Abstract

In every industrial application, operating units tend to experience random failure. With progress, people are becoming more dependent on machining systems, and machines have become a part of human's daily lives, providing comfort in all walks of life. Random failure of operating units leads the necessity for relevant research to develop a systematic approach for studying the phenomena of occurrence & maintenance of failure, and for optimal & economical design of machining systems. Reliability theory, a branch of mathematical science, has been widely used to understand the laws of occurrence of failures in machining systems. The reliability theory plays a vital role in the prediction and improvement of industrial systems, service systems, etc. which are operating in a machining environment. Queueing theory, a modernistic mathematical technique, is often used as a powerful tool to solve the blocking and delay problems of complex machining systems. A finite population queueing model, also commonly known as machine repair problem (MRP), has a lot of significant applications of practical nature in many organizations that are working in the environments of machines, breakdowns, repairs, deterioration, blocking, delay, etc. The machine repair problems are in general supplement with applications of machining systems in several fields like production and manufacturing systems, power supply, computer & communication systems, distribution plants, and many more.

With the advancement in technology and over utility, the machining systems are becoming more complicated and sophisticated because of which it becomes quite challenging for the system designers and the technologists to maintain systems efficiencies. Besides the uninterrupted operation of a machining system, the primary aim of the industrial organization is to proliferation the quantity and quality of production by minimizing the expected total cost. Sometimes the working of the machining system is disrupted due to the improper functioning of some operating units. In such a hinderance situation, to avoid the possibility of stoppage of operation, services and production loss, just-in-time (JIT) & efficient repair facility and state-of-the-art maintenance policy is usually necessary to repair the improperly working units or to maintain service threshold as per requirement. The spare unit redundancy is the alternative means of continuing the function of machining system when operating unit becomes inoperative due to failure and is one of the primary approaches to enhance reliability attributes. Another approach to improve the system reliability traits is to opt robust preventive, corrective, and predictive maintenance strategies for the machining system according to some schedule and policies depending upon associated

cost and other characteristics such as the number of permanent and additional repairmen, phase repair, increased service rate, vacation, etc. The maintenance action can be performed while the system is in operation without degrading its operation or by stopping the system for some time to avoid the un-pleasure hinderance, stoppage, and consequences.

In this thesis, the objective of learning is

- to model a repairable redundant machining system via queueing theoretic approach;
- to sensitivity and optimal analysis of fault-tolerant machining system for predictive, preventive, and corrective purpose; and
- to measure the effects on reliability indices of distinct failure and delay variants, maintenance policies.

The present study will be helpful for the strategic implementation of such system in a real-time machining environment. The findings of current investigation will enable the system engineers and decision-makers to use the machining system from designing to development, and to applications in a more efficient way to achieve desired reliability and availability of the system. The findings of the present study will be of great prominence in improving the many reliability attributes associated with the machining systems which will lead to high-cost saving strategies in service rendering by the concerned system.

The fault-tolerant redundant repairable machining system is investigated with various variants and the transient-state, steady-state, and vagueness involved results are analyzed. The thesis is divided into three parts and comprises seven chapters and bibliography. The brief descriptions for all chapters are as follows.

In chapter 1, the briefs of machine repair problems from basic to advance have been discussed. Some fundamental concepts involved in machining system and related definition, formulation, literature, etc. have been given to provide insights into various issues related to redundant repairable machining systems. It may be useful for the system designers to plan effective strategies for an efficient machining system. Some critical factors such as spares, K-out-of-M machining system, mean time-to-failure ($MTTF$), reliability, vacation, discouragement, switching failure, degraded failure, common cause failure, fuzzy set theory, and many more have also been discussed. The analytical, as well as the numerical methods for solving the repairable systems, have been elaborated. The historical development of research on reliability and maintainability analysis of redundant repairable systems (RRS) is presented. A brief review of the fault-tolerant repairable machining systems, queueing theory, reliability, availability, and maintainability has been presented.

In chapter 2, the Markovian warm spare units $M/M/1$ machine repair problem (MRP) is investigated wherein spare units may be prone to failure in switching from standby state to the operating state. The realistic and economical repairman's modified working vacation policy is also incorporated with its threshold-based controlled vacation interruption and failed units' synchronized abandon behavior following binomial distribution for abandonment. Reliability and queueing characteristics have been derived using transient-state probabilities, which have been computed using the theory of Quasi-Birth-and-Death process, Laplace transforms, Eigenvalue, and Eigenvector. The critical analysis of reliability characteristics has also been done. This chapter has been enriched with numerical results in form of tables and graphs for sensitivity analysis of performance indices with respect to various governing parameters to provide a glance at the investigation. The concluding remarks and future scope have also been included.

In chapter 3, the fault-tolerant redundant repairable machining system is investigated, that is a vital part of manufacturing and production systems, computer and communication systems, security systems, etc. The present study is visualized as machine repair problem (MRP) having finite number of operating units along with the provision of a mix of cold and warm spare units that are prone to independent random failure. The machining system is also prone to probabilistic common cause failure. Failed units are under the care of two in-house repairmen who are explicitly dexterous for repair of operating and spare units, respectively. An automatic switch of available spare unit in place of a failed operating unit with a significant switching lag is a key concern of this chapter with unpredictable switching failure and reboot delay. The workload is collectively shared in general with M operating units and remains continuously in short mode as overload until there are at least $M-K$ units in the system with degradable failure rate. All types of units follow independent and identical exponentially distributed failure time, repair time, switchover time and reboot delay. Numerical simulation, comparative analyses, and optimal analyses of queue characteristics are also made significantly, and the conclusion is drawn for system designers, experts, and decision-makers, etc. to develop state-of-the-art maintenance and repair policies as per their necessity.

The internet of things (IoT) is an emerging archetype of technology for the guaranteed quality of services (QoS). The availability of the uninterrupted power supply (UPS) is one of the most challenging criteria in the successful implementation of the service system of IoT. In chapter 4, the fault-tolerant power generation system of finite operating units along with warm spare unit provisioning is considered. The time-to-failure for each of the operating and spare units are assumed to be exponentially distributed. The time-to-repair by the single service facility for the failed unit follows the arbitrary distribution. For modeling purposes, the realistic machining behaviors like imperfect coverage of the failure of units, switching failure of the spare unit, reboot delay, switchover delay, etc are also incorporated. For the evaluation of the explicit expression for steady-state probabilities of the system, the only required input is the Laplace-Stieltjes transform (LST) of the repair time distribution. The step-wise recursive procedure, illustrative examples, numerical results have been presented for the different type of repair time distribution: exponential (M), n-stage Erlang (Er_n), deterministic (D), uniform ($U(a,b)$), n-stage generalized Erlang (GE_n) and hyperexponential (HE_n). Concluding remarks and future scopes have also been included.

The concept of catastrophe, happening at random due to some internal or external causes or natural calamities and having potency to abandon all present customers to be served, data to be processed, failed units to be repaired immediately and the instantly inoperative of the service facilities until a new arrival of the customer, failed unit, or data, is common in many practical problems of the industrial systems. In chapter 5, the process to compute the membership function of characteristics of the single machine (server) $M/M/1$ fuzzy machining system having fuzzified exponentially distributed inter-arrival time and service time with fuzzy catastrophe is presented. The α-cut approach is employed to transform fuzzy queues into a family of the conventional crisp intervals for the characteristics, which are evaluated with a set of the nonlinear parametric program using their membership functions. In a $FM/FM/1$ fuzzy machining system with a fuzzy catastrophe, the arrival rate, service rate, catastrophe are characterized with fuzzy numbers. Fuzzy arithmetic fundamentals, Zadeh's extension principle, Yager's ranking index have been used to establish fuzzy relations among different rates and to compute corresponding defuzzified values. An illustrative example is presented to show practicality and tractability of the process in detail. The informative membership function of machining system characteristics have also been derived using fuzzy operations and arithmetic, and results are tabulated in tables and depicted in graphs for providing better insight to management along with their sensitivity to parameters.

The suppositions of indistinguishable multiple-repair facilities in machine repair problem (MRP) may not be precise, and if there is a significant difference in the operating attributes of the repair facilities associated with two-operating units redundant machining system, more complex mathematical model will result and presented in chapter 6. To provide some exposure to the intricacy involved in modeling distinguishable multiple-repair facilities within a machining system, the heterogeneous multiple-repair facilities are considered, and the associated mathematical problem for the state probabilities is developed. The problem of heterogeneous multiple-repairman redundant machining systems is often encountered in computer and communication systems, manufacturing systems, service industries and so forth. To explore the vagueness, uncertainty, linguistic problem, etc, a membership function of the reliability characteristics of the redundant repairable system with heterogeneous repair facilities where the failure rate and repair rate are characterized by fuzzy numbers, are derived. The α-cut and Zadeh's extension principle are employed to transform the heterogeneous repair facilities, fuzzy redundant machine repair problem to a family of conventional crisp interval machine repair problem (MRP), A set of non-linear parametric programs is formulated to determine the upper and lower bounds of the reliability characteristics viz mean time-to-failure and availability of the machining system. The illustrative example of fuzzy machine repair problem is solved, and numerical simulation is also performed, and results are tabulated in tables and depicted in graphs. Since the reliability characteristics are articulated by membership functions rather than by crisp values, broad information is provided for managerial decision-making.

Finally, the main findings of the thesis are summarized in the chapter 7. The future scope of the thesis is also outlined in this chapter. At last,the references are provided in bibliography.