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A knowledge management system for series-parallel availability optimization and design

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Abstract

System availability is an important subject in the design field of industrial system as the system structure becomes more complicated. While improving the system's reliability, the cost is also on the upswing. The availability is increased by a redundancy system. Redundancy Allocation Problem (RAP) of a series-parallel system is traditionally resolved by experienced system designers. We proposed a genetic algorithm based optimization model to improve the design efficiency. The objective is to determine the most economical policy of components' mean-time-between-failure (MTBF) and mean time-to-repair (MTTR). We also developed a knowledge-based interactive decision support system to assist the designers set up and to store component parameters during the intact design process of repairable series-parallel system.

Keywords: Knowledge management system; Availability optimization; Genetic algorithms; Series-parallel system

1. Introduction

In 1952, the Advisory Group on the Reliability of Electronic Equipment (AGREE) defined the reliability in a broader sense: reliability indicates the probability implementing specific performance or function of products and achieving successfully the objectives within a time schedule under a certain environment (Wang, 1992). In general, a higher priority is placed on quality control rather than reliability in the process of manufacturing. Nonetheless, high quality is not equivalent to high reliability. For example, a certain component, which has passed quality control procedure in conformity to the specifications, may lead to problems when operating with other components. This involves reliability design that is related to electrical or mechanical interface compatibility among spare parts.

With the rapid technological progress and increasing complexity of system structure, any failure of any component may lead to system malfunction or serious damage. For instance, a weapon system is a precise and sophisticated system that comprises several sub-systems, components and spare parts. Failure of even a single element will likely have adverse impact upon the operability of the weapon system, or even threat the national security.

System availability, a concept closely related to reliability, refers to the scale of measuring the reliability of a repairable system. Repairable system indicates a system that can be repaired to operate normally in the event of any failure, such as computer network, manufacturing system, power plant or fire prevention system. Availability comprises ''reliability'' and ''recovery part of unreliability after repair'', indicating the probability that repairable systems, machines or components maintain the function at a specific moment'' (Wang, 1992). It is generally expressed as the operable time over total time.

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In recent years, reliability and availability have expanded their influence in various industries and fields, thus serve as an integral quality element in the organization system and manufacturing process. To maintain the reliability of sophisticated systems to a higher level, the system's structural design or system components of higher reliability shall be required, or both of them are performed simultaneously (Henley & Kumampto, 1985).

The system structure is virtually designed under the limitations such as weight, volume or other technologies, so the reliability cannot be further improved. In this case, replacing highly reliable components can improve the system reliability. While improving the reliability of systems and components, the associated cost also increases. Thus, it is a very important topic for decision-makers to fully consider both the actual business and the quality requirements. Redundancy Allocation Problem (RAP) of a series-parallel system refers to difficult NP-hard problems (Chern, 1992). Redundancy allocation is designed depending upon the experience of system designers, with the advantages (Chisman, 1998): (1) time-saving and convenient policy-making depending upon years of experience and (2) decision making via experience in the absence of information. The disadvantages include: (1) decision-making is subjective, without scientific support or evidence and (2) individual experience-based decision cannot offer an accurate or optimal design, thus leading to excessive cost. Due to potential risks, the experience-based empirical law may not be universally applied (Li, 2001). Additionally, given the fact of difficult accumulation and inheritance of design expertise, it would be very helpful to transfer, accumulate and manage design knowledge by applying systematic methods and by employing information technologies. Jeang (1999) suggested that computer-aided simulation software could contribute to system design or parameterization. Many information systems were built and a wide variety of methods were used for the reliability design (Chen & Hsu, 2006; Liu & Yang, 1999; Moon, Divers, & Kim, 1998; Varde, Sankar, & Verma, 1998). However, a well-defined knowledge system for reliability design and availability optimization was not found in the literature.

Under repairable series-parallel system framework, there are many methods to determine the optimal parameters of components, such as dynamic planning, integer programming, non-linear integer programming and heuristic or metaheuristic algorithms. As a member of metaheuristic algorithm, Genetic Algorithm (GA) has proved itself to be able to approaching optimal solution against any problem.

The purpose of this study is first to utilize Genetic Algorithms to determine MTBF (mean time between failure, MTBF) and MTTR (mean time to repair, MTTR) of various components, during the design phase of the repairable system, and to optimize availability parameters. We proposed an optimization model of repairable series-parallel system and utilized Genetic Algorithms to find solutions. We then constructed a knowledge-based information system so that the design knowledge can be stored and accumulated. The optimization model and GA procedures ensure that the cost-effective parameters of system availability can be obtained, which helps the system designers formulate optimal design policies and repair policies. The information system stored the system designs and parameters in the knowledge base and can be retrieved by significant features, which facilitates design complexity and increases design efficiency. Specifically, the objective of this study is threefold: (1) develop an optimization model of repairable series-parallel system availability and analyze the model behavior; (2) utilize genetic algorithms to obtain optimal parameter of system components in a cost-effective manner; and (3) construct a knowledge-based information system to accumulate the design knowledge.

2. Literature review

2.1. Reliability of series-parallel system

Series-parallel system indicates sub-systems in which several components are connected in parallel, and then in series, or sub-systems that several components are connected in series, and then in parallel. A series-parallel system can be improved by four methods (Wang, 1992): (1) use more reliable components; (2) increase redundant components in parallel; (3) utilize both #1 and #2; and (4) enable repeatedly the allocation of entire system framework. For the framework of series-parallel system, it is very difficult to find out an optimal solution under multiple constraint conditions (Chern, 1992). Misra Algorithm proposed by Misra and Sharma (1991) solves problems by integer programming, which serves as an algorithm searching for nearby boundary of the domain of feasible solution. Prasad and Kuo (2000) pointed out that Misra algorithm sometimes cannot yield an optimal solution, and suggested a method of searching for the upper limit of reliability's objective function. Gen, Ida, and Lee (1990, 1993) also studied how to solve the problem by integer programming.

The reliability of a series-parallel system has drawn continuous attention in both problem characteristics and solution methodologies. Nakagawa and Miyazaki (1981) utilized several examples to compare the mean failure rate of these methods. After combining Lagrange multiplier and branch-and-bound technologies, Kohda and Inoue (1982) and Kim and Yum (1993) solved the reliability of a series-parallel system by using heuristic algorithm. Kuo, Lin, Xu, and Zhang (1987) proposed a heuristic algorithm LMBB. It obtains rapidly the solution close to the optimal one via Lagrange multiplier. Other large systems, such as those placing limitation on linear resources proposed by Li and Haimes (1992), suggested a three-layer decomposition method for the optimization of system reliability. Mohan and Shanker (1998) selected system components via random selection method according to cost limitation. Hsieh, Chen, and Bricker (1998) utilized genetic algorithms to solve various reliability design problems, which include series systems, series-parallel systems and complex (bridge)