\varphi ɹ = \alpha 0 + \alpha 1 \beta ɹ 1 + \alpha 2 \beta ɹ 2 + \alpha 3 \beta ɹ_3 + \ldots >= 0.02$ (3.25)

Forecast model for failure rate is;

$\varphi ɹ = \alpha 0 + 0.002 \beta ɹ 1 + 0.001 \beta ɹ + 0.001 \beta ɹ_3 + 0.002 \beta ɹ_4 + 0.001 \beta ɹ_5 + \ldots >= 0.02$ (3.25)

$\psi_n = \mu (\psi \sigma_n <= 0.3, \psi \sigma_n + \psi \nabla_n, \psi \sigma_n)$ (3.26)

$\Omega_n = \Omega (\Omega \Theta_n >= 0.02, \Omega \Theta_n - \Omega \nabla_n, \Omega \Theta_n)$ (3.27)

Where ψ_n is reliability and $(\psi \sigma_n <= 0.3, \psi \sigma_n + \psi \nabla_n, \psi \sigma_n)$ is the highest and lowest reliability distribution.

$\Omega_n$is failure rate, while ($\Omega\Theta_n$ >=0.02, $\Omega\Theta_n$ - $\Omega\nabla_n$, $\Omega\Theta_n$) is the highest and lowest distribution.

3.11.1 Schedule maintenance of reliability for individual components

Multi regression model schedule maintenance for individual reliability

$$\varphi ꓤH = \alpha 0 + \alpha 1\beta ꓤH1 + \alpha 2 \beta ꓤH2 + \alpha 3\beta ꓤH_3 + \ldots <= 0.3 \quad (3.28)$$

$$\varphi ꓤI = \alpha 0 + \alpha 1\beta ꓤI1 + \alpha 2 \beta ꓤI2 + \alpha 3\beta ꓤI_3 + \ldots <= 0.3 \quad (3.29)$$

$$\varphi ꓤC = \alpha 0 + \alpha 1\beta ꓤC1 + \alpha 2 \beta ꓤC2 + \alpha 3\beta ꓤ_{C3} + \ldots <= 0.3 \quad (3.30)$$

$$\varphi ꓤM = \alpha 0 + \alpha 1\beta ꓤM1 + \alpha 2 \beta ꓤM2 + \alpha 3\beta ꓤM_3 + \ldots <= 0.3 \quad (3.31)$$

$$\varphi ꓤL = \alpha 0 + \alpha 1\beta ꓤL1 + \alpha 2 \beta ꓤL2 + \alpha 3\beta ꓤL_3 + \ldots <= 0.3 \quad (3.32)$$

3.11.2Condition based reliability software interpretation

$$\psi_{nH} = \mu\ (\psi\sigma_{nH} <=0.3, \psi\sigma_{nH} + \psi\nabla_{nH}, \psi\sigma_{nH}) \quad (3.33)$$

$$\psi_{nI} = \mu\ (\psi\sigma_{nI} <=0.3, \psi\sigma_{nI} + \psi\nabla_{nI}, \psi\sigma_{nI}) \quad (3.34)$$

$$\psi_{nC} = \mu\ (\psi\sigma_{nc} <=0.3, \psi\sigma_{nc} + \psi\nabla_{nc}, \psi\sigma_{nc}) \quad (3.35)$$

$$\psi_{nM} = \mu\ (\psi\sigma_{nM} <=0.3, \psi\sigma_{nM} + \psi\nabla_{nM}, \psi\sigma_{nM}) \quad (3.36)$$

$$\psi_{nL} = \mu\,(\psi\sigma_{nL} <= 0.3,\ \psi\sigma_{nL} + \psi\nabla_{nL},\ \psi\sigma_{nL}) \qquad (3.37)$$

3.11.3 Schedule maintenance of failure rate for individual components

$$\varphi ℲH = \alpha 0 + \alpha 1\beta ℲH1 + \alpha 2\,\beta ℲH2 + \alpha 3\beta ℲH_3 + \ldots >= 0.02 \qquad (3.38)$$

$$\varphi ℲI = \alpha 0 + \alpha 1\beta ℲI1 + \alpha 2\,\beta ℲI2 + \alpha 3\beta ℲI_3 + \ldots >= 0.02 \qquad (3.39)$$

$$\varphi ℲC = \alpha 0 + \alpha 1\beta ℲC1 + \alpha 2\,\beta ℲC2 + \alpha 3\beta ℲC_3 + \ldots >= 0.02 \qquad (3.40)$$

$$\varphi ℲM = \alpha 0 + \alpha 1\beta ℲM1 + \alpha 2\,\beta ℲM2 + \alpha 3\beta ℲM_3 + \ldots >= 0.02 \qquad (3.41)$$

$$\varphi ℲL = \alpha 0 + \alpha 1\beta ℲL1 + \alpha 2\,\beta ℲL2 + \alpha 3\beta ℲL_3 + \ldots >= 0.02 \qquad (3.42)$$

3.11.4 Linear maintenance multi regression model

$$y_r = b_0 + b_1x_{i1} + b_2x_{i2} + b_3x_{i3} + b_4x_{i4} + b_5x_{i5} \ldots <= 0.3 \qquad (3.43)$$

i=1,2,3……5

Where yr denotes reliability rate for preventive maintenance in unit per month of the Injection mould system.

x_{i1}, x_{i2}, x_{i3}, x_{i4} and x_{i5}denotes the input component variables of the system.

b_0, b_2, b_3, b_4 and b_5 are the fixed but unknown estimators of the independent variables. While 0.3 is the fixed preventive maintenance factor developed.

3.11.5 Condition based failure rates software interpretation

$$\Omega_{nH} = \mu\,(\Omega\Theta_{nH} >= 0.02,\ \Omega\Theta_{nH} - \Omega\nabla_{nH},\ \Omega\Theta_{nH}) \tag{3.44}$$

$$\Omega_{nI} = \mu\,(\Omega\Theta_{nI} >= 0.02,\ \Omega\Theta_{nI} - \Omega\nabla_{nI},\ \Omega\Theta_{nI}) \tag{3.45}$$

$$\Omega_{nC} = \mu\,(\Omega\Theta_{nC} >= 0.02,\ \Omega\Theta_{nC} - \Omega\nabla_{nC},\ \Omega\Theta_{nC}) \tag{3.46}$$

$$\Omega_{nM} = \mu\,(\Omega\Theta_{nM} >= 0.02,\ \Omega\Theta_{nM} - \Omega\nabla_{nM},\ \Omega\Theta_{nM}) \tag{3.47}$$

$$\Omega_{nL} = \mu\,(\Omega\Theta_{nL} >= 0.02,\ \Omega\Theta_{nL} - \Omega\nabla_{nL},\ \Omega\Theta_{nL}) \tag{3.48}$$

3.12Downtime cost efficiency improvement tool (PASW 18)

1. First have to upload your data with the necessary variables for the forecasting.

2. From the menus choose:

Analyze

Forecasting

Sequence Charts.

3. Select the variables you want and move it into the Variables list.

► Select Date and move it into the Time Axis Labels box.

► Click OK.

4. From the menus choose:

Analyze

Forecasting

Create Models

5. Select independent variables for dependent variable

6. Click on criteria.

7. Deselect Expert Modeler considers seasonal models in the Model Type group

8. Click Continue.

9. Click the Options tab on the Time Series Modeler dialog box.

10. Select First case after end of estimation period through a specified date in the Forecast Period group, you select the year by what month interval you want the forecast.

11. Click the Save tab.

12. Select (check) the entry for Predicted Values in the Save column, and leave the default value Predicted as the Variable Name Prefix.

13. Click the Browse button on the Save tab.,, This will take you to a standard dialog box for saving a file.

14. Click the Statistics tab., Select Display forecasts.

15. Click the Plots tab. Deselect Series in the Plots for Individual Models group…………… Select Mean absolute percentage error and Maximum absolute percentage error in the Plots for Comparing Models group.

16. Click OK in the Time Series Modeler dialog box equals the Result.

3.12.1 Model for estimating downtime cost

PASW 18 software uses model of this form:

$$\mu = MOD\_\beta MUL \quad (3.49)$$

where μ is the estimated downtime cost, MOD_β represent the downtime cost of the IMM which is the dependent variable

Linear Trend Model for Downtime cost:

$$Y_t = 54.283 + 0.170*t \quad (3.50)$$

3.13Models for Statistical Process Control (SPC),productivity improvement tool

The X, R and S charts were usedfor quality characteristics variables. They were used:

(a) To establish whether the process is in statistical control or not.

(b) To determine if the process capability are compatible with the specifications.

(c) To detect trends in the process so as to assist in planning adjustment and resetting of the process.

(d) To show when the process is likely to be out of control.

For $\overline{X}$ Chart

Upper Control Limit, $UCL_{\overline{X}} = \overline{X} + A_2\overline{R}$ (3.51)

Lower Control Limit $LC_{\overline{X}} = \overline{X} - A_2\overline{R}$ (3.52)

For R Chart

Upper Control Limit, $UCL_R = D_4R$ (3.53)

Lower Control Limit $LC_R = D_3R$ (3.54)

For S Chart

Upper Control Limit, $UCL_S = \frac{B_4S}{2}$ (3.55)

Lower Control Limit $LC_S = \frac{B_3S}{2}$ (3.56)

Where $\overline{X}$, R and S Charts are control charts for variables. While A_2, B_3, B_4, D_3, and D_4 are obtained fromStatistical Quality Control tables. (Laplante, Philip, 2005).

Using control charts for monitoring of the process is called statistical process control (SPC).

Calculation of control limits (2014)

(a) Average of all X values X = 4.8

(b) Average of Range R = 3.92

(c) Variance = $\frac{\sum(X-x)2}{n-1}$ = 462

So the Variance S = 462

(i) Using mean (X chart)

Applying the formular,

UCL = Upper control limits

$= X + A_2R$ (3.51)

LCL = Lower control limits

$= X - A_2R$ (3.52)

Where,

X is the average of all x values = 4.8

R is the average of Ranges = 3.92 and A_2 is the factor dependent on the sample size n = 5.

A_2 from control chart (n= 5) = 0.577 substituting A_2 into equations (3.51) and (3.52),

For UCL = $X + A_2 R$

Upper control limits = 7.06

For LCL = $X - A_2R$

Lower control limits = 2.54

(ii) For variables Ranges (R-Chart)

Applying the formula,

For UCL = D_4R (3.53)

LCL = D_3R (3.54)

Where D_3 and D_4 are values of n = 5 obtained from control chart 2, while R is the average of Ranges.

Therefore, D_3 (n=5) = 0

D_4 (n=5) = 2.114

R = 3.92

Substituting the values into equation (3.53) and (3.54)

For UCL = D_4R

Upper control limit = 8.2868

For LCL = D_3R

Lower control limits = 0

(iii) Using Variance (S chart)

Applying the formular,

$$UCL = B_4 \ X \ \frac{S}{2} \qquad (3.55)$$

$$LCL = B_3 \ X \ \frac{S}{2} \qquad (3.56)$$

Since variance is the square of standard deviation,

Where B_3 and B_4 are values of n = 5, obtained from control chart 2. While S is the variance. Substituting the values into equation (3.55) and (3.56)

For UCL = 501.3

Upper control limit = 501.3

LCL = 0

Lower control limit = 0

Calculation of control limits (2012)

(a) Average of all X values = 43.6
(b) Average of Range R = 4.167
(c) Variance = $\frac{\sum(X-x)2}{n-1}$

So the variance S = 33232.6

(i) Using mean (X Chart),

Applying the formular,

$$UCL = X + A_2R \qquad (3.51)$$

$$LCL = X - A_2R \qquad (3.52)$$

Where,

X is the average of all X values

= 43.6

R is the average of Ranges = 4.167 and A_2 is the factor dependent on the sample size n =5,

A_2 from control chart (n=5) = 0.5777

Substituting A_2 into equations (3.51) and (3.52)

For UCL = X + A_2R

Upper control limits = 46.00

For LCL = X - A_2R

Lower control limits = 41.20

(ii) For variables Range (R-chart), applying the formular,

For UCL = D_4R (3.53)

LCL = D_3R (3.54)

Where D_3 and D_4 are values of n=5 obtained from control chart 2, while R is the average of Ranges.

D_3 (n= 5) = 0

D_4 (n=5) = 2,114

R = 4.167 (Calculated)

Substituting the values into equation (3.53) and (3.54)

For UCL = D_4R

Upper control limits = 8.809

For LCL = D_3R

Lower control limits = 0

$$UCL \;=\; B_4 \; X \;\; \frac{S}{2} \tag{3.55}$$

$$LCL \;=\; B_3 \; X \frac{S}{2} \tag{3.56}$$

Since variance is the square of standard deviation where B_3 and B_4 are values of n = 5 obtained from control chart 2. While S is the variance. Substituting the values into equation (3.55) and (3.56).

For UCL, Upper control limits= 31929.7

LCL, Lower control limits = 0

3.14 Matlab time series for system validity

YEAR, FE2004, MA2004, AP2004, MY2004, JN2004, JY2004, AG2004, SP2004, OC2004, NV2004, DM2004,

HYDRAULIC SYSTEM R_{1}, 0.600, 0.600, 0.600, 0.600, 0.992, 0.992, 0.994, 0.994, 0.993, 0.993, 0.992,

HYDRAULIC SYSTEM λ_{1},0.015, 0.015, 0.015, 0.015, 0.012, 0.012, 0.014, 0.014, 0.014, 0.014, 0.012,

INJECTION SYSTEM R_{2},0.700, 0.700, 0.700, 0.700, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.900,

INJECTION SYSTEMλ_{2}, 0.008, 0.008, 0.008, 0.008, 0.012, 0.012, 0.012, 0.012, 0.012, 0.012,

0.012,

CONTROL SYSTEM R_3 0.600, 0.600, 0.600, 0.600, 0.992, 0.992, 0.994, 0.994, 0.993, 0.993, 0.992,

C0NTROL SYSTEMSλ_3 , 0.015, 0.015, 0.015, 0.015, 0.012, 0.012, 0.014, 0.014, 0.014, 0.014, 0.012

MOLD SYSTEM R_4, 0.700, 0.700, 0.700, 0.700, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.900

MOLD SYSTEM λ_4 0.008, 0.008, 0.008, 0.008, 0.012, 0.012, 0.012, 0.012, 0.012, 0.012,

0.012, CLAMPING SYSTEM R_5 0.500, 0.500, 0.500, 0.500, 0.992, 0.992,0.994, 0.994, 0.993,

0.993, 0.992,

CLAMPING SYSTEM λ_5 0.013, 0.013, 0.013, 0.013, 0.012, 0.012, 0.014, 0.014, 0.014, 0.014, 0.012,

YEAR , JA2005, FE2005, MA2005, AP2005, MY2005, JN2005, JY2005, AG2005, SP2005, OC2005, NV2005, DM2005,

HYDRAULIC SYSTEM R_1, 0.992, 0.994, 0.994, 0.994, 0.993, 0.992, 0.991, 0.991, 0.992, 0.990, 0.990, 0.990,

HYDRAULIC SYSTEM λ_1, 0.012, 0.014, 0.014, 0.014, 0.014, 0.012, 0.010, 0.010, 0.012, 0.010, 0.010, 0.010,

INJECTION SYSTEM R_2 0.900, 0.900, 0.900, 0.900, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850,

INJECTION SYSTEM λ_2 0.012 , 0.012, 0.012, 0.012, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003,

CONTROL SYSTEM R_3 0.992, 0.994, 0.994, 0.994, 0.993, 0.992, 0.991, 0.991, 0.992, 0.990, 0.990, 0.990,

CONTROL SYSTEM λ_3 0.012, 0.014, 0.014, 0.014, 0.014, 0.012, 0.010, 0.010, 0.012, 0.010, 0.010, 0.010,

MOLD SYSTEM R_4 0.900, 0.900, 0.900, 0.900, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850,

MOLD SYSTEM λ_4 0.012, 0.012, 0.012, 0.012, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003,

CLAMPING SYSTEM R_5 0.992, 0.994, 0.994, 0.994, 0.993, 0.992, 0.991, 0.991, 0.992, 0.990, 0.990, 0.990,

CLAMPING SYSTEM λ_5 0.012, 0.014, 0.014, 0.014, 0.014, 0.012, 0.010, 0.010, 0.012, 0.010, 0.010, 0.010,

YEAR , JA2008, FE2008, MA2008, AP2008, MY2008, JN2008, JY2008, AG2008, SP2008, OC2008, NV2008, DM2008,

HYDRAULIC SYSTEM R_1 0.970, 0.970, 0.970, 0.960, 0.960, 0.960, 0.950, 0.950, 0.940, 0.940, 0.900, 0.900,

HYDRAULIC SYSTEM λ_1 0.080, 0.080, 0.080, 0.070, 0.070, 0.070, 0.060, 0.060, 0.059, 0.059, 0.055, 0.055,

INJECTION SYSTEM R_2 0.900, 0.900, 0.900, 0.900, 0.900, 0.890, 0.890, 0.890, 0.890, 0.890, 0.890, 0.890,

INJECTION SYSTEM λ_2 0.004, 0.004, 0.004, 0.004, 0.004, 0.015, 0.015, 0.015, 0.015, 0.015, 0.015, 0.015,

CONTROL SYSTEM R_3 0.970, 0.970, 0.970, 0.960, 0.960, 0.960, 0.950, 0.950, 0.940, 0.940, 0.900, 0.900,

CONTROL SYSTEM λ_3 0.080, 0.080, 0.080, 0.070, 0.070, 0.070, 0.060, 0.060, 0.059, 0.059, 0.055, 0.055,

MOLD SYSTEM R_4 0.900, 0.900, 0.900, 0.900, 0.900, 0.890, 0.890, 0.890, 0.890, 0.890, 0.890, 0.890,

MOLD SYSTEM λ_4 0.004, 0.004, 0.004, 0.004, 0.004, 0.015, 0.015, 0.015, 0.015, 0.015, 0.015, 0.015,

CLAMPING SYSTEM R_5 0.970, 0.970, 0.970, 0.960, 0.960, 0.960, 0.950, 0.950, 0.940, 0.940, 0.900, 0.900,

CLAMPING SYSTEM λ_5 0.080, 0.080, 0.080, 0.070, 0.070, 0.070, 0.060, 0.060, 0.059, 0.059, 0.055, 0.055,

YEAR , JA2009, FE2009, MA2009, AP2009, MY2009, JN2009, JY2009, AG2009, SP2009, OC2009, NV2009, DM2009,

HYDRAULIC SYSTEM R_1 0.900, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800,

HYDRAULIC SYSTEM λ_1 0.055, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054,

INJECTION SYSTEM R_2 0.890, 0.890, 0.890, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850,

INJECTION SYSTEM λ_2 0.015, 0.015, 0.015, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003,

CONTROL SYSTEM R_3 0.900, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800,

CONTROL SYSTEM λ_3 0.055, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054,

MOLD SYSTEM R_4 0.890, 0.890, 0.890, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850, 0.850,

MOLD SYSTEM λ_4 0.015, 0.015, 0.015, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003, 0.003,

CLAMPING SYSTEM R_5 0.900, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800, 0.800,

CLAMPING SYSTEM λ_5 0.055, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054, 0.054,

YEAR , JA2013, FE2013, MA2013, AP2013, MY2013, JN2013, JY2013, AG2013, SP2013, OC2013, NV2013, DM2013,

HYDRAULIC SYSTEM R_1 0.800, 0.790, 0.790, 0.790, 0.790, 0.790, 0.700, 0.700, 0.600, 0.600, 0.600, 0.600,

HYDRAULIC SYSTEM λ_1 0.054, 0.050, 0.050, 0.050, 0.050, 0.050, 0.040, 0.040, 0.015, 0.015, 0.015, 0.015, **INJECTION SYSTEM R_2** 0.650, 0.650, 0.650, 0.650, 0.650, 0.650, 0.700, 0.700, 0.700, 0.700, 0.700, 0.700,

INJECTION SYSTEM λ_2 0.004, 0.004, 0.004, 0.004, 0.004, 0.004, 0.004, 0.008, 0.008, 0.008, 0.008, 0.008,

CONTROL SYSTEM R_3 0.800, 0.790, 0.790, 0.790, 0.790, 0.790, 0.700, 0.700, 0.600, 0.600, 0.600, 0.600,

CONTROL SYSTEM λ_3 0.054, 0.050, 0.050, 0.050, 0.050, 0.050, 0.040, 0.040, 0.015, 0.015, 0.015, 0.015,

MOLD SYSTEM R_4 0.650, 0.650, 0.650, 0.650, 0.650, 0.650, 0.650, 0.710, 0.710, 0.710, 0.710, 0.710,

MOLD SYSTEM λ_4 0.004, 0.004, 0.004, 0.004, 0.004, 0.004, 0.004, 0.018, 0.018, 0.018, 0.018, 0.018,

CLAMPING SYSTEM R_5 0.800, 0.790, 0.790, 0.790, 0.790, 0.790, 0.700, 0.700, 0.500, 0.500, 0.500, 0.500,

CLAMPING SYSTEM λ_5 0.054, 0.050, 0.050, 0.050, 0.050, 0.050, 0.040, 0.040, 0.013, 0.013, 0.013, 0.013,

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Field data results

Table 4a shows field data obtained from the production engineer of Innoson Plastic Industry, Enugu.

Table 4a:Raw data of reliability and failure rate for the components

YEARS	HYDRAULIC SYSTEM R_1	HYDRAULIC SYSTEM λ_1	INJECTION SYSTEM R_2	INJECTION SYSTEM λ_2	CONTROL SYSTEM R_3	CONTROL SYSTEM λ_3	MOLD SYSTEM R_4	MOLD SYSTEM λ_4	CLAMPING SYSTEM R_5	CLAMPING SYSTEM λ_5
FE2004	0.600	0.015	0.700	0.008	0.600	0.015	0.700	0.008	0.500	0.013
MA2004	0.600	0.015	0.700	0.008	0.600	0.015	0.700	0.008	0.500	0.013
AP2004	0.600	0.015	0.700	0.008	0.600	0.015	0.700	0.008	0.500	0.013
MY2004	0.600	0.015	0.700	0.008	0.600	0.015	0.700	0.008	0.500	0.013
JN2004	0.992	0.012	0.800	0.012	0.992	0.012	0.800	0.012	0.992	0.012
JY2004	0.992	0.012	0.800	0.012	0.992	0.012	0.800	0.012	0.992	0.012
AG2004	0.994	0.014	0.800	0.012	0.994	0.014	0.800	0.012	0.994	0.014
SP2004	0.994	0.014	0.800	0.012	0.994	0.014	0.800	0.012	0.994	0.014
OC2004	0.993	0.014	0.800	0.012	0.993	0.014	0.800	0.012	0.993	0.014
NV2004	0.993	0.014	0.800	0.012	0.993	0.014	0.800	0.012	0.993	0.014
DM2004	0.992	0.012	0.900	0.012	0.992	0.012	0.900	0.012	0.992	0.012

JA2005	0.992	0.012	0.900	0.012	0.992	0.012	0.900	0.012	0.992	0.012
FE2005	0.994	0.014	0.900	0.012	0.994	0.014	0.900	0.012	0.994	0.014
MA2005	0.994	0.014	0.900	0.012	0.994	0.014	0.900	0.012	0.994	0.014
AP2005	0.994	0.014	0.900	0.012	0.994	0.014	0.900	0.012	0.994	0.014
MY2005	0.993	0.014	0.850	0.003	0.993	0.014	0.850	0.003	0.993	0.014
JN2005	0.992	0.012	0.850	0.003	0.992	0.012	0.850	0.003	0.992	0.012
JY2005	0.991	0.010	0.850	0.003	0.991	0.010	0.850	0.003	0.991	0.010
AG2005	0.991	0.010	0.850	0.003	0.991	0.010	0.850	0.003	0.991	0.010
SP2005	0.992	0.012	0.850	0.003	0.992	0.012	0.850	0.003	0.992	0.012
OC2005	0.990	0.010	0.850	0.003	0.990	0.010	0.850	0.003	0.990	0.010
NV2005	0.990	0.010	0.850	0.003	0.990	0.010	0.850	0.003	0.990	0.010
DM2005	0.990	0.010	0.850	0.003	0.990	0.010	0.850	0.003	0.990	0.010
JA2006	0.980	0.009	0.850	0.003	0.980	0.009	0.850	0.003	0.980	0.009
FE2006	0.980	0.009	0.850	0.003	0.980	0.009	0.850	0.003	0.980	0.009
MA2006	0.981	0.009	0.850	0.003	0.981	0.009	0.850	0.003	0.981	0.009
AP2006	0.981	0.009	0.850	0.003	0.981	0.009	0.850	0.003	0.981	0.009
MY2006	0.982	0.010	0.890	0.015	0.982	0.010	0.890	0.015	0.982	0.010
JN2006	0.982	0.010	0.890	0.015	0.982	0.010	0.890	0.015	0.982	0.010
JY2006	0.982	0.010	0.890	0.015	0.982	0.010	0.890	0.015	0.982	0.010
AG2006	0.982	0.010	0.890	0.015	0.982	0.010	0.890	0.015	0.982	0.010
SP2006	0.981	0.009	0.890	0.015	0.981	0.009	0.890	0.015	0.981	0.009
OC2006	0.981	0.009	0.890	0.015	0.981	0.009	0.890	0.015	0.981	0.009

NV2006	0.981	0.009	0.890	0.015	0.981	0.009	0.890	0.015	0.981	0.009
DM2006	0.980	0.009	0.890	0.015	0.980	0.009	0.890	0.015	0.980	0.009
JA2007	0.980	0.009	0.890	0.015	0.980	0.009	0.890	0.015	0.980	0.009
FE2007	0.980	0.009	0.890	0.015	0.980	0.009	0.890	0.015	0.980	0.009
MA2007	0.985	0.012	0.890	0.015	0.985	0.012	0.890	0.015	0.985	0.012
AP2007	0.985	0.012	0.900	0.012	0.985	0.012	0.900	0.012	0.985	0.012
MY2007	0.985	0.012	0.900	0.012	0.985	0.012	0.900	0.012	0.985	0.012
JN2007	0.979	0.009	0.900	0.012	0.979	0.009	0.900	0.012	0.979	0.009
JY2007	0.979	0.009	0.900	0.012	0.979	0.009	0.900	0.012	0.979	0.009
AG2007	0.979	0.009	0.900	0.012	0.979	0.009	0.900	0.012	0.979	0.009
SP2007	0.979	0.009	0.900	0.004	0.979	0.009	0.900	0.004	0.979	0.009
OC2007	0.976	0.088	0.900	0.004	0.976	0.088	0.900	0.004	0.976	0.088
NV2007	0.976	0.088	0.900	0.004	0.976	0.088	0.900	0.004	0.976	0.088
DM2007	0.976	0.088	0.900	0.004	0.976	0.088	0.900	0.004	0.976	0.088
JA2008	0.970	0.080	0.900	0.004	0.970	0.080	0.900	0.004	0.970	0.080
FE2008	0.970	0.080	0.900	0.004	0.970	0.080	0.900	0.004	0.970	0.080
MA2008	0.970	0.080	0.900	0.004	0.970	0.080	0.900	0.004	0.970	0.080
AP2008	0.960	0.070	0.900	0.004	0.960	0.070	0.900	0.004	0.960	0.070
MY2008	0.960	0.070	0.900	0.004	0.960	0.070	0.900	0.004	0.960	0.070
JN2008	0.960	0.070	0.890	0.015	0.960	0.070	0.890	0.015	0.960	0.070
JY2008	0.950	0.060	0.890	0.015	0.950	0.060	0.890	0.015	0.950	0.060
AG2008	0.950	0.060	0.890	0.015	0.950	0.060	0.890	0.015	0.950	0.060

SP2008	0.940	0.059	0.890	0.015	0.940	0.059	0.890	0.015	0.940	0.059
OC2008	0.940	0.059	0.890	0.015	0.940	0.059	0.890	0.015	0.940	0.059
NV2008	0.900	0.055	0.890	0.015	0.900	0.055	0.890	0.015	0.900	0.055
DM2008	0.900	0.055	0.890	0.015	0.900	0.055	0.890	0.015	0.900	0.055
JAN2009	0.900	0.055	0.890	0.015	0.900	0.055	0.890	0.015	0.900	0.055
FE2009	0.800	0.054	0.890	0.015	0.800	0.054	0.890	0.015	0.800	0.054
MA2009	0.800	0.054	0.890	0.015	0.800	0.054	0.890	0.015	0.800	0.054
AP2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
MY2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
JN2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
JY2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
AG2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
SP2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
OC2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
NV2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
DM2009	0.800	0.054	0.850	0.003	0.800	0.054	0.850	0.003	0.800	0.054
JA2010	0.780	0.050	0.850	0.003	0.780	0.050	0.850	0.003	0.780	0.050
FE2010	0.790	0.050	0.850	0.003	0.790	0.050	0.850	0.003	0.790	0.050
MA2010	0.790	0.050	0.800	0.012	0.790	0.050	0.800	0.012	0.790	0.050
AP2010	0.790	0.050	0.800	0.012	0.790	0.050	0.800	0.012	0.790	0.050
MY2010	0.790	0.050	0.800	0.012	0.790	0.050	0.800	0.012	0.790	0.050
JN2010	0.790	0.050	0.800	0.012	0.790	0.050	0.800	0.012	0.790	0.050

JY2010	0.790	0.050	0.800	0.012	0.790	0.050	0.800	0.012	0.790	0.050
AG2010	0.850	0.055	0.800	0.012	0.850	0.055	0.800	0.012	0.850	0.055
SP2010	0.850	0.055	0.800	0.012	0.850	0.055	0.800	0.012	0.850	0.055
OC2010	0.850	0.055	0.800	0.012	0.850	0.055	0.800	0.012	0.850	0.055
NV2010	0.850	0.055	0.800	0.012	0.850	0.055	0.800	0.012	0.850	0.055
DM2010	0.850	0.055	0.800	0.012	0.850	0.055	0.800	0.012	0.850	0.055
JA2011	0.850	0.055	0.800	0.012	0.850	0.055	0.800	0.012	0.850	0.055
FE2011	0.800	0.054	0.800	0.012	0.800	0.054	0.800	0.012	0.800	0.054
MA2011	0.800	0.054	0.800	0.012	0.800	0.054	0.800	0.012	0.800	0.054
AP2011	0.800	0.054	0.600	0.008	0.800	0.054	0.890	0.015	0.800	0.054
MA2011	0.800	0.054	0.600	0.008	0.800	0.054	0.890	0.015	0.800	0.054
JN2011	0.790	0.050	0.600	0.008	0.790	0.050	0.890	0.015	0.790	0.050
JY2011	0.790	0.050	0.600	0.008	0.790	0.050	0.890	0.015	0.790	0.050
AG2011	0.790	0.050	0.600	0.008	0.790	0.050	0.890	0.015	0.790	0.050
SP2011	0.790	0.050	0.600	0.008	0.790	0.050	0.900	0.012	0.790	0.050
OC2011	0.790	0.050	0.600	0.008	0.790	0.050	0.900	0.012	0.790	0.050
NV2011	0.700	0.040	0.600	0.008	0.700	0.040	0.900	0.012	0.700	0.040
DM2011	0.700	0.040	0.600	0.008	0.700	0.040	0.900	0.012	0.700	0.040
JA2012	0.600	0.015	0.600	0.008	0.600	0.015	0.900	0.012	0.500	0.013
FE2012	0.600	0.015	0.600	0.008	0.600	0.015	0.900	0.004	0.500	0.013
MA2012	0.600	0.015	0.600	0.008	0.600	0.015	0.900	0.004	0.500	0.013
AP2012	0.600	0.015	0.600	0.008	0.600	0.015	0.900	0.004	0.500	0.013

MA2012	0.600	0.015	0.600	0.008	0.600	0.015	0.900	0.004	0.500	0.013
JN2012	0.850	0.055	0.600	0.008	0.850	0.055	0.900	0.004	0.850	0.055
JY2012	0.850	0.055	0.600	0.008	0.850	0.055	0.900	0.004	0.850	0.055
AG2012	0.850	0.055	0.600	0.008	0.850	0.055	0.900	0.004	0.850	0.055
SP2012	0.800	0.054	0.600	0.008	0.800	0.054	0.900	0.004	0.800	0.054
OC2012	0.800	0.054	0.600	0.008	0.800	0.054	0.900	0.004	0.800	0.054
NV2012	0.800	0.054	0.600	0.008	0.800	0.054	0.700	0.008	0.800	0.054
DM2012	0.800	0.054	0.650	0.004	0.800	0.054	0.650	0.004	0.800	0.054
JA2013	0.800	0.054	0.650	0.004	0.800	0.054	0.650	0.004	0.800	0.054
FE2013	0.790	0.050	0.650	0.004	0.790	0.050	0.650	0.004	0.790	0.050
MA2013	0.790	0.050	0.650	0.004	0.790	0.050	0.650	0.004	0.790	0.050
AP2013	0.790	0.050	0.650	0.004	0.790	0.050	0.650	0.004	0.790	0.050
MA2013	0.790	0.050	0.650	0.004	0.790	0.050	0.650	0.004	0.790	0.050
JN2013	0.790	0.050	0.650	0.004	0.790	0.050	0.650	0.004	0.790	0.050
JY2013	0.700	0.040	0.650	0.004	0.700	0.040	0.650	0.004	0.700	0.040
AG2013	0.700	0.040	0.700	0.008	0.700	0.040	0.710	0.018	0.700	0.040
SP2013	0.600	0.015	0.700	0.008	0.600	0.015	0.710	0.018	0.500	0.013
OC2013	0.600	0.015	0.700	0.008	0.600	0.015	0.710	0.018	0.500	0.013
NV2013	0.600	0.015	0.700	0.008	0.600	0.015	0.710	0.018	0.500	0.013
DM2013	0.600	0.015	0.700	0.008	0.600	0.015	0.710	0.018	0.500	0.013

4.2 Analysis and discussion of results

The field data of Table 4a are analysed with relevant to tools such as Monte Carlo simulation, multi regression model, PASW18 and Shewhart control chart; played a vital role in answering the research questions, and also led to the identification of the numerous benefits of reliability analysis in production.The system reliability was high in the early years till it began to degrade as years went by. Each components began to wear demanding maintenance, their reliability was peak in 2004, but by 2013 it came to lowest while the failure rates have started showing.

4.3 Statistical reliability evaluation

Table 4b: Reliability and Failure Distribution

Determine Distribution for Each Component on Based Historical Data as Derived from Table 4a					
Reliability Distribution - lowest & highest					
HYDRAULIC SYSTEM Ɽ1	**0.60**	**0.99**			
INJECTION SYSTEMⱤ2	**0.6**	**0.9**			
CONTROL SYSTEMⱤ3	**0.6**	**0.994**			
MOLD SYSTEMⱤ4	**0.65**	**0.9**			
CLAMPING SYSTEMⱤ5	**0.5**	**0.994**			

Failure Rate Distribution - lowest & highest					
HYDRAULIC SYSTEM λ1	**0.009**	**0.088**			
INJECTION SYSTEMλ2	**0.003**	**0.015**			
CONTROL SYSTEMλ3	**0.009**	**0.088**			
MOLD SYSTEMλ4	**0.003**	**0.018**			
CLAMPING SYSTEMλ5	**0.009**	**0.088**			

Table 4b shows distribution for each component based on historical data reliability distribution with the clamping system having the lowest as 0.5 and peak of 0.994 along with the control system. Distribution for each, failure distribution with the mold and injection system as lowest of 0.03, while 0.88 as peak of hydraulic, control and clamping system. The reliability distribution showed hydraulic component as the highest, while the Injection was the lowest for the failure rate.

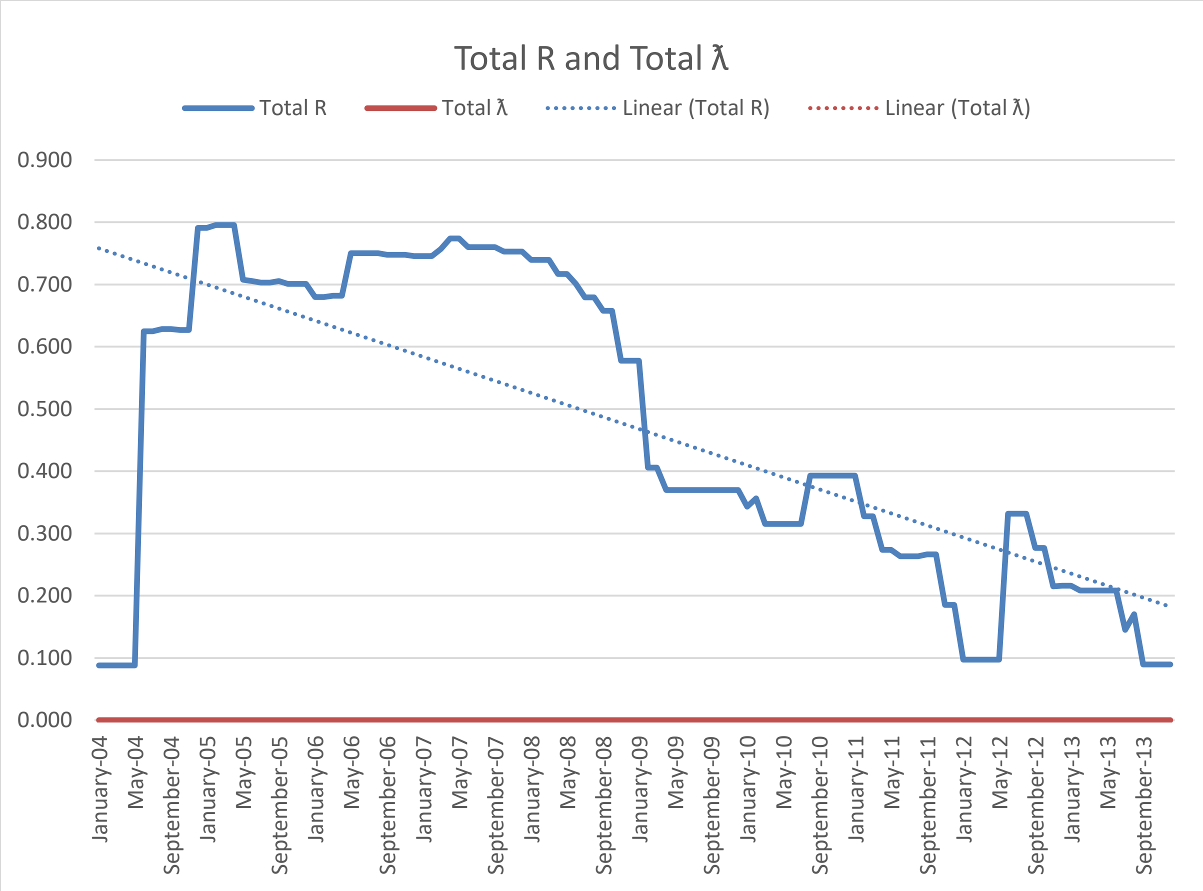

Figure 4a: Total reliability and failure rates

Figure 4a depicts total reliability and failure rate from January 2004 to September 2013 showing a downward slope in trend with time. Reliability of the entire system declined as the month increased. The system failure rate was normal, from January 2004 to September 2013. The system reliability fluctuated withn time.

Table 4c: Total reliability and failure

Years	Total R	Total ƛ
January-04	0.088	0.00000000019
February-04	0.088	0.00000000019
March-04	0.088	0.00000000019
April-04	0.088	0.00000000019
May-04	0.088	0.00000000019
June-04	0.625	0.00000000025
July-04	0.625	0.00000000025
August-04	0.629	0.00000000040
September-04	0.629	0.00000000040
October-04	0.627	0.00000000040
November-04	0.627	0.00000000040
December-04	0.791	0.00000000025
January-05	0.791	0.00000000025
February-05	0.796	0.00000000040
March-05	0.796	0.00000000040
April-05	0.796	0.00000000040
May-05	0.707	0.00000000002
June-05	0.705	0.00000000002
July-05	0.703	0.00000000001
August-05	0.703	0.00000000001
September-05	0.705	0.00000000002
October-05	0.701	0.00000000001
November-05	0.701	0.00000000001
December-05	0.701	0.00000000001
January-06	0.680	0.00000000001
February-06	0.680	0.00000000001
March-06	0.682	0.00000000001
April-06	0.682	0.00000000001
May-06	0.750	0.00000000023
June-06	0.750	0.00000000023
July-06	0.750	0.00000000023
August-06	0.750	0.00000000023
September-06	0.748	0.00000000016
October-06	0.748	0.00000000016
November-06	0.748	0.00000000016
December-06	0.746	0.00000000016
January-07	0.746	0.00000000016

Table 4c shows both the failure rate and reliability of the injection mould systemfrom January 2004 to January 2007 with the peak reliability in January 2007 as 0.746 and the least as 0.088 in January 2004. The system reliability dropping and rising in between months indicates change of system condition.

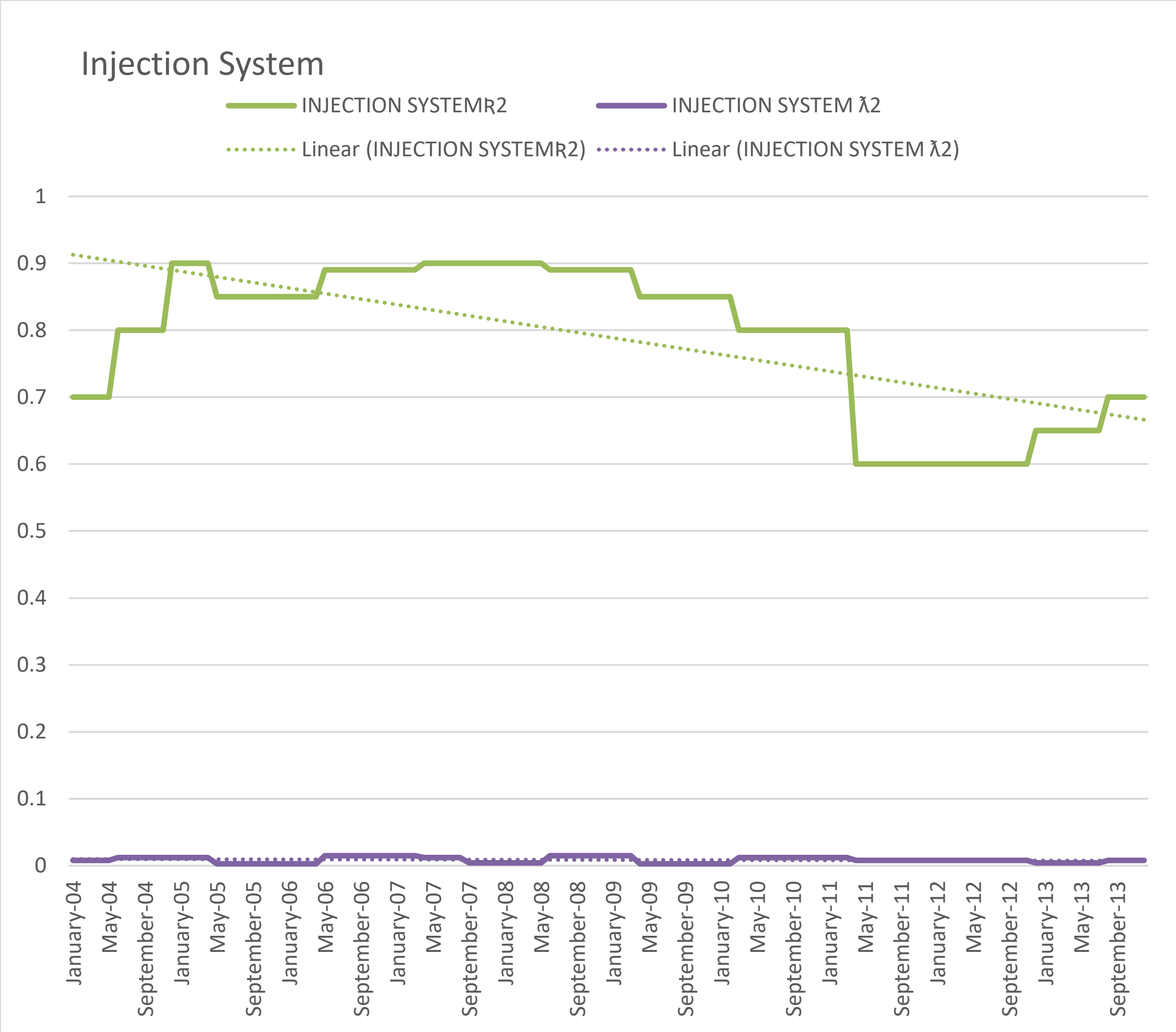

Figure 4b: Injection system time series

Figure 4b shows how the failure rates fluctuated through the system running stage. The system reliability fails from month to month with its peak at at 0.9 and falls lowest at 0.6. The injection system reliability and failure rate from January 2004 to September 2013 showed a downward slope in trend, depicting systems degradation.

Table 4d: Injection system

Forecast: ***Injection System is reliable 75.08% of the time. Injection System will be down 24.92% of the time.***

Average	MIN	MAX	STD Dev	Reliability
0.7502	0.6002	0.8997	0.0879	0.7502
0.7570	0.6016	0.8999	0.0879	0.7570
0.7517	0.6002	0.8999	0.0865	0.7517
0.7515	0.6007	0.8998	0.0862	0.7515
0.7552	0.6002	0.8999	0.0880	0.7552
0.7520	0.6002	0.9000	0.0864	0.7520
0.7505	0.6005	0.8996	0.0875	0.7505
0.7480	0.6005	0.8996	0.0852	0.7480
0.7497	0.6006	0.8997	0.0880	0.7497
0.7555	0.6000	0.8998	0.0870	0.7555
0.7551	0.6001	0.8999	0.0856	0.7551
0.7496	0.6000	0.8989	0.0852	0.7496
0.7518	0.6000	0.8999	0.0870	0.7518
0.7451	0.6003	0.8999	0.0865	0.7451
0.7522	0.6001	0.9000	0.0866	0.7522
0.7510	0.6003	0.8995	0.0870	0.7510
0.7496	0.6000	0.8999	0.0859	0.7496
0.7487	0.6003	0.8992	0.0876	0.7487
0.7473	0.6007	0.8991	0.0849	0.7473
0.7451	0.6002	0.9000	0.0869	0.7451

Table 4d and Figure 4b shows that from November 2004 to March 2005,March 2006 and March 2009 had peak reliability, after failures were observed because corrective maintenance were done. The trending line shows downward slope, depicting system failure with times. From the forecast in Table 4b, Injection system is reliable 75.06% of the time, and its down time is 24.94%. The component reliability will if this corrective maintained is scheduled into preventive maintenance. The reliability was 0.7487, the minimum of 0.6002, its maximum reliability was 0.8999 and the systems standard deviation was 0.0889. Peak reliability from November 2004 to March 2005 and March 2006 and March 2009 after corrective maintenance. Trend lines shows downward slope. Reliable for 75.06% and down time of 24.94%, with standard deviation 0.0889.

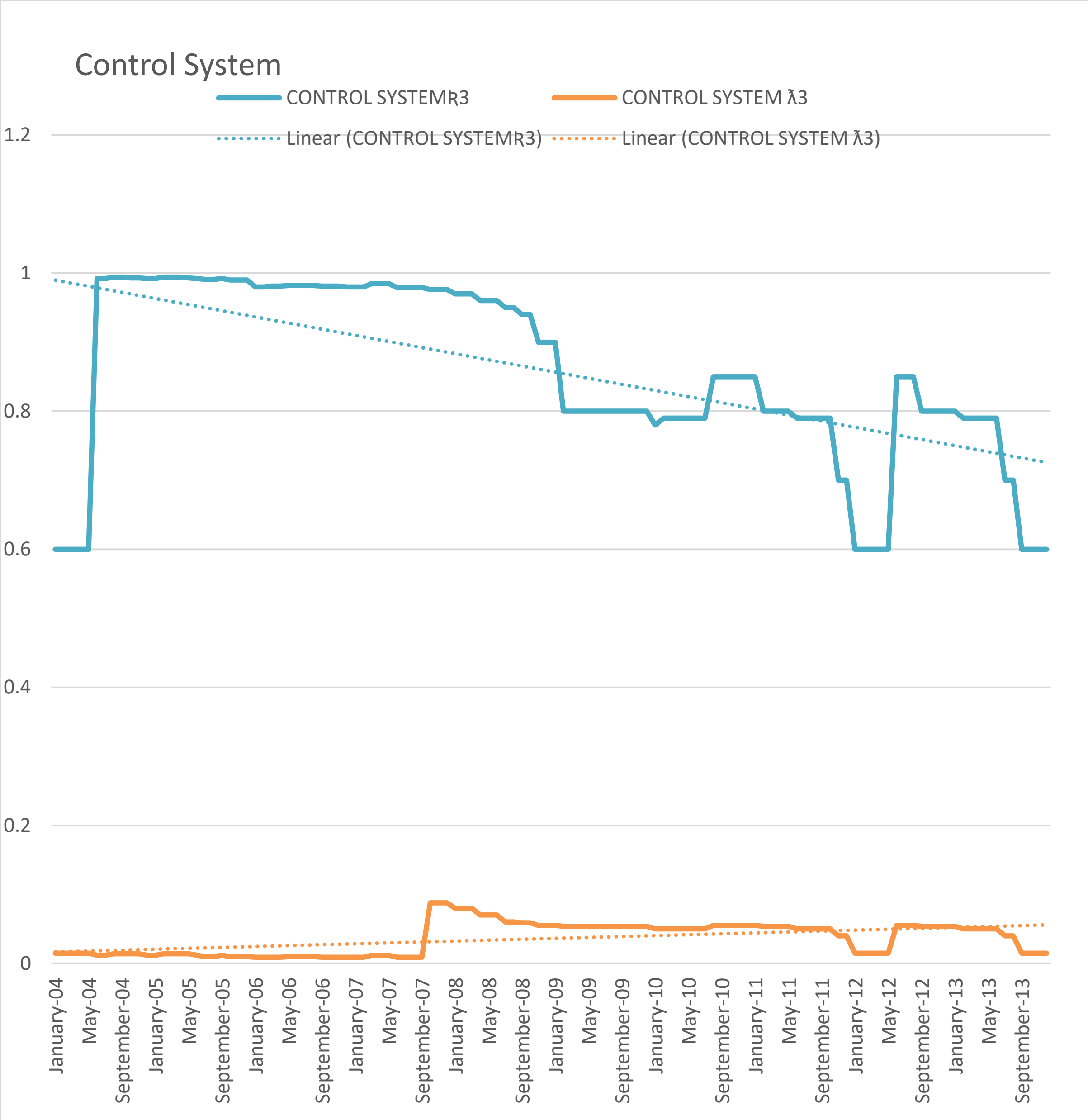

Figure 4d: Control system time series

Figure 4d shows the reliability for Control system that models system behavior from March 2004 to Januray 2005. The reliability was constant but began to fall and eventually fell to 0.6 in September 2013. Failure rate for the system was normal from January 2004 to September 2007, and then it began to increase and later became normal in September 2013, thus showing system degradation.

Table 4e: Control system

Forecast:	Control System is reliable 75.79% of the time. Control System will be down 24.21% of the time.				
	Average	MIN	MAX	STD Dev	Reliability
	0.7998	0.6004	0.9931	0.1126	0.7998
	0.7975	0.6004	0.9939	0.1127	0.7975
	0.8010	0.6005	0.9936	0.1128	0.8010
	0.7987	0.6003	0.9938	0.1157	0.7987
	0.8006	0.6005	0.9937	0.1116	0.8006
	0.7953	0.6001	0.9940	0.1130	0.7953
	0.7998	0.6004	0.9938	0.1105	0.7998
	0.8006	0.6005	0.9937	0.1104	0.8006
	0.7955	0.6000	0.9938	0.1133	0.7955
	0.7976	0.6006	0.9938	0.1157	0.7976
	0.8008	0.6003	0.9936	0.1149	0.8008
	0.7983	0.6000	0.9936	0.1107	0.7983
	0.7885	0.6005	0.9936	0.1135	0.7885
	0.8007	0.6011	0.9940	0.1122	0.8007
	0.7973	0.6002	0.9938	0.1157	0.7973
	0.7988	0.6004	0.9937	0.1143	0.7988
	0.7984	0.6000	0.9930	0.1148	0.7984
	0.7957	0.6012	0.9934	0.1122	0.7957
	0.7925	0.6002	0.9927	0.1132	0.7925
	0.8046	0.6003	0.9940	0.1144	0.8046

Table 4e and Figure 4d shows that corrective maintenance was sustained for a while thus the peak of it reliability was from the month of September 2004 through to January 2009. Thus, the Control System is reliable 75.67% of time. Control system will be down 24.33% of the time, from the forecast in table 4d. These values in turns affect the injection moulding system availability being a series system. Its minimum reliability is 0.6001, while the maximum is 0.9938. its standard deviation is 0.1149 giving a reliability of 0.7887. Peak reliability was from September 2004 to January 2009. Reliable 75.67% and down time 24.33%, standard deviation 0.7887, the system showed degradation with time.

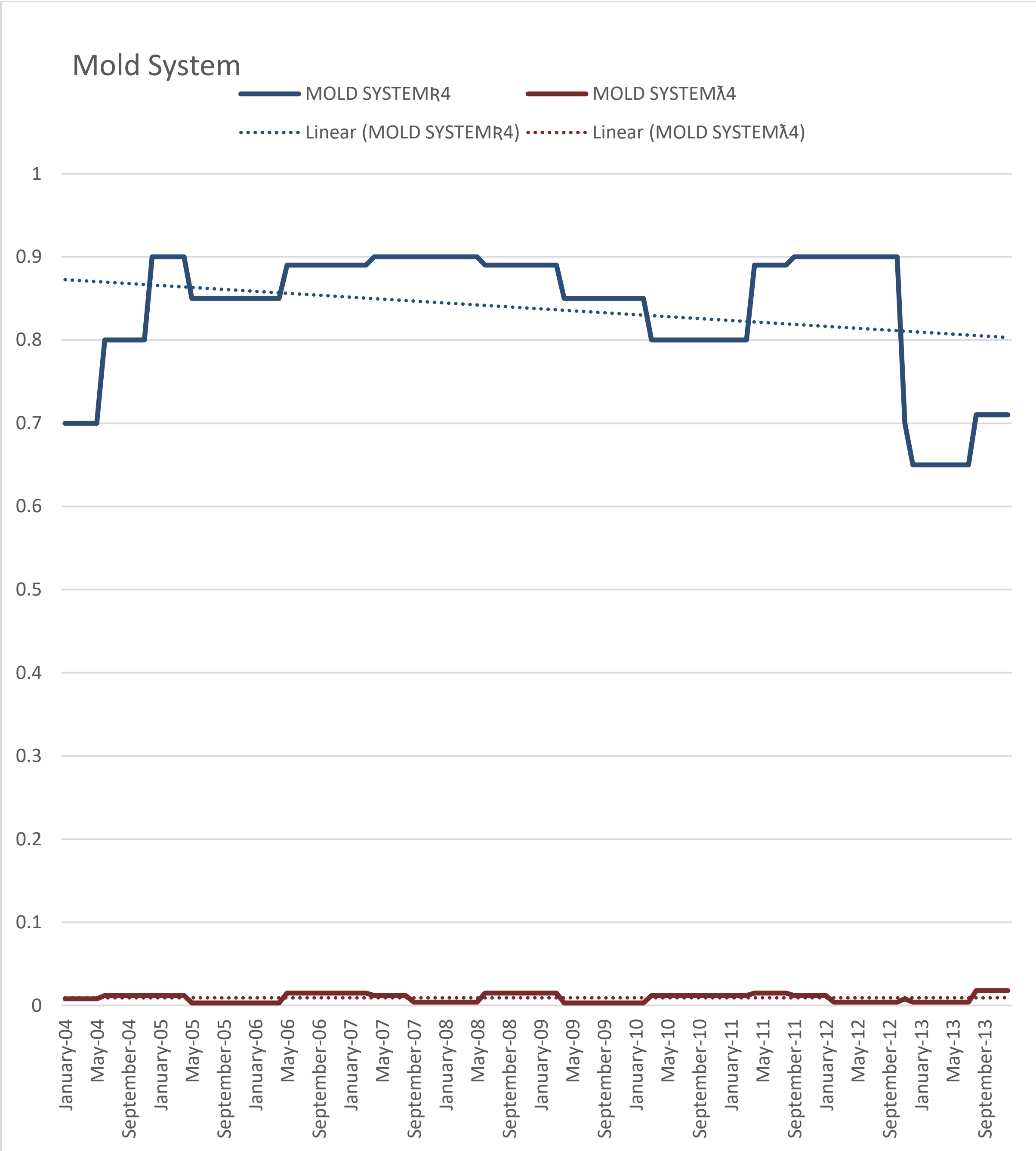

Figure 4e: Mold system time series

Table 4f: Mold system

42% of the time.

	Average	MIN	MAX	STD Dev	Reliability
	0.7725	0.6502	0.8998	0.0727	0.7725
	0.7748	0.6500	0.8996	0.0728	0.7748
	0.7755	0.6502	0.8997	0.0732	0.7755
	0.7738	0.6502	0.8999	0.0738	0.7738
	0.7732	0.6503	0.8997	0.0723	0.7732
	0.7737	0.6500	0.8993	0.0729	0.7737
	0.7790	0.6502	0.8998	0.0713	0.7790
	0.7726	0.6502	0.8996	0.0721	0.7726
	0.7763	0.6500	0.8998	0.0721	0.7763
	0.7704	0.6505	0.8998	0.0717	0.7704
	0.7809	0.6503	0.8999	0.0721	0.7809
	0.7753	0.6501	0.8999	0.0725	0.7753
	0.7742	0.6501	0.8995	0.0725	0.7742
	0.7781	0.6503	0.8997	0.0721	0.7781
	0.7726	0.6502	0.8998	0.0726	0.7726
	0.7736	0.6500	0.8997	0.0701	0.7736
	0.7743	0.6505	0.8999	0.0726	0.7743
	0.7742	0.6505	0.8999	0.0732	0.7742
	0.7720	0.6501	0.8998	0.0722	0.7720
	0.7740	0.6502	0.8999	0.0713	0.7740

The mold servicing was rather random, from Table 4fthis reflected also in Figure 4e. It peak time were random, they were in March 2004, September 2006 and November 2012. From the forecast in table 4e, the Mold System is reliable 73.61% of the time. Mold system will be down 26.39% of the time. With a minimum reliability of 0.6500, and maximum of 0.8996, the standard deviation is 0.0739 with reliability of 0.7737.Random peak times March 2004, September 2006 and November 2012. Reliable for 73.61%, downtime of 26.39% and standard deviation of 0.0739, system availability was affected.

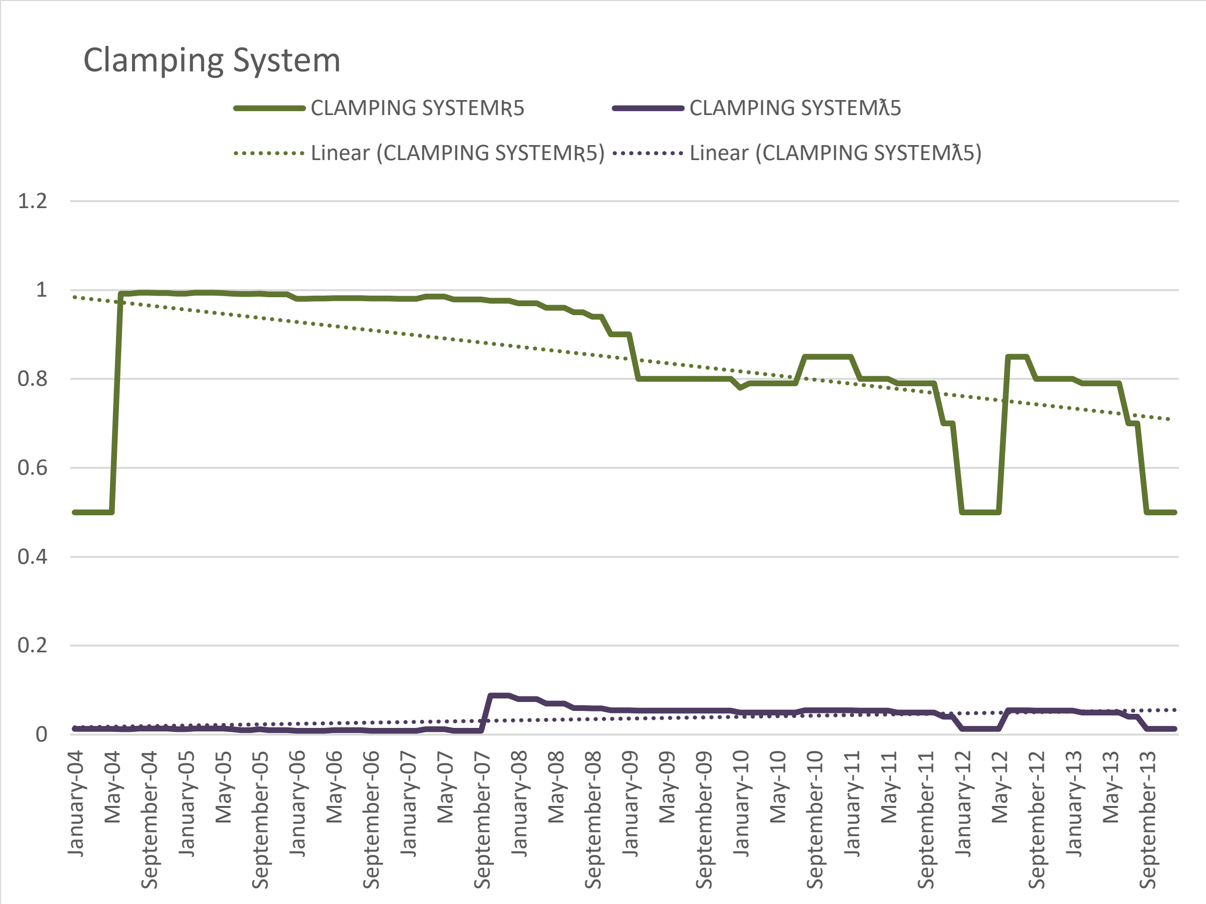

Figure 4f: Clamping system time series

Neglecting systems till they fail is very degradable to the system. From Figure 4f above and Table 4g, May 2004 to January 2009 had good servicing on the Clamping system till there was neglect then it began to fail. The trending line shows a downward slope, which points to system degradation with time. Using the forecast in table 4f, the Clamping System is reliable 74.47% of the time. Clamping System will be down 25.47% of the time. With minimum reliability of 0.5003, maximum reliability of 0.9940, standard deviation of 0.1412 and reliability of 0.7458.Trend line slopes downward, which shows system degradation with time.Reliable for 74.47% and downtime was 25.47% with standard deviation 0.1412.

Table 4g: Clamping system

Forecast: *Clamping System is reliable 74.69% of the time. Clamping System will be down 25.31% of the time.*

Average	MIN	MAX	STD Dev	Reliability
0.7469	0.5004	0.9938	0.1392	0.7469
0.7412	0.5004	0.9938	0.1425	0.7412
0.7460	0.5000	0.9940	0.1439	0.7460
0.7414	0.5003	0.9932	0.1439	0.7414
0.7497	0.5002	0.9935	0.1451	0.7497
0.7489	0.5013	0.9928	0.1443	0.7489
0.7490	0.5006	0.9937	0.1410	0.7490
0.7431	0.5004	0.9930	0.1443	0.7431
0.7420	0.5005	0.9937	0.1405	0.7420
0.7517	0.5002	0.9933	0.1416	0.7517
0.7438	0.5029	0.9937	0.1411	0.7438
0.7520	0.5001	0.9938	0.1428	0.7520
0.7521	0.5002	0.9938	0.1457	0.7521
0.7501	0.5001	0.9938	0.1464	0.7501
0.7444	0.5001	0.9939	0.1430	0.7444
0.7471	0.5002	0.9938	0.1438	0.7471
0.7438	0.5008	0.9939	0.1377	0.7438
0.7533	0.5003	0.9939	0.1450	0.7533
0.7482	0.5015	0.9939	0.1424	0.7482
0.7439	0.5006	0.9929	0.1417	0.7439

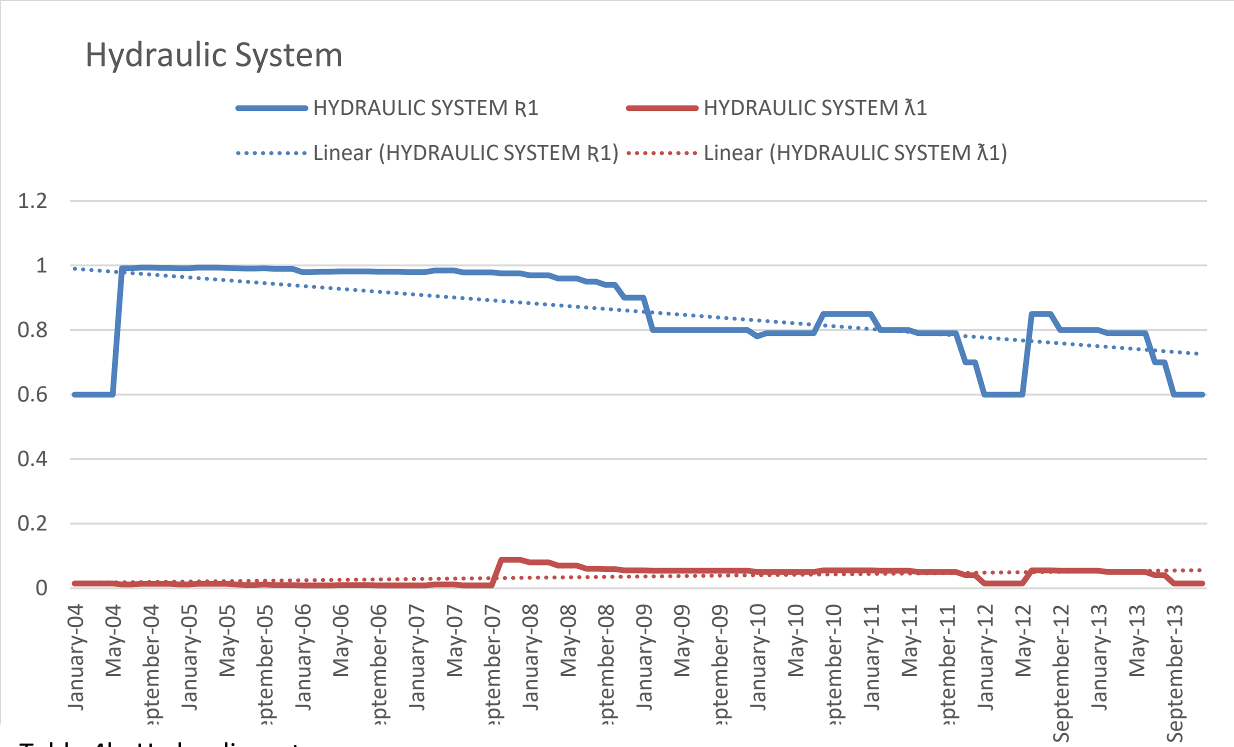

Table 4h: Hydraulic system

Forecast:	*Hydraulic System is reliable 71.71% of the time. Hydraulic System will be down 28.29% of the time.*				
	Average	**MIN**	**MAX**	**STD Dev**	**Reliability**
	0.7963	0.6000	0.9938	0.1153	0.7963
	0.7921	0.6009	0.9931	0.1120	0.7921
	0.7959	0.6003	0.9933	0.1127	0.7959
	0.7979	0.6005	0.9936	0.1155	0.7979
	0.7978	0.6002	0.9936	0.1131	0.7978
	0.7978	0.6007	0.9939	0.1130	0.7978
	0.7983	0.6002	0.9935	0.1140	0.7983
	0.7929	0.6001	0.9939	0.1138	0.7929
	0.7967	0.6000	0.9932	0.1150	0.7967
	0.7967	0.6004	0.9938	0.1163	0.7967
	0.7967	0.6001	0.9936	0.1136	0.7967
	0.8045	0.6002	0.9940	0.1163	0.8045
	0.7961	0.6007	0.9939	0.1144	0.7961
	0.7913	0.6002	0.9935	0.1126	0.7913
	0.7972	0.6010	0.9939	0.1126	0.7972
	0.7966	0.6005	0.9934	0.1125	0.7966
	0.7897	0.6004	0.9917	0.1135	0.7897
	0.7994	0.6019	0.9927	0.1125	0.7994
	0.7997	0.6004	0.9940	0.1146	0.7997
	0.7967	0.6005	0.9935	0.1124	0.7967

Figure 4g: Hydraulic system time series

Most of the components experience initial failure due to design error or operators inadequacy then after servicing and acclimatization to the system, their reliability improved as depicted in figure 4g and table 4h. The system reliability experience peak in months of May 2004 to January 2009 before it dropped. Using forecast on table 4g, the Hydraulic System is reliable 71.75% of the time. Hydraulic System will be down 28.25% of the time. Its minimum and maximum reliability are 0.600 and 0.9938 respectively, while the reliability is 0.8036 with standard deviation of 0.8036.Peak reliability was from May 2004 to January 2009. Reliable for 71.75% with downtime 28.25% and standard deviation 0f 0.8036.

4.2.1 Data analysis of DT series system

Neglecting systems till they fail is very degradable to the system as shown in table 4i and figure 4g, for total reliability and failure rate of the entire system. The trend line shows downward slope indicating how the system degrade with time. The reliability was lowest at the start of the machine usage as a result of various factors ranging from operators incompetency or not acclimatize to the system to environmental factors. Towards the end of the research, we see how the machine degrades. The system reliability fell to as low as 0.170 in September2011, but through the aid of corrective maintenance it was improved again 2013 to 0.089. Corrective maintenance cost more as a result of its nature. If preventive maintenance was done from the beginning of the machine usage, the industry would have saved more. Reliability was lowest at the beginning. Trend line shows downward slope indicating how system degrade with time. Reliability was lowest in September 2011 due to corrective maintenance as it rise to 0.089 in 2013. Reliability injection moulding series system is 48.97%.

4.2.2 Assumptions in reliability model

1. To get maximum reliability, number of elements must be kept minimum.
2. If one element probability of functioning is improved the whole system's reliability is improved.
3. By increasing the reliability of the system, the probability of failure is reduced to half, hence system is time reliable.
4. The components attributes are known and deterministic.
5. Failures of components are dependent events.
6. Randomness, system failures occur at random times and random circumstances, Working time distribution between failures are independently distributed random variables.

4.2.3 Monte Carlo simulation flow Chart

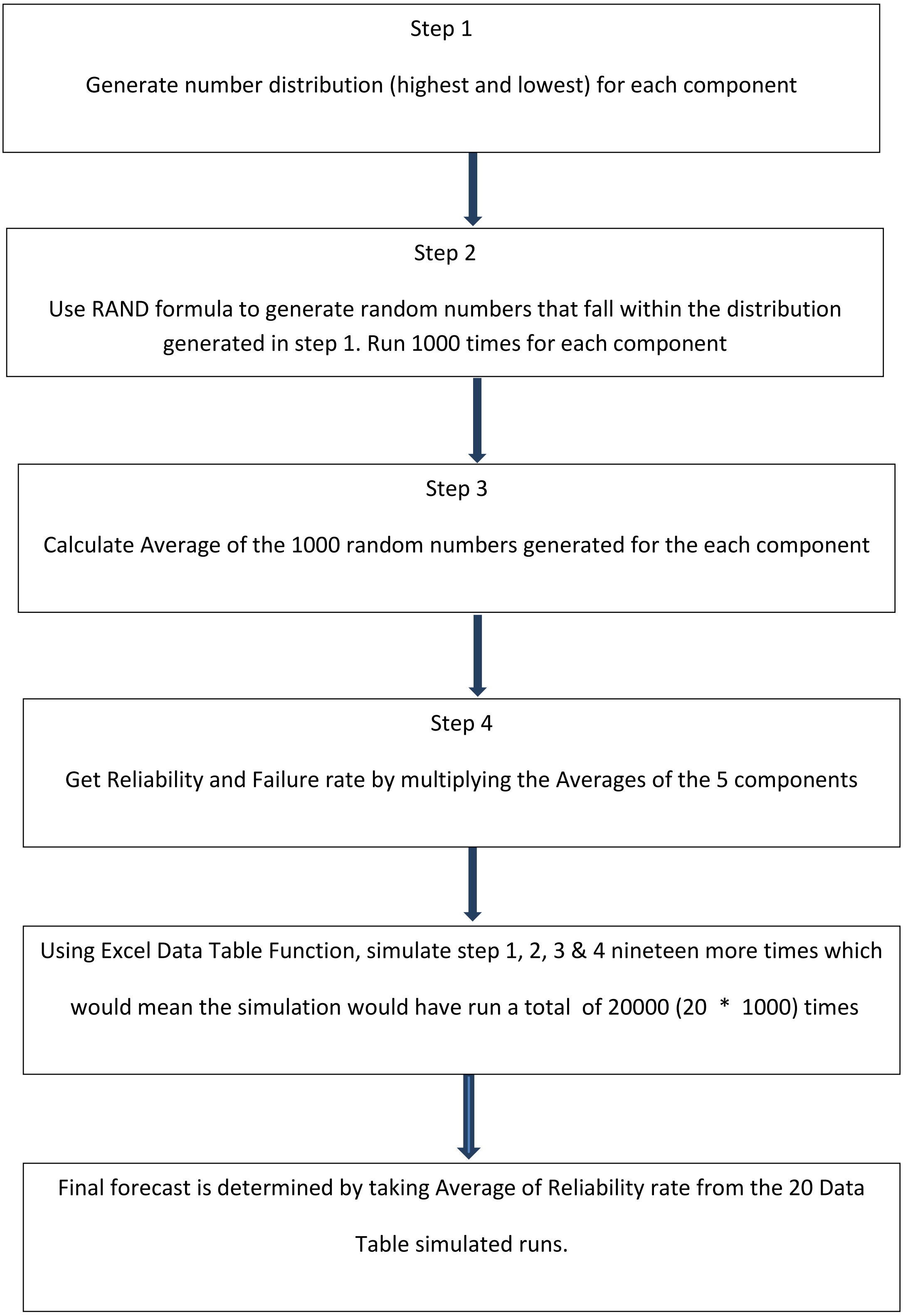

Figure 4h: Monte Carlo simulation flow Chart

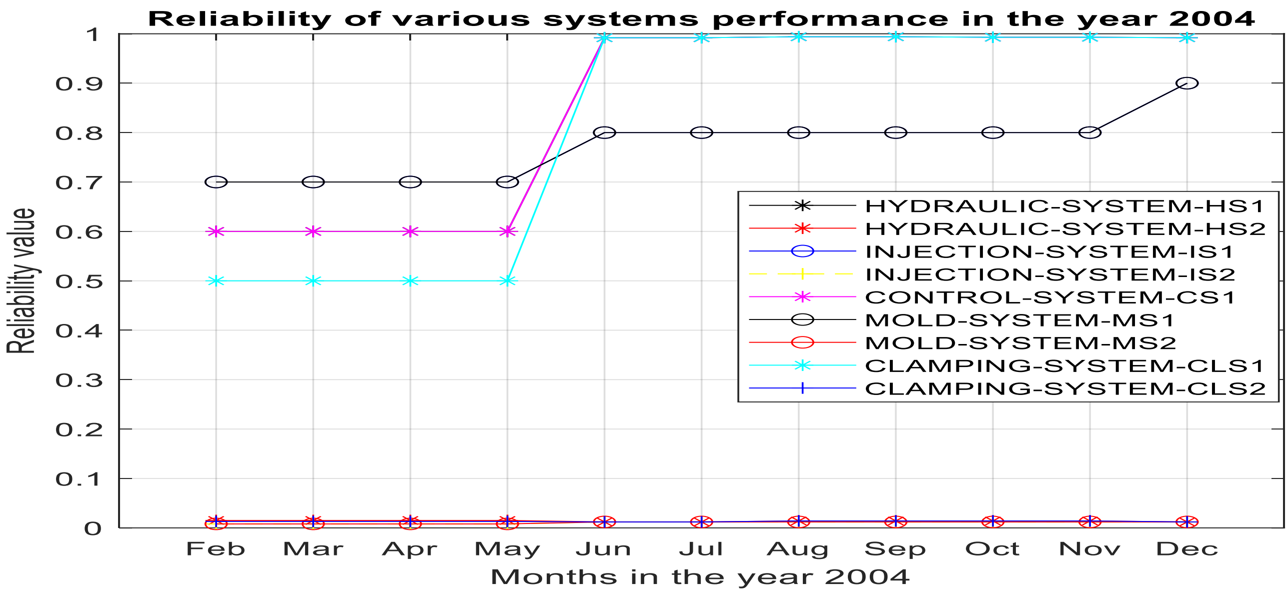

Figure 4i: Matlab time series 2004

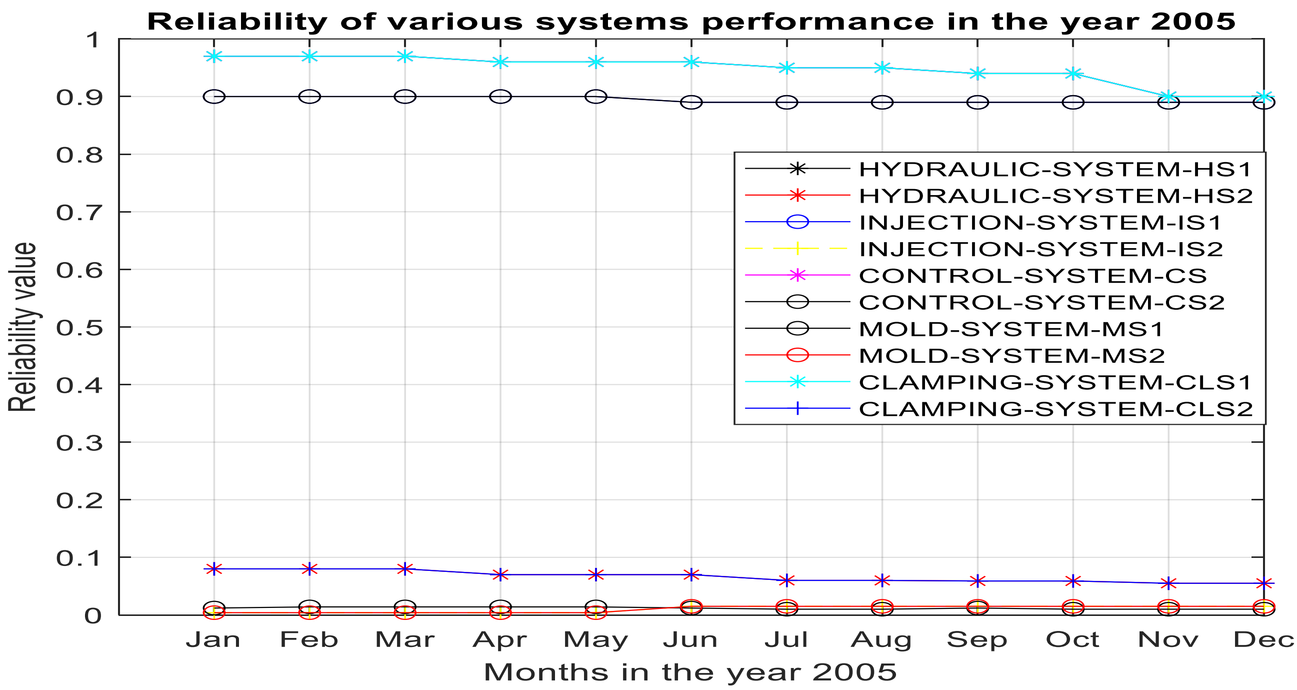

Figure 4j: Matlab time series 2005

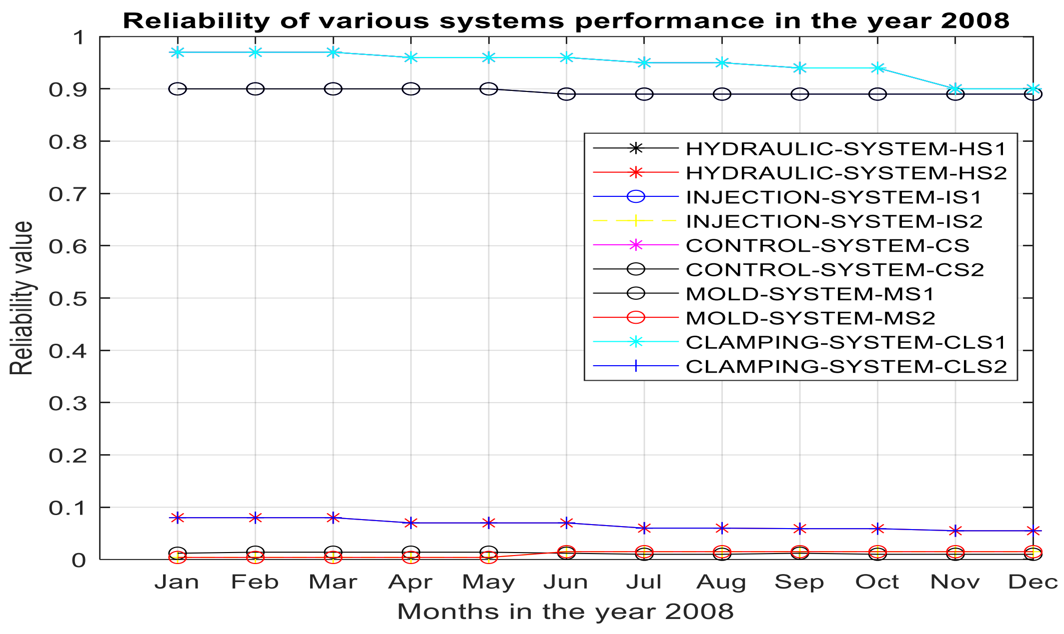

Figure 4k: Matlab time series 2008

Matlab Simulation Time Series Graph for 2005 System Performance

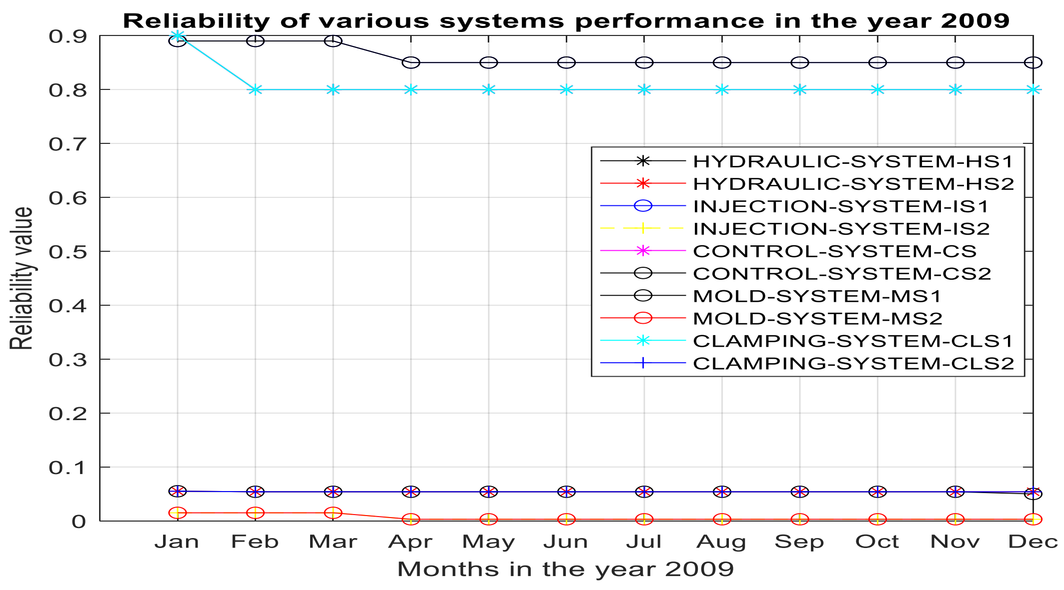

Figure 4l: Matlab time series 2009

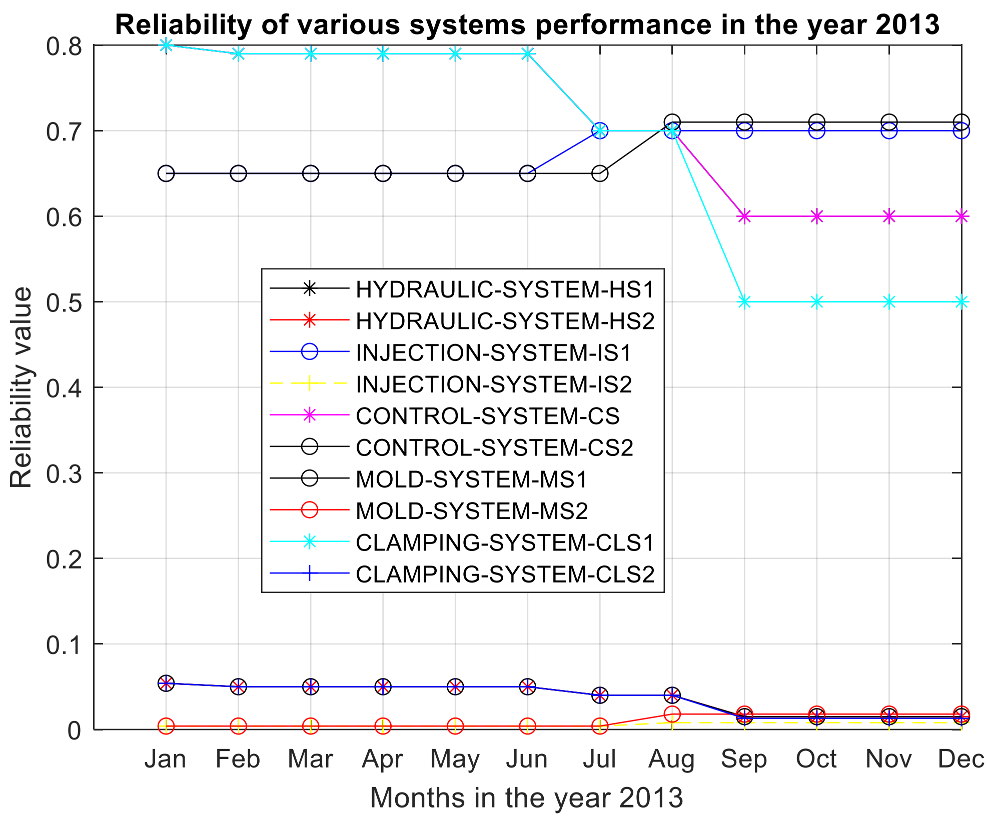

Figure 4m:Matlab time series 2013

Matlab time series shows that reliability was lowest at the start of the system usage as a result of various factors ranging from operator incompetency or not acclimatize to the system, to environmental factors. Neglecting system till they fail is very degradable to the system. The trend line shows downward slope indicating that the system degrade with time. Matlab models system behavior with time, to show that the system will eventually fail if proper maintenance is not implemented.

4.3 Condition based maintenance analysis

Maintenance as a support function in production systems has been valued as a critical role. This, of course, implies that maintenance must be performed effectively, in other words, the correct maintenance action should be taken at the proper time. Inadequate maintenance, on the other hand, can result in increased costs due to the following:

1. Lost production,
2. Rework,
3. Scrap,
4. Labor,
5. Spare parts,
6. Fines for late orders, and
7. Lost orders due to unsatisfied customers.

The prime target of maintenance should be to ensure the system function of production equipment. Further, maintenance should provide the right parameters of: cost, reliability, maintainability, and productivity, for any automated manufacturing system. Maintenance objective, stating that: “It is the task of the maintenance function to support the production process with adequate levels of availability, reliability and operability at an acceptable cost”. Various approaches to performing maintenance exist. Also, various definitions of maintenance have been suggested through the years, the common point being that they have moved away from the traditional perception of maintenance. Maintenance is defined as a "combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function."

Preventive maintenance has been defined as: "Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item." Preventive maintenance is divided into two types, predetermined maintenance and condition based maintenance. Predetermined maintenance is scheduled and planned without the occurrence of any monitoring activities. The scheduling can be based on the number of hours in use, the number of times an item has been used; the number of kilometers the items has been used, according to prescribed dates, and so on. Predetermined maintenance is best suited to an item that has a visible age or wearout characteristic and where maintenance tasks can be made at a time that for sure will prevent a failure from occurring. Predetermined maintenance is sometimes referred to as time-based maintenance and planned preventive maintenance. The other preventive maintenance type, condition based maintenance, does not utilize predetermined intervals and schedules. Instead, it monitors the condition of items in order to decide on a dynamic preventive schedule. Condition based maintenance is defined as: “Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions.”. It is thus a maintenance type that utilizes on-condition tasks in order to monitor the condition over time and usage. This is done in order to give input to decide maintenance actions dynamically. Condition based maintenance is performed to detect and identify specific components in the items that are degrading and diagnose the problem.

Data acquisition from reliability and failure rate is thus the first component. Normally, when used in an objective context, sensors are components of the data acquisition and considered parts of a condition monitor module. Sensors is a device that receives a signal and responds with an electrical signal.”. It is thus the equipment that captures the dynamic effect caused by the incipient failure. The purpose of the signal processors is three-fold: (1) to remove distortions and restore the signal to its original shape, (2) to remove irrelevant sensor data for diagnostics or prognostics, and (3) to transform the signal to make relevant features more explicit. In the condition monitoring module, the measured data is compared to normal data with either threshold values or other techniques such as artificial intelligence. If normal levels are exceeded or other unnatural phenomenon occur, such as sudden increases or decreases in the level (but still not exceeding normal levels), the data needs to be diagnosed. Warning limits can be established that are either static or dynamic. Static warning limits utilize pre-determined threshold values.

Table 4i : Multi regression model

	HYDRAULIC SYSTEM		INJECTION SYSTEM		CONTROL SYSTEM		MOLD SYSTEM		CLAMPING SYSTEM	
	Ɽ1	ƛ1	Ɽ2	ƛ2	Ɽ3	ƛ3	Ɽ4	ƛ4	Ɽ5	ƛ5
January-04	0.6	0.02	0.7	0.008	0.6	0.015	0.7	0.01	0.5	0.013
February-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
March-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
April-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
May-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
June-04	0.992	0.01	0.8	0.012	0.99	0.012	0.8	0.01	0.992	0.012
July-04	0.992	0.01	0.8	0.012	0.99	0.012	0.8	0.01	0.992	0.012
August-04	0.994	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.994	0.014
September-04	0.994	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.994	0.014
October-04	0.993	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.993	0.014
November-04	0.993	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.993	0.014
December-04	0.992	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.992	0.012
January-05	0.992	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.992	0.012
February-05	0.994	0.01	0.9	0.012	0.99	0.014	0.9	0.01	0.994	0.014
March-05	0.994	0.01	0.9	0.012	0.99	0.014	0.9	0.01	0.994	0.014
April-05	0.994	0.01	0.9	0.012	0.99	0.014	0.9	0.01	0.994	0.014
May-05	0.993	0.01	0.85	0.003	0.99	0.014	0.85	0	0.993	0.014
June-05	0.992	0.01	0.85	0.003	0.99	0.012	0.85	0	0.992	0.012
July-05	0.991	0.01	0.85	0.003	0.99	0.01	0.85	0	0.991	0.01
August-05	0.991	0.01	0.85	0.003	0.99	0.01	0.85	0	0.991	0.01
September-05	0.992	0.01	0.85	0.003	0.99	0.012	0.85	0	0.992	0.012
October-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0	0.99	0.01
November-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0	0.99	0.01
December-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0	0.99	0.01
January-06	0.98	0.01	0.85	0.003	0.98	0.009	0.85	0	0.98	0.009
February-06	0.98	0.01	0.85	0.003	0.98	0.009	0.85	0	0.98	0.009
March-06	0.981	0.01	0.85	0.003	0.98	0.009	0.85	0	0.981	0.009
April-06	0.981	0.01	0.85	0.003	0.98	0.009	0.85	0	0.981	0.009
May-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
June-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01

July-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
August-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
September-06	0.981	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.981	0.009
October-06	0.981	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.981	0.009
November-06	0.981	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.981	0.009
December-06	0.98	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.98	0.009
January-07	0.98	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.98	0.009
February-07	0.98	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.98	0.009
March-07	0.985	0.01	0.89	0.015	0.99	0.012	0.89	0.02	0.985	0.012
April-07	0.985	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.985	0.012
May-07	0.985	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.985	0.012
June-07	0.979	0.01	0.9	0.012	0.98	0.009	0.9	0.01	0.979	0.009
July-07	0.979	0.01	0.9	0.012	0.98	0.009	0.9	0.01	0.979	0.009
August-07	0.979	0.01	0.9	0.012	0.98	0.009	0.9	0.01	0.979	0.009
September-07	0.979	0.01	0.9	0.004	0.98	0.009	0.9	0	0.979	0.009
October-07	0.976	0.07	0.9	0.004	0.98	0.068	0.9	0	0.976	0.068
November-07	0.976	0.07	0.9	0.004	0.98	0.068	0.9	0	0.976	0.068
December-07	0.976	0.07	0.9	0.004	0.98	0.068	0.9	0	0.976	0.068
January-08	0.97	0.06	0.9	0.004	0.97	0.06	0.9	0	0.97	0.06
February-08	0.97	0.06	0.9	0.004	0.97	0.06	0.9	0	0.97	0.06
March-08	0.97	0.06	0.9	0.004	0.97	0.06	0.9	0	0.97	0.06
April-08	0.96	0.05	0.9	0.004	0.96	0.05	0.9	0	0.96	0.05
May-08	0.96	0.05	0.9	0.004	0.96	0.05	0.9	0	0.96	0.05
June-08	0.96	0.05	0.89	0.015	0.96	0.05	0.89	0.02	0.96	0.05
July-08	0.95	0.04	0.89	0.015	0.95	0.04	0.89	0.02	0.95	0.04
August-08	0.95	0.04	0.89	0.015	0.95	0.04	0.89	0.02	0.95	0.04
September-08	0.94	0.04	0.89	0.015	0.94	0.039	0.89	0.02	0.94	0.039
October-08	0.94	0.04	0.89	0.015	0.94	0.039	0.89	0.02	0.94	0.039
November-08	0.9	0.04	0.89	0.015	0.9	0.035	0.89	0.02	0.9	0.035
December-08	0.9	0.04	0.89	0.015	0.9	0.035	0.89	0.02	0.9	0.035
January-09	0.9	0.04	0.89	0.015	0.9	0.035	0.89	0.02	0.9	0.035
February-09	0.8	0.03	0.89	0.015	0.8	0.034	0.89	0.02	0.8	0.034
March-09	0.8	0.03	0.89	0.015	0.8	0.034	0.89	0.02	0.8	0.034
April-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
May-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
June-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
July-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
August-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
September-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034

October-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
November-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
December-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
January-10	0.78	0.03	0.85	0.003	0.78	0.03	0.85	0	0.78	0.03
February-10	0.79	0.03	0.85	0.003	0.79	0.03	0.85	0	0.79	0.03
March-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
April-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
May-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
June-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
July-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
August-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
September-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
October-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
November-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
December-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
January-11	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
February-11	0.8	0.03	0.8	0.012	0.8	0.034	0.8	0.01	0.8	0.034
March-11	0.8	0.03	0.8	0.012	0.8	0.034	0.8	0.01	0.8	0.034
April-11	0.8	0.03	0.9	0.008	0.8	0.034	0.89	0.02	0.8	0.034
May-11	0.8	0.03	0.9	0.008	0.8	0.034	0.89	0.02	0.8	0.034
June-11	0.79	0.03	0.9	0.008	0.79	0.03	0.89	0.02	0.79	0.03
July-11	0.79	0.03	0.9	0.008	0.79	0.03	0.89	0.02	0.79	0.03
August-11	0.79	0.03	0.9	0.008	0.79	0.03	0.89	0.02	0.79	0.03
September-11	0.79	0.03	0.9	0.008	0.79	0.03	0.9	0.01	0.79	0.03
October-11	0.79	0.03	0.9	0.008	0.79	0.03	0.9	0.01	0.79	0.03
November-11	0.7	0.02	0.9	0.008	0.7	0.02	0.9	0.01	0.7	0.02
December-11	0.7	0.02	0.9	0.008	0.7	0.02	0.9	0.01	0.7	0.02
January-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0.01	0.8	0.013
February-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
March-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
April-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
May-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
June-12	0.85	0.04	0.9	0.008	0.85	0.035	0.9	0	0.85	0.035
July-12	0.85	0.04	0.9	0.008	0.85	0.035	0.9	0	0.85	0.035
August-12	0.85	0.04	0.9	0.008	0.85	0.035	0.9	0	0.85	0.035
September-12	0.8	0.03	0.9	0.008	0.8	0.034	0.9	0	0.8	0.034
October-12	0.8	0.03	0.9	0.008	0.8	0.034	0.9	0	0.8	0.034
November-12	0.8	0.03	0.9	0.008	0.8	0.034	0.7	0.01	0.8	0.034
December-12	0.8	0.03	0.65	0.004	0.8	0.034	0.65	0	0.8	0.034

January-13	0.8	0.03	0.65	0.004	0.8	0.034	0.65	0	0.8	0.034
February-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
March-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
April-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
May-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
June-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
July-13	0.7	0.02	0.65	0.004	0.7	0.02	0.65	0	0.7	0.02
August-13	0.7	0.02	0.7	0.008	0.7	0.02	0.71	0.02	0.7	0.02
September-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013
October-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013
November-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013
December-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013

From table 4i, failure rate improvement is as a result of maintenance at 0.02 while system reliability rate improvement is as a result of maintenance at 0.3. Reliability rate of injection moulding system without maintenance is 41.17% , while with maintenance is 48.97%.

4.3.1 Assumptions in Multi regression model

1. The periodic preventive maintenance has sufficient data to enable them being used for application.
2. System reliability depends on its age and the maintenance policy applied.
3. Change the current maintenance policy.

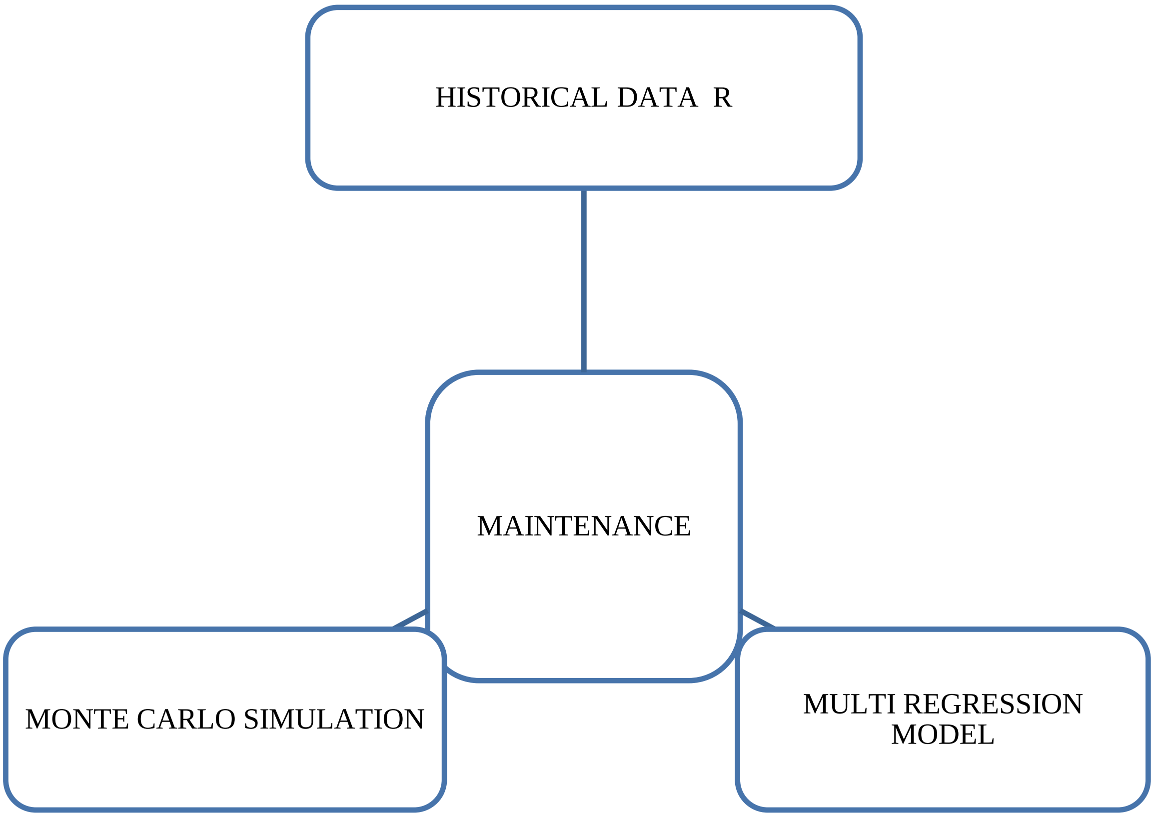

Figure 4n: Diagram representing the relationship between historical data R, Monte Carlo simulation and Multi regression model.

4.4 System down time analysis

This section presents a model that has the capability to quantify the consequential costs of downtime and lack of availability in three categories.

The first, associated resource impact costs, deals with the costs that arise when failure in one component impacts on the productivity and cost effectiveness of other components working in close association with it.

The second category, lack-of-readiness costs, addresses the cost that may be incurred when a capital asset is rendered idle by the downtime resulting from a prior failure.

The third cost category, alternative method impact costs, deals with the consequential costs that arise when failure causes a change in the method of operations. The methodology developed represents a significant step toward the rational quantification of consequential costs. An understanding of the philosophy behind each category, as well as the methodology used for quantification, should make it possible to model most situations, given a little thought and creativity in applying the model.

Table 4j : Raw data of downtime cost of IMM

YEAR	JANC	FEBC	**MARC**	APLC	MAYC	JUNC	JLYC	AGTC	SEPC	OCTC	NOVC	DECC
2004	60	55	55	60	60	55	55	55	50	50	50	60
2005	60	55	55	60	60	55	55	55	60	60	60	60
2006	60	50	50	65	65	50	50	50	60	60	60	65
2007	65	60	60	65	65	60	60	60	65	65	65	65
2008	65	60	60	65	65	65	65	65	65	65	65	65
2009	65	65	65	70	70	65	65	65	65	65	65	70
2010	70	65	65	70	70	65	65	65	65	65	65	70

Table 4j, shows raw data of cost of system downtime. In 2004, ₦60,000 was the peak cost but by 2010 the price had raise to ₦ 70,000. This shows that as the system age, the downtime increases with system failures.

4.4.1 Assumptions in downtime cost

The dependent variable and independent variable are treated as time series, meaning that each case represents a timepoint.

4.4.2 Understanding Pasw 18 Downtime cost output(qualitative improvement tool)

Seasonal Decomposition procedure creates four new variables which are:

1. SAF, Seasonal Adjustment Factors, representing seasonal variation.
2. SAS, Seasonal Adjusted Series, representing the original series with seasonal variation.
3. STC, Smoothed Trend-cycle component, which both smoothed that cyclic components.
4. ERR. The residual component of the series fora particular observation.

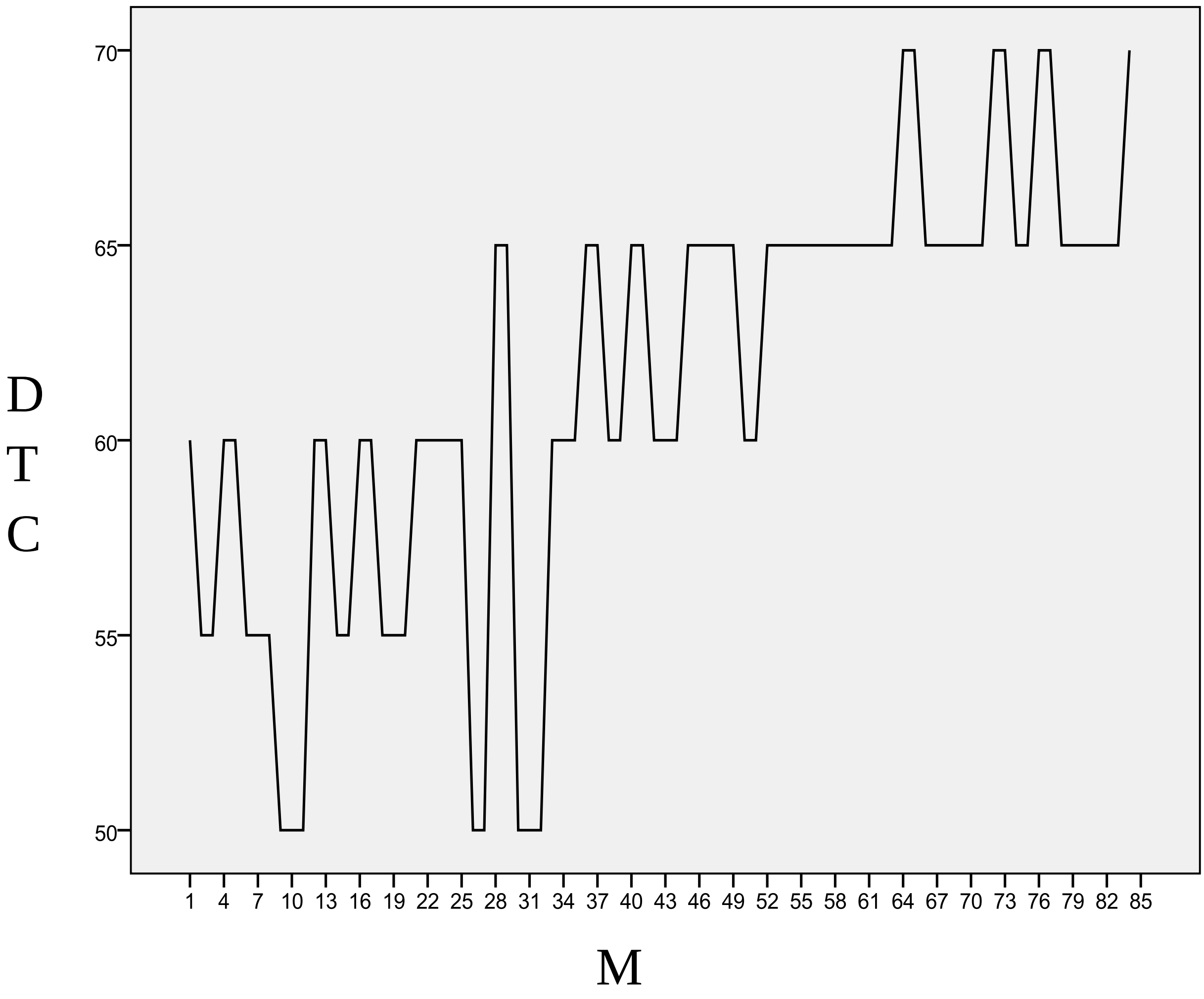

Figure 4o: Raw data Downtime cost OF IMM

Figure 4o displays how the former cost and how cost fluctuate by months within the year, as well as how the cost have period influence and the fluctuations are not predictable.

The series below exhibits a number of peaks, but they do not appear to be equally spaced. This output suggests that if the series has a periodic component, it also has fluctuations that are not periodic, the typical case for real–time series.

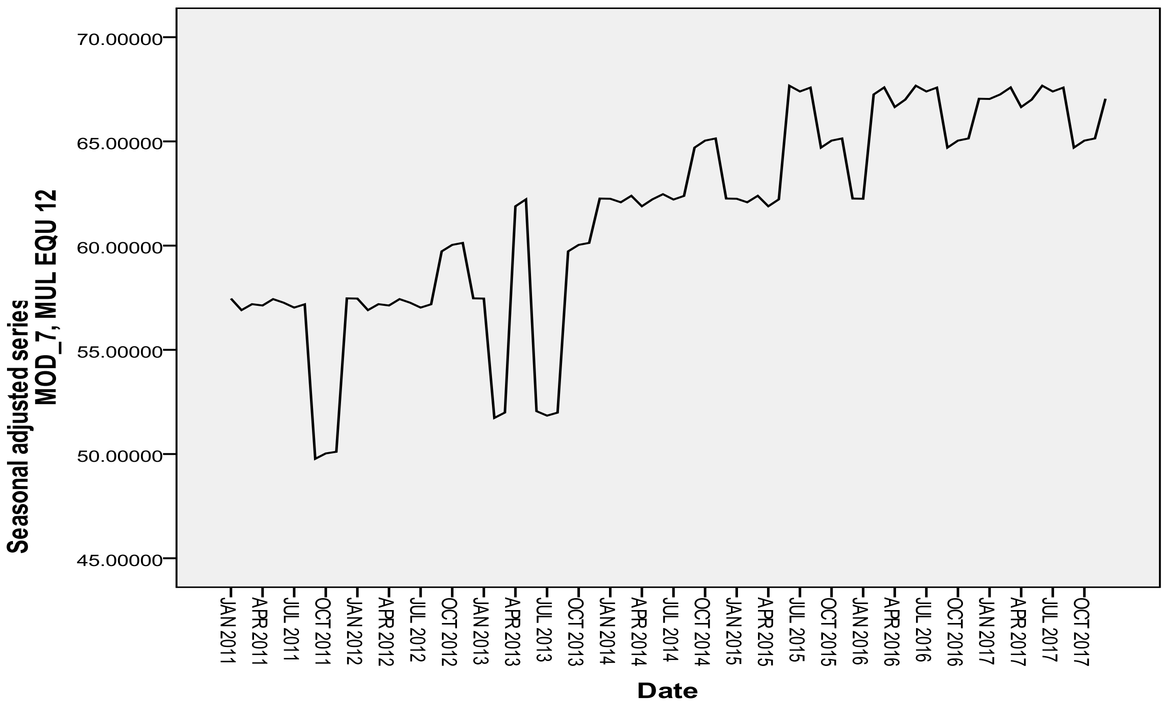

Figure 4p: Seasonal Adjusted Series

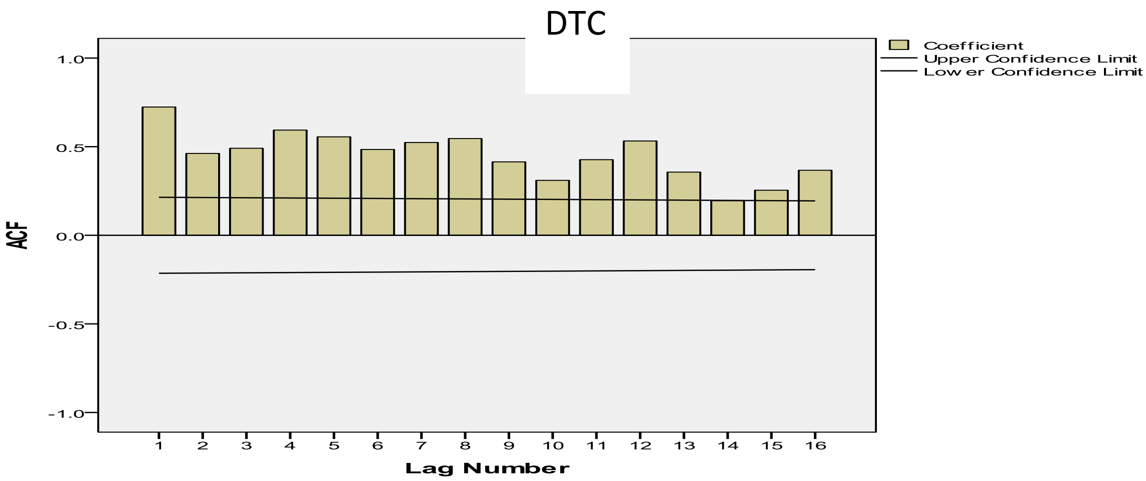

Figure 4q: Autocorrelation time series

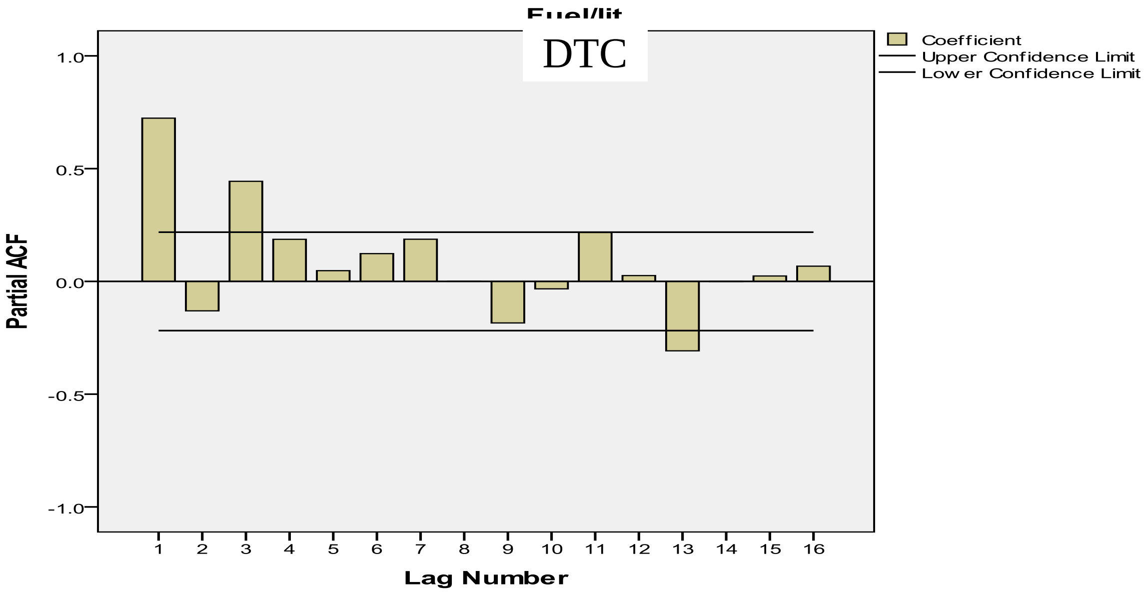

Figure 4r: Partial autocorrelation time series

Examining the autocorrelations and partial autocorrelations of a time series provides a more quantitative conclusion about the underlying periodicity.

The autocorrelation function shows a significant peak at a lag of 1 with a long exponential tail—a typical pattern for time series, showing weak Productivity.

The significant peak at a lag of 1 suggests the presence of an annual seasonal component in the data. Examination of the partial autocorrelation function will allow a more definitive conclusion.The downtime cost increases with time if preventive maintenance is not implemented.

4.5 PRODUCTS QUALITY CONTROL ANALYSIS

Control chart was for attainment of statistical stability of a production process. Currently, control charts are used in a wide variety of production, research, and development environments. This chapter presents a summary of the main contributions and current state of the art in the area of control chart design. This section address some open questions in the area of quality of X-bar charts when "warning lines" are used as part of the control scheme. Mathematical and statistical tools necessary for answering these questions are discussed and numerical examples are presented to illustrate the relevance of this work. The following paragraphs provide some background information on control charts: their uses, some of the most commonly used control schemes, and the primary considerations involved in the design of control charts. The Uses of Control Charts, the original intention of such control chart was to attain a state of statistical stability for a given process ("process 2 control"), since its introduction, many modifications have been suggested and other schemes have been introduced. Currently, Shewhart control charts are being used for at least one of the following different purposes.

1. Testing for statistical control. One of the uses of the control charts that was first contemplated is determining whether a process has achieved a state of statistical control. For this purpose, a defect product statistic is to charted, has

been selected depending on the process to be controlled and appropriate data are gathered and checked against trial control limits.

2. Maintaining current control. One of the many problems that arises in the applications of statistics in industry is the detection of changes in parameters specifying the quality of the output from a production process, so that some preventive action can be taken to restore the parameters to satisfactory values. Many control charts are being used to give an alarm when it is believed that the process has gone out of statistical control. Control limits computed from a given standard are used to detect when a process, which is in control at certain target values of the distribution parameters, departs from those value. Little justification has been given for the selection of these limits and many alternatives of this control method have been introduced. One of these alternatives that is widely used is to call for preventive action when a certain number of points out of a specified number of observations fall outside of a predetermined "warning line,"

3. Historical search The visual record provided by a Shewhart chart is a great help in identifying when changes in the process characteristics occurred so the search for assignable causes is facilitated.

Table 4k: Evaluating quality of defective production during corrective maintenance 2012

SAMPLENo	1	2	3	4	5	X	x/n = X	Max Min = R	X-x= D	$(X-x)^2$ D^2=S
JAN	43	42	46	49	43	223	44.6	7	178.4	31826.56
FEB	44	43	46	42	45	220	44.0	4	176	30976
MAR	46	47	47	44	45	229	45.8	3	183.2	33562.24
APR	42	43	40	45	43	213	42.6	5	170.4	29036.16
MAY	43	42	45	46	44	220	44.0	4	176.0	30976
JUNE	45	44	43	44	45	221	44.2	2	176.8	31187
JULY	42	43	45	46	42	218	43.6	4	114.4	30415.36
AUG	43	40	41	43	40	207	41.4	3	165.6	27423.36
SEPT	44	44	42	41	46	217	43.4	5	173.6	30136.96
OCT	42	42	44	41	44	213	42.6	3	170.4	29036.2
NOV	45	45	43	40	46	219	43.8	6	175.2	30695.0
DEC	45	45	41	44	42	217	43.4	4	173.2	299982
							523.4	50		
							12	12		336263

Analysis of quality of defective production from Table 4k, for five sample products during corrective maintenece 2012 shows peak mean in March, maximum range and standard deviation still in March.

Table 4l: Evaluating quality of defective production during preventive maintenance

Sample No	1	2	3	4	5	x	x/n=X	R	D	S
Jan	5	4	8	11	5	33	6.6	7	26.4	697.96
Feb	6	5	8	4	7	30	6.0	4	24	576
Mar	8	9	9	6	7	39	7.8	3	31.2	973.44
Apl	2	1	2	3	2	10	2.0	2	8	64
May	5	4	7	8	1	25	5.0	6	20	400
Jun	7	6	5	6	7	31	6.2	2	24.8	615.04
Jul	4	5	7	8	4	28	5.6	4	22.4	501.76
Aug	5	2	1	5	2	15	3.0	4	12	144
Sep	5	6	4	3	8	26	5.2	5	20.8	432.64
Oct	6	4	6	3	1	20	4.0	5	16	256
Nov	1	1	1	1	2	6	1.2	1	4.8	23.04
Dec	5	7	3	6	4	25	5.0	4	20	400

2014

Evaluation of quality of defective production during preventive maintenance for the same five sample products reflects maximum range, standard deviation and mean from table 4l.

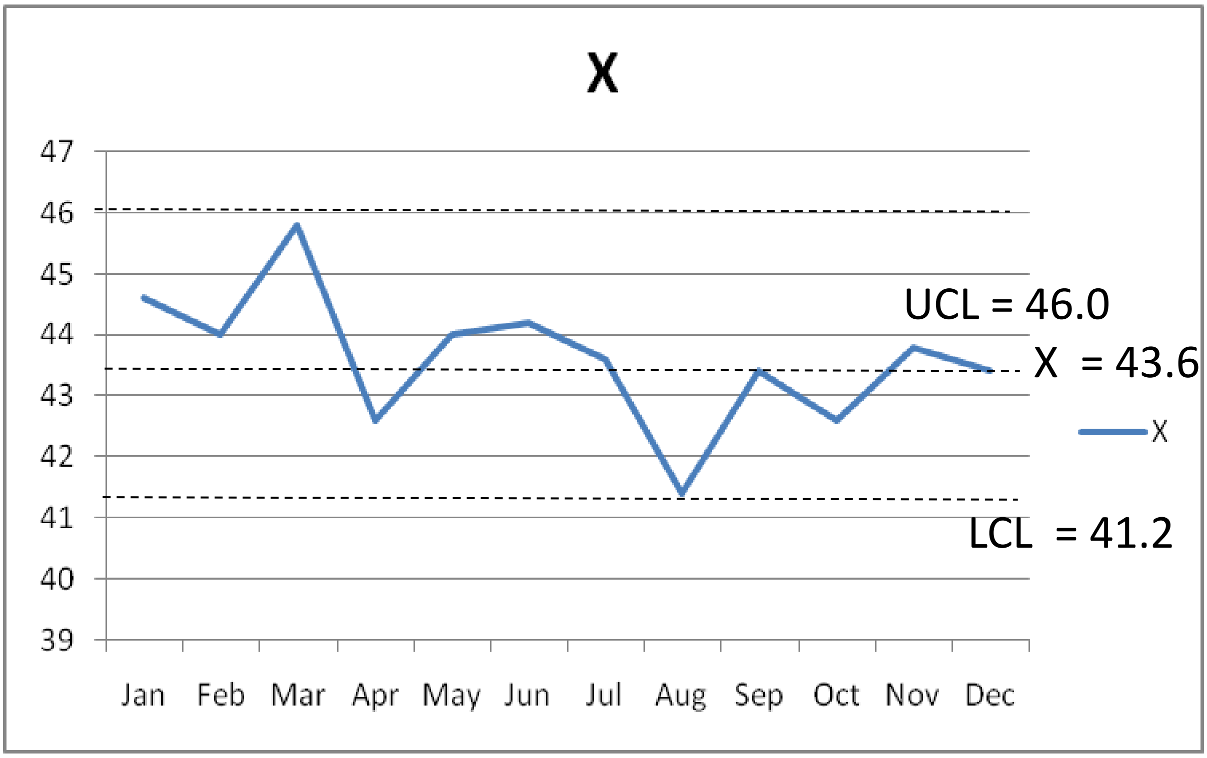

Figure 4s: Control charts for defective production in 2012 X-Chart

Figure 4s above, the X-chart shows highest rate of production of defective (45.8) falling under the upper control limit. Also, the least production (42.6) comes aboves the lower control limit. Thus X-chart in defective production 2012, indicates that the process has highest defective production.

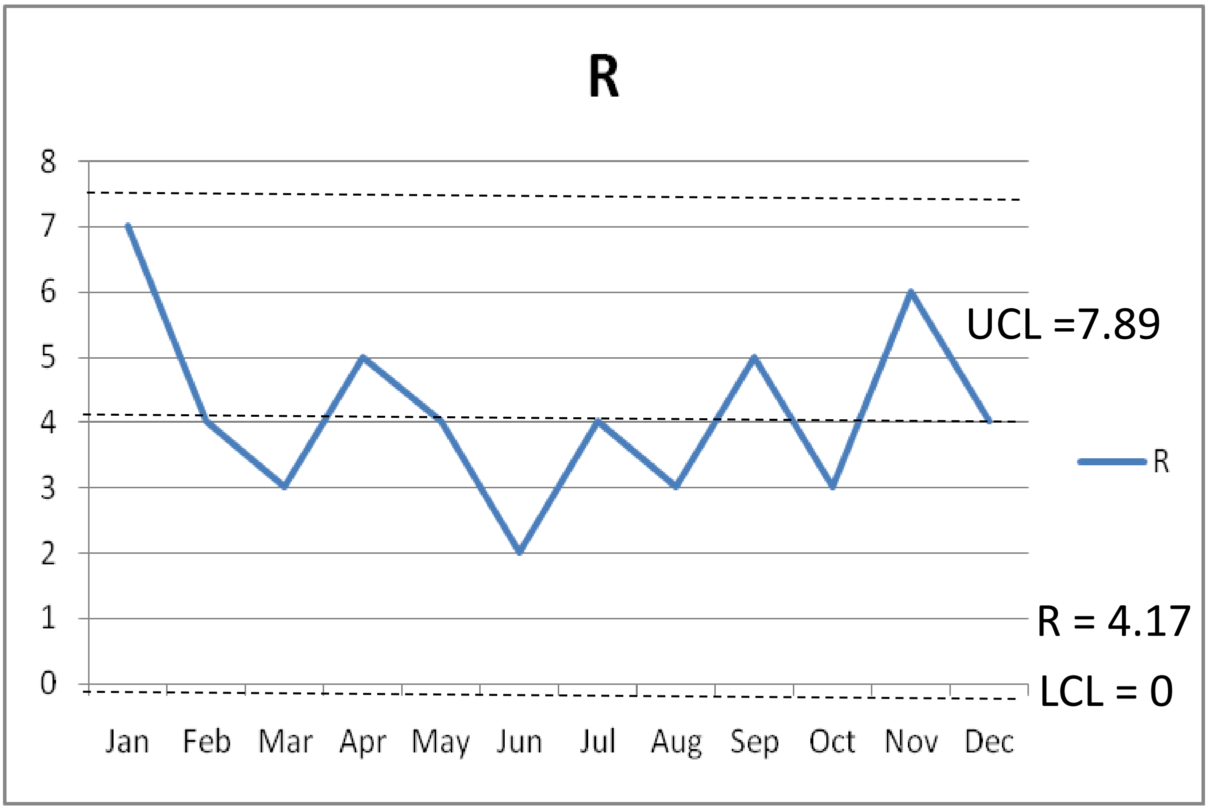

Figure 4m: Control charts for defective production in 2012 R-Chart

Figure 4m shows the ranges are all in control, showing high defective production, with the peak less than the upper control limit.

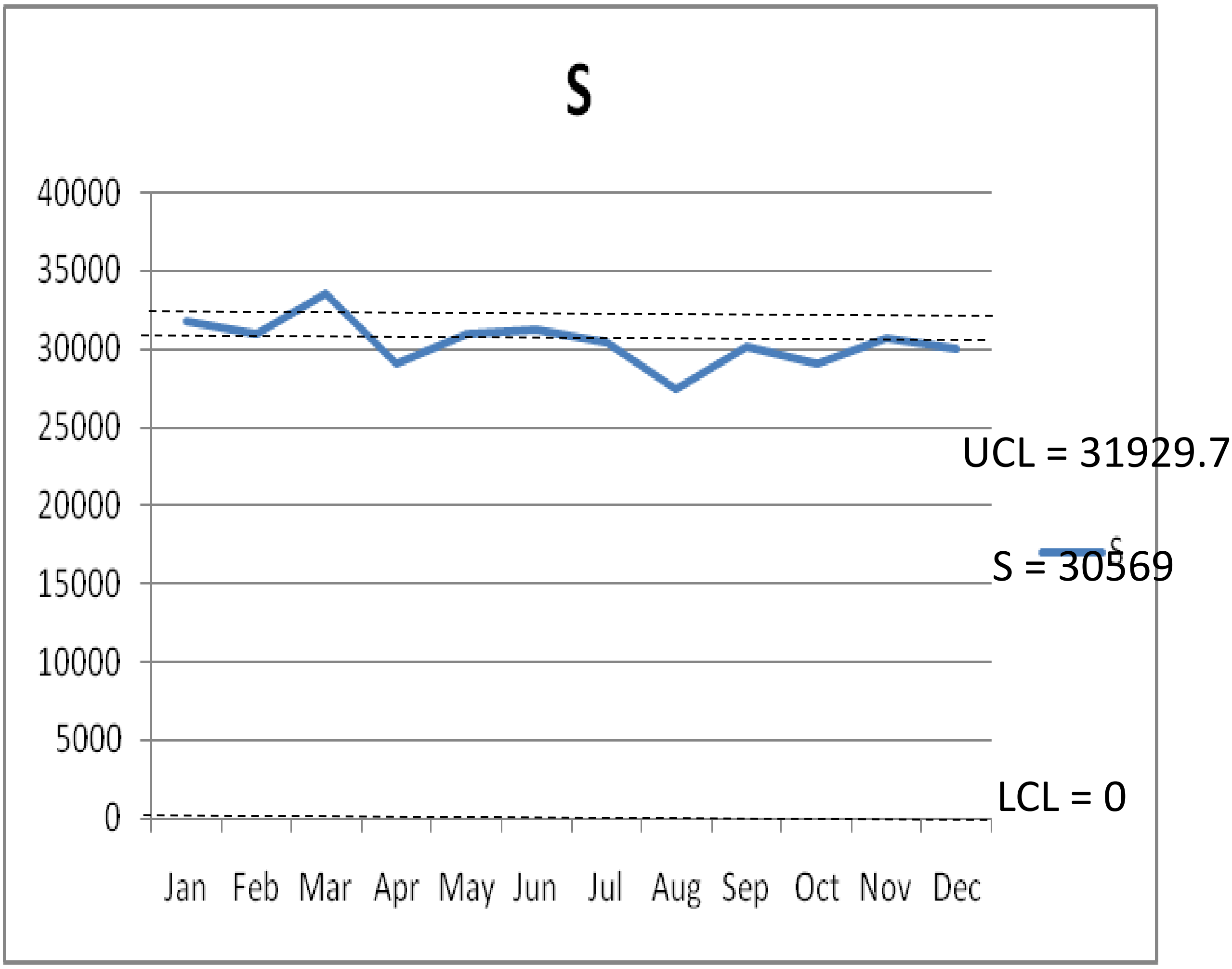

Figure 4t: Control charts for defective production in 2012 S-Chart

S-chart from figure 4n shows how the defective production varies, the variance all fell within the upper and lower control limits. It reflects excess defective production.

4.5.1 Result of SPC monitor during corrective maintenance 2012

1. For the X-chart in defective production 2012, it indicates that the process has highest defective production, showing system needs adequate maintaince.

2. S-chart shows how the defective production varies, supporting excess defective production.

3. R-chart explains the process as being high in defective production still.

4. Management has to think of implementing preventive maintenance.

The said charts were used to analyse the quality of defective production all through the year 2012 and 2014.

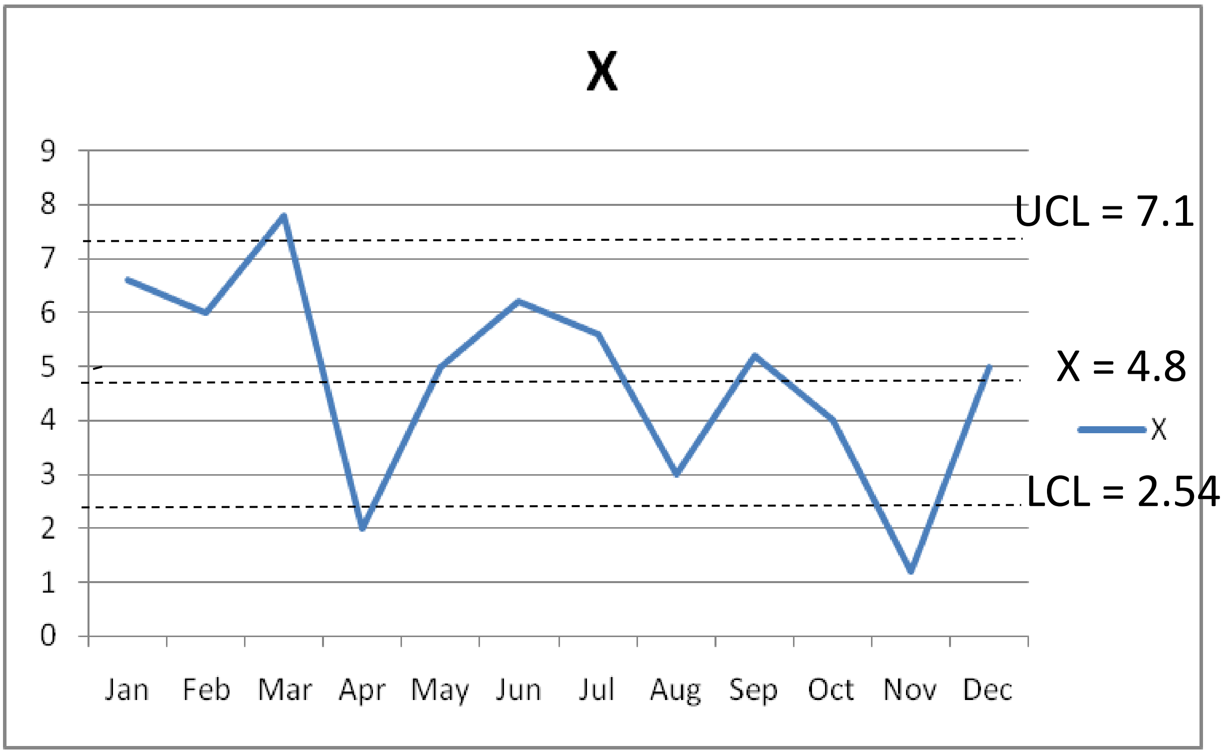

Figure 4u: Control charts during preventive maintenance in 2014, X-Chart

The X-chart from figure 4o, shows out of control, with process in March(7.8) was above the upper control limit, while November(1.2) was below the lower control limit. This depicts out of control from defective production.

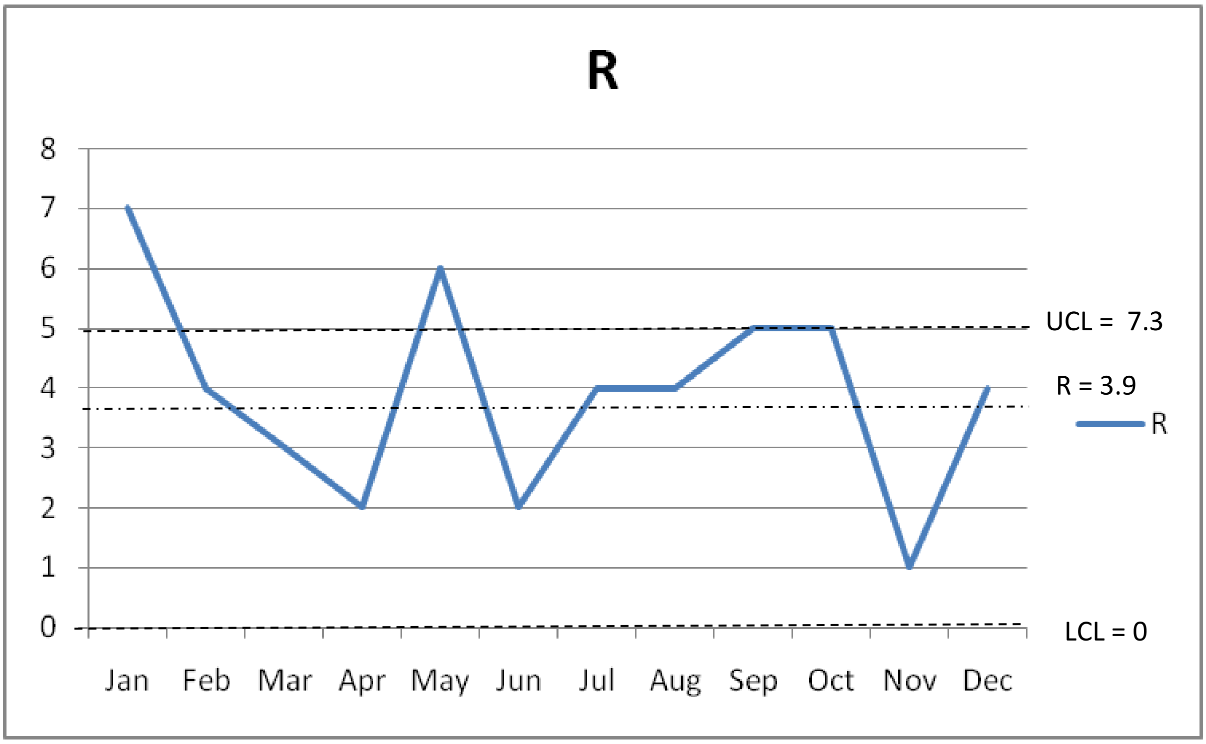

Figure 4v: Control charts during preventive maintenance in 2014, R-Chart

R-chart shows implementation of preventive maintenance with peak range of 7, while the upper control limit was 7.3

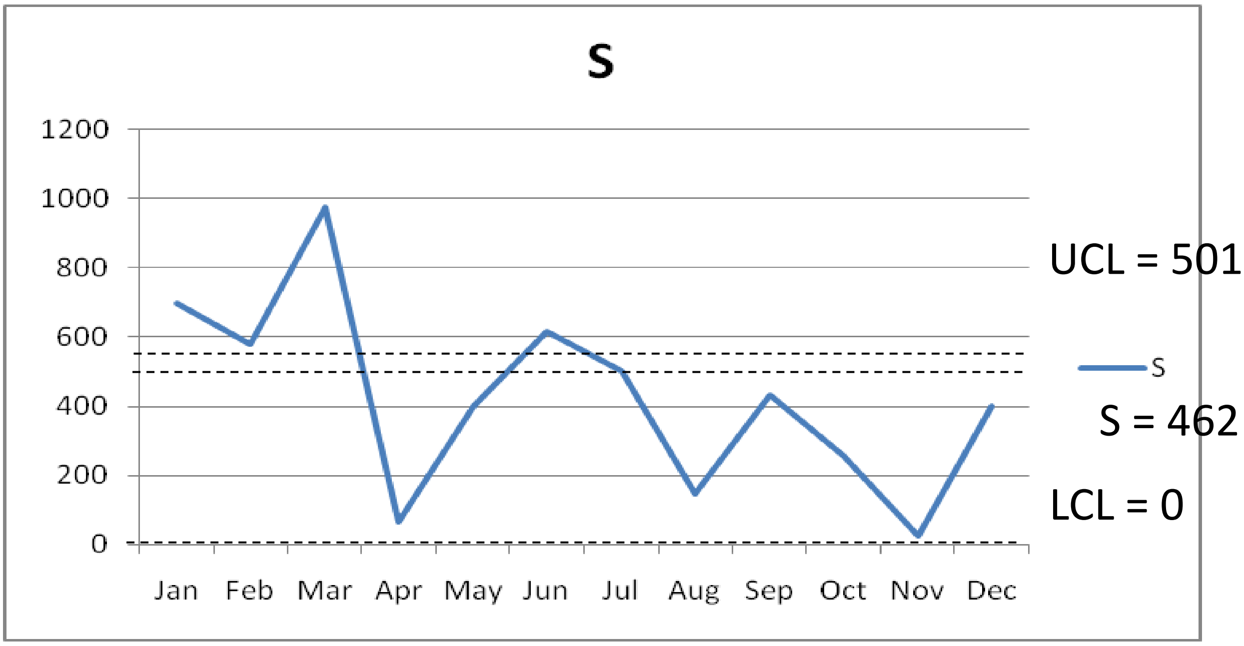

Figure 4w: Control charts during preventive maintenance In 2014, S-Chart

S-chart above shows, defective production being minimal with upper control limit 501 being less than it peak.

4.5.2 Result of SPC monitor during preventive maintenance 2014

1. X-chart showed out of control from defective production.

2. R-chart showed implementation of preventive maintenance

3. S-chart showed out of defective production control with its peak in March.

4. Preventive maintenance was effectively done which reflected in the output.

4.5.3 Assumptions in Control chart

1. The historical production data used to calculate productivity factor is accurate.
2. Production managers involved in the operations will be willing and able to learn the principle of evaluating production chart.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

Manufacturing companies have over the years been bedeviled with barrage of problems which were attributed to their traditional system of maintenance which involves a lot of wastes. Some of these problems facing them include stiff competition, low quality of products as well as loss of market shares. This explain why the companies began to question their maintenance policy in a bid to identify the merits and demerits it has over other systems. The main objectives of this research were to evaluate and analysis; Reliability, Maintenance, Downtime cost and Quality of product.

This exercise brought out various important issues such as, how aging affect system performance due to poor maintenance implementation that affect system's availability; which in turn destroys quality of production. Quality of production places industries at competitive advantage over others. This gives industries profit to fulfilling its strategic national goals: such as provision of employment, diversification of national. Although preventive maintenance approaches are emphasized here, there is much room for improvements to be made.The following recommendations are forwarded for the industry and related manufacturing industries that are executing maintenance work in their regular activity; Replacement or repair cost, benefit from operating the equipment, labor cost etc. should be collected with high degree of accuracy.This paper shows that reliability deals with management of high levels of "lifetime" engineering uncertainty and risks of failure that determines systems availability. Analysis of reliability and Maintainability of injection mould system was to ensure maximization of production throughput. Statistical analysis of the data should be done frequently using model to checkmate system maintenance. To achieve competitive advantages, companies should do the right thing, e.g. use the most cost effective maintenance policy that enhances reliability, and right competence. Furthermore, they should apply the never-ending improvement cycle, on system reliability, maintenance, downtime and quality of product which requires identifying problem areas by assessing the savings and profits generated by maintenance and monitoring the economic impact of the applied maintenance policy. Thus, they would know where investments should be allocated to eliminate the basic reasons for losses and increase savings. Proper maintenance would improve the reliability, quality, efficiency and effectiveness of production systems, and hence enhance company competitiveness, i.e. productivity and value advantages, and long-term profitability.This paper introduces a novel decision-model to help managers to select the best SPC approach to monitor the critical to quality characteristics in any type of short-run production process. To validate the model, it was applied to the case of a manufacturing process of a textile company; however, despite the successful implementation, the usefulness and applicability of the model need to be further tested in other kinds of processes, in order to take additional conclusions about its effectiveness to other situations. A critical foundation for developing this model was the literature review that was undertaken, and the identification of the different existing methods on SPC for short-run processes. As future research work, in addition of testing the model in other short-run contexts, it is our intention to incorporate the model within control framework, so the control and improvement initiatives can be properly linked, using the tools provided as part of the Innoson Plastic and Technical Industries. This concluding chapter examined the key findings of the research objectives, contributions to knowledge, the limitations of the research, as well as recommendations for future research.

5.1 The limitation of the research

Although there were many limitations encountered during the course of the research which threatened its successful completion, the lessons learnt from criticality analysis of Innoson injection moulding system can be summarized thus:

The major limitation faced by the research was the initial inability to secure interviews from the production company, as the targeted respondents which included Chief Executives, Production Managers and the Quality Control manager often cited their very busy schedules as the major reason for declining to grant the interviews. However, with constant visits, calls and the use of electronic mails, the target of the maximum of six interviews required for the research was achieved.

Conclusively,

1. This paper has presented a rapid method for reliability analysis using Monte Carlo Normal Distribution Model which interacts with multi regression Model, showing how reliability degrades with time.
2. The study shows that system fails more during the time of corrective maintenance then when preventive maintenance was implemented.
3. It can forecast outcome showing how system eventually collapses if preventive maintenance measures were not implemented 48.97% with maintained and 41.17% without, dependent on age.
4. Systems downtimes increased with time as reliability decreased, showing reliability and availability are parallel.
5. The quality of production shows excessive defective products when corrective maintenance was implemented compare to few defective products when preventive maintence was done.

5.2 Recommendations for Future Research

Implementation of preventive maintenance programmes can be improved by training and re-training of staff in maintenance planning methodology. The procedure for performing a Monte Carlo simulation is mathematically simple to use, and therefore, lends itself well to spreadsheet modeling. The failure data bank should be recognized and used to develop regressing models using trend analysis. The purpose of the trend line analysis was to obtain mathematical models for predicting future failure pattern of the systems.Accurate reliability and failure data is required for making good reliability analysis. Thus, industries must educate and train their personnel (engineers) to recognize the value in the data banks, and always use them when making reliability improvements. Although a lot of work and efforts were channeled into the successful completion of this research, it is far from been completed as there are still rooms for innovations and improvement. Future research on Performance Enhancement can therefore concentrate on its application on Small and Medium Scale Enterprises (SME) where the results can be compared with the findings of this work.

Finally, various studies have shown that there are many concepts and practical engineering tools available for making reliability analysis. Also available are wide variety of statistical analysis tools for studying reliability by the modern reliability specialist, but Monte Carlo simulation technique in particular, has been proven to be highly useful tool for predicting equipment failure compare to other software: reliability specialists can examine equipment failure models without having to wade through complex mathematics.

5.3 Contribution to Knowledge

This dissertation has made significant contributions to the body of knowledge in the following ways:

1. Monte Carlo normal distribution model, which interacts with multi regression maintenance based model, was used to establish a preventive maintenance-scheduling threshold for injection moulding system. This contribution is a novel approach in reliability analysis for injection moulding system.
2. A PASW 18 model has been introduced, established, and validated for predicting cost of downtimes for injection moulding system.
3. A Matlab time series simulation was implemented to validate the reliability results obtained from Monte Carlo normal distribution model. This contribution confirms the suitability of Monte Carlo normal distribution based multi-regression maintenance model, for systems reliability analysis.

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APPENDIX I

Multi Regression Model Forecast

	HYDRAULIC SYSTEM		INJECTION SYSTEM		CONTROL SYSTEM		MOLD SYSTEM		CLAMPING SYSTEM	
	Ʀ1	ƛ1	Ʀ2	ƛ2	Ʀ3	ƛ3	Ʀ4	ƛ4	Ʀ5	ƛ5
January-04	0.6	0.02	0.7	0.008	0.6	0.015	0.7	0.01	0.5	0.013
February-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
March-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
April-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
May-04	0.9	0.02	0.7	0.008	0.9	0.015	0.7	0.01	0.8	0.013
June-04	0.992	0.01	0.8	0.012	0.99	0.012	0.8	0.01	0.992	0.012
July-04	0.992	0.01	0.8	0.012	0.99	0.012	0.8	0.01	0.992	0.012
August-04	0.994	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.994	0.014
September-04	0.994	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.994	0.014
October-04	0.993	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.993	0.014

November-04	0.993	0.01	0.8	0.012	0.99	0.014	0.8	0.01	0.993	0.014
December-04	0.992	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.992	0.012
January-05	0.992	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.992	0.012
February-05	0.994	0.01	0.9	0.012	0.99	0.014	0.9	0.01	0.994	0.014
March-05	0.994	0.01	0.9	0.012	0.99	0.014	0.9	0.01	0.994	0.014
April-05	0.994	0.01	0.9	0.012	0.99	0.014	0.9	0.01	0.994	0.014
May-05	0.993	0.01	0.85	0.003	0.99	0.014	0.85	0	0.993	0.014
June-05	0.992	0.01	0.85	0.003	0.99	0.012	0.85	0	0.992	0.012
July-05	0.991	0.01	0.85	0.003	0.99	0.01	0.85	0	0.991	0.01
August-05	0.991	0.01	0.85	0.003	0.99	0.01	0.85	0	0.991	0.01
September-05	0.992	0.01	0.85	0.003	0.99	0.012	0.85	0	0.992	0.012
October-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0	0.99	0.01
November-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0	0.99	0.01
December-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0	0.99	0.01
January-06	0.98	0.01	0.85	0.003	0.98	0.009	0.85	0	0.98	0.009
February-06	0.98	0.01	0.85	0.003	0.98	0.009	0.85	0	0.98	0.009
March-06	0.981	0.01	0.85	0.003	0.98	0.009	0.85	0	0.981	0.009
April-06	0.981	0.01	0.85	0.003	0.98	0.009	0.85	0	0.981	0.009
May-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
June-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
July-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
August-06	0.982	0.01	0.89	0.015	0.98	0.01	0.89	0.02	0.982	0.01
September-06	0.981	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.981	0.009
October-06	0.981	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.981	0.009
November-06	0.981	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.981	0.009
December-06	0.98	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.98	0.009
January-07	0.98	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.98	0.009
February-07	0.98	0.01	0.89	0.015	0.98	0.009	0.89	0.02	0.98	0.009
March-07	0.985	0.01	0.89	0.015	0.99	0.012	0.89	0.02	0.985	0.012
April-07	0.985	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.985	0.012
May-07	0.985	0.01	0.9	0.012	0.99	0.012	0.9	0.01	0.985	0.012
June-07	0.979	0.01	0.9	0.012	0.98	0.009	0.9	0.01	0.979	0.009
July-07	0.979	0.01	0.9	0.012	0.98	0.009	0.9	0.01	0.979	0.009
August-07	0.979	0.01	0.9	0.012	0.98	0.009	0.9	0.01	0.979	0.009
September-07	0.979	0.01	0.9	0.004	0.98	0.009	0.9	0	0.979	0.009
October-07	0.976	0.07	0.9	0.004	0.98	0.068	0.9	0	0.976	0.068
November-	0.976	0.07	0.9	0.004	0.98	0.068	0.9	0	0.976	0.068

07										
December-07	0.976	0.07	0.9	0.004	0.98	0.068	0.9	0	0.976	0.068
January-08	0.97	0.06	0.9	0.004	0.97	0.06	0.9	0	0.97	0.06
February-08	0.97	0.06	0.9	0.004	0.97	0.06	0.9	0	0.97	0.06
March-08	0.97	0.06	0.9	0.004	0.97	0.06	0.9	0	0.97	0.06
April-08	0.96	0.05	0.9	0.004	0.96	0.05	0.9	0	0.96	0.05
May-08	0.96	0.05	0.9	0.004	0.96	0.05	0.9	0	0.96	0.05
June-08	0.96	0.05	0.89	0.015	0.96	0.05	0.89	0.02	0.96	0.05
July-08	0.95	0.04	0.89	0.015	0.95	0.04	0.89	0.02	0.95	0.04
August-08	0.95	0.04	0.89	0.015	0.95	0.04	0.89	0.02	0.95	0.04
September-08	0.94	0.04	0.89	0.015	0.94	0.039	0.89	0.02	0.94	0.039
October-08	0.94	0.04	0.89	0.015	0.94	0.039	0.89	0.02	0.94	0.039
November-08	0.9	0.04	0.89	0.015	0.9	0.035	0.89	0.02	0.9	0.035
December-08	0.9	0.04	0.89	0.015	0.9	0.035	0.89	0.02	0.9	0.035
January-09	0.9	0.04	0.89	0.015	0.9	0.035	0.89	0.02	0.9	0.035
February-09	0.8	0.03	0.89	0.015	0.8	0.034	0.89	0.02	0.8	0.034
March-09	0.8	0.03	0.89	0.015	0.8	0.034	0.89	0.02	0.8	0.034
April-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
May-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
June-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
July-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
August-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
September-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
October-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
November-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
December-09	0.8	0.03	0.85	0.003	0.8	0.034	0.85	0	0.8	0.034
January-10	0.78	0.03	0.85	0.003	0.78	0.03	0.85	0	0.78	0.03
February-10	0.79	0.03	0.85	0.003	0.79	0.03	0.85	0	0.79	0.03
March-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
April-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
May-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
June-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
July-10	0.79	0.03	0.8	0.012	0.79	0.03	0.8	0.01	0.79	0.03
August-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
September-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
October-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
November-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035

December-10	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
January-11	0.85	0.04	0.8	0.012	0.85	0.035	0.8	0.01	0.85	0.035
February-11	0.8	0.03	0.8	0.012	0.8	0.034	0.8	0.01	0.8	0.034
March-11	0.8	0.03	0.8	0.012	0.8	0.034	0.8	0.01	0.8	0.034
April-11	0.8	0.03	0.9	0.008	0.8	0.034	0.89	0.02	0.8	0.034
May-11	0.8	0.03	0.9	0.008	0.8	0.034	0.89	0.02	0.8	0.034
June-11	0.79	0.03	0.9	0.008	0.79	0.03	0.89	0.02	0.79	0.03
July-11	0.79	0.03	0.9	0.008	0.79	0.03	0.89	0.02	0.79	0.03
August-11	0.79	0.03	0.9	0.008	0.79	0.03	0.89	0.02	0.79	0.03
September-11	0.79	0.03	0.9	0.008	0.79	0.03	0.9	0.01	0.79	0.03
October-11	0.79	0.03	0.9	0.008	0.79	0.03	0.9	0.01	0.79	0.03
November-11	0.7	0.02	0.9	0.008	0.7	0.02	0.9	0.01	0.7	0.02
December-11	0.7	0.02	0.9	0.008	0.7	0.02	0.9	0.01	0.7	0.02
January-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0.01	0.8	0.013
February-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
March-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
April-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
May-12	0.9	0.02	0.9	0.008	0.9	0.015	0.9	0	0.8	0.013
June-12	0.85	0.04	0.9	0.008	0.85	0.035	0.9	0	0.85	0.035
July-12	0.85	0.04	0.9	0.008	0.85	0.035	0.9	0	0.85	0.035
August-12	0.85	0.04	0.9	0.008	0.85	0.035	0.9	0	0.85	0.035
September-12	0.8	0.03	0.9	0.008	0.8	0.034	0.9	0	0.8	0.034
October-12	0.8	0.03	0.9	0.008	0.8	0.034	0.9	0	0.8	0.034
November-12	0.8	0.03	0.9	0.008	0.8	0.034	0.7	0.01	0.8	0.034
December-12	0.8	0.03	0.65	0.004	0.8	0.034	0.65	0	0.8	0.034
January-13	0.8	0.03	0.65	0.004	0.8	0.034	0.65	0	0.8	0.034
February-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
March-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
April-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
May-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
June-13	0.79	0.03	0.65	0.004	0.79	0.03	0.65	0	0.79	0.03
July-13	0.7	0.02	0.65	0.004	0.7	0.02	0.65	0	0.7	0.02
August-13	0.7	0.02	0.7	0.008	0.7	0.02	0.71	0.02	0.7	0.02
September-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013
October-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013
November-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013
December-13	0.9	0.02	0.7	0.008	0.9	0.015	0.71	0.02	0.8	0.013

APPENDIX II

DT Series Forecast

YEARS	HYDRAULIC SYSTEM R_1	HYDRAULIC SYSTEM λ_1	INJECTION SYSTEM R_2	INJECTION SYSTEM λ_2	CONTROL SYSTEM R_3	CONTROL SYSTEM λ_3	MOLD SYSTEM R_4	MOLD SYSTEM λ_4	CLAMPING SYSTEM R_5	CLAMPING SYSTEM λ_5
January-04	0.6	0.015	0.7	0.008	0.6	0.015	0.7	0.008	0.5	0.013
February-04	0.6	0.015	0.7	0.008	0.6	0.015	0.7	0.008	0.5	0.013
March-04	0.6	0.015	0.7	0.008	0.6	0.015	0.7	0.008	0.5	0.013
April-04	0.6	0.015	0.7	0.008	0.6	0.015	0.7	0.008	0.5	0.013
May-04	0.6	0.015	0.7	0.008	0.6	0.015	0.7	0.008	0.5	0.013
June-04	0.992	0.012	0.8	0.012	0.992	0.012	0.8	0.012	0.992	0.012
July-04	0.992	0.012	0.8	0.012	0.992	0.012	0.8	0.012	0.992	0.012
August-04	0.994	0.014	0.8	0.012	0.994	0.014	0.8	0.012	0.994	0.014
September-04	0.994	0.014	0.8	0.012	0.994	0.014	0.8	0.012	0.994	0.014
October-04	0.993	0.014	0.8	0.012	0.993	0.014	0.8	0.012	0.993	0.014
November-04	0.993	0.014	0.8	0.012	0.993	0.014	0.8	0.012	0.993	0.014

December-04	0.992	0.012	0.9	0.012	0.992	0.012	0.9	0.012	0.992	0.012
January-05	0.992	0.012	0.9	0.012	0.992	0.012	0.9	0.012	0.992	0.012
February-05	0.994	0.014	0.9	0.012	0.994	0.014	0.9	0.012	0.994	0.014
March-05	0.994	0.014	0.9	0.012	0.994	0.014	0.9	0.012	0.994	0.014
April-05	0.994	0.014	0.9	0.012	0.994	0.014	0.9	0.012	0.994	0.014
May-05	0.993	0.014	0.85	0.003	0.993	0.014	0.85	0.003	0.993	0.014
June-05	0.992	0.012	0.85	0.003	0.992	0.012	0.85	0.003	0.992	0.012
July-05	0.991	0.01	0.85	0.003	0.991	0.01	0.85	0.003	0.991	0.01
August-05	0.991	0.01	0.85	0.003	0.991	0.01	0.85	0.003	0.991	0.01
September-05	0.992	0.012	0.85	0.003	0.992	0.012	0.85	0.003	0.992	0.012
October-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0.003	0.99	0.01
November-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0.003	0.99	0.01
December-05	0.99	0.01	0.85	0.003	0.99	0.01	0.85	0.003	0.99	0.01
January-06	0.98	0.009	0.85	0.003	0.98	0.009	0.85	0.003	0.98	0.009
February-06	0.98	0.009	0.85	0.003	0.98	0.009	0.85	0.003	0.98	0.009
March-06	0.981	0.009	0.85	0.003	0.981	0.009	0.85	0.003	0.981	0.009
April-06	0.981	0.009	0.85	0.003	0.981	0.009	0.85	0.003	0.981	0.009
May-06	0.982	0.01	0.89	0.015	0.982	0.01	0.89	0.015	0.982	0.01
June-06	0.982	0.01	0.89	0.015	0.982	0.01	0.89	0.015	0.982	0.01
July-06	0.982	0.01	0.89	0.015	0.982	0.01	0.89	0.015	0.982	0.01
August-06	0.982	0.01	0.89	0.015	0.982	0.01	0.89	0.015	0.982	0.01
September-06	0.981	0.009	0.89	0.015	0.981	0.009	0.89	0.015	0.981	0.009
October-06	0.981	0.009	0.89	0.015	0.981	0.009	0.89	0.015	0.981	0.009
November-06	0.981	0.009	0.89	0.015	0.981	0.009	0.89	0.015	0.981	0.009
December-06	0.98	0.009	0.89	0.015	0.98	0.009	0.89	0.015	0.98	0.009
January-07	0.98	0.009	0.89	0.015	0.98	0.009	0.89	0.015	0.98	0.009
February-07	0.98	0.009	0.89	0.015	0.98	0.009	0.89	0.015	0.98	0.009
March-07	0.985	0.012	0.89	0.015	0.985	0.012	0.89	0.015	0.985	0.012
April-07	0.985	0.012	0.9	0.012	0.985	0.012	0.9	0.012	0.985	0.012
May-07	0.985	0.012	0.9	0.012	0.985	0.012	0.9	0.012	0.985	0.012
June-07	0.979	0.009	0.9	0.012	0.979	0.009	0.9	0.012	0.979	0.009
July-07	0.979	0.009	0.9	0.012	0.979	0.009	0.9	0.012	0.979	0.009
August-07	0.979	0.009	0.9	0.012	0.979	0.009	0.9	0.012	0.979	0.009
September-07	0.979	0.009	0.9	0.004	0.979	0.009	0.9	0.004	0.979	0.009
October-07	0.976	0.088	0.9	0.004	0.976	0.088	0.9	0.004	0.976	0.088

November-07	0.976	0.088	0.9	0.004	0.976	0.088	0.9	0.004	0.976	0.088
December-07	0.976	0.088	0.9	0.004	0.976	0.088	0.9	0.004	0.976	0.088
January-08	0.97	0.08	0.9	0.004	0.97	0.08	0.9	0.004	0.97	0.08
February-08	0.97	0.08	0.9	0.004	0.97	0.08	0.9	0.004	0.97	0.08
March-08	0.97	0.08	0.9	0.004	0.97	0.08	0.9	0.004	0.97	0.08
April-08	0.96	0.07	0.9	0.004	0.96	0.07	0.9	0.004	0.96	0.07
May-08	0.96	0.07	0.9	0.004	0.96	0.07	0.9	0.004	0.96	0.07
June-08	0.96	0.07	0.89	0.015	0.96	0.07	0.89	0.015	0.96	0.07
July-08	0.95	0.06	0.89	0.015	0.95	0.06	0.89	0.015	0.95	0.06
August-08	0.95	0.06	0.89	0.015	0.95	0.06	0.89	0.015	0.95	0.06
September-08	0.94	0.059	0.89	0.015	0.94	0.059	0.89	0.015	0.94	0.059
October-08	0.94	0.059	0.89	0.015	0.94	0.059	0.89	0.015	0.94	0.059
November-08	0.9	0.055	0.89	0.015	0.9	0.055	0.89	0.015	0.9	0.055
December-08	0.9	0.055	0.89	0.015	0.9	0.055	0.89	0.015	0.9	0.055
January-09	0.9	0.055	0.89	0.015	0.9	0.055	0.89	0.015	0.9	0.055
February-09	0.8	0.054	0.89	0.015	0.8	0.054	0.89	0.015	0.8	0.054
March-09	0.8	0.054	0.89	0.015	0.8	0.054	0.89	0.015	0.8	0.054
April-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
May-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
June-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
July-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
August-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
September-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
October-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
November-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
December-09	0.8	0.054	0.85	0.003	0.8	0.054	0.85	0.003	0.8	0.054
January-10	0.78	0.05	0.85	0.003	0.78	0.05	0.85	0.003	0.78	0.05
February-10	0.79	0.05	0.85	0.003	0.79	0.05	0.85	0.003	0.79	0.05
March-10	0.79	0.05	0.8	0.012	0.79	0.05	0.8	0.012	0.79	0.05
April-10	0.79	0.05	0.8	0.012	0.79	0.05	0.8	0.012	0.79	0.05
May-10	0.79	0.05	0.8	0.012	0.79	0.05	0.8	0.012	0.79	0.05
June-10	0.79	0.05	0.8	0.012	0.79	0.05	0.8	0.012	0.79	0.05
July-10	0.79	0.05	0.8	0.012	0.79	0.05	0.8	0.012	0.79	0.05
August-10	0.85	0.055	0.8	0.012	0.85	0.055	0.8	0.012	0.85	0.055
September-10	0.85	0.055	0.8	0.012	0.85	0.055	0.8	0.012	0.85	0.055

October-10	0.85	0.055	0.8	0.012	0.85	0.055	0.8	0.012	0.85	0.055
November-10	0.85	0.055	0.8	0.012	0.85	0.055	0.8	0.012	0.85	0.055
December-10	0.85	0.055	0.8	0.012	0.85	0.055	0.8	0.012	0.85	0.055
January-11	0.85	0.055	0.8	0.012	0.85	0.055	0.8	0.012	0.85	0.055
February-11	0.8	0.054	0.8	0.012	0.8	0.054	0.8	0.012	0.8	0.054
March-11	0.8	0.054	0.8	0.012	0.8	0.054	0.8	0.012	0.8	0.054
April-11	0.8	0.054	0.6	0.008	0.8	0.054	0.89	0.015	0.8	0.054
May-11	0.8	0.054	0.6	0.008	0.8	0.054	0.89	0.015	0.8	0.054
June-11	0.79	0.05	0.6	0.008	0.79	0.05	0.89	0.015	0.79	0.05
July-11	0.79	0.05	0.6	0.008	0.79	0.05	0.89	0.015	0.79	0.05
August-11	0.79	0.05	0.6	0.008	0.79	0.05	0.89	0.015	0.79	0.05
September-11	0.79	0.05	0.6	0.008	0.79	0.05	0.9	0.012	0.79	0.05
October-11	0.79	0.05	0.6	0.008	0.79	0.05	0.9	0.012	0.79	0.05
November-11	0.7	0.04	0.6	0.008	0.7	0.04	0.9	0.012	0.7	0.04
December-11	0.7	0.04	0.6	0.008	0.7	0.04	0.9	0.012	0.7	0.04
January-12	0.6	0.015	0.6	0.008	0.6	0.015	0.9	0.012	0.5	0.013
February-12	0.6	0.015	0.6	0.008	0.6	0.015	0.9	0.004	0.5	0.013
March-12	0.6	0.015	0.6	0.008	0.6	0.015	0.9	0.004	0.5	0.013
April-12	0.6	0.015	0.6	0.008	0.6	0.015	0.9	0.004	0.5	0.013
May-12	0.6	0.015	0.6	0.008	0.6	0.015	0.9	0.004	0.5	0.013
June-12	0.85	0.055	0.6	0.008	0.85	0.055	0.9	0.004	0.85	0.055
July-12	0.85	0.055	0.6	0.008	0.85	0.055	0.9	0.004	0.85	0.055
August-12	0.85	0.055	0.6	0.008	0.85	0.055	0.9	0.004	0.85	0.055
September-12	0.8	0.054	0.6	0.008	0.8	0.054	0.9	0.004	0.8	0.054
October-12	0.8	0.054	0.6	0.008	0.8	0.054	0.9	0.004	0.8	0.054
November-12	0.8	0.054	0.6	0.008	0.8	0.054	0.7	0.008	0.8	0.054
December-12	0.8	0.054	0.65	0.004	0.8	0.054	0.65	0.004	0.8	0.054
January-13	0.8	0.054	0.65	0.004	0.8	0.054	0.65	0.004	0.8	0.054
February-13	0.79	0.05	0.65	0.004	0.79	0.05	0.65	0.004	0.79	0.05
March-13	0.79	0.05	0.65	0.004	0.79	0.05	0.65	0.004	0.79	0.05
April-13	0.79	0.05	0.65	0.004	0.79	0.05	0.65	0.004	0.79	0.05
May-13	0.79	0.05	0.65	0.004	0.79	0.05	0.65	0.004	0.79	0.05
June-13	0.79	0.05	0.65	0.004	0.79	0.05	0.65	0.004	0.79	0.05
July-13	0.7	0.04	0.65	0.004	0.7	0.04	0.65	0.004	0.7	0.04
August-13	0.7	0.04	0.7	0.008	0.7	0.04	0.71	0.018	0.7	0.04

September-13	0.6	0.015	0.7	0.008	0.6	0.015	0.71	0.018	0.5	0.013
October-13	0.6	0.015	0.7	0.008	0.6	0.015	0.71	0.018	0.5	0.013
November-13	0.6	0.015	0.7	0.008	0.6	0.015	0.71	0.018	0.5	0.013
December-13	0.6	0.015	0.7	0.008	0.6	0.015	0.71	0.018	0.5	0.013

APPENDIX III

System Simulation Run

Run simulation of the components rate 1000 times

HYDRAULIC SYSTEM		INJECTION SYSTEM		CONTROL SYSTEM		MOLD SYSTEM		CLAMPING SYSTEM	
Ʀ1	ƛ1	Ʀ2	ƛ2	Ʀ3	ƛ3	Ʀ4	ƛ4	Ʀ5	ƛ5
0.898	0.025	0.756	0.003	0.720	0.019	0.673	0.012	0.658	0.047

0.762	0.056	0.815	0.009	0.810	0.049	0.711	0.010	0.875	0.015
0.704	0.040	0.752	0.007	0.774	0.009	0.669	0.013	0.641	0.054
0.670	0.048	0.850	0.010	0.633	0.078	0.758	0.011	0.806	0.056
0.875	0.035	0.769	0.009	0.731	0.034	0.660	0.006	0.700	0.020
0.642	0.015	0.821	0.011	0.751	0.079	0.899	0.015	0.709	0.038
0.687	0.082	0.782	0.015	0.848	0.014	0.731	0.016	0.803	0.080
0.921	0.082	0.605	0.009	0.916	0.021	0.798	0.010	0.902	0.010
0.887	0.033	0.679	0.006	0.639	0.064	0.726	0.009	0.965	0.066
0.784	0.016	0.709	0.005	0.962	0.036	0.847	0.003	0.619	0.044
0.610	0.025	0.788	0.009	0.899	0.046	0.789	0.011	0.806	0.021
0.782	0.083	0.841	0.004	0.909	0.038	0.677	0.006	0.988	0.026
0.666	0.047	0.801	0.007	0.794	0.059	0.899	0.014	0.788	0.039
0.612	0.069	0.808	0.009	0.783	0.021	0.849	0.010	0.614	0.087
0.961	0.026	0.724	0.015	0.912	0.011	0.877	0.013	0.565	0.049
0.872	0.067	0.808	0.007	0.738	0.046	0.704	0.009	0.737	0.037
0.820	0.024	0.735	0.010	0.671	0.048	0.831	0.011	0.843	0.018
0.980	0.041	0.679	0.007	0.682	0.015	0.775	0.007	0.684	0.018
0.636	0.035	0.843	0.011	0.739	0.012	0.776	0.006	0.575	0.015
0.940	0.041	0.716	0.009	0.802	0.040	0.665	0.009	0.669	0.014
0.851	0.045	0.871	0.004	0.949	0.032	0.765	0.011	0.737	0.014
0.710	0.040	0.739	0.010	0.601	0.049	0.846	0.013	0.515	0.009
0.951	0.080	0.865	0.014	0.717	0.050	0.844	0.008	0.624	0.032
0.961	0.028	0.828	0.008	0.795	0.079	0.815	0.018	0.790	0.073
0.956	0.049	0.703	0.015	0.757	0.068	0.805	0.003	0.690	0.026
0.887	0.083	0.835	0.005	0.676	0.070	0.779	0.012	0.760	0.071
0.794	0.033	0.879	0.013	0.616	0.015	0.657	0.006	0.858	0.021
0.821	0.070	0.740	0.010	0.659	0.046	0.736	0.013	0.874	0.047
0.672	0.070	0.672	0.015	0.834	0.013	0.747	0.008	0.928	0.074
0.837	0.059	0.694	0.009	0.669	0.030	0.715	0.008	0.519	0.070
0.809	0.047	0.675	0.004	0.671	0.069	0.806	0.010	0.854	0.015
0.708	0.085	0.848	0.009	0.782	0.054	0.730	0.016	0.769	0.035
0.960	0.061	0.697	0.007	0.901	0.029	0.686	0.013	0.627	0.064
0.841	0.011	0.715	0.015	0.871	0.062	0.754	0.006	0.993	0.063
0.794	0.017	0.612	0.008	0.963	0.013	0.855	0.015	0.649	0.013
0.720	0.032	0.877	0.013	0.760	0.072	0.723	0.009	0.944	0.055
0.765	0.082	0.733	0.014	0.909	0.057	0.757	0.017	0.819	0.021
0.736	0.072	0.766	0.010	0.965	0.016	0.858	0.006	0.804	0.034
0.919	0.059	0.767	0.005	0.986	0.077	0.736	0.009	0.553	0.072
0.613	0.058	0.880	0.004	0.646	0.084	0.771	0.017	0.550	0.056
0.823	0.033	0.842	0.012	0.749	0.078	0.738	0.010	0.553	0.058
0.691	0.063	0.692	0.012	0.629	0.030	0.825	0.016	0.977	0.015

0.731	0.078	0.644	0.008	0.839	0.044	0.881	0.013	0.984	0.074
0.654	0.051	0.712	0.013	0.884	0.022	0.761	0.013	0.745	0.064
0.976	0.067	0.662	0.008	0.821	0.065	0.679	0.009	0.764	0.046
0.831	0.035	0.663	0.011	0.935	0.058	0.776	0.012	0.898	0.063
0.979	0.051	0.891	0.011	0.990	0.032	0.795	0.007	0.826	0.043
0.625	0.014	0.891	0.005	0.721	0.049	0.749	0.008	0.771	0.073
0.968	0.041	0.798	0.011	0.938	0.062	0.791	0.008	0.618	0.029
0.796	0.046	0.614	0.011	0.778	0.017	0.754	0.015	0.609	0.043
0.959	0.039	0.647	0.013	0.692	0.069	0.654	0.015	0.519	0.071
0.628	0.020	0.622	0.014	0.793	0.074	0.701	0.004	0.505	0.024
0.722	0.021	0.635	0.009	0.637	0.025	0.879	0.005	0.953	0.022
0.747	0.042	0.786	0.010	0.783	0.018	0.729	0.015	0.884	0.042
0.859	0.052	0.674	0.010	0.644	0.011	0.864	0.016	0.795	0.071
0.830	0.013	0.799	0.012	0.806	0.046	0.807	0.016	0.830	0.055
0.813	0.040	0.724	0.014	0.717	0.012	0.803	0.013	0.857	0.037
0.745	0.016	0.868	0.013	0.973	0.051	0.834	0.010	0.518	0.070
0.602	0.010	0.731	0.007	0.948	0.043	0.866	0.007	0.661	0.021
0.632	0.013	0.892	0.011	0.858	0.013	0.841	0.008	0.939	0.041
0.641	0.041	0.762	0.011	0.764	0.079	0.897	0.003	0.849	0.036
0.925	0.019	0.898	0.004	0.857	0.019	0.798	0.013	0.862	0.056
0.872	0.082	0.696	0.008	0.660	0.024	0.847	0.015	0.924	0.079
0.848	0.064	0.714	0.013	0.926	0.046	0.657	0.010	0.714	0.062
0.656	0.056	0.714	0.012	0.683	0.055	0.672	0.007	0.790	0.021
0.765	0.011	0.810	0.005	0.806	0.044	0.868	0.007	0.595	0.040
0.863	0.038	0.693	0.008	0.856	0.054	0.857	0.006	0.832	0.014
0.765	0.058	0.832	0.012	0.920	0.011	0.665	0.018	0.513	0.028
0.889	0.030	0.715	0.009	0.855	0.079	0.741	0.016	0.968	0.062
0.806	0.018	0.835	0.010	0.700	0.065	0.818	0.011	0.795	0.052
0.773	0.072	0.772	0.008	0.814	0.045	0.778	0.016	0.844	0.084
0.881	0.083	0.682	0.004	0.891	0.087	0.816	0.013	0.939	0.080
0.897	0.080	0.763	0.008	0.614	0.082	0.760	0.017	0.888	0.051
0.643	0.020	0.765	0.004	0.927	0.040	0.865	0.017	0.953	0.027
0.917	0.047	0.826	0.014	0.609	0.075	0.877	0.004	0.662	0.080
0.688	0.054	0.807	0.003	0.683	0.065	0.701	0.014	0.764	0.065
0.910	0.074	0.660	0.004	0.965	0.043	0.866	0.007	0.769	0.066
0.799	0.022	0.626	0.007	0.720	0.078	0.877	0.006	0.804	0.074
0.751	0.009	0.749	0.013	0.819	0.081	0.870	0.009	0.620	0.028
0.781	0.033	0.857	0.015	0.662	0.057	0.726	0.008	0.804	0.071
0.628	0.021	0.760	0.012	0.864	0.029	0.863	0.013	0.571	0.018
0.917	0.071	0.790	0.006	0.961	0.020	0.761	0.006	0.911	0.074
0.955	0.082	0.636	0.005	0.798	0.016	0.783	0.005	0.906	0.024
0.796	0.039	0.833	0.005	0.984	0.021	0.726	0.006	0.899	0.088

0.885	0.050	0.772	0.011	0.683	0.041	0.757	0.016	0.977	0.062
0.876	0.012	0.786	0.003	0.699	0.063	0.828	0.007	0.733	0.039
0.781	0.017	0.830	0.010	0.634	0.046	0.657	0.015	0.633	0.060
0.833	0.030	0.680	0.010	0.612	0.038	0.819	0.013	0.925	0.064
0.722	0.047	0.765	0.004	0.817	0.055	0.681	0.018	0.604	0.042
0.853	0.032	0.605	0.012	0.840	0.071	0.781	0.008	0.812	0.051
0.891	0.063	0.675	0.010	0.947	0.051	0.777	0.015	0.838	0.075
0.769	0.011	0.776	0.014	0.639	0.034	0.805	0.005	0.703	0.059
0.945	0.029	0.678	0.005	0.887	0.016	0.807	0.008	0.939	0.039
0.642	0.013	0.875	0.012	0.634	0.036	0.691	0.009	0.622	0.037
0.878	0.074	0.798	0.013	0.740	0.087	0.829	0.005	0.781	0.044
0.715	0.082	0.834	0.006	0.907	0.087	0.833	0.005	0.985	0.016
0.663	0.034	0.854	0.007	0.859	0.055	0.800	0.004	0.795	0.061
0.797	0.069	0.662	0.010	0.698	0.012	0.745	0.018	0.971	0.078
0.955	0.037	0.812	0.010	0.680	0.067	0.807	0.011	0.928	0.065
0.736	0.012	0.706	0.012	0.600	0.045	0.670	0.016	0.683	0.060
0.935	0.043	0.807	0.011	0.655	0.018	0.698	0.006	0.673	0.030
0.791	0.055	0.686	0.015	0.789	0.015	0.797	0.007	0.654	0.046
0.818	0.042	0.778	0.008	0.980	0.062	0.689	0.011	0.773	0.077
0.625	0.031	0.665	0.003	0.774	0.014	0.833	0.005	0.691	0.037
0.622	0.083	0.790	0.013	0.913	0.044	0.743	0.003	0.683	0.035
0.818	0.028	0.603	0.015	0.943	0.029	0.751	0.004	0.969	0.063
0.682	0.074	0.610	0.015	0.816	0.056	0.714	0.011	0.920	0.083
0.870	0.030	0.738	0.003	0.905	0.055	0.798	0.017	0.720	0.069
0.748	0.017	0.631	0.012	0.754	0.017	0.748	0.016	0.519	0.059
0.875	0.021	0.696	0.004	0.768	0.034	0.880	0.012	0.979	0.013
0.906	0.027	0.778	0.009	0.953	0.039	0.792	0.005	0.968	0.028
0.610	0.045	0.757	0.005	0.775	0.071	0.660	0.014	0.573	0.053
0.771	0.071	0.766	0.012	0.948	0.017	0.715	0.011	0.887	0.054
0.789	0.018	0.695	0.006	0.837	0.017	0.751	0.009	0.653	0.074
0.762	0.023	0.798	0.006	0.857	0.054	0.839	0.018	0.528	0.018
0.699	0.052	0.636	0.014	0.908	0.061	0.836	0.005	0.866	0.073
0.660	0.070	0.638	0.011	0.628	0.073	0.654	0.005	0.887	0.079
0.906	0.012	0.723	0.012	0.822	0.078	0.800	0.007	0.653	0.040
0.776	0.015	0.845	0.012	0.647	0.030	0.671	0.015	0.925	0.014
0.656	0.060	0.844	0.010	0.881	0.068	0.837	0.015	0.650	0.022
0.853	0.088	0.650	0.012	0.640	0.077	0.804	0.013	0.873	0.048
0.779	0.066	0.601	0.014	0.682	0.041	0.665	0.009	0.635	0.049
0.921	0.074	0.702	0.014	0.978	0.039	0.776	0.015	0.794	0.024
0.844	0.015	0.781	0.004	0.610	0.076	0.771	0.012	0.524	0.042
0.895	0.060	0.825	0.003	0.641	0.071	0.811	0.007	0.670	0.051
0.709	0.043	0.856	0.015	0.622	0.060	0.886	0.016	0.988	0.060

0.694	0.021	0.882	0.013	0.730	0.081	0.847	0.011	0.743	0.073
0.672	0.074	0.781	0.015	0.820	0.039	0.696	0.012	0.731	0.072
0.624	0.031	0.703	0.012	0.971	0.033	0.665	0.010	0.827	0.063
0.759	0.025	0.728	0.006	0.829	0.023	0.811	0.006	0.793	0.038
0.637	0.078	0.772	0.005	0.910	0.063	0.890	0.013	0.870	0.047
0.772	0.058	0.712	0.007	0.937	0.053	0.864	0.008	0.516	0.043
0.906	0.049	0.873	0.003	0.857	0.025	0.822	0.017	0.908	0.088
0.712	0.024	0.806	0.006	0.678	0.046	0.876	0.011	0.775	0.017
0.734	0.020	0.887	0.013	0.811	0.052	0.861	0.015	0.512	0.019
0.792	0.019	0.799	0.007	0.879	0.073	0.844	0.012	0.794	0.033
0.945	0.021	0.785	0.003	0.718	0.027	0.749	0.005	0.602	0.084
0.625	0.027	0.863	0.007	0.744	0.014	0.750	0.005	0.631	0.084
0.792	0.016	0.642	0.005	0.718	0.038	0.719	0.015	0.501	0.067
0.700	0.064	0.607	0.006	0.806	0.012	0.883	0.014	0.579	0.053
0.733	0.052	0.860	0.012	0.850	0.062	0.866	0.014	0.940	0.021
0.633	0.068	0.625	0.012	0.933	0.037	0.731	0.007	0.795	0.055
0.993	0.015	0.610	0.004	0.880	0.047	0.734	0.014	0.610	0.012
0.943	0.013	0.687	0.006	0.990	0.025	0.821	0.017	0.556	0.054
0.984	0.061	0.894	0.012	0.783	0.029	0.844	0.016	0.902	0.077
0.950	0.022	0.717	0.005	0.760	0.023	0.869	0.010	0.864	0.026
0.862	0.062	0.824	0.006	0.964	0.036	0.772	0.008	0.873	0.074
0.913	0.043	0.797	0.007	0.961	0.031	0.667	0.017	0.599	0.033
0.866	0.048	0.811	0.011	0.714	0.076	0.719	0.014	0.607	0.085
0.605	0.055	0.697	0.012	0.777	0.055	0.860	0.012	0.626	0.083
0.836	0.051	0.899	0.009	0.890	0.049	0.673	0.017	0.667	0.054
0.758	0.010	0.702	0.007	0.785	0.049	0.888	0.006	0.940	0.068
0.937	0.017	0.841	0.010	0.894	0.063	0.774	0.016	0.719	0.039
0.814	0.069	0.768	0.005	0.861	0.060	0.857	0.007	0.994	0.023
0.844	0.073	0.687	0.006	0.906	0.016	0.709	0.016	0.532	0.012
0.860	0.020	0.618	0.010	0.697	0.072	0.735	0.004	0.638	0.042
0.735	0.067	0.722	0.014	0.888	0.034	0.734	0.005	0.503	0.019
0.891	0.048	0.833	0.005	0.694	0.043	0.871	0.012	0.524	0.041
0.659	0.055	0.868	0.014	0.625	0.027	0.657	0.007	0.807	0.065
0.694	0.086	0.608	0.012	0.761	0.012	0.864	0.004	0.587	0.083
0.855	0.081	0.607	0.010	0.913	0.054	0.690	0.009	0.862	0.041
0.608	0.071	0.886	0.006	0.678	0.037	0.773	0.012	0.941	0.053
0.779	0.065	0.651	0.010	0.689	0.087	0.834	0.003	0.696	0.062
0.677	0.084	0.735	0.010	0.723	0.031	0.753	0.007	0.947	0.067
0.914	0.053	0.759	0.009	0.685	0.073	0.847	0.014	0.986	0.051
0.918	0.053	0.804	0.014	0.814	0.027	0.765	0.012	0.559	0.082
0.837	0.081	0.717	0.010	0.835	0.064	0.795	0.011	0.849	0.010
0.853	0.071	0.681	0.003	0.607	0.010	0.769	0.009	0.657	0.075

0.824	0.036	0.781	0.007	0.765	0.035	0.791	0.017	0.966	0.038
0.635	0.085	0.650	0.011	0.767	0.074	0.809	0.012	0.724	0.015
0.790	0.026	0.718	0.009	0.756	0.020	0.708	0.015	0.952	0.085
0.845	0.054	0.846	0.005	0.874	0.071	0.657	0.014	0.755	0.041
0.884	0.062	0.621	0.007	0.992	0.074	0.697	0.005	0.689	0.033
0.944	0.077	0.662	0.013	0.672	0.045	0.716	0.007	0.943	0.070
0.867	0.059	0.682	0.006	0.689	0.017	0.743	0.006	0.538	0.028
0.768	0.070	0.675	0.006	0.620	0.072	0.821	0.008	0.615	0.028
0.829	0.063	0.718	0.007	0.790	0.029	0.665	0.009	0.810	0.063
0.872	0.011	0.808	0.010	0.985	0.062	0.877	0.007	0.937	0.077
0.791	0.037	0.807	0.014	0.685	0.082	0.879	0.004	0.587	0.080
0.813	0.029	0.686	0.011	0.618	0.044	0.869	0.008	0.650	0.049
0.909	0.051	0.843	0.005	0.605	0.035	0.668	0.008	0.772	0.029
0.841	0.084	0.750	0.013	0.756	0.080	0.747	0.008	0.725	0.059
0.665	0.045	0.747	0.006	0.900	0.078	0.793	0.006	0.802	0.058
0.967	0.011	0.767	0.004	0.655	0.021	0.816	0.013	0.615	0.075
0.627	0.055	0.703	0.004	0.746	0.087	0.795	0.007	0.590	0.057
0.923	0.040	0.665	0.007	0.822	0.041	0.891	0.015	0.525	0.085
0.756	0.053	0.641	0.003	0.617	0.071	0.670	0.008	0.612	0.015
0.688	0.078	0.709	0.006	0.787	0.025	0.680	0.004	0.674	0.019
0.766	0.062	0.679	0.009	0.708	0.076	0.688	0.013	0.941	0.070
0.794	0.045	0.874	0.010	0.718	0.025	0.784	0.013	0.864	0.081
0.882	0.037	0.747	0.015	0.749	0.083	0.754	0.005	0.912	0.029
0.700	0.036	0.738	0.014	0.666	0.066	0.723	0.017	0.976	0.022
0.905	0.064	0.687	0.009	0.818	0.021	0.806	0.005	0.839	0.064
0.656	0.063	0.888	0.013	0.652	0.040	0.822	0.009	0.526	0.062
0.688	0.022	0.612	0.012	0.907	0.034	0.665	0.014	0.798	0.081
0.669	0.077	0.693	0.007	0.796	0.054	0.690	0.006	0.763	0.071
0.707	0.081	0.609	0.013	0.603	0.085	0.714	0.006	0.637	0.072
0.981	0.013	0.855	0.012	0.927	0.053	0.669	0.016	0.968	0.037
0.771	0.056	0.700	0.010	0.611	0.024	0.799	0.006	0.595	0.063
0.839	0.046	0.631	0.012	0.830	0.015	0.889	0.014	0.576	0.047
0.862	0.053	0.832	0.006	0.957	0.071	0.840	0.006	0.877	0.036
0.825	0.011	0.641	0.011	0.813	0.026	0.821	0.006	0.937	0.033
0.848	0.069	0.749	0.011	0.606	0.059	0.826	0.004	0.888	0.026
0.676	0.010	0.604	0.006	0.817	0.029	0.784	0.009	0.550	0.083
0.742	0.080	0.631	0.006	0.828	0.052	0.715	0.010	0.760	0.070
0.960	0.065	0.713	0.006	0.763	0.074	0.750	0.010	0.703	0.073
0.916	0.068	0.652	0.006	0.857	0.071	0.686	0.012	0.734	0.012
0.830	0.070	0.634	0.007	0.925	0.065	0.823	0.004	0.905	0.051
0.950	0.083	0.891	0.004	0.729	0.022	0.768	0.012	0.687	0.023
0.720	0.062	0.708	0.014	0.962	0.036	0.771	0.009	0.856	0.040

0.938	0.071	0.779	0.012	0.678	0.010	0.747	0.012	0.899	0.016
0.770	0.033	0.726	0.009	0.952	0.049	0.888	0.009	0.681	0.088
0.672	0.015	0.699	0.013	0.818	0.085	0.656	0.016	0.760	0.046
0.948	0.070	0.741	0.006	0.978	0.033	0.697	0.008	0.791	0.057
0.688	0.018	0.802	0.006	0.612	0.057	0.881	0.008	0.533	0.076
0.761	0.080	0.675	0.011	0.972	0.029	0.654	0.013	0.592	0.028
0.978	0.059	0.747	0.004	0.820	0.084	0.819	0.007	0.848	0.018
0.935	0.021	0.658	0.004	0.771	0.062	0.703	0.008	0.757	0.038
0.663	0.075	0.604	0.011	0.746	0.037	0.842	0.014	0.755	0.030
0.683	0.068	0.774	0.011	0.692	0.021	0.846	0.007	0.877	0.014
0.934	0.048	0.718	0.003	0.808	0.026	0.716	0.012	0.696	0.049
0.884	0.050	0.617	0.007	0.694	0.037	0.679	0.017	0.748	0.040
0.769	0.024	0.898	0.008	0.866	0.016	0.855	0.017	0.813	0.026
0.881	0.038	0.675	0.009	0.838	0.026	0.667	0.010	0.751	0.078
0.746	0.047	0.646	0.009	0.921	0.044	0.737	0.013	0.909	0.032
0.947	0.029	0.704	0.007	0.727	0.034	0.717	0.007	0.791	0.077
0.844	0.026	0.720	0.014	0.770	0.040	0.857	0.012	0.923	0.012
0.605	0.074	0.609	0.014	0.914	0.078	0.823	0.009	0.515	0.021
0.931	0.041	0.649	0.013	0.765	0.033	0.859	0.017	0.868	0.070
0.631	0.024	0.799	0.004	0.624	0.045	0.848	0.011	0.950	0.082
0.671	0.071	0.733	0.007	0.655	0.077	0.792	0.005	0.728	0.071
0.799	0.071	0.665	0.008	0.696	0.019	0.752	0.011	0.780	0.071
0.830	0.038	0.853	0.008	0.907	0.012	0.857	0.015	0.558	0.033
0.774	0.058	0.699	0.013	0.609	0.047	0.652	0.006	0.906	0.054
0.941	0.076	0.799	0.008	0.624	0.028	0.655	0.018	0.569	0.066
0.605	0.022	0.800	0.011	0.938	0.082	0.660	0.008	0.532	0.017
0.713	0.075	0.805	0.009	0.636	0.029	0.737	0.006	0.804	0.060
0.859	0.040	0.841	0.004	0.905	0.038	0.697	0.016	0.971	0.034

APPENDIX IV

Control Chart Constants.

X-bar Chart Constants | For sigma Estimate | R Chart Constants | S Chart Constants

Sample Size=m	A_2	A_3	d_2	D_3	D_4	B_3	B_4
2	1.880	2.659	1.128	0	3.267	0	3.267
3	1.023	1.954	1.693	0	2.574	0	2.568
4	0.729	1.6.28	2.059	0	2.282	0	2.266
5	0577	1.427	2.326	0	2.114	0	2.089

6	0.483	1.287	2.535	0	2.004	0.030	1.970
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.970	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	.1777	0.284	1.716
11	0.285	0.927	3.173	0.256	1.744	0.321	1.679
12	0266	0.886	3.258	0.283	1.717	0.354	1.646
13	0.249	0.850	3.336	0.307	1.693	0.382	1.618
14	0.225	0.817	3.407	0.328	1.672	0.406	1.594
15	0.223	0.789	3.472	0.347	1.672	0.428	1.552
16	0.212	0.739	3.532	0.363	1.637	0.448	1.552
17	0.203	0.739	3.588	0.378	1.622	0.466	1.534
18	0.194	0.718	3.640	0.391	1.608	0.482	1.518
19	0.187	0.698	3.689	0.403	1.597	0.497	1.503
20	0.180	0.680	3.735	0.415	1.585	0.510	1.490
21	0173	0.663	3.778	0.425	1.575	0.523	1.477
22	0.167	0.647	3.819	0.434	1.566	0.534	1.466
23	0.162	0.633	3.858	0.443	1.557	0.545	1.455
24	0.157	0.619	3.895	0.451	1.548	0.555	1.445
25	0.153	0.606	3.931	0.459	1.541	0.565	1.435

Control chart constants for X-bar, R,S, Individuals (called "X" or "I" charts), and MRS (Moving Range) CAHRTS.

NOTES: To construct the "X" and "MR" Charts (these are companions) we compute the Moving Ranges as:

R_2 = range of 1st and 2nd observation, R_3 = range of 2nd and 3rd observation, R_4 = range 3rd and 4th observations, etc with the "average" moving range or "MR"-bar being the average of these ranges with the "sample size" for each of these ranges n = 2 since each is based on consecutive observations …. This should provide an estimated standard deviation (needed for the "I" chart) of

O = (MR-bar)/d_2 where the value of d_2 is based on, as just stated, m = 2.

Similarly, the UCL and LCL for MR chart will be: UCL = d_4 (MR-bar) and LCL = D_3 (MR-bar)

But, since D3 = 0 when n = 0 (or, more accurately, is "not applicable") there will be no LCL for the MR chart. Just a UCL.

4.5.2 Forecast Reliability of Injection Moulding Machine

The following are results gotten as the reliability of the entire system;

Table 4n: Forecast Reliability for Injection Moulding Machine Reliable 27.59% of the Time, 72.41% Down Time

COMPONENT	UP TIME %	DOWN TIME %
Hydraulic System	71.76	28.24
Injection System	74.95	25.05
Control System	75.76	24.24
Mold System	73.62	26.38
Clamping System	74.61	25.39

4.5.2a Data Analysis of the Reliability of the Injection Moulding Machine

It can be deduce from table 4.1 that the component with peak reliability is the Control system with 75.76% uptime and 24.24 % down time also been the least of all. While Hydraulic system had the least reliability with uptime 71.76% and the Peak down time of 28.24 %. Since it a series system, the total reliability of the system is dependent on each component performance thus making the system availability low with reliability of the entire system 27.59% uptime and down time of 72.41%.

4.5.2bDetermine Distribution for Each Component Based On Historical Data

Table 4o: Reliability and Failure rate distribution.

Reliability Distribution - lowest & highest		
HYDRAULIC SYSTEM Ʀ1	0.60	0.99
INJECTION SYSTEMƦ2	0.6	0.9
CONTROL SYSTEMƦ3	0.6	0.994
MOLD SYSTEMƦ4	0.65	0.9
CLAMPING SYSTEMƦ5	0.5	0.994

Failure Rate Distribution - lowest & highest		
HYDRAULIC SYSTEM ƛ1	0.009	0.088
INJECTION SYSTEMƛ2	0.003	0.015
CONTROL SYSTEMƛ3	0.009	0.088
MOLD SYSTEMƛ4	0.003	0.018
CLAMPING SYSTEMƛ5	0.009	0.088

At the end of the end of the 20,000 simulation run from the above data, it is deduce that the reliability of the entire system is 27.59% uptime and down time of 72.41%. From table 4f, clamping system has the lowest reliability distribution, while it and the control system have the highest reliability distribution. In the case of the failure rate distribution, injection system and mold system have the lowest failure rate distributions, while the injection system is of the least high failure rate distribution.

Table 4: Forecast Reliability For Injection Moulding system Reliable 27.59% Of The Time, 72.41% Down Time

System Component	Up Time	Down Time

Hydraulic	71.76	28.24
Injection	74.95	25.05
Control	75.76	24.24
Mold	73.62	26.38
Clamping	74.61	25.39