Reliability Allocation and Optimization for (ROSS) of a Spacecraft by using Genetic Algorithm

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Abstract

This paper focuses on the reliability of Reduction Oxygen Supply System (ROSS) of a Spacecraft which was calculated as a complex system using probability theory. The reliability of this system was assigned to study the possible approaches of the allocation of reliability values based on the minimization of the total cost in this system. The original results was included:

(i) a critical point is a fixed purpose of a appropriate application.
(ii) Using the reduction oxygen supply system of a spacecraft of with the cost of exponential behavior model.
(iii) The results also obtained by genetic algorithm to solve the optimization problems of the given reliability network.

Keywords: Reliability network, Reliability Optimization, Reliability Allocation, Genetic algorithm.
1 Introduction

The study of the (ROSS) of a Spacecraft system was first mentioned by the researcher Aggarwal, K. K. [2], and because of its importance in terms of engineering and scientific research space, it was recently re-highlighted by researchers Hassan, Z. A. H. and Mutar, E. K., where the researchers discussed the reliability of this system and study the expected time to failure (MTTF) by using the geometric properties of its reliability polynomial (form more details see [4],[5],[6],[10]).

This paper studies the problem of optimal allocating reliability as a mathematical problem even though it’s roots belong to network. The reliability standards between the different subsystems and components are allocated on the basis of criticality, complexity, estimated achievable reliability, or many other factors treated suitable by the analyst creating the allocation ([1],[11],[12]). The (ROSS) of a Spacecraft is applied by using a set of connected subsystems. A designer requests to either achieve the goal reliability while minimizing the overall cost, or maximize the reliability while using only the existing budget. Naturally, some of the lowest reliability component may request special interest to rise the total reliability level. Also, these problems of optimization may be existed in electrical or mechanical systems. These problems have tested by number of studies. The allocation model of reliability to a component according to the cost of increasing the its own reliability. The most costly elements will be (the cost expressing by weight, cost, size, or any other amount) Increases in reliability. By using this method the reliability can be allocated to the elements of any kind of system, complex or not, and to a mixture of failure distribution for the elements of the system. There are two main features have contributed to this state. First, the model needs cost as a basis of the element’s reliability as an input, and this is not always existing for engineers. The parameters of the suggested cost function can be changed, that make the engineers examine various allocation scenarios. After that, the reliability and design engineers can decide and plan on how to reach the allocated minimum needed reliability for each of the element. Second, the model needs the system’s analytic reliability balance as in an input. Even if this attitudes not main problem in easy systems, it can become a very a challenge in complex systems. The cost with exponential behavior model is Euclidean convex and the results can be achieved by using the genetic algorithm will help to solve the optimization problems of reliability network.
2 Optimization for of (ROSS) of a spacecraft

Consider a (ROSS) of a Spacecraft consisting of elements connected reliability [7]. We use the notations: $0 \leq R_i \leq 1$ is the reliability of element $i$; $C_i(R_i)$ is the cost of element $i$; $C(R_1, ..., R_n) = \sum_{i=1}^{n} a_i c_i(R_i)$ is the total system cost, where $a_i > 0$; $R_s$ is the system reliability; $R_G$ is the system reliability goal.

The functionality of each part for (ROSS) of a Spacecraft is unique and there are many options, many of system parts give us the same functionality with different reliability levels. The goal is to achieve reliability allocation to some or all parts of the system. The problem Q is included as an important problem in nonlinear programming, cost and function that can be analyzed and are non-linear constraint. Q: Find

$$\text{Minimize} \quad C(R_1, ..., R_n) = \sum_{i=1}^{n} a_i C_i(R_i), \quad a_i > 0, \quad (2.1)$$

subject to

$$R_s \geq R_G, \quad (2.2)$$
$$0 \leq R_i \leq 1, \quad i = 1, 2, ..., n. \quad (2.3)$$

It is reasonable to assume that the partial cost function $C_i(R_i)$ satisfies some conditions [9]: differentiable, positive function, increasing $\Rightarrow \frac{dC_i}{dR_i} \geq 0$.

Euclidean convexity of the the partial cost function $C_i(R_i)$ is equivalent to the fact that its derivative $\frac{dC_i}{dR_i}$ is monotonically increasing, i.e., $\frac{d^2C_i}{dR_i^2} \geq 0$.

The previous plan is intended to accomplish a base all out framework cost[3], subject to $R_G$, a lower limit on the system reliability.
2.1 Exponential behavior model

Let $0 < R_i < 1$, $i = 1, 2, ..., n$ and $a_i, b_i$ be constants. The most important cost function has an exponential behavior. It was proposed by ([3],[8],[12]), in the form

$$C_i(R_i) = a_i e^{b_i (\frac{1}{1-R_i})}, i = 1, 2, ..., n. \quad (2.4)$$

Let $a_i > 0, b_i > 0$. After computation, we find

$$\frac{dC_i}{dR_i} = \frac{a_i b_i}{(R_i - 1)^2} e^{b_i \left( \frac{1}{R_i - 1} - 1 \right)} > 0. \quad (2.5)$$

$$\text{Hess} \; C_i = \frac{a_i b_i}{(R_i - 1)^3} e^{b_i \left( \frac{1}{R_i - 1} - 1 \right) \left( \frac{1}{R_i - 1} - 2 \right)} > 0. \quad (2.6)$$

Consequently, each $C_i(R_i)$ is an increasing and convex function in Euclidean sense. The total cost

$$C(R_1, ..., R_n) = \sum_{i=1}^{n} a_i C_i(R_i)$$

has similar properties.

2.2 Solving the optimal reliability allocation problem by using genetic algorithm.

Genetic algorithm (GA) is a well-known stochastic search iterative method based on the evolutionary theory of Charles Darwin "survival of the fittest" and natural genetics. GA is successfully applied on various problems, such as engineering design, optimization of reliability, optimal control, transport problems and allocation. The basic idea of the genetic algorithm is to imitate the process of natural evolution artificially experienced by the population constant changes through genetic factors, such as crossover, mutation and selection. Concept (G.A) was introduced for the first time before by Prof. John Holland of the University of Michigan, Ann Arbor. He is considered to be the father of GA. The idea of (G.A) was first used in optimization problems by De-Jang (1975). Thereafter, a researcher has contributed much to the major development of this field. Genetic algorithm can easily be implemented with the help of computer programming. In particular, the (G.A) it is used to solve the complicated optimization problems which can not be found easily solved through direct or gradient mathematical techniques.
Algorithm

Step-1: Set population size (p-size), reliability (p-cross), mutation reliability (p-mute), maximum generation (max-gen) and bounds of the variables.

Step-2: Initialize the reliability of each component of the population $R_i$ [$R_i$ represents the population at j-th generation].

Step-3: Evaluate the cost function of each component of $R_i$ considering the objective function as the cost function.

Step-4: Find the best reliability from the population $R_i$.

Step-5: If the termination criterion is satisfied go to Step-12, otherwise, go to next step.

Step-6: Select the population $R_i$ iteration j from the population $R_i$ iteration k, of earlier generation by tournament selection process.

Step-7: Alter the population $R_i$ by crossover, mutation and elitism operators.

Step-8: Evaluate the cost function value of each component of $R_i$.

Step-9: Find the best reliability of each component from

Step-10: Compare the best reliability of each component of $R_i$ iteration j and the reliability of each component iteration j and store better one.

Step-11: Print the best reliability of each component (which is the solution of the optimization problem).

Step-12: End.
Application to (ROSS) of a spacecraft

The (ROSS) of a Spacecraft shown in Fig.(1), has the same primary reliability in all its vehicles at 90% at a specified time. The goal of system reliability at a specified time is 90%. The reliability polynomial of the given system has been calculated by using probability theorem approach.

\[ R_s = R_1 R_2 R_3 R_5 R_7 + R_1 R_3 R_5 R_7 + R_1 R_3 R_6 R_7 + R_1 R_4 R_6 R_7 - R_1 R_2 R_3 R_5 R_7 
- R_1 R_3 R_4 R_6 R_7 - R_1 R_3 R_5 R_6 R_7 - R_1 R_2 R_4 R_5 R_6 R_7 + R_1 R_2 R_3 R_4 R_5 R_6 R_7. \]

The optimization problem becomes:

Minimize \[ C(R_1, \ldots, R_n) = \sum_{i=1}^{n} a_i \exp\left(\frac{b_i}{1 - R_i}\right), \quad i = 1, 2, \ldots, n. \]

subject to

\[ R_s = R_1 R_2 R_3 R_5 R_7 + R_1 R_3 R_5 R_7 + R_1 R_3 R_6 R_7 + R_1 R_4 R_6 R_7 - R_1 R_2 R_3 R_5 R_7 
- R_1 R_3 R_4 R_6 R_7 - R_1 R_3 R_5 R_6 R_7 - R_1 R_2 R_4 R_5 R_6 R_7 + R_1 R_2 R_3 R_4 R_5 R_6 R_7 \geq R_G \]

\[ 0 \leq R_i \leq 1, \quad i = 1, 2, \ldots, n. \]
Figure 1: Reliability Oxygen supply system of a spacecraft.

The figure (2) represents the (ROSS) of a spacecraft after the reduction of the components,

Figure 2: (ROSS) of a spacecraft.
before solving the problem of reliability distribution. In order to evaluate the outcome of the solution the preliminary analysis can be performed. Achieve it through calculate the importance of system reliability for each component. Using the equation \( I_R(i) = \frac{\partial R_s}{\partial R_i} \), this equation is used to calculate the reliability importance of each units for the complex system. As shown in the following equations:

\[
\frac{\partial R_s}{\partial R_1} = R_2R_3R_7 + R_3R_5R_7 + R_3R_6R_7 + R_4R_6R_7 - R_2R_3R_5R_7 - R_3R_4R_6R_7 - R_2R_4R_5R_6R_7 + R_2R_3R_4R_5R_6R_7,
\]

\[
\frac{\partial R_s}{\partial R_2} = R_1R_5R_7 - R_1R_3R_5R_7 - R_1R_4R_5R_6R_7 + R_1R_3R_4R_5R_6R_7,
\]

\[
\frac{\partial R_s}{\partial R_3} = R_1R_5R_7 + R_1R_6R_7 - R_1R_2R_5R_7 - R_1R_4R_6R_7 - R_1R_5R_6R_7 + R_1R_2R_4R_5R_6R_7,
\]

\[
\frac{\partial R_s}{\partial R_4} = R_1R_6R_7 - R_1R_3R_6R_7 - R_1R_2R_3R_6R_7 + R_1R_2R_3R_5R_6R_7,
\]

\[
\frac{\partial R_s}{\partial R_5} = R_1R_2R_7 + R_1R_3R_7 - R_1R_2R_3R_7 - R_1R_3R_6R_7 - R_1R_2R_4R_6R_7 - R_1R_2R_3R_4R_6R_7,
\]

\[
\frac{\partial R_s}{\partial R_6} = R_1R_3R_7 + R_1R_4R_7 - R_1R_3R_4R_7 - R_1R_3R_5R_7 - R_1R_2R_4R_5R_7 + R_1R_2R_3R_4R_5R_7,
\]

\[
\frac{\partial R_s}{\partial R_7} = R_1R_2R_5 + R_1R_3R_5 + R_1R_3R_6 + R_1R_4R_6 - R_1R_2R_3R_5 - R_1R_3R_4R_6 - R_1R_3R_5R_6 + R_1R_2R_3R_4R_5R_6.
\]
3.1 Discuss the results

The following results were obtained by using the application of the genetic algorithm as shown in Figures (1, 2 and 3), the results show that the optimization includes all
the components of the (ROSS) of a Spacecraft and the importance and feasibility of assigning the reliability values based on the location of each component in the (ROSS) of a Spacecraft. Where the position and determine the importance and improve the components of the (ROSS) of a Spacecraft and the results showed that the components 1 and 7 have the largest allocation and importance in the system are almost the same values of importance for the reliability of the (ROSS) of a Spacecraft where the failure 1 and 7 means this failure of the (ROSS) of a Spacecraft completely, but the rest of the components are important and different assignment according to the location of each component where component 6 is less important than 1 and 7, then comes in terms of allocation and importance component 5, 3 and 4 are close in terms of allocation finally, the component 2 is less important in the system. It can also improve the components of the (ROSS) of a Spacecraft as long as the reliability equation of the system can be obtained analytically. The table below shows the results of genetic algorithm to reliability allocation:

| Component   | Reliability allocation | Reliability importance |
|-------------|------------------------|-----------------------|
| Component 1 | 0.9956                 | 0.995                 |
| Component 2 | 0.8843                 | 0.0021                |
| Component 3 | 0.9628                 | 0.008                 |
| Component 4 | 0.9554                 | 0.0051                |
| Component 5 | 0.9702                 | 0.0169                |
| Component 6 | 0.9843                 | 0.0334                |
| Component 7 | 0.9957                 | 0.9948                |

4 Conclusion

In this paper the reliability of system optimization problem through reliability allocation at the component level was examined using geometrical concepts. The problem was discuss as a nonlinear programming problem with exponential behavior model(cost function) and the active constraints (the reliability of (ROSS)of a Spacecraft). The
optimization problem was solved by using genetic algorithm. The advantage of model is that the used mathematical technology can be applied to any system with high complexities.

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