CHAPTER 1

INTRODUCTION

1.1 OPERATIONS RESEARCH

Operational Research or Operations Research is a discipline which deals with the study and applications of sophisticated analytical methods for helping to make healthy decisions. The terms decision science and management science are often considered synonyms and as a branch of mathematics. By using other mathematical techniques such as, mathematical modelling, statistical analysis and mathematical optimization, it arrives at feasible and optimal solutions to complex engineering problems. Its importance as well as interaction on human technology is the spotlight on realistic applications. Operations research extends beyond to other areas such as, operations management, reliability engineering and industrial engineering. It is often concerned to settle on, with the maximum of turnover or minimum of thrashing in the real world state.

The field operations research is sometimes referred to as management science. Even though its foundations were laid very early, it became an independent area only in late 1930s. The occurrence of this discipline has been inspired based on the requirement of a plan of similar military operations that played a crucial role in the Second World War; hence the name is “Operations” research. A suitable definition for this discipline, along with all of its branches is still in progress, and it is very difficult to furnish.
The term “Operations Research” was coined by “Harvey M. Wager” during the Second World War in 1934. The primitive mathematical programming model was developed by an Economist Quesnay in 1959 and Warlas in 1874. The mathematical foundations of linear models were recognized at the end of the 19th century by Jordan in the year of 1873. The dynamic models were developed by Russian Mathematician, Andrey Markov who lived in the year 1856 – 1922.

Several definitions are available in literature; the following are a few of them. According to Fabrycky and Torgersen, “Operations research is the application of scientific methods to problems arising from the operations involving incorporated system by men, materials and machines. It generally utilizes the skill of an interdisciplinary research team and the knowledge to give the managers of such systems with optimum solutions”. In another words T.L. Saaty has explained, that “Operations research is the art of giving bad answers”.

According to the Institute of Operations Research and Management Sciences, “Operations research and management sciences are the professional disciplines that deal with the applications of information technology for informed decision making”. However, this definition may not be adequately explicit to differentiate it from its related field.

Originating from the military efforts during the Second World War, its techniques have grown up abruptly to the problem in a variety of industries, and covers a broad area of problem solving methods and techniques applied in the quest of improving the process of decision making and efficiency in terms of simulation, optimization, queuing theory, stochastic models, economic methods,
data analysis, Markov process, neural networks, decision analysis, reliability analysis, expert systems and analytical hierarchy process. Almost, all these techniques involve the building of mathematical models that endeavor to describe the system with a strong relationship with computer science and analytics, because the most of the fields are being computational and statistical in nature.

In Britain, around 1,000 men and women were involved in Military operations and nearly 200 operations research scientists were exclusively employed for the British Army. Patrick Blackett worked in the War for a number of different organizations, apart from working for the Royal Aircraft Establishment (RAE) in 1941. He constituted a separate team “Circus” that helped to diminish the number of anti aircraft weaponry needed to shoot down the enemies’ aircrafts on an average of 20,000 of Britain to 4,000 at the beginning of the battle.

The field of operations research always tried to maintain its multi-disciplinary character and its uniqueness. In all these branches many real life problems are conceptualized as mathematical models and stochastic models. Based on the consideration of all available options, Operations research provides the executives control to make effective decisions and construct creative systems, accurate data, careful predictions of conclusion, estimation of hazard, latest decision techniques and software tools etc.

During the course of building models in operations research, the researcher draws attention to the latest analytical technologies which are explained below:
a) Statistics and probability for helping to mine data, measure risk and to find suitable connections, test conclusions and make reliable foretells.

b) Simulation is giving the capability to overcome with new techniques and test the ideas for its development.

c) Optimization is reducing the choice to the best when these are having practically numerous feasible options.

The present research focuses on developing mathematical models based on the concept of reliability with the aim of improving the accuracy and predictions for complex operating systems.

1.2 RELIABILITY ENGINEERING

Considering the overwhelming number of factors that affect overall plant production, a number of methods have been developed, both qualitative and quantitative, and software tools are available today to support reliability study of plant life cycle.

In literature, many research papers have appeared in the last few decades that provide a detailed survey of topics that include reliability-availability analysis methods by Dhillon et al. [1], reliability optimization by Kuo et al. [2] and maintenance optimization by Dekker et al. [3]. The detailed information on these topics is found in standard reliability engineering books, Henley et al. [4], Billinton et al. [5], and Kuo [6].

The reliability of a product and equipment is an important attribute for quality, accurate performance and its estimated life span. Indeed, continuous service and hazard free operation is a necessary condition for complex engineering systems such as, power generation and production plants,
railways, airways and other transportation etc. The system or assembly results in health hazard, accident or disruption in continuity of service in sudden failure for even a single component.

A repairable system is usually defined as the system that will be repaired to make progress in functions even after the failure. Physical assets such as machines, buildings and vehicles are often a repairable system. The strategy for optimal maintenance requires accurate prediction of reliability for the complex systems. Numerous mathematical models and methodologies have been developed, for predicting the reliability of the system.

1.3 RELIABILITY ASSESSMENT TECHNIQUES

A number of engineering techniques have been put to use for risk assessment in reliability, such as human error analysis (HEA), manufacturing defect analysis (MDA), reliability hazard analysis (RHA), reliability centered maintenance load (RCML) and material stress and wear calculations (MSWC), fault tree analysis (FTA), failure mode effects analysis (FMEA) and reliability testing analysis (RTA) etc. The reliability should clearly provide a strategy for the availability control. A proper reliability should always address problem of reliability, availability, maintainability and testability (RAMT) analysis in its total context.

1.4 BASICS OF RELIABILITY, MAINTAINABILITY AND AVAILABILITY

The following are some of the basic, existing and recently developed concepts in mathematics and statistics that are used to analyze reliability engineering.
1.4.1 RELIABILITY

The term reliability is more precisely expressed as, it is the probability of success over a given period of time. According to the Electronics Industries Association (EIA) of U.S.A., “reliability is the probability of performing its purpose passably for the period of time proposed under the operating and environmental conditions meet”. It is considered to be the standard definition so far, as it stresses on four important factors viz. probability, performance, time and operating conditions.

According to British Standards Institution (BSI), “reliability is the characteristic of an item expressed by the probability, which will perform a required function under stated conditions for a stated period of time”. Thus, the reliability of a component/system for a given period of time \( t \) is defined as,

\[
R(t) = e^{-\alpha t}
\]  

(1.1)

Where, \( \alpha \) is a mean failure rate

The reliability concept is expressed in number of different ways,

a) It is a tool for assuming the capacity of equipment to maintain its properties under specific conditions for a given duration.

b) It is the probability where the device operates under specific operating conditions without failure for a given duration.

c) It is a failure free operation with minimum loss of time for repair as well as preventive maintenance during a definite period.

1.4.2 AVAILABILITY

Availability performance is a criterion where the repairable system accounts for both aspects of maintainability and reliability of the system. It is
also known as the probability of a system operating properly when it is required for use. Mathematically, the term availability is used for indicating the probability of the system being in operating condition at any time \( t \), but numerically it is expressed as the probability lying between 0 and 1. Nevertheless, the availability of a repairable system can be calculated in terms of properties (failure and repairs) for its subsystems. Depending on the types of downtimes considered for analysis, the definition of availability is quite flexible and hence the different classifications of availability are as under.

a) **Point or Instantaneous Availability** \( A(t) \): It is the probability of a system being in operation at any arbitrary time \( t \). The expected up time of the system is given by,

\[
A(t) = E[Z(t)]
\]  

Where, \( Z(t) \) is an indicator function with value of one in failed state at time \( t \), otherwise 0 and \( E \) stands for expectations.

b) **Average Up-Time Availability** \( A(T) \): The mean availability is the proportion of time during a mission or time period when the system is available for use in a specified interval \((0, T)\).

\[
A(T) = \frac{1}{T} \int_0^T A(t) dt
\]  

(1.3)

c) **Steady State Availability** \( A(\infty) \): It is the probability of the system being in operation for infinite interval of time,

\[
A_m(\infty) = \lim_{t \to \infty} A(t) = \lim_{T \to \infty} \frac{1}{T} \int_0^T A(t) dt
\]  

(1.4)

d) **Inherent Availability** \( A_i \): It is the proportion of time during which the system is operational by considering only corrective maintenance
downtime, excluding ready time, logistics (supply) down time, preventive maintenance down time and waiting down time,

\[ A_i = \frac{MTBF}{MTBF + MTTF} \]  \hspace{1cm} (1.5)

Where, \( MTBF \) is mean time between failures

\( MTTF \) is mean time to failure

e) **Achieved Availability** \( A_a \): It is the proportion of the time in which the system is in operation by considering both corrective and preventive maintenance down times and excluding ready time, logistics time and waiting downtime,

\[ A_a = \frac{MTBM}{MTBM + MAMDT} \]  \hspace{1cm} (1.6)

Where, \( MTBM \) is mean time between maintenance

\( MAMDT \) is mean active maintenance down time

f) **Operational Availability** \( A_o \): It is the probability of a system being able to operate adequately when used under specific conditions with ability to supply of environment availability of parts, tools and manpower etc. at any given point of time. It rejects ready time, preventive maintenance down time, supply down time and administrative down time etc. the equation of operational availability is,

\[ A_o = \frac{MTBM}{MTBM + MDT} \]  \hspace{1cm} (1.7)

Where, \( MTBM \) is mean time between maintenance

\( MDT \) is mean down time

g) **Description of Availability Model:** Availability modelling is the procedure for predicting the availability of a system. Availability model for a particular
system, paper industry has been developed on the basis of probabilistic considerations. First, differential equations are formulated using Markovian birth and death process and then the equations are recursively solved under steady state conditions. Steady state probabilities obtained are further solved by using normalizing conditions,

$$\sum_{i=1}^{n} P_i = 1$$  \hspace{1cm} (1.8)

Where $n$ is the total number of state

Steady state availability $A_v$ of that system can be obtained by summing up the all the ‘$k$’ working state probabilities,

$$A_v = \sum_{j=0}^{k} P_j$$  \hspace{1cm} (1.9)

The developed availability model is generally a function of failure rates $\alpha_k$ and repair rates $\beta_k$ of various subsystems,

$$\therefore A_v = f(\alpha_k, \beta_k)$$  \hspace{1cm} (1.10)

Where $k$ is the number of subsystems in a system

In the present work, the availability models have been developed for evaluation of the performance of various subsystems of a paper plant. Mathematical modelling has been deduced on the basis of certain assumptions and then a numerical analysis of the model has been done. The optimum system availability values are determined by using a genetic algorithm (GA) which provides the different combinations of failure and repair rates for the subsystems. The whole process of development and analysis of the performance operating system of a paper plant may facilitate decision making regarding maintenance work for future use.
1.4.3 MAINTAINABILITY

The term maintainability is explained as; any action that keeps non failed units in an operative or restores failed units into an operative condition. In previous days, only few terms were involved in maintenance such as repair, overhauling and preventive etc. Several new terms have been invented now, based on the involvement of specialists in maintenance management such as breakdown, planned, scheduled, routine, corrective, periodic and predictive maintenance etc. the following different classification of maintenance are listed below.

a) Breakdown Maintenance (BM): The equipment is allowed to run undisturbed till it fails. In this system, repairs are taken up only after the failure of the equipment. This system cannot work in a capital intensive industry having large number of equipments.

b) Corrective Maintenance (CM): In this system, a failed system can be restored into operational status by some actions. It generally involves replacing or repairing a component which is responsible for the failure of the entire system.

c) Preventive Maintenance (PM): It is a process of replacing components or systems, in order to support continuous operation system before failure. It is also known as planned maintenance of plants and equipment in order to obviate or minimize the breakdown time and the reduction rates.

1.5 MARKOV MODEL

A Markov process is named after Russian Mathematician Andrey Markov in the probability theory. It is a stochastic process which satisfies the Markov
property i.e. a stochastic process \( \{X_s, t \geq 0\} \) with state space \( S \) called a Markov process provided that,

\[
P\{X_{t+u} = j \mid X_s = i\}, \quad 0 \leq u \leq 1
\]

for all \( i, j \in S \) states and all \( s, t \geq 0 \).

The detailed study based on this concept is given in Chapter 3 and Chapter 4.

### 1.6 EXPONENTIAL DISTRIBUTION

The exponential distribution that describe the time between events in a Poisson process in probability theory i.e. a process in which events occur continuously and independently at a constant average rate. Therefore, a random variable \( X \) has an exponential distribution with parameter \( \lambda \) if its probability density function is given by,

\[
f(x) = \begin{cases} 
\lambda e^{-\lambda x} & , \quad x \geq 0 \\
0 & , \quad x < 0
\end{cases}
\]

The use of this concept is given in Chapter 3.

### 1.7 FUZZY WEIBULL DISTRIBUTION

Weibull distribution is named after Waloddi Weibull 1951, who described in detail that the probability theory, is a continuous time probability distribution. Even though it was first identified by Frechet in 1927 it was first applied by Rosin and Rammler in 1933 to describe the size distribution of a particle. Now, it is widely used in reliability engineering too, therefore its probability density function is given by,

\[
f(x) = \frac{\beta}{\theta} \left( \frac{x-\delta}{\theta} \right)^{\beta-1} e^{-\left( \frac{x-\delta}{\theta} \right)^\beta}
\]
Where $\theta$ is a scale parameter, $\beta$ is a shape parameter and $\delta$ is a location parameter and they are crisps in nature. Concept of Fuzzy Weibull distribution is explained in Chapter 5.

1.8 FUZZY RELIABILITY FUNCTION

In the fuzzy set theory, fuzzy reliability is explained by Zadeh [7]. Fuzzy reliability or fuzzy survival function ($\tilde{S}(t)$) means the fuzzy probability where a unit survives beyond time $t$. A random variable $X$ denotes the lifetime of a component of the system, and let $X$ have a probability density function and fuzzy cumulative distribution function $\tilde{F}_X(t) = \tilde{P}(X \leq t)$, and the fuzzy reliability function at time $t$ is defined as,

$$\tilde{S}(t) = \tilde{P}(X > t) = 1 - \tilde{F}_X(t) = \{1 - F_{\max}(x)[\alpha], 1 - F_{\min}(x)[\alpha], \mu_{F(x)} = \alpha\}, t > 0 \quad (1.14)$$

The use of Fuzzy reliability function discussed in detail is given in Chapter 5.

1.9 FUZZY HAZARD FUNCTION

Fuzzy hazard function plays a very important role in reliability theory. Therefore, the concept of a fuzzy hazard function is proposed as based on the fuzzy probability measure and is called its $\alpha$-cuts. The fuzzy hazard function $\tilde{h}(t)$ is the fuzzy conditional probability of an item lying in the interval $t$ to $(t + dt)$ given that it has not failed by time $t$, where $\tilde{\theta}$ is a fuzzy number. Sometimes the hazard function is also called the instantaneous failure rate and defined as,
\[
\tilde{h}(t)[\alpha] = \lim_{\Delta t \to 0} \frac{P(t < X < t + \Delta t \mid X > t)}{\Delta t} = \left\{ \lim_{\Delta t \to 0} \frac{S(t) - S(t + \Delta t)}{\Delta t S(t)} \mid \theta \in \tilde{\vartheta}[\alpha] \right\} = \left\{ \frac{-S'(t)}{S(t)} \mid \theta \in \tilde{\vartheta}[\alpha] \right\} = \left\{ \frac{f(t)}{S(t)} \mid \theta \in \tilde{\vartheta}[\alpha] \right\}.
\] (1.15)

Chapter 5 involves the use of these concepts in obtaining the optimal solution.

1.10 PERFORMANCE ANALYSIS OF OPERATING SYSTEM

High capital investment is required with upcoming demand for mechanization in diverse industrial sectors for the installation of plants, especially in manufacturing plants like sugar, fertilizer, chemical, thermal and paper plant etc. It is essential to have a high productivity and maximum output for their survival in manufacturing plants. Therefore, the availability and reliability of equipment must be maintained at the highest order to get the desired result. But, failure is an inevitable phenomenon though it can be reduced by proper maintenance, inspections, proper training to the operators and motivation by making a positive approach to the workers. The performance of the system may also affect its design quality and the optimization tools used. Thus, the performance of the system may be improved by optimization at the designing stage, by giving proper design and by maintaining the same in service life span. Improving the quality and increasing the availability of manufacturing system and also helping a lot in the production through proper maintenance planning plays an important role in reducing of production costs.

It is necessary to emphasize more on operational management, for improving the output and quality of a manufacturing related curriculum. The deficiency of failure in technological capability is most common requiring considerable attention. In manufacturing procedure the inputs are in the form of;
energy, labour, raw materials, machines facilities, information and technology etc. The success of a plant depends on its outstanding performance which is openly related to quantitative and qualitative areas of production. The performance of three main systems viz. operational, financial and management systems are known, the results may predict the profit for the plant. The following operational performances improve profitability,

a) Implementing new technology to increase the manufacturing production.

b) Production capacity should also increase.

c) Improve the system performance by planning the current capacity.

d) Manage the inventory right quantity at the right time.

e) Maintain the balance between maintenance and manpower requirement.

In process industries such as chemical, sugar, brewery, iron and steel, cement, food processing, thermal power plants, fertilizer plants and paper plant achievement of goals of high system availability and utilizing maximum plant capacity, to the maximum extent is necessary. That is to say, the various subsystems should remain active for a longer period. Even though, these systems or subsystems are subordinate to random failures, depending on the nature and extent of failure, they may result into reduced or zero production. No doubt the failed systems can be brought back to operating state but only after repairs or replacements of the particular components. But, in this case the factory operating conditions and adoption of suitable repair policies in the organizations play a prominent role for maintaining the system operative in full capacity for maximum duration of time. Designing such process, from the view point of high system availability, would require a prior knowledge of the system
behaviour, available repair facilities etc. This would also yield a framework for system design based on availability and optimum repair policy.

In this direction, analysis of a system behavior along with a scientific maintenance planning will help, to precise the system upstate in quantitative terms. It is necessary to develop mathematical models of real existing systems and analyze their performance under actual operating conditions. The analysis will be helpful in predicting system behaviour and it will further help the process designer to incorporate some changes in the existing system design in real operative conditions. Such analysis will also be useful to the maintenance engineer in monitoring the system performance and planning in advance to keep system failure free for long duration.

The work presented here, is mainly concerned with the performance evaluation of the various operating systems of a paper plant. The reported work has two parts i.e. performance analysis and optimization of operating systems of the paper plant referred to. Paper plants are having a large and complex system. They involve a wide range of problems by tackling and ensuring a best performance for both individual equipments the system as whole. These systems are repairable but the repair time varies randomly and so the repair policies used would have a direct impact on the system performance and its operations. The failed components, if not attended to promptly, would affect the performance of other subsystems which may lead to accelerated failure of interconnected equipments.

The study has been conducted in Tamil Nadu Newsprint and Paper Limited, (TNPL), a plant situated in Kagithapuram, Karur District of Tamil Nadu producing about 4,00,000 tonnes per annum from the year July 2010. The
Chapman Kolmogorov’s differential equations associated with these real models are very complex in nature and difficult to solve with the use of time dependent parameters. In any process industry it is imperative for various systems or subsystems to remain perpetually operative for an infinitely long duration. Hence the steady state conditions (time independent) are introduced and the differential equations are reduced to steady state equations which are solved recursively. The probability of each state is derived and hence the steady state availability of each system is computed. A detailed study of these industries has been conducted with special reference to failure and repair time data and the existing maintenance policies being followed. In varying operating conditions, steady state availabilities are computed, tabulated and analyzed.

Performance optimization for each operating system of the paper plant has also been worked out. The analysis gives the plant management, a deep understanding regarding the optimum system availability achieved, and the maintenance efforts needed to maintain an appropriate level of working and profit, how and at what limit the profit earned will be allocated for maintenance to achieve high availability, improved process and hence a good.

1.11 SIGNIFICANCE OF PRESENT WORK

Availability analysis of various systems has a wide scope in various manufacturing industries. A lot of research has taken place in this direction in different industries like sugar plant, fertilizer plant, soap industry, iron and steel industry, foundry units and cotton mills etc. but quality research is not seen in the paper industry which forms an important segment of process industry in the state of Tamil Nadu. The Plant situated in the district of Karur; Kagithapuram
has been selected for performance analysis and optimization of various operating systems of a paper plant.

1.12 RESEARCH OBJECTIVES

The main research objectives of the present study are:

1. Mathematical formulation and development of performance models for various systems of the paper plant.
2. Detailed availability analysis of various operating systems in the paper plant.
3. To find optimum system availability by using Genetic Algorithm for improving overall performance of the paper plant.

1.13 ARRANGEMENT OF CHAPTERS

An effort has been made in this thesis to develop mathematical models, performance analysis and optimization availability of operating system of paper plant while keeping the objectives in mind as discussed in Section 1.12, based on random data taken from the industries. However, manufacturing plants like Iron and Steel plant, Polytube plant, Fertilizer plant, Sugar plant and Thermal plant etc. have been extensively investigated by several researchers for analysis of their reliability and availability with the assumptions of frequent failure and repair rates.
1.14 ORGANIZATION OF THE THESIS

Chapter 1

A brief introduction to operations research, reliability engineering and its applications to real life problems has been provided. Mathematical modelling, performance analysis and optimization of some operating systems of a paper plant by using genetic algorithm tool and fuzzy logic technique are also discussed with indication of results presented in the chapters that follow.

Chapter 2

A brief summary of research papers published by various authors is given in the form of review of literature. These include an overall survey of reliability engineering and to identify research topics. An intensive review to focus on the research topic of the thesis has been carried out.

Chapter 3

In this chapter, a methodological scheme is proposed to compute performance metric of the manufacturing process of a paper plant. This scheme utilizes the concept of stochastic process to build mathematical modelling and performance analysis of stock preparation unit of the paper plant and decision support system for modern paper machine (Fourdrinier Machine). Further both models have been optimized by using a Genetic Algorithm Technique. A system of difference differential equations have been developed by using probabilistic approach. Kolmogorov’s forward equations have also been
developed by using Markovian approach, which is explained in the form of Model 3.1 and Model 3.2.

Chapter 4

This chapter is concerned with the study of mathematical modelling, analysis and behavior of the digesting system of the paper plant based on queuing theory. The digestive system of paper plant is modeled using several queues in tandem with different serving rates. Assuming that the serving rate of first part is much lower than the serving rate of last and taken into consideration that the capacity of each part is different. The simulation of this model is done using SLAM – II. The best behavior of the digestive system ‘chipping’ is deduced. Finding of this work is discussed with the plant management; such results are found highly beneficial for the behavior of some parts of digestive system of paper plant.

Chapter 5

Three important criteria on the mission of reliability engineering: (a) Weibull distribution (b) fuzzy reliability function (c) fuzzy hazard function and their \(\alpha\)-cuts have been investigated in this chapter. The approach of reliability theory based on some traditional statistical methods may be inappropriate, whenever the lifetimes of a components and parameters contain the randomness and fuzziness respectively. Reliability of fuzzy system is based on the concept of fuzzy set. Fuzzy probability theory is considered in the researcher’s method and the scale parameter is considered as a fuzzy trapezoidal number. In addition, the shape and location parameters can be
measured in terms of fuzzy either separately or in combination. Further research is required for studying some important topics in fuzzy reliability theory such as mean residual life.

Chapter 6

In this chapter a detailed discussion on mathematical modelling and analysis of job scheduling problem in a small scale measure for paper industry and a novel approach for no-wait flowshop scheduling problem with hybrid genetic algorithm, is explained in form of Model 6.1 and Model 6.2. Johnson two machine algorithms have been successfully applied to job scheduling in the paper making Industry in the first model. The second model presented is a Hybrid Genetic Algorithm (HGA) for flowshop scheduling in a No-Wait Flowshop Scheduling Problem (NWFSSP). Therefore, this approach is able to find an optimal solution for all the problems with different objective functions. The search for efficiency of the genetic algorithm was enhanced by the specific heuristic in the form of genetic operators.

Chapter 7

In this chapter, the problem of scheduling the jobs in permutation flowshop scheduling problem is considered. The main aim of this research is to explore the potential of genetic algorithms. The overall inference of the studies demonstrates that the genetic algorithm provides good results for permutation flowshop scheduling problem for large sizes and reaching a nearer to optimal solution. The study of permutation flowshop scheduling problem using genetic
algorithm provides a rich experience for the constrained combinatorial optimization problems.

**Chapter 8**

This chapter presents the conclusion of the thesis, limitations and scope of the present work. Mathematical modelling and performance analysis of each operating system of a paper plant using Genetic Algorithm, gives the optimum levels of system availability for different combinations of failure and repair rates of the subsystems of each operating system of the paper plant. The industrial significance of the results as well as a scope for further work on this topic is also presented in the concluding chapter.