

**RELIABILITY AND AVAILABILITY ANALYSIS OF PISTON
RING MANUFACTURING PLANT**

Thesis submitted in partial fulfillment of the requirement for

The award of the degree of

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In

Mathematics and Computing

Submitted by

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CERTIFICATE

I hereby certify that work which is being presented in thesis entitled **“Reliability and Availability Analysis of Piston Ring Manufacturing Plant”** in partial fulfillment of the requirements for the award of degree of Master of Science, School of Mathematics, Thapar Institute of Engineering and Technology, Patiala is an authentic record of my own work carried out under the supervision of Dr. Arvind Kumar Lal.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge



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ABSTRACT

The Thesis titled “RELIABILITY AND AVAILABILITY ANALYSIS OF PISTON RING MANUFACTURING PLANT” is an endeavor to build up a mathematical model for evaluates the reliability of piston ring manufacturing plant.

First chapter is introductory in nature. A short overview of literature available on this topic is likewise examined in this section.

In second Chapter, we have discussed the behavior analysis of Piston ring manufacturing plant. The entire procedure comprises of nine sub-systems-Rough Section, Finish Section, Chrome Section (plating), Chrome Finish Section, Coil Widing, Moly Section, CNC Section, Quality Assurance/Inspection Department, and Tool Store. In this thesis, we have considered Rough section only. Rough Section consists of 5 sub-system namely rough grinding, medium grinding, finish grinding, double cam turning & gap cutting, axial width inspection. The mathematical model of this manufacturing industry has been formulated with assistance of markovain technique and Chapman Kolomorgov differential equations. Using available data for repair and failure rate of their sub-system, the procedure has been carried out numerically to obtain reliability of piston ring manufactory plant. The effect of failure and repair rates has been considered in detail with the assistance of graphs and tables.

In third chapter, availability has been discussed. The effect of failure and repair rates has been studied in detail with the assistance of graphs and tables. On the availability of this plant, certain conclusions based on the present study are discussed.

In view of present study, industrial understanding and future extent of present work have been introduced in the end.

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CHAPTER 1
INTRODUCTION

INTRODUCTION

In today logical world the general public has turned out to be completely subjected to science and innovation for all its every day needs. So as to accomplish most extreme advantage of headway in science and innovation, safe and reliable systems are in extraordinary demand. In this way, reliability has been turned into a matter of incredible worry for all in this day and age. The issue of guaranteeing and keeping up reliability has numerous dependable factors, for example, gear design, quality control and life testing and structure changes.

The word reliability is being used since long time. Thought of reliability is significant in planning, design and activity of the system. Reliability engineering appeared because of unpredictability and mechanization of types of gear utilized in World War II which brought about a few issues identified with maintenance and repair. By reliability we mean the capacity of the system to work as arranged. We express this capacity utilizing probabilities and anticipated values.

1.1 Literature Review

Understanding the significance of the subject, reliability theory has been developed and various creators have been given a decent commitment. In 1960, first reading material on reliability by Dummer and Griffen showed up in literature. Barlow and Hunter (1961) investigated the reliability of a one-unit system. Initially, Verma and his colleagues Garg, Mohan and Singla (1962) started the study on some problems of reliability. The reliability analysis of (k, n) system was discussed by Linton and Saw (1974). Singh et al. (1991, 1992)

and Kumar et. al (1991,1992) extensively discussed reliability of complex systems.. The majority of these researchers investigated about the systems illustrating Markovian properties. Fredrick and Hunziker (1990) considered for its behavioral analysis of butter industry.

When a system comprises of more than one unit there is plausibility for complete failure of the system because of single cause. Such failures are named as basic cause failure and these are exceedingly full efficient as far as reliability of the system is considered. Habchi (2002) investigated an improved strategy of reliability evaluation for suspended tests.

Gagloft (1975) characterized the normal reason failure in a system when different units or parts at any moment fail because of single basic reason. Cate et al. (1977) stretched out this plan to complex systems and built up a PC based methodology. Dhillon and Misra (1984) presented the significant factor of basic human blunder which cause total failure of the system. Chung (1990) extended this approach to repairable system, which is liable to failures because of regular reason and basic human mistakes. Such system is exceptionally basic in our day by day life. Gupta (2004) investigated mathematical analysis of reliability and availability of some process industries. Gupta et al.(2005) investigated the behavioral analysis of cement manufacturing plant by using numerical method. Further Gupta et al.(2007) analyzed the Reliability and Availability of sequential procedures of Plastic-Pipe Manufacturing plant-a contextual study using matrix calculus method.

Agnihotri et al (2008) have examined the reliability of boiler utilized in readymade clothing industry. Goyal (2008) discussed reliability and benefit for a 2-out of-3 unit system. The standby allotment in series and parallel systems was investigated by Misra et al(2011). Different reliability models with fluctuating conditions were studied by Narang et al(2011). The reliability models with various constraints of activity and repair on standby units were investigated by Bhatia(2012).

Lata (2013) analyzed the behavioral study of piston manufacturing plant through stochastic model. Reliability distribution of an industrial process was further investigated by Kaur (2013). Singh and Kumar (2014) examined the availability analysis and performance optimization of a butter oil production system. Kumar and Saini (2018) discussed fuzzy availability analysis of Marine Power plant. Mathematical modeling and performance evaluation of a pan crystallization system in a sugar industry was discussed by Dahiya (2019). Although various authors discussed the reliability and availability analysis of different types of manufacturing process but not satisfactory work has been done for piston ring plant so far.

1.2 Basic Definitions:

Reliability

The reliability of an item (or framework) can be represented as the probability that an item will execute a required purpose under indicated conditions for a specific time period. The four factors for which this definition bring into focus are:

- (a) The reliability of a device is indicated as a probability.

(b) The device is required to give adequate performance.

(c) The period of adequate work is described.

(d) The environmental or working conditions are recommended.

These four elements are very significant in assurance of reliability.

Reliability indicated as probability: Probability is the proportion of the number of times we can await that an event should jump out at the all out number of trials attempted. Essentially reliability factor of zero would imply in practically all cases the equipment would neglect to meet the required exhibition level. It is important to remember that reliability factor of one would not imply that there is a guarantee that each unit of the device which is utilized will perform attractively.

Adequate performance: - This is the second component in the meaning of reliability. It specifies in unambiguous terms, what is anticipated from a device or system. There may be occurrences, anyway, of a system giving suitably performance even when a couple of its components may not be working. As an example, consider the sparkplugs of an eight-cylinder automobile. If one attachment isn't working properly, the automobile may at present achieve its goal in the prescribed time and in this manner meet the desired performance satisfactorily.

Period of Adequate performance: - This is a standout amongst the most significant components in the definition since it express a measure of the period for which performance is satisfactory. Most units fail when worked over long periods. Deterioration of materials and parts is regular and therefore the performance level of the unit will likewise go down with time. Therefore, it is important to

determine a period limit inside which the performance of a unit is to be surveyed as being satisfactory or unsatisfactory.

Working conditions: - The ecological or working conditions, for example, vibration, shock, humidity, temperature, etc ought to be determined in which we anticipate that a device should work adequately. For example, an air conditioner which performs satisfactorily in temperature zone might not have similar qualities for hot and arid climate conditions.

Failure Rate: This is the ratio of number of failures of items experiencing test to test time. Failure rate is communicated as far as number of failures per unit time.

Repair Rate: This is ratio of quantity of repairs of things experiencing test to the test time. Repair rate is communicated as far as number of failures per unit time, for instance repairs every hour or repair step by step or repair per year. Sometimes, it is called instantaneous repair rate.

Mean Time to Failures (MTTF): MTTF is the statistical normal time before failure of the system. When failure rate is genuinely constant, MTTF is characterized as :

$$MTTF = \int_0^{\infty} R(t) dt \quad (1.1)$$

Availability: This is the probability that the system will almost certainly work inside the tolerances at a given moment of time.

Markov Process

Markov process can be defined as a stochastic process in a physical system if occurrence of any future condition of the system is free of any past state and depends just on present state. In markov procedure, we manage two arbitrary factors both of which can be discrete or continuous. For the most part one of the arbitrary factors refers to the condition of a physical system and other random factor refers to time.

Chapman- Kolmogrov differential equations

Using mnemonic rule, one needs to form a system of linear differential equations to find reliability of system. This method expresses that derivative of t probability of each state is equivalent to the total of all probabilities flows which originates from different states to the given state subtracting the total of all probability flows which go out from the given state to different states. The differential equations in this manner derived are called as Chapman- Kolmogrov differential equations.

1.3 Summary of the present work

In the present work, we have studied the reliability of piston rings manufacturing plant-Federal Mogul Company situated in Bahadurgarh near Patiala. This thesis consists of three chapters. A brief summary of work is presented in subsequent chapter of this thesis is as follows: First chapter is introductory in nature. A short overview of literature available on this topic is likewise examined in this section.

In second Chapter, we have discussed the behavior analysis of Piston ring manufacturing plant. The entire procedure comprises of nine sub-systems-Rough Section, Finish Section, Chrome Section (plating),

Chrome Finish Section, Coil Widing, Moly Section, CNC Section, Quality Assurance/Inspection Department, Tool Store. In this thesis, we have considered Rough section only. Rough Section consists of 5 sub-system namely rough grinding, medium grinding, finish grinding, double cam turning & gap cutting, axial width inspection. The mathematical model of this manufacturing industry has been formulated with assistance of markovain technique and Chapman Kolomorgov differential equations. Using available data for repair and failure rate of their sub-system, the procedure has been carried out numerically to obtain reliability of piston ring manufactory plant. The effect of failure and repair rates have been considered in detail with the assistance of graphs and tables.

In third chapter, availability has been discussed. The effect of failure and repair rates has been studied in detail with the assistance of graphs and tables. On the availability of this plant, certain conclusions based on the present study are discussed. Finally, the limitations and scope of the present work are also presented in this chapter.

CHAPTER 2
BEHAVIOR ANALYSIS OF PISTON RING
MANUFACTURING PLANT

In this chapter, the reliability of piston ring manufacturing plant has been figure out with the real information taken from the industry Federal Mogul Goetze (INDIA) LTD established in Bahadurgarh, Patiala. This chapter is organized as follows:

A brief description of each sub-system has been discussed. In section 2.1 the process of rough section has been explained with the help of flowchart. The assumptions considered are presented in section 2.2. In section 2.3 we formulate mathematical model determining reliability of piston ring manufacturing plant. Performance study of system has been given in section 2.4. Finally, in section 2.5 certain conclusions have been explained with graphs and tables.

In order to study reliability of manufacturing plant, we have chosen Federal Mogul Goetze (INDIA) LTD situated near Bahadurgarh (Punjab). This industry manufactures piston rings. Various piston rings are set and then machining activities on piston rings are begun to make it complete item, it has following nine sub-systems-Rough section, Finish Section, Chrome Section(plating), Chrome Finish Section, Coil Winding, Moly Section, CNC Section, Quality Assurance/Inspection Department, Tool Store. But due to unavailability of sufficient data, we have taken one section i.e. Rough section. In Rough section, there are five sub-systems-Rough grinding, medium grinding, finish grinding, double cam turning & gap cutting, axial width inspection.

The brief description of each sub systems is as follows:

1) Rough Section: - It is the main area where the rings want machining activity from store. It for the most part does the rough tasks

on every one of the rings. Ring is totally machined from every one of the sides before it leaves the area.

2) Finish Section: - It mostly does the tasks after rough activity. It gives the completing activities to all the non-chrome rings.

3) Chrome Section (plating):- Chrome plating is a standout amongst the most widely recognized techniques for surface treatment. It is commonly utilized on the running surface of the piston rings and on the landing surfaces

4) Chrome Finish Section:- It principally does the tasks after rough activity. It gives the completing task to the chrome rings.

5) Coil winding:- This segment provides the ring for the Moly area. A coil is shaped which is compacted in a mandrel. It is utilized for two widths i.e. 83 and 97mm, the material is steel. This is an extremely delivered ring of the Moly section.

6) Moly Section: - It is a significant area of ring machine shop as well as the GOETZE INDIA LTD. In this area a covering of molybdenum is done on the rings. Moly is a said for molybdenum covering which is sustained as a wire, the wire is then liquefied and splashed on the rings. It is done to keep away from the scraping and to build the life of the rings.

7) CNC Section: - The CNC definition is 'PC numerical control machining.' It is a subtractive assembling process which commonly utilizes electronic controls and machine devices to expel layers of material from a stock piece—known as the clear or work piece and produces a hand crafted part.

8) Quality Assurance/Inspection Department: - This division is bothered about the quality and inspection. All the kind of rings at last results in this branch for investigation and it here that they are at long last named great piece and revise rings. The great rings are at last sent to the dispatch area.

The quality is estimated from the filled diagrams. It is the duty of this department; the charts in the whole shop ought to be filled appropriately. Since just from these charts the analysis can be pictured and the remedial activities can be dealt with. From here it is discovered that where the defect is lying whether with the machine or with the administrator.

9) Tool Store: - All the devices and types of materials important for the shop are taken from here and it the duty of this store that each administrator ought to get the necessity tools and other fundamental items.

Due to unavailability of data for all units, we have focused only on units of rough Section of this manufacturing plant for which sufficient data has been provided.

The brief description of each sub-system of Rough Section is as follows:

2.1 Sub-Systems of Rough Section

1. Rough Grinding
2. Medium Grinding
3. Finish Gridding
4. Double Cam turning & Gap Cutting
5. Axial Width Inspection

- 1) **Sub-system A (Rough Grinding):-** It is the main area where the rings want machining activity from store. Rings acquired from foundry have poor surface completion and less dimensional accuracy. Ring blanks are granulated pivotally to accomplish the measurements required. This Sub-System results in main failure.
- 2) **Sub-system B (Medium Grinding):-** It essentially does the tasks after harsh activity. It gives the completing activities to all the non-chrome rings. This Sub-system results in main failure.
- 3) **Sub-system C (Finish Grinding):-** It mostly does the activities after medium grinding. It gives the completing operations to all the non-chrome rings. This Sub-system results in major failure.

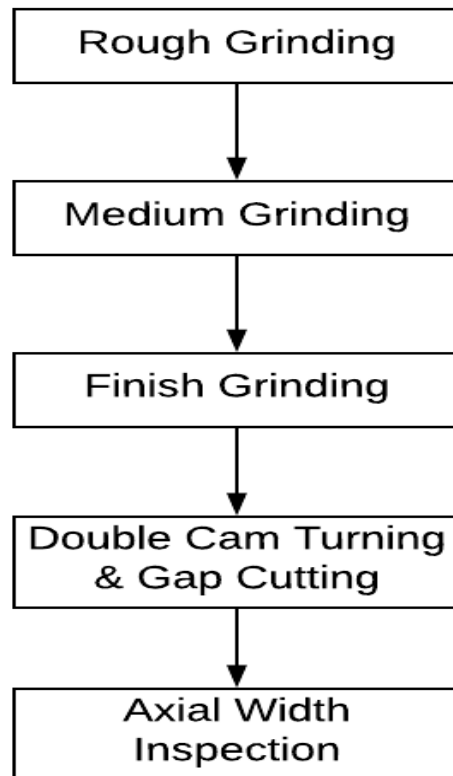


Fig 2.1:- Process Of Rough Section

- 4) Sub-system D (Double cam turning and Gap turning):-**This operation is of most significance because a number of parameters are subjected on this operation like major diameter, minor diameter, radial thickness etc. Gap cutting operation is performed on the same station as of turning. It is a semi-automatic machine. In gap-cutting, the rings are held pneumatically in gap-cutting machine and a milling cutter is used to cut the gap in two passes. This Sub-system results in major failure.

5) Sub-system E (Axial width inspection):- Ring is stacked and in a plan which drives the ring one by one under a axial width checking instrument. Then this arrangement separates out the good, over-size, & under-size rings. In this way every one of these classifications of rings are gathered independently. This Sub-system results in major failure.

2.2 Notations

The symbols A, B ,C ,D ,E signify good states of the sub-systems and small letters a, b, c, d, e demonstrate the failed states of the sub-systems A, B, C, D, E.

μ_i (i=1 to 5) express steady failure rates of sub-systems A, B, C, D, E.

$P_j(t)$ = Probability that the system is in j^{th} state at time t, (j=0, 1, 2, 3, 4, 5).

Assumptions

- (i) Failure and Repair rate are independent with each other and their unit is per hour.
- (ii) There are no simultaneous failures among the sub-systems.
- (iii) Repair and failure rates of sub-system are assumed to be constant.

Following above mentioned assumptions and notations a transition layout of system is given in Fig.2.2.

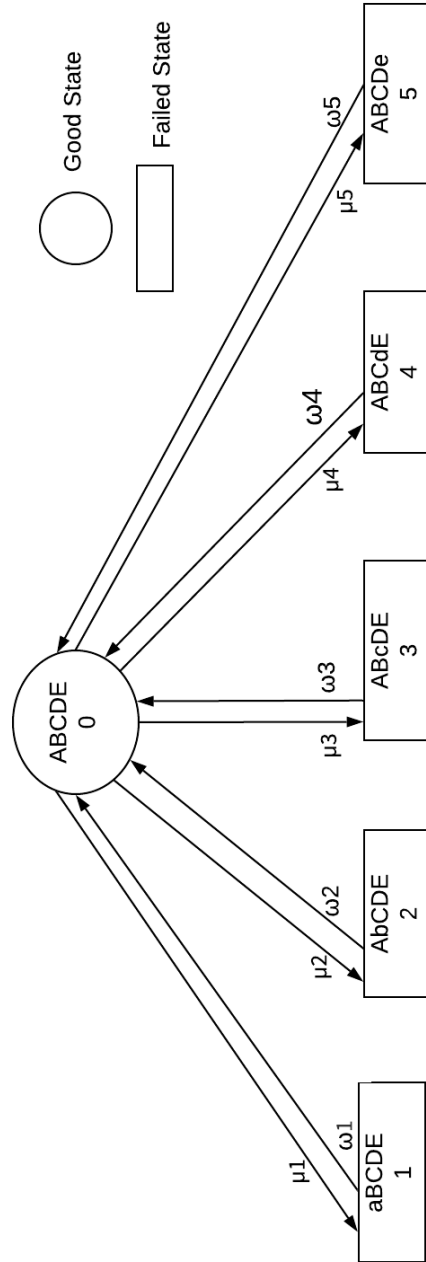


Fig 2.2 Transition Diagram for Sub-system

In the light of above assumption and transition diagram (shown in Fig 2.2) a mathematical formulation of Chapman-Kolomorgov differential difference equation has been developed as follows.

2.3 Mathematical Formulation

$$P_0'(t) + \phi P_0(t) = \omega_1 P_1(t) + \omega_2 P_2(t) + \omega_3 P_3(t) + \omega_4 P_4(t) + \omega_5 P_5(t) \quad (2.1)$$

$$P_1'(t) + \omega_1 P_1(t) = \mu_1 P_0(t) \quad (2.2)$$

$$P_2'(t) + \omega_2 P_2(t) = \mu_2 P_0(t) \quad (2.3)$$

$$P_3'(t) + \omega_3 P_3(t) = \mu_3 P_0(t) \quad (2.4)$$

$$P_4'(t) + \omega_4 P_4(t) = \mu_4 P_0(t) \quad (2.5)$$

$$P_5'(t) + \omega_5 P_5(t) = \mu_5 P_0(t) \quad (2.6)$$

$$\text{Where, } \phi = \mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5$$

$$\text{With initial conditions } P_0(0)=1 \text{ and } 0 \text{ otherwise} \quad (2.7)$$

2.4 Behavior Study

The system of above differential equations (2.1-2.7) with initial conditions has been solved numerically using Runge - Kutta fourth order technique. The calculations have been performed up to 360 days for different values of failure and repair rates of the sub-system, by taking the data for failure rates and repair rates of the sub-system according to days. The outcomes of different parameters on reliability are studied in this section. If the failure and repair rates are altered, the reliability is affected.

- (i) **Outcomes of failure rate of rough grinding (μ_1) on reliability of the system:** Outcomes of rough grinding on reliability of system is obtained by changing its values. The parameter μ_1 is

investigated at the level of 0.3, 0.4, 0.5, 0.6, 0.7 and remaining are taken as $\mu_2=0.233, \mu_3= 0.2, \mu_4=0.8, \mu_5= 0.2, \omega_1= 1.95, \omega_2= 3.01, \omega_3= 4.371, \omega_4=1.536, \omega_5= 1.20$. The Table (2.1(a)) demonstrates the outcomes of rough grinding (μ_1) on reliability of system. The reliability of system increases by 9.45% with increment in rough grinding from 0.3 to 0.7 and remain same with the increment in time from 30 to 360 days.

Table 2.1(a): OUTCOMES OF ROUGH GRINDING (μ_1) ON RELIABILITY OF SYSTEM

$\mu_1 \rightarrow$ Days \downarrow	0.3	0.4	0.5	0.6	0.7
30	0.509033	0.496083	0.483775	0.472064	0.460906
60	0.509033	0.496083	0.483775	0.472064	0.460906
90	0.509033	0.496083	0.483775	0.472064	0.460906
120	0.509033	0.496083	0.483775	0.472064	0.460906
150	0.509033	0.496083	0.483775	0.472064	0.460906
180	0.509033	0.496083	0.483775	0.472064	0.460906
210	0.509033	0.496083	0.483775	0.472064	0.460906
240	0.509033	0.496083	0.483775	0.472064	0.460906
270	0.509033	0.496083	0.483775	0.472064	0.460906
300	0.509033	0.496083	0.483775	0.472064	0.460906
330	0.509033	0.496083	0.483775	0.472064	0.460906
360	0.509033	0.496083	0.483775	0.472064	0.460906
MTTF	162.8904	158.7464	154.8081	151.0604	147.4899

- (ii) **Outcomes of failure rate of medium grinding(μ_2) on reliability of the system:** Outcomes of medium grinding on reliability of system is obtained by changing its values as $\mu_2=0.233, 0.333, 0.433, 0.533, 0.633$ and other are taken as $\mu_1=0.3, \mu_3=0.2, \mu_4=0.8, \mu_5=0.2, \omega_1=1.95, \omega_2=3.01, \omega_3=4.371, \omega_4=1.536, \omega_5=1.20$. The Table (2.1(b)) demonstrates the outcomes of medium grinding (μ_2) on reliability of system. Reliability of system reduces by 6.3% with the increment in medium grinding from 0.233 to 0.633 and remains same with the increment in time from 30 to 360 days.

Table 2.1(b): OUTCOMES OF FAILURE RATE OF MEDIUM GRINDING (μ_2) ON RELIABILITY OF THE SYSTEM

$\mu_2 \rightarrow$ Days↓	0.233	0.333	0.4333	0.533	0.633
30	0.509033	0.500567	0.492379	0.484454	0.476780
60	0.509033	0.500567	0.492379	0.484454	0.476780
90	0.509033	0.500567	0.492379	0.484454	0.476780
120	0.509033	0.500567	0.492379	0.484454	0.476780
150	0.509033	0.500567	0.492379	0.484454	0.476780
180	0.509033	0.500567	0.492379	0.484454	0.476780
210	0.509033	0.500567	0.492379	0.484454	0.476780
240	0.509033	0.500567	0.492379	0.484454	0.476780
270	0.509033	0.500567	0.492379	0.484454	0.476780
300	0.509033	0.500567	0.492379	0.484454	0.476780
330	0.509033	0.500567	0.492379	0.484454	0.476780
360	0.509033	0.500567	0.492379	0.484454	0.476780
MTTF	162.8904	160.1815	160.1815	155.0253	152.5697

(iii) **Outcomes of failure rate of finish grinding (μ_3) on reliability of the system:** Outcomes of finish grinding on reliability of system is obtained by changing its values as $\mu_3=0.2, 0.3, 0.4, 0.5, 0.6$ and other are taken as $\mu_1 =0.3, \mu_2=0.233, \mu_4=0.8, \mu_5=0.2, \omega_1=1.95, \omega_2=3.01, \omega_3=4.371, \omega_4=1.536, \omega_5=1.20$. The Table (2.1 (c)) demonstrates the outcomes of finish grinding (μ_3) on reliability of system. The reliability of system reduces by 4.45% with the increment in

finish grinding from 0.2 to 0.6 and remains same with the increment in time from 30 to 360 days.

(iv) **Table 2.1(c) OUTCOMES OF FAILURE RATE OF FINISH GRINDING (μ_3) ON RELIABILITY OF SYSTEM**

$\mu_3 \rightarrow$ Days \downarrow	0.2	0.3	0.4	0.5	0.6
30	0.509033	0.503173	0.497446	0.491849	0.486376
60	0.509033	0.503173	0.497446	0.491849	0.486376
90	0.509033	0.503173	0.497446	0.491849	0.486376
120	0.509033	0.503173	0.497446	0.491849	0.486376
150	0.509033	0.503173	0.497446	0.491849	0.486376
180	0.509033	0.503173	0.497446	0.491849	0.486376
210	0.509033	0.503173	0.497446	0.491849	0.486376
240	0.509033	0.503173	0.497446	0.491849	0.486376
270	0.509033	0.503173	0.497446	0.491849	0.486376
300	0.509033	0.503173	0.497446	0.491849	0.486376
330	0.509033	0.503173	0.497446	0.491849	0.486376
360	0.509033	0.503173	0.497446	0.491849	0.486376
MTTF	162.8904	161.0152	159.1828	157.3916	155.6402

(v) **Outcomes of failure rate of double cam turning and gap cutting (μ_4) on reliability of system:** Outcomes of double cam turning & gap cutting on reliability of system is obtained by changing its values as $\mu_4=0.8, 0.9, 1, 1.1, 1.2$ and other are taken as $\mu_1= 0.3, \mu_2= 0.233, \mu_3= 0.2, \mu_5= 0.2, \omega_1= 1.95, \omega_2=$

3.01, $\omega_3 = 4.371$, $\omega_4 = 1.536$, $\omega_5 = 1.20$. The table demonstrates outcomes of double cam turning & gap cutting (μ_4) on reliability of system. Reliability of system reduces by 11.7% with increment in double cam turning & gap cutting from 0.8 to 1.2 and remains same with the increment in time from 30 to 360 days.

Table 2.1(d): OUTCOMES OF DOUBLE CAM TURNING & GAP TURNING (μ_4) ON RELIABILITY OF THE SYSTEM

$\mu_4 \rightarrow$ Days \downarrow	0.8	0.9	1	1.1	1.2
30	0.509033	0.492704	0.477391	0.463001	0.449453
60	0.509033	0.492704	0.477391	0.463001	0.449453
90	0.509033	0.492704	0.477391	0.463001	0.449453
120	0.509033	0.492704	0.477391	0.463001	0.449453
150	0.509033	0.492704	0.477391	0.463001	0.449453
180	0.509033	0.492704	0.477391	0.463001	0.449453
210	0.509033	0.492704	0.477391	0.463001	0.449453
240	0.509033	0.492704	0.477391	0.463001	0.449453
270	0.509033	0.492704	0.477391	0.463001	0.449453
300	0.509033	0.492704	0.477391	0.463001	0.449453
330	0.509033	0.492704	0.477391	0.463001	0.449453
360	0.509033	0.492704	0.477391	0.463001	0.449453
MTTF	162.8904	157.6653	152.7651	148.1602	143.8249

(vi) **Outcomes of axial width inspection (μ_5) on reliability of the system:** Outcomes of axial width inspection on the reliability of system is computed by changing its values as $\mu_5=0.2, 0.3, 0.4, 0.5, 0.6$ and other are taken as $\mu_1=0.3, \mu_2=0.233, \mu_3=0.2, \mu_4=0.8, \omega_1=1.95, \omega_2=3.01, \omega_3=4.371, \omega_4=1.536, \omega_5=1.20$. The Table (2.1 (e)) demonstrates the outcomes of axial width inspection (μ_5) on reliability of system. The reliability of system reduces by 14.5% with the increment in axial width inspection from 0.2 to 0.6 and remains same with increment in time from 30 to 360 days.

Table 2.1(e): OUTCOMES OF FAILURE RATE OF AXIAL WIDTH INSPECTION (μ_5) ON RELIABILITY OF SYSTEM

$\mu_5 \rightarrow$ Days \downarrow	0.2	0.3	0.4	0.5	0.6
30	0.509033	0.488318	0.469224	0.451567	0.435191
60	0.509033	0.488318	0.469224	0.451567	0.435191
90	0.509033	0.488318	0.469224	0.451567	0.435191
120	0.509033	0.488318	0.469224	0.451567	0.435191
150	0.509033	0.488318	0.469224	0.451567	0.435191
180	0.509033	0.488318	0.469224	0.451567	0.435191
210	0.509033	0.488318	0.469224	0.451567	0.435191
240	0.509033	0.488318	0.469224	0.451567	0.435191
270	0.509033	0.488318	0.469224	0.451567	0.435191
300	0.509033	0.488318	0.469224	0.451567	0.435191
330	0.509033	0.488318	0.469224	0.451567	0.435191
360	0.509033	0.488318	0.469224	0.451567	0.435191
MTTF	162.8904	156.261884	150.151730	144.501433	139.260962

We now consider outcomes of repair rates of sub-systems on reliability of system.

(vii) Outcomes of repair rate of rough grinding (ω_1) on reliability of system:-.

Reliability of system is measured by utilizing following combinations of failure and repair rates as $\mu_1 = 0.3$, $\mu_2 = 0.233$, $\mu_3 = 0.2$, $\mu_4 = 0.8$, $\mu_5 = 0.2$, $\omega_2 = 3.01$, $\omega_3 = 4.371$, $\omega_4 = 1.536$, $\omega_5 = 1.20$ with values of ω_1 as 1.95, 2.05, 2.15, 2.25, 2.35. The table (2.1(f)) demonstrates

the outcomes of rough grinding (ω_1) on reliability of system. The reliability of system increases by 0.46% with the increment in rough grinding from 3.01 to 3.41 and remain same with increment in time from 30 to 360 days.

Table 2.1(f) OUTCOMES OF REPAIR RATE OF ROUGH GRINDING(ω_1) ON RELIABILITY OF SYSTEM

$\omega_1 \rightarrow$ Days \downarrow	1.95	2.05	2.15	2.25	2.35
30	0.509033	0.510985	0.512768	0.514404	0.515910
60	0.509033	0.510985	0.512768	0.514404	0.515910
90	0.509033	0.510985	0.512768	0.514404	0.515910
120	0.509033	0.510985	0.512768	0.514404	0.515910
150	0.509033	0.510985	0.512768	0.514404	0.515910
180	0.509033	0.510985	0.512768	0.514404	0.515910
210	0.509033	0.510985	0.512768	0.514404	0.515910
240	0.509033	0.510985	0.512768	0.514404	0.515910
270	0.509033	0.510985	0.512768	0.514404	0.515910
300	0.509033	0.510985	0.512768	0.514404	0.515910
330	0.509033	0.510985	0.512768	0.514404	0.515910
360	0.509033	0.510985	0.512768	0.514404	0.515910
MTTF	162.8904	163.5150	164.0857	164.6092	165.0910

(viii) **Outcomes of repair rate of medium grinding (ω_2) on reliability of system:** - The reliability of system is measured by utilizing the following combinations of failure and repair rates

as $\mu_1 = 0.3$, $\mu_2 = 0.233$, $\mu_3 = 0.2$, $\mu_4 = 0.8$, $\mu_5 = 0.2$, $\omega_1 = 1.95$, $\omega_3 = 4.371$, $\omega_4 = 1.536$, $\omega_5 = 1.20$ with the values of ω_2 as 3.01, 3.11, 3.21, 3.31, 3.41. The table (2.1(g)) demonstrates the outcomes of medium grinding (ω_2) on reliability of system. The reliability of system increases by 0.46% with the increment in medium grinding from 3.01 to 3.41 and remain same with increment in time from 30 to 360 days.

Table 2.1(g) OUTCOMES OF REPAIR RATE OF MEDIUM GRINDING (ω_2) ON RELIABILITY OF SYSTEM

$\omega_2 \rightarrow$ Days \downarrow	3.01	3.11	3.21	3.31	3.41
30	0.509033	0.509678	0.510285	0.510857	0.511396
60	0.509033	0.509678	0.510285	0.510857	0.511396
90	0.509033	0.509678	0.510285	0.510857	0.511396
120	0.509033	0.509678	0.510285	0.510857	0.511396
150	0.509033	0.509678	0.510285	0.510857	0.511396
180	0.509033	0.509678	0.510285	0.510857	0.511396
210	0.509033	0.509678	0.510285	0.510857	0.511396
240	0.509033	0.509678	0.510285	0.510857	0.511396
270	0.509033	0.509678	0.510285	0.510857	0.511396
300	0.509033	0.509678	0.510285	0.510857	0.511396
330	0.509033	0.509678	0.510285	0.510857	0.511396
360	0.509033	0.509678	0.510285	0.510857	0.511396
MTTF	162.8904	163.0970	163.2913	163.4742	163.6468

(ix) **Outcomes of repair rate of finish grinding (ω_3) on reliability of system:-** The reliability of the system is measured by utilizing the following combinations of failure and repair rates as $\mu_1 = 0.3$, $\mu_2 = 0.233$, $\mu_3 = 0.2$, $\mu_4 = 0.8$, $\mu_5 = 0.2$, $\omega_1 = 1.95$, $\omega_2 = 3.01$, $\omega_4 = 1.536$, $\omega_5 = 1.20$ with the values of ω_3 as 4.371, 4.471, 4.571, 4.671, 4.771. The table (2.1(h)) demonstrates the outcomes of finish grinding (ω_3) on reliability of system. The reliability of system increases by 0.19% with increment in finish grinding from 4.371 to 4.771 and remain same with increment in time from 30 to 360 days.

Table 2.1(h) OUTCOMES OF REPAIR RATE OF FINISH GRINDING (ω_3) ON RELIABILITY OF SYSTEM

$\omega_3 \rightarrow$ Days \downarrow	4.371	4.471	4.571	4.671	4.771
30	0.509033	0.509298	0.509552	0.509795	0.510029
60	0.509033	0.509298	0.509552	0.509795	0.510029
90	0.509033	0.509298	0.509552	0.509795	0.510029
120	0.509033	0.509298	0.509552	0.509795	0.510029
150	0.509033	0.509298	0.509552	0.509795	0.510029
180	0.509033	0.509298	0.509552	0.509795	0.510029
210	0.509033	0.509298	0.509552	0.509795	0.510029
240	0.509033	0.509298	0.509552	0.509795	0.510029
270	0.509033	0.509298	0.509552	0.509795	0.510029
300	0.509033	0.509298	0.509552	0.509795	0.510029
330	0.509033	0.509298	0.509552	0.509795	0.510029
360	0.509033	0.509298	0.509552	0.509795	0.510029
MTTF	162.8904	162.9753	163.0565	163.1344	163.2091

(x) **Outcomes of repair rate of double cam turning & gap cutting(ω_4) on reliability of system:-** The reliability of system is measured by utilizing following combinations of failure and repair rates as $\mu_1 = 0.3$, $\mu_2 = 0.233$, $\mu_3 = 0.2$, $\mu_4 = 0.8$, $\mu_5 = 0.2$, $\omega_1 = 1.95$, $\omega_2 = 3.01$, $\omega_3 = 4.371$, $\omega_5 = 1.20$ with values of ω_4 as 1.536, 1.636, 1.736, 1.836, 1.936. The table

(2.1(i)) demonstrates outcomes of double cam turning & gap cutting (ω_4) on reliability of system. The reliability of system increases by 5.7% with increment in double cam turning & gap cutting from 1.536 to 1.936 and remain same with increment in time from 30 to 360 days.

Table 2.1(i) OUTCOMES OF REPAIR RATE OF DOUBLE CAM TURNING & GAP CUTTING (ω_4) ON RELIABILITY OF SYSTEM

$\omega_4 \rightarrow$ Days \downarrow	1.536	1.636	1.736	1.836	1.936
30	0.509033	0.517418	0.525070	0.532083	0.538532
60	0.509033	0.517418	0.525070	0.532083	0.538532
90	0.509033	0.517418	0.525070	0.532083	0.538532
120	0.509033	0.517418	0.525070	0.532083	0.538532
150	0.509033	0.517418	0.525070	0.532083	0.538532
180	0.509033	0.517418	0.525070	0.532083	0.538532
210	0.509033	0.517418	0.525070	0.532083	0.538532
240	0.509033	0.517418	0.525070	0.532083	0.538532
270	0.509033	0.517418	0.525070	0.532083	0.538532
300	0.509033	0.517418	0.525070	0.532083	0.538532
330	0.509033	0.517418	0.525070	0.532083	0.538532
360	0.509033	0.517418	0.525070	0.532083	0.538532
MTTF	162.890416	165.573611	168.022479	170.266434	172.330161

(x) **Outcomes of repair rate of axial width inspection (ω_5) on reliability of system:-** The reliability of the system is measured by

utilizing the following combinations of failure and repair rates as $\mu_1 = 0.3$, $\mu_2 = 0.233$, $\mu_3 = 0.2$, $\mu_4 = 0.8$, $\mu_5 = 0.2$, $\omega_1 = 1.95$, $\omega_2 = 3.01$, $\omega_3 = 4.371$, $\omega_4 = 1.536$ with the values of ω_5 as 1.20, 1.3, 1.4, 1.5, 1.6. The table (2.1(j)) demonstrates outcomes of axial width inspection (ω_5) on reliability of system. The reliability of system increases by 2.16% with the increment in axial width inspection from 1.20 to 1.6 and remain same with the increment in time from 30 to 360 days.

Table 2.1(j) OUTCOMES OF REPAIR RATE OF AXIAL WIDTH INSPECTION (ω_5) ON RELIABILITY OF SYSTEM

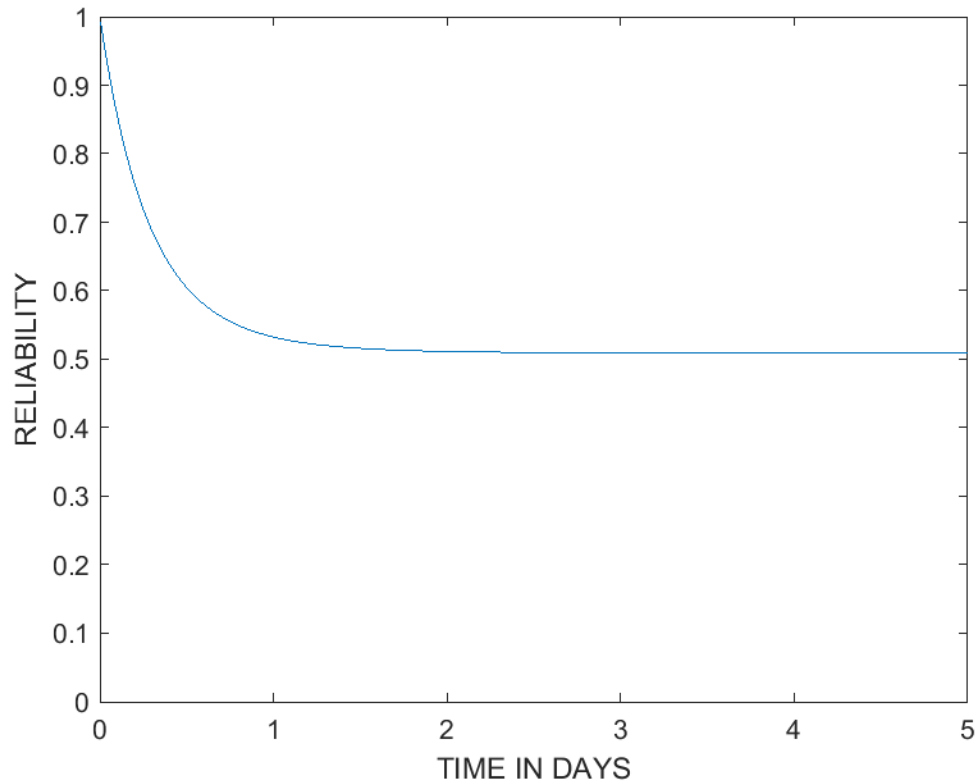
$\omega_5 \rightarrow$ Hours↓	1.20	1.3	1.4	1.5	1.6
30	0.509033	0.512376	0.515278	0.517819	0.520063
60	0.509033	0.512376	0.515278	0.517819	0.520063
90	0.509033	0.512376	0.515278	0.517819	0.520063
120	0.509033	0.512376	0.515278	0.517819	0.520063
150	0.509033	0.512376	0.515278	0.517819	0.520063
180	0.509033	0.512376	0.515278	0.517819	0.520063
210	0.509033	0.512376	0.515278	0.517819	0.520063
240	0.509033	0.512376	0.515278	0.517819	0.520063
270	0.509033	0.512376	0.515278	0.517819	0.520063
300	0.509033	0.512376	0.515278	0.517819	0.520063
330	0.509033	0.512376	0.515278	0.517819	0.520063
360	0.509033	0.512376	0.515278	0.517819	0.520063
MTTF	162.890416	163.960432	164.888840	165.702007	166.420136

2.5 Conclusion

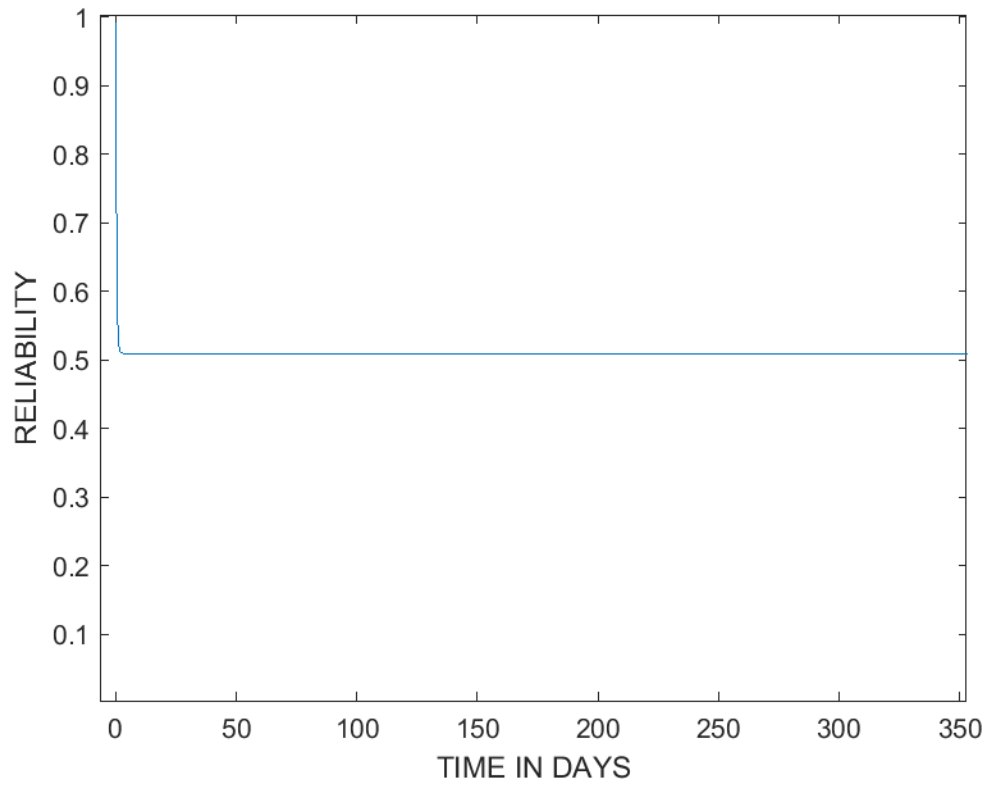
On comparing the results shown in tables, we conclude that the sub-systems E, that is, axial width inspection affects the reliability more than any of the other sub-systems.

Therefore administration have to pay more attention to this sub-system. The result shows the reliability of this plant remains the same throughout the year. However, it is observed that there is insignificant change in reliability by varying repair and failure rate of this sub-

system. In each model reliability drastically decreases for the short period as shown in Graphs (2.1-2.2) and remains same onward.



Graph 2.1-Graph of reliability for five days



Graph 2.2-Graph of reliability for 1 year

Chapter 3
AVAILABILITY STUDY OF PISTON RING
MANUFACTURING

The executives ordinarily are interested in long run availability of system in process enterprises. Availability has been gotten by taking various mixes of constant failures and repair rates of sub-systems gathered from concerned management. Till now we are dealing with first order differential equation in transient state associated with transition diagram. This chapter is organized as follows:

Mathematical formulation of determining long-run availability has been developed in section 3.1. In section 3.2; we discuss the behavioral analysis of piston ring manufacturing plant.

3.1 Mathematical Formulation

The executives ordinarily are interested in long run availability of system in process enterprises. Availability has been gotten by taking various mixes of constant failures and repair rates of sub-systems gathered from concerned management. Till now we are dealing with first order differential equation in transient state associated with transition diagram.

Steady state probabilities of system are required for availability which are gotten by taking $\frac{d(P)}{dt} \rightarrow 0$ as $t \rightarrow \infty$. The differential equations (2.1-2.7) have been reduced to the following system of linear equations of system.

$$\omega_1 P_0(t) = \omega_1 P_1(t) + \omega_2 P_2(t) + \omega_3 P_3(t) + \omega_4 P_4(t) + \omega_5 P_5(t) \quad (3.1)$$

$$\omega_1 P_1(t) = \mu_1 P_0(t) \quad (3.2)$$

$$\omega_2 P_2(t) = \mu_2 P_0(t) \quad (3.3)$$

$$\omega_3 P_3(t) = \mu_3 P_0(t) \quad (3.4)$$

$$\omega_4 P_4(t) = \mu_4 P_0(t) \quad (3.5)$$

$$\omega_5 P_5(t) = \mu P_0(t) \quad (3.6)$$

Where, $\phi_1 = \mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5$

The normalizing condition is given as:

$$P_0(0) = 1 \text{ and } 0 \text{ otherwise} \quad (3.7)$$

$$\sum_{i=1}^5 P_i(t) = 1 \quad (3.8)$$

Solving the linear system of (3.1-3.8) recursively, we attain

$$P_1(t) = \frac{\mu_1}{\omega_1} P_0(t) \quad (3.9)$$

$$P_2(t) = \frac{\mu_2}{\omega_2} P_0(t) \quad (3.10)$$

$$P_3(t) = \frac{\mu_3}{\omega_3} P_0(t) \quad (3.11)$$

$$P_4(t) = \frac{\mu_4}{\omega_4} P_0(t) \quad (3.12)$$

$$P_5(t) = \frac{\mu_5}{\omega_5} P_0(t) \quad (3.13)$$

$$P_0 = \left[1 + \frac{\mu_1}{\omega_1} + \frac{\mu_2}{\omega_2} + \frac{\mu_3}{\omega_3} + \frac{\mu_4}{\omega_4} + \frac{\mu_5}{\omega_5} \right]^{-1} \quad (3.14)$$

Finally, long run availability of system can be obtained as by using the following relation

$$A(\infty) = P_0(t) \quad (3.15)$$

3.2 Behavior Analysis

In order to solve system of linear equation (3.1-3.8) we have used Gauss elimination method. As this is a homogenous arrangement of linear equation and gives a trivial solution, we have retrieved any one equation among (3.1-3.6) by the condition (3.8) to make it non homogenous. For various values of failure and repair rates, we have determined the long run-availability of the system and abridged the outcomes as pursues.

Availability as defined in (3.15) is characterized is for various values of repair and failure rates as follows:

(a) Outcomes is contemplated by fluctuating values as $\mu_1=0.3, 0.4, 0.5, 0.6, 0.7$ and $\omega_1= 1.95, 2.05, 2.15, 2.25, 2.35$ and other are taken as $\mu_2=0.233, \mu_3=0.2, \mu_4=0.8, \mu_5=0.2$ and $\omega_2=3.01, \omega_3=4.371, \omega_4=1.536, \omega_5=1.20$. The table 3.1(a) demonstrates the outcomes of availability of system under the failure and repair rate of sub-system rough section (A). The figured result as indicated in table 3.1(a) declare that increment in μ_1 reduces availability by 9.45% and ω_1 increases the availability by 1.35%.

Table 3.1(a) OUTCOMES OF FAILURE RATE(μ_1) AND REPAIR RATE(ω_1) ON AVAILABILITY OF SYSTEM

$\mu_1 \rightarrow$ $\omega_1 \downarrow$	0.3	0.4	0.5	0.6	0.7
1.95	0.509033	0.496083	0.483775	0.472064	0.460906
2.05	0.510985	0.498557	0.486721	0.475433	0.464656
2.15	0.512768	0.500824	0.489423	0.478530	0.468111
2.25	0.514404	0.502906	0.491911	0.481387	0.471303
2.35	0.515910	0.504827	0.494210	0.484031	0.474262

(b) Outcomes is contemplated by fluctuating values as $\mu_2=0.233, 0.333, 0.433, 0.533, 0.633$ and $\omega_2= 3.01, 3.11, 3.21, 3.31, 3.41$ and other are taken as $\mu_1=0.3, \mu_3=0.2, \mu_4=0.8, \mu_5=0.2$ and $\omega_1=1.95, \omega_3=4.371, \omega_4=1.536, \omega_5=1.20$. The table 3.1(b) demonstrates the outcomes of availability of system under the failure and repair rate of sub-system medium grinding (B). The figured result as indicated in table 3.1(b) declare that increment in μ_2 reduces availability by 6.3% and ω_2 increases the availability by 0.4%.

Table 3.1(b) OUTCOMES OF FAILURE RATE(μ_2) AND REPAIR RATE(ω_2) ON AVAILABILITY OF THE SYSTEM

$\mu_2 \rightarrow$ $\omega_2 \downarrow$	0.233	0.333	0.433	0.533	0.633
3.01	0.509033	0.500567	0.492379	0.484454	0.476780
3.11	0.509678	0.501460	0.493503	0.485794	0.478323
3.21	0.510285	0.502300	0.494561	0.487057	0.479778
3.31	0.510857	0.503092	0.495560	0.488250	0.481153
3.41	0.511396	0.503840	0.496504	0.489379	0.482455

(c) Outcomes is contemplated by fluctuating values as $\mu_3=0.2, 0.3, 0.4, 0.5, 0.6$, and $\omega_3= 4.371, 4.471, 4.571, 4.671, 4.771$ and other are taken as $\mu_1=0.3, \mu_2=0.233, \mu_4=0.8, \mu_5=0.2$ and $\omega_1=1.95, \omega_2=3.01, \omega_4=1.536, \omega_5=1.20$. The table 3.1(c) demonstrates the outcomes of availability of system under the failure and repair rate of sub-system medium grinding(C). The figured result as indicated in table 3.1(c) declare that increment in μ_3 reduces availability by 4.5% and ω_3 increases the availability by 0.19%.

Table 3.1(c) OUTCOMES OF FAILURE RATE(μ_3) AND REPAIR RATE(ω_3) ON AVAILABILITY OF THE SYSTEM

$\mu_3 \rightarrow$ $\omega_3 \downarrow$	0.2	0.3	0.4	0.5	0.6
4.371	0.509033	0.503173	0.497446	0.491849	0.486376
4.471	0.509298	0.503562	0.497953	0.492469	0.487103
4.571	0.509552	0.503934	0.498439	0.493063	0.487801
4.671	0.509795	0.504291	0.498905	0.493633	0.488470
4.771	0.510029	0.504634	0.499352	0.494180	0.489114

(d) Outcomes is contemplated by fluctuating values as $\mu_4=0.8, 0.9, 1.0, 1.1, 1.2$, and $\omega_4= 1.536, 1.636, 1.736, 1.836, 1.936$ and other are taken as $\mu_1=0.3, \mu_2=0.233, \mu_3=0.2, \mu_5=0.2$ and $\omega_1=1.95, \omega_2=3.01, \omega_3=4.371, \omega_5=1.20$. The table 3.1(d) demonstrates the outcomes of availability of system under the failure and repair rate of sub-system double cam turning & gap cutting (D). The figured result as indicated in table 3.1(d) declare that increment in μ_4 reduces availability by 11.7% and ω_4 increases the availability by 5.7%.

Table 3.1(d) OUTCOMES OF FAILURE RATE(μ_4) AND REPAIR RATE (ω_4) ON AVAILABILITY OF SYSTEM

$\mu_4 \rightarrow$ $\omega_4 \downarrow$	0.8	0.9	1.0	1.1	1.2
1.536	0.509033	0.492704	0.477391	0.463001	0.449453
1.636	0.517418	0.501555	0.486636	0.472579	0.459311
1.736	0.525070	0.509655	0.495119	0.481390	0.468401
1.836	0.532083	0.517097	0.502932	0.489523	0.476810
1.936	0.538532	0.523957	0.510150	0.497053	0.484611

(e) Outcomes is contemplated by fluctuating values as $\mu_5=0.2, 0.3, 0.4, 0.5, 0.6$, and $\omega_5= 1.20, 1.30, 1.40, 1.50, 1.60$ and other are taken as $\mu_1=0.3, \mu_2=0.233, \mu_3=0.2, \mu_4=0.8$ and $\omega_1=1.95, \omega_2=3.01, \omega_3=4.371, \omega_4=1.536$. The table 3.1(e) demonstrates the outcomes of availability of system under the failure and repair rate of sub-system axial width inspection (E). The figured result as indicated in table 3.1(e) declare that increment in μ_5 reduces availability by 14.5% and ω_5 increases the availability by 2.16%.

Table 3.1(e) OUTCOMES OF FAILURE RATE(μ_5) AND REPAIR RATE (ω_5) ON AVAILABILITY OF THE SYSTEM

$\mu_5 \rightarrow$	0.2	0.3	0.4	0.5	0.6
$\omega_5 \downarrow$					
1.20	0.509033	0.488318	0.469224	0.451567	0.435191
1.30	0.512376	0.492948	0.474938	0.458199	0.442599
1.40	0.515278	0.496986	0.479948	0.464040	0.449152
1.50	0.517819	0.500540	0.484376	0.469224	0.454991
1.60	0.520063	0.503691	0.488318	0.473856	0.460226

Further, the system of linear equation (3.1-3.6) has been solved analytically by using expressions (3.9-3.13) to obtain long run availability. The long run availability of piston ring plant has been computed for the same data combination of repair/failure as used in table 3.1(a).The results are shown in table 3.1(f).

Table 3.1(f) OUTCOMES OF FAILURE RATE(μ_1) AND REPAIR RATE (ω_1) ON AVAILABILITY OF SYSTEM

$\mu_1 \rightarrow$ $\omega_1 \downarrow$	0.3	0.4	0.5	0.6	0.7
1.95	0.509528	0.496548	0.484214	0.472500	0.461318
2.05	0.511482	0.499026	0.487163	0.475873	0.465073
2.15	0.513267	0.501303	0.489883	0.478973	0.468537
2.25	0.514906	0.503397	0.492416	0.481834	0.471720
2.35	0.516422	0.505305	0.494682	0.484472	0.474698

On comparing the results of tables 3.1(a) and 3.1(f), we conclude that they are agreeing upto three decimal place. This validates our results obtained for the availability of piston ring manufacturing plant.

3.3 Conclusion

The relative investigation of table 3.1(a) - 3.1(e) uncovers that the sub system E i.e Axial width inspection influences the availability of the entire system more than other sub system. Therefore, we will recommend the administration that they should give more consideration to the sub component Axial width inspection to improve overall performance of piston ring manufacturing unit of Federal Mogul Goetz (INDIA) LTD. These elements help in future arranging so that industry gets more benefit and furthermore helps in the assembling of further reliable items. Our investigation of result

depends on the real information of failure and repair rates of the sub systems. The end drawn from the analysis of our outcome is logical with the genuine performance of the assembling plant. Our proposals will help them a lot to expand performance of the system.

3.3 Limitations of Research work

The present mathematical study of finding reliability and availability of this system has industrial significance.

There are a few imperatives looked during the research work done which are recorded as:

- (i) It was extremely troublesome task to collect real information of industry. Federal Mogul Goetze (INDIA) LTD provided some data for piston rings to find failure/repair rates. Due to non- availability of certain information, a few measures were to be assumed..
- (ii) The Runge - Kutta method used in this thesis is simple when the arrangement of differential equations is small however it becomes complex for enormous arrangement of differential equations.
- (iii) We haven't investigated the reliability and availability of entire piston ring plant for other units of this plant due to unavailability of data.

3.4 Industrial Understanding of Study

As reliability turns out to be significant factor of each item in industry, the procedures in this thesis are intended for contemplating the issues of reliability. In industrial issues, reliability and MTTF are generally used..

3.5 Future Extent of Present Study

In the present work, to solve differential equation with given initial condition, we have used Runge - Kutta fourth order method. One can explore other numerical strategy for tackling the issue. We have utilized numerical techniques to examine the effect of failure and repair rate on reliability and availability of one of the component of Federal Mogul Goetze (INDIA) LTD .In future, we can think about reliability of every part of piston ring plant to increment the reliability of the machine. While computing reliability, we are not taking into account the cost required for repair of sub-system. The cost factor assumes significant job to get the maximum reliability of the system.

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