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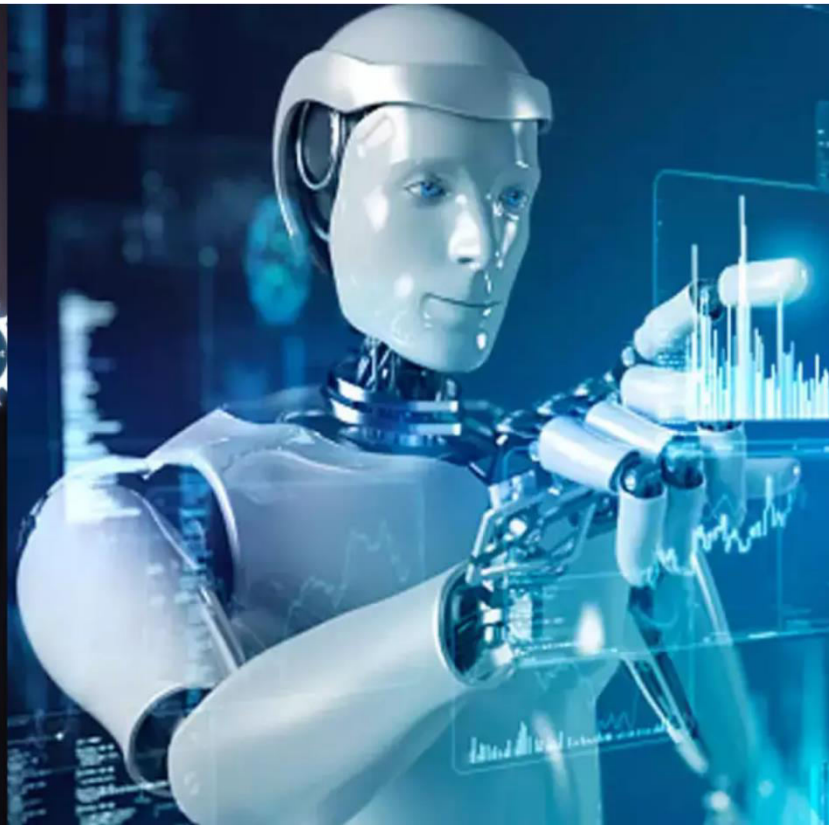

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Assessment of the Redundancy Allocation for Optimizing System Reliability

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ABSTRACT: In this manuscript, we analyse that only one element can be added to a stage with the lowest reliability due to the constraints, but multiple elements can be added to a stage with higher reliability due to the constraints. Any number of linear or nonlinear constraints can be addressed with minimal increases in computational effort. There will always be components in every complex practical system that is nearly equally reliable but have very different costs due to their varied nature. Optimization techniques for dependability redundancy allocation problems are an ever-evolving subject of study. We address the relevance of the mathematical formulations to reliability redundancy allocation issues and evaluate them. The algorithm reliability effectiveness has significantly improved, according to a survey of recent literature. For applications requiring high reliability, this enhancement has proven challenging to accomplish. This research also discusses upcoming challenges and insights in reliability redundancy allocation situation optimization.

KEYWORDS: Software Reliability, Redundancy Allocation, Reliability, optimal stages, component

I. INTRODUCTION

The complexity of modern manufactured systems is rising as a result of high performance requirements and technological breakthroughs. Human mistake during use, however, can have a detrimental effect on the system's intended life cycle and overall effectiveness. Because it guarantees the possibility of accomplishing functionality goals within a certain time period and regulated environment, system dependability is essential for developing and increasing efficiency. Sharma, *et al.,* (2010) analyses the construction of a reliable system and reliability allocation for components, as well as the analysis of a component's reliability, failure rate, and failure density functions at various times with related hazard rate and inverted hazard rate orders established, are crucial considerations [1]. Sharma, *et al.,* (2011 & 2012) study focused on how a variety of factors, including belt pricing, splicing costs, joint and belt durability, type of splicing, and the duration and cost of planned and emergency repairs, impact the total cost of belting [(2), (3)]. By maximizing or minimizing necessary resources while adhering to design limitations, reliability optimization challenges seek to increase system reliability. Redundancy allocation, reliability allocation, and reliability-redundancy allocation problems (RRAP) are the three categories into which these issues fall. In order to maximize system reliability under limitations like cost, volume, or weight, RRAP combines the two other methods to determine component reliabilities and redundancy levels. Tyagi *et al.,* (2015) and, Ardakan, *et al.,* (2016) an original formulation of the Reliability-Redundancy Allocation Problem (RRAP) is presented, and its advantages over conventional methods

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are clearly shown. The article presents a novel redundancy approach known as the "mixed" strategy, which has been shown to outperform active and standby strategies alone in the RRAP. In a more complicated RRAP, the mixed strategy is used and contrasted with standby and active techniques. To maximize system reliability, benchmark issues on the RRAP are chosen, and the dependability of benchmark problems using the mixed approach is contrasted with the best outcomes of active or standby techniques [(4), (5)]. Sharma, *et al.,* (2019 & 2020) talk about the reliability of a component system up to the unreliability of the basic three-phase mission block diagram [(6), (7)]. Govindan, *et al.,* (2016) and, Sharma, *et al.,* (2022) proposed a new multi-objective method for optimizing systems resilience in the big data era is presented in this research. By employing an evolutionary approach and the outcome surface method to estimate parameters, it hybridizes NSGA-II with an adjustable population-based simulate annealing (APBSA) technique. Four performance metrics the mean ideal distance, the diversification metric, the degree of supremacy, and data envelopment analysis are used to compare the method with other well-known algorithms. Computational studies demonstrate the effectiveness of the suggested algorithm for risk management and system reliability [(8), (9), (10)].

As mathematics, computing power, and optimization techniques advanced in the first half of the 20th century, so did system reliability optimization techniques. These methods initially employed sophisticated mathematics to solve analytical equations, but as computers were developed, more mathematical approaches became available, enabling the handling of large datasets and the creation of dynamic programming, linear programming, nonlinear programming, and integer programming. Singh, *et al.,* (2024) define to specify that the component must remain constant throughout the process while the failure rate is constant. After each failure, the process can proceed because just one component is tested and repairable. The straight procedure time is determined by the failure rate and the unit hour, which establish a framework that requires dependability (or unreliability) to either decline simultaneously or remain constant throughout the process [(11), (12), (13)]. Kim, *et al.,* (2017) enhanced the reliability-redundancy assignment problem (RRAP) that takes into account the best redundancy tactics active or cold standby is presented in this study. An exact dependability function for a cold standby redundant device with an imperfect detector/switch is proposed, along with novel examples. Using numerical examples on three benchmark problems, the performance of a parallel evolutionary technique for solving the RRAP as a mixed-integer nonlinear algorithm model is compared with that of earlier research [(14), (15), (16)]. Guan, *et al.,* (2025) define the redundancy allocation problem (RAP), which seeks to allocate redundant components in a system design in order to improve dependability or decrease cost, is reviewed in this article along with its history and research contributions. Numerous RAP problem types are covered, along with their development, modeling frameworks, and approaches to solving them. The significance of system reliability modeling in RAPs and how it integrates with other optimization issues is also emphasized in the essay [(17), (18), (19)].

By installing redundant components, active and standby redundancy solutions improve system resilience. Active redundancy creates equal failure potentials by subjecting primary and secondary components to operating stressors. To identify primary component failures and activate standby components, standby systems need a fault detector/switch. There are three types of standby redundancy strategies: cold, warm, and hot standby. Because it presumes that standby components are protected from stress, cold standby works best. While warm standby is appropriate for power plants, redundant hard drives, and wireless sensor networks, hot standby is utilized for uninterruptible systems. Depending on component reliability and fault detector/switch performance, active or cold standby is typically the recommended redundancy approach. Sharma, et al., (2025) use exact expressions to study the transformation of a delta-star network into a star network. It makes complicated dependability block diagrams with numerous state devices easier to understand and shows that, under some circumstances, the Delta-star transformation is manageable. The feasibility of transforming a star in a dependability network into an equivalent delta under particular conditions is also explained in the study, demonstrating that the probability of an element failing in an equivalent star is equal to the probability of the corresponding element succeeding [(20), (21), (22)].

In Section II, define the objective of this article. Section III; discuss the basic concept regarding this research. In Section IV, define the methodology for Redundant Allocation of Optimal Stages. In Section V, examine a four-stage system with two linear constraints to determine the best way to allocate redundancy and, Section VI, conclude that the maximizing optimum and minimizing unreliability parameters are both necessary for optimal redundancy allocation with multi-state constraints.

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II. OBJECTIVE

Our objective of this study is to just one element contributes to the lowest reliability stage, indicating that limitations can have an impact on stage dependability and, higher reliability stages can have more than one element, and any number of restrictions can be handled with little computing work and also, this study assesses the usefulness of mathematical formulations and examines their applicability to reliability redundancy allocation problems.

III. BASIC PRELIMINARIES

In this section, we can define the basic concept which is related in this work as below:

A. Probability

In the domain of probability, the concepts of failure or malfunction are intimately associated with satisfactory performance. The equipment is either operating well or has failed or malfunctioned when it is in operation because these two occurrences are mutually exclusive. Probability is defined by

$$P(c) = \lim_{n\to\infty}\left(\frac{N}{n}\right)$$

$P(c)$, is the probability that event c will occur in repeated experiments, where it occurs N times. $0 \le P(c) \le 1$ is the reliability of an event, let's say c, occurring.

B. Reliability

Reliability is the capacity of a system to operate without failure for a predetermined amount of time under specific operating circumstances and with the least amount of time lost for repairs and preventive maintenance. Reliability is defined as

$$\mathrm{R}(t)=\int_{t}^{\infty} f(x)dx$$

IV. METHODOLOGY

Reaching the target level of system dependability or making the system as reliable as feasible is one of the main goals of reliability engineering. Structured redundancy is the most popular and successful approach. We've looked at a system with n stages connected in series, where stage- i is a parallel arrangement of c_i components, each of which has dependability p_i. For a stage to fail, all of these components must fail as it is presumed that they are all operating at the same time. System dependability is demonstrated by the requirement that every stage of the system function in order for the entire system to function as below;

$$S_R = \prod_{i=1}^{n}\{1-(1-p_i)c_i\}$$
$$= \prod_{i=1}^{n} 1 - q_i c_i \qquad \ldots (1)$$

The objective is to maximize R considering into account

$$\sum_{i=1}^{t}\tau_{ij}(c_i) \le a_j; j = 1,2,3,...,t \qquad \ldots (2)$$

Notation

p_i : i^{th} -Component Reliability

q_i : i^{th} -Component Unreliability

S_R : System Reliability

S_Q : System Unreliability

c_i : Total Number of components

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n Number of Stages

a_j : Resource availability for constraint j

t : The total number of distinct constraint types

$\tau_{ij}(c_i)$: Resource j consumed in stage- i with c_i components connected

C. Working Algorithms:

The following are the measures that must be taken in order to solve the problem:

- ***i.*** Identify the most dependable stage.
- ***ii.*** Determine the total of every restriction across all phases.
- ***iii.*** Determine the ratios between the constraints' maximum values and their sum.
- ***iv.*** The minimum of the ratios can be used to determine the redundancy for this specific stage.
- ***v.*** Identify the most dependable stage from the remaining stages.
- ***vi.*** Add up all of the restrictions of a certain kind, except the stages for which redundancies have already been determined.
- ***vii.*** Determine the ratios between the sums determined in step *vi* and the maximum value of the restrictions that are still available (minus the sum of the products of redundancies and constraints of the earlier steps).
- ***viii.*** The minimum of the ratios can be used to determine the redundancy at this point. Proceed from step *v* until all of the phases' redundancies have been identified.

V. RESULTS AND DATA DISCUSSION

Examine a four-stage system with two linear constraints to determine the best way to allocate redundancy. Assume the following data:

	$n = 4$	$K_1 \leq 40$	$K_2 \leq 90$
Stage I	$P_1 = 0.70$	$C_{11} = 1.5$	$C_{12} = 5$
Stage II	$P_2 = 0.75$	$C_{21} = 2.5$	$C_{22} = 6$
Stage III	$P_3 = 0.80$	$C_{31} = 3.5$	$C_{32} = 8$
Stage IV	$P_4 = 0.85$	$C_{41} = 4.5$	$C_{42} = 7$

Here, highest reliability has stage IV so consequently, the optimal value of x_4 is selected so that,

$$\left.\begin{array}{l}(1.5+2.5+3.5+4.5)x_4 \leq 40 \\ \& \\ (5+6+8+7)x_4 \leq 90 \\ or, \\ x_4 = 3\end{array}\right\} \quad \ldots (3)$$

Eliminating stage IV, and consider stage III, so consequently, the optimal value of x_3 is selected so that,

$$\left.\begin{array}{l}(1.5+2.5+3.5)x_3 \leq 40-3(4.5) = 26.5 \\ \& \\ (5+6+8)x_3 \leq 90-3(7) = 69 \\ or, \\ x_3 = 3\end{array}\right\} \quad \ldots (4)$$

Eliminating stage III, and consider stage II, so consequently, the optimal value of x_2 is selected so that,

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$$\left.\begin{array}{l}(1.5+2.5)x_2 \le 26.5-3(3.5)=16\\ \&\\ (5+6)x_2 \le 69-3(8)=45\\ or,\\ x_2=4\end{array}\right\} \quad \ldots (5)$$

Eliminating stage II, and consider stage I, so consequently, the optimal value of x_1 is selected so that,

$$\left.\begin{array}{l}(1.5)x_1 \le 16-4(2.5)=6\\ \&\\ (5)x_1 \le 45-4(6)=21\\ or,\\ x_1=4\end{array}\right\} \quad \ldots (6)$$

Therefore, the optimal solution is

$$O_S = [4 \quad 4 \quad 3 \quad 3]$$

$$R = \prod_{i=1}^{n}(1-q_i\tau_i) \cong 0.93836$$

VI. CONCLUSION AND FUTURE DIRECTION

The reliability redundancy allocation difficulties, series, series-parallel, and bridge are the main topics of this paper's discussion of system reliability optimization. It draws attention to recent studies that combine several approaches to produce superior outcomes. The study also discusses contemporary problems that need for multi-state, uncertain data and complex systems with realistic component reliability behaviours. In order to handle new problems and increasingly complex systems, new viewpoints are arising and efficient methods are required. An improved method based on the best four-stage solution with the maximum reliability R≅0.938364. Maximizing optimum and minimizing unreliability parameters are both necessary for optimal redundancy allocation with multi-state constraints. If these conditions are not met, the stages are removed and more pertinent parameters are obtained again in order to find the stages with the highest reliability.

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AUTHOR CONTRIBUTION

C K Sharma organized the original work and Neeraj and Nitin; review; Rajeev and, Sunil performed the work's simulations, methodology, and data conceptualization.

CONFLICT OF INTEREST

There are no conflicts of interest regarding the publication of this article.

ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

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