

Application of the Jaya algorithm to solve the optimal reliability allocation for reduction oxygen supply system of a spacecraft

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ABSTRACT

In this paper the reliability of reduction oxygen supply system (ROSS) of a spacecraft which was calculated as a complex system using minimal cut method. The reliability of each component of system was calculated as well as the reliability importance of the system. The cost of each component of the system was possible approaches of the allocation values of reliability based the minimization of the overall cost in this system. The advantage of this algorithm can be used to allocate the optimization of reliability for simple or complex system. This optimization is achieved using the Jaya algorithm. The proposed technique is based on the notion that a conclusion reached on a particular problem should pass near the best results and avoid the worst outcome. The original findings of this paper are: i) the system used in this paper is a spacecraft's reduced oxygen supply system with the logarithmic cost function; and ii) the results obtained were by using the Jaya algorithm to solve specific system reliability optimization problems.

Keywords:

JAYA algorithm
Reliability Allocation
Reliability network
Reliability Optimization
Unreliability

1. INTRODUCTION

One of the first researchers to take up the reduction oxygen supply system (ROSS) study of a spacecraft system for the first time by Aggarwal [1], and due to the importance of the topic in terms of engineering and science, light was re-shed by several researchers such as Hassan and Mutar where the researchers discussed the reliability of this system and the study of mean time to failure (MTTF) using the engineering properties of many reliability limits [2-6], [7], [8]. Abedet *et al.* [9] also discussed the issue of optimizing the reliability of this system has solved by using a genetic algorithm.

A ROSS of a spacecraft consists of a group of subsystems that are interconnected in a specific way, that requires the designer to either maximize the reliability of the system while reducing the total cost or reduce the costs to the lowest possible level with appropriate reliability so that the system works in a suitable performance and in a specific period of time due to the current budget only. Many researchers have addressed the problem of optimizing the reliability of this in electrical or mechanical and electromagnetic systems and in many fields. The complexity or reliability appropriate for the system's continuous operation for a specific period of time and there are other factors that the specialist considers appropriate [10-14]. This paper studies the problem of optimal allocating reliability as a mathematical problem even though problems roots belong to network. In our research, we dealt with the problem of optimization of the device ROSS [15-18].

The system consists of subsystems or components where the reliability requirements between the subsystems or components are determined based on the importance of reliability or the location of the component in the system. The model for a component's reliability allocation is based on the cost of increasing reliability that's own. The costliest elements will be (the cost expressing by weight, cost, size, or any other amount) increases in reliability. By using these algorithms, it is possible to assign reliability to some or all of the components of any system, whether that system is complex or not [19-23]. parameters are possible to be change the of the proposed cost function according to business requirements or the actual need for the system to function well, which will have engineers examine allocation scenarios for reliability in all respects before making decisions. The logarithmic cost function is increasing and convex. Also, the results obtained after solving the optimization problem using the Jaya algorithm contributed to improving the optimization of the system reliability with appropriate costs [23-28].

2. RESEARCH METHOD

2.1 Optimization for Ross of a Spacecraft

Consider a ROSS of a spacecraft consisting of elements connected reliability [1]. The following notes are used the: $0 \leq R_i \leq 1$ is the element reliability; $C_i(Q_i)$ is the cost of the element i ; $C(Q_1, \dots, Q_n) = \sum_{i=1}^n a_i C_i(Q_i)$. The system's total cost, where $a_i > 0$; Q_i unreliability; Q_G is the unreliability goal of the system. The main goal of the problem is to allocate reliability to some or all components of the system to reduce costs to the least possible. The problem P will be formulated as the objective function (cost function) and the constraints as the optimization problem in nonlinear programming.

$$P: \text{Find Minimize } C(Q_1, \dots, Q_n) = \sum_{i=1}^n a_i C_i(Q_i), a_i > 0 \text{ subject to } (1 - Q_s) \geq (1 - Q_G) \quad (1)$$

$$\leq Q_i \leq 1, i = 1, 2, \dots, n$$

where $R_i + Q_i = 1$, assuming $C_i(Q_i)$ the cost function be positive and differentiable [11]: $\left[\Rightarrow \frac{dC_i}{dQ_i} \geq 0 \right]$. The cost function Convexity of Euclidean, this is the same as the derivative $\frac{dC_i}{dQ_i}$ is monotonically increasing, i.e., $\frac{d^2 C_i}{dQ_i^2} \geq 0$. The purpose of the previous plan is to achieve an all-out framework cost base [4], subject to R_G , the lower system reliability limit.

2.2 Model of logarithmic function

Let $0 < Q_i < 1$ and K_i , constant, $i = 1, 2, \dots, n$, the cost function has been proposed in a number of references. The most important of which are: [13],[14],[15,16] in the form Fratta give the following cost unreliability curve in (2).

$$c_i = K_i \ln \left(\frac{1}{1 - (1 - Q_i)} \right), K_i > 0 \quad (2)$$

Consequently, each $C_i(Q_i)$ it is a monotony increasing and convex function in. The cost of the entire $C(Q_1, \dots, Q_n) = \sum_{i=1}^n a_i C_i(Q_i)$ has similar characteristics [3].

2.3 Jaya Algorithm

In Jaya algorithm is a metaphoric algorithm capable of solving optimization problems and it is one of the methods used to solving linear and nonlinear problems (with constraint or unconstraint), and this algorithm has been applied in many of the most difficult optimization problems. An important difference between Jaya and the other algorithms in optimization is that parameters of Jaya does not require tuning (a process required in other algorithms to avoid unwanted convergence). Another difference is Jaya's efficiency in always choosing the best solution. Next is the steps of Jaya algorithm and Figure 1 shows in flowchart form.

- Step-1 : Set population size (p-size), unreliability, mutation unreliability (p-mute), maximum generation (max-gen) and bounds of the variables.
- Step-2 : Initialize the unreliability of individual components Q_i [Q_i represents the component i -th generation].
- Step-3 : Evaluate each component's cost function $c_i(Q_i)$ consider the function of an objective as a cost function.
- Step-4 : Find the component's lowest unreliability Q_i .
- Step-5 : Go to Step-12 if the termination criterion is met, otherwise go to the next step.
- Step-6 : Component selection Q_i component iteration j Q_i iteration j , by tournament selection process of the earlier generation.
- Step-7 : Change the unreliability Q_i by operators of crossover, mutation and elitism.
- Step-8 : Assess the cost function value of each Q_i .
- Step-9 : Find each component's best reliability
- Step-10 : Compare and better store the lowest unreliability of each Q_i iteration component j and the unreliability of each component iteration j Q_i .
- Step-11 : Print the best unreliability of each component (Which is the solution to the problem of optimization).
- Step-12 : Calculate the Reliability of each component R_i by the equation $R_i + Q_i = 1$.

Step-13 : The end.

3. RESULTS AND DISCUSSIONS

Let us have a ROSS system consisting of 11 components, which is as shown in Figure 2 and after reducing the number of components, the number of components became 7 as shown in Figure 3, where (check valve, shut off valve, non-return automatic emergency valve) was connected in parallel in one component, so that the component number was (5) as well in the same way for the component number (6), has the same primary unreliability in all components that have at 0.2% at a specified time. The system unreliability objective at a specified time is 0.1%. The polynomial unreliability of the given system was calculated using the minimal cut method.

$$\begin{aligned}
 (1 - Q_s) = & (1 - Q_1)(1 - Q_2)(1 - Q_5)(1 - Q_7) + (1 - Q_1)(1 - Q_3)(1 - Q_5)(1 - Q_7) \\
 & + (1 - Q_1)(1 - Q_3)(1 - Q_6)(1 - Q_7) + (1 - Q_1)(1 - Q_4)(1 - Q_6)(1 - Q_7) \\
 & - (1 - Q_1)(1 - Q_2)(1 - Q_3)(1 - Q_5)(1 - Q_7) \\
 & - (1 - Q_1)(1 - Q_3)(1 - Q_4)(1 - Q_6)(1 - Q_7) - (1 - Q_1) \\
 & - (1 - Q_1)(1 - Q_3)(1 - Q_5)(1 - Q_6)(1 - Q_7) \\
 & - (1 - Q_1)(1 - Q_2)(1 - Q_5)(1 - Q_6)(1 - Q_7) \\
 & + (1 - Q_1)(1 - Q_2)(1 - Q_3)(1 - Q_4)(1 - Q_5)(1 - Q_6)(1 - Q_7)
 \end{aligned} \quad (3)$$

The final formulation of the optimization problem for allocation reliability becomes as given in equation (4):

$$\text{Minimize } C(Q_1, \dots, Q_n) = \sum_{i=1}^n K_i \ln \left(\frac{9}{1 - (1 - Q_i)} \right), K_i > 0, i = 1, 2, \dots, n \quad (4)$$

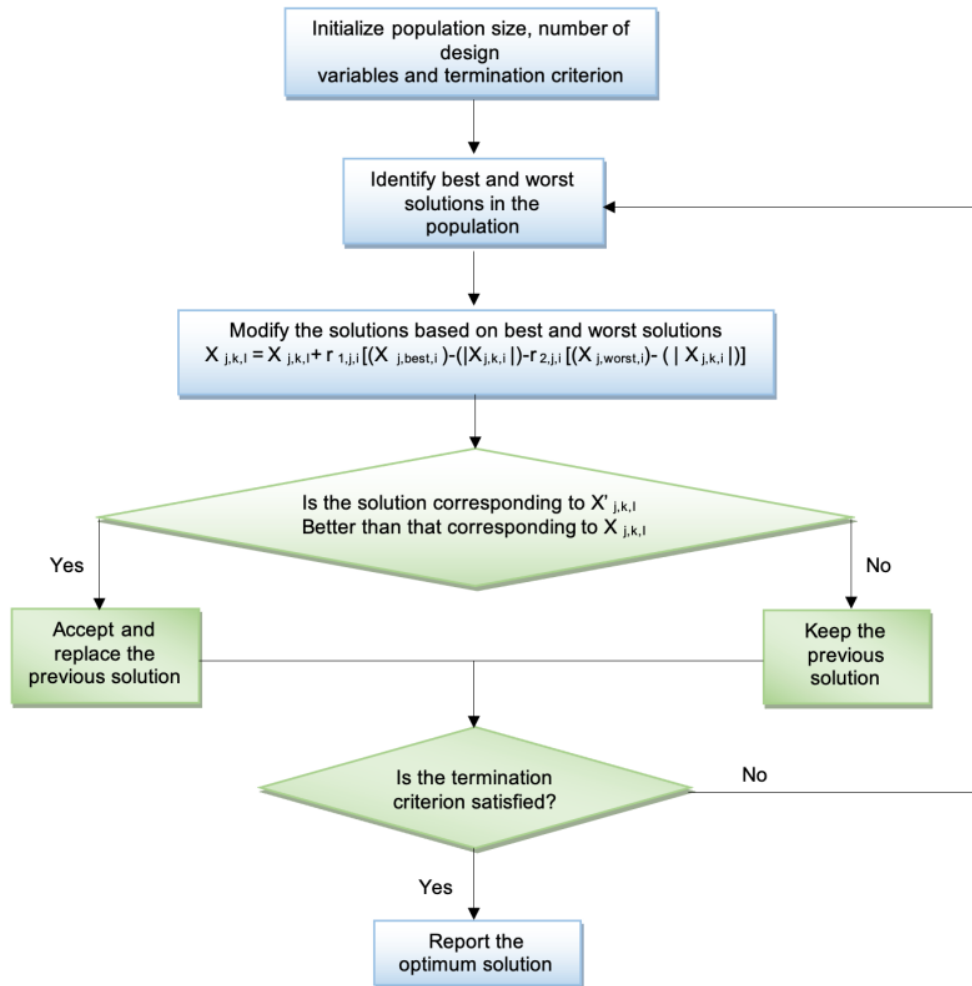


Figure 1. Flowchart of the Jaya algorithm

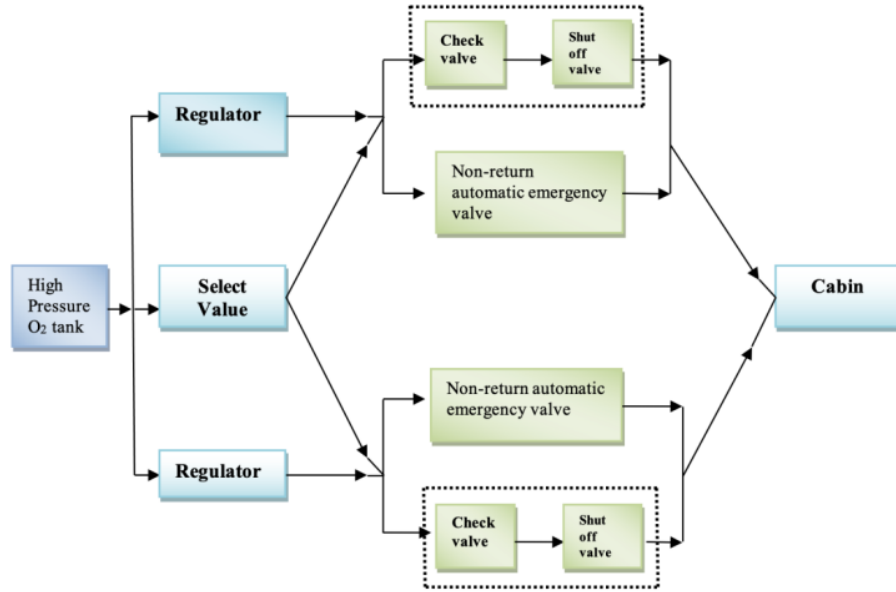


Figure 2. Oxygen supply system of a spacecraft

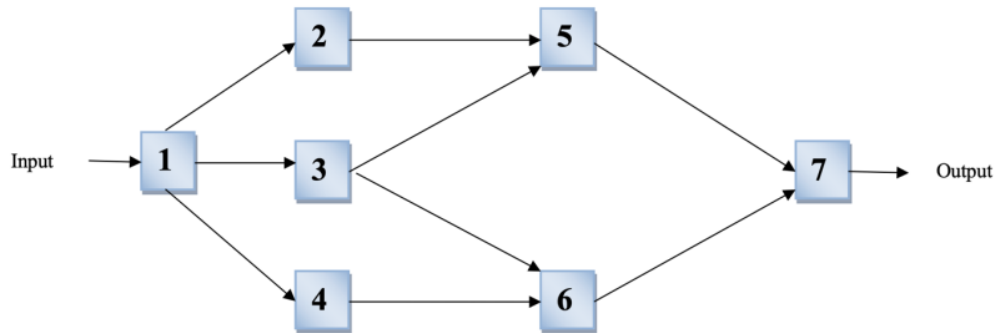


Figure 3. ROSS of a spacecraft after reducing

Before solving the problem of assigning reliability to each part of the system, an initial evaluation can be performed to evaluate the outcome of the solution. This is achieved by calculating the reliability importance of each of the seven components of the system for each component. Using the equation 5 as follows:

$$I_Q(i) = \frac{\partial(1 - Q_i)}{\partial Q_i} \quad (5)$$

where this equation is used to calculate the reliability importance of each component. As shown in the equation 6:

$$\begin{aligned}
\frac{\partial R_s}{\partial R_1} &= R_2 R_5 R_7 + R_3 R_5 R_7 + R_3 R_6 R_7 + R_4 R_6 R_7 - R_2 R_3 R_5 R_7 - R_3 R_4 R_6 R_7 - R_3 R_5 R_6 R_7 \\
&\quad - R_2 R_4 R_5 R_6 R_7 + R_2 R_3 R_4 R_5 R_6 R_7 \frac{\partial R_8}{\partial R_2} \\
&= R_1 R_5 R_7 - R_1 R_3 R_5 R_7 - R_1 R_4 R_5 R_6 R_7 + R_1 R_3 R_4 R_5 R_6 R_7 \frac{\partial R_s}{\partial R_3} \\
&= R_1 R_5 R_7 + R_1 R_6 R_7 - R_1 R_2 R_5 R_7 - R_1 R_4 R_6 R_7 - R_1 R_5 R_6 R_7 \\
&\quad + R_1 R_2 R_4 R_5 R_6 R_7 \frac{\partial R_8}{\partial R_4} \\
&= R_1 R_6 R_7 - R_1 R_3 R_6 R_7 - R_1 R_2 R_5 R_6 R_7 + R_1 R_2 R_3 R_5 R_6 R_7 \frac{\partial R_8}{\partial R_5} \\
&= R_1 R_2 R_7 + R_1 R_3 R_7 - R_1 R_2 R_3 R_7 - R_1 R_3 R_6 R_7 - R_1 R_2 R_4 R_6 R_7 \\
&\quad + R_1 R_2 R_3 R_4 R_6 R_7 \frac{\partial R_s}{\partial R_6} \\
&= R_1 R_3 R_7 + R_1 R_4 R_7 - R_1 R_3 R_4 R_7 - R_1 R_3 R_5 R_7 - R_1 R_2 R_4 R_5 R_7 \\
&\quad + R_1 R_2 R_3 R_4 R_5 R_7 \frac{\partial R_s}{\partial R_7} \\
&= R_1 R_2 R_5 + R_1 R_3 R_5 + R_1 R_3 R_6 + R_1 R_4 R_6 - R_1 R_2 R_3 R_5 - R_1 R_3 R_4 R_6 - R_1 R_3 R_5 R_6 \\
&\quad - R_1 R_2 R_4 R_5 R_6 + R_1 R_2 R_3 R_4 R_5 R_6
\end{aligned} \tag{6}$$

Figure 4 depict the result of reliability allocation and importance for the ROSS of a spacecraft. Component No. (1) and Component No. (7) were among the most important components in the system used for this. Therefore, greater reliability and costs were allocated to these two components. As the failure of the component (1) or component (7) may lead to a complete failure of the system. By calculating the importance of reliability, the results are shown, in Table (1). Component No. (5) and component No. (6), as in the results obtained using the Jaya algorithm which was added to them with approximately the same reliability, based on the location pf the component in the system. The value of the two composite reliability is also very close by using the importance of reliability equation. The reliability of component No. (3) was calculated an the Jaya algorithm allocated a reliability of component No. 3 (3) less than the two components No. (5) and the component No. (6), as shown in Table (1). Component No. (2), compone-4 No. (4), and as in the results obtained using Jaya algorithm, they have approximately the same reliability, depending on the location of the 16 pponent in the system. The significance of the two-component reliability is also closely conveyed through the use of the significance equation. The results shown in Table 1 show the importance of each of the vehicles making up the system. They can be arranged according to the importance of reliability and the position of the component in the system: (i) component No. 1, componeny No. 7, (ii) component No. 5, component No. 6, (iii) component No.3, (iv) component No. 2, component No. 4. The results obtained can be illustrates using the Jaya algorithm shown in Table 1.

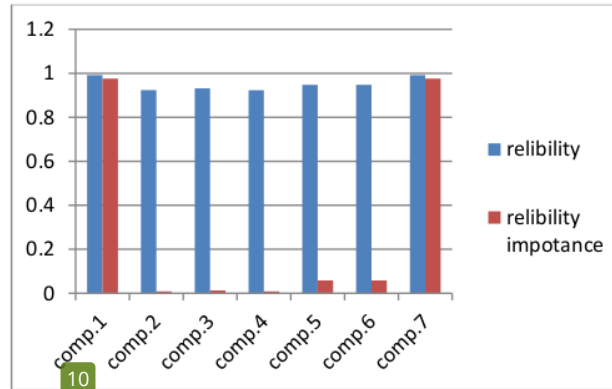


Figure 4. Reliability allocation and importance for the ROSS of a spacecraft

1 Table 1. Summary Table for optimal reliability allocation of ROSS of spacecraft **2** components

	Reliability allocation	Reliability importance
Component 1	0.992	0.9762
Component 2	0.924	0.0086
Component 3	0.932	0.0129
Component 4	0.923	0.0084
Component 5	0.948	0.0582
Component 6	0.948	0.0582
Component 7	0.992	0.9762

4. CONCLUSION

12 In this paper, the problem was formulated as a non-linear programming problem, the main objective of which is to reduce costs to the lowest possible level while ensuring increased reliability of the system (ROSS). The objective function is the cost function (the logarithmic function), which depends on the unreliability variables, as well as the constraints also depend on the unreliability variables. The problem was solved by using the G algorithm, which proved its effectiveness in finding solutions in the fastest time compared to other algorithms and the accuracy of the solution.

ACKNOWLEDGEMENTS

This work was supported/funded by the Ministry of Higher Education under Fundamental Research Grant Scheme (FRGS/1/2018/ICT01/UTM/02/4).

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