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Analysis of System Reliability of the System with Different Configurations Using Event Space Method

By

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Abstract

In this study, we discussed system reliability of complex system, in different configurations (also known as Reliability Block Diagram) as system having two components, three components, four components and compare the system reliability. Such systems can be analysed by calculating the reliabilities for the individual series and parallel section then combining in the appropriate manner. The aim of this study is to established a goal to calculate the reliability of each system of various configuration using event space method. The result obtained is also shown graphically and compare the system reliability of system with various configurations.

Keywords: Reliability, Reliability Block Diagram, event space method, failure rate.

1. Introduction

A system is a collection of components, subsystems that are arranged in a specific design in order to achieve acceptable performance and reliability levels. The types of components/subsystems included in the system and the manner in which they are arranged within the system have a direct effect on the system reliability. The main objective of system reliability evaluation is the construction of a model (life distribution) that represents the times-to-failure of the entire system based on the life distributions of the each components/subsystems from which it is composed (Reliasoft 2003).

Reliability analysis is a method by which the degree of successful performance of a system under certain stipulated conditions may be expressed in quantitative terms. In order to establish a degree of successful performance, it is necessary to define both the performance requirement of the system and the expected performance achievement of the system. A.E. Green and A.J. Bourne [1], discussed the correlation between these two can then be used to formulate a sui-

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table expression of reliability.

Osman Hasan and Waqar Ahmed, Sofiène Tahar and Mohamed Salah Hamdi [2] provides a concise survey of RBD analysis techniques and compare them based on their accuracy, user friendliness and computational requirements. They also analyze RBD based reliability analysis techniques while highlighting their strengths and weaknesses and formalize other commonly used RBDs, such as parallel, series-parallel and parallel-series.

Abd-Allah [3] discussed various structure of RBD and based on this RBD, the failure characteristics of the overall system can be judged based on the failure rates of individual components, whereas the overall system failure happens if all the paths for successful execution fail. The RBD-based analysis enables us to evaluate the impact of component failures on the overall system safety and reliability and thus is widely used for assessing the trade-offs of various possible system configurations at the system design stage.

Reliability is defined as the probability of a component performing its desired task over certain interval of time t and denoted by $R(t)$. Mathematically it expressed as

$$R(t) = Pr\,(X > t) = 1 - Pr\,(X \leq t) = 1 - F_X(t) \tag{1}$$

where $F_X(t)$ is the CDF. The random variable X, in the above definition, models the time to failure of the system. The RBD based reliability analysis of a system have following steps in processing of their function as

(i) partitioning the given system into segments of components and constructing its equivalent structure in series, parallel and mixed configuration (i.e. RBD)
(ii) evaluating the reliability of the individual component/ segments and
(iii) evaluating the reliability, availability, dependability and maintainability characteristics of the complete system based on the RBD and the reliability of its individual components/segments.

The RBD configurations which are used commonly are described as

(a) Series Reliability Block Diagram
(b) Parallel Reliability Block Diagram
(c) Series – Parallel Reliability Block Diagram
(d) Parallel – Series Reliability Block Diagram
(e) Mixed or Complex Reliability Block Diagram.

Reliability analysis by using the method of event space method is the most well known analytic method studying the failure modes of complex systems. Salvatore Distefano, Antonio Puliafito [4] explain how to use the DRBD notation in system modeling and analysis, coming inside a methodology that, starting from the system structure, drives to the over all system availability evaluation following modeling and analysis phases. They also he effectiveness of the DRBD methodology in representing and analysis dynamic reliability/availability.

Most of the mathematical models used to help better understand system reliability have been studied by the many authors in this field and their applications have been tested during the aforementioned designs. This work is an effort to further develop the analytical methods that have been established earlier by many authors.

The mathematical description of the system is the key to the determination of the reliability of the system. In fact, Manna A. [7] discussed the system's reliability function is that mathematical description (obtained using probabilistic methods) and it defines the system reliability in terms of the component reliabilities.

2. Objective

Reliability evaluation is an important step in design and analyzes systems or complex system, acquiring importance with the systems complexity growth. When the complexity of a system is high and/or increases, for example expanding some parts in existing system, full of life effects could arise or become significant in terms of reliability/availability. The system could be affected by common cause failures, the system components could interfere each other or could become inter/sequence-dependent, effects due to load sharing arise and therefore should be considered, and so on In this paper aim to develop some systems with different configuration and evaluate their system reliability using reliability of components for each configure system by event space method.

3. Analysis Technique: Event Space Method

The event space method is an application of the mutually exclusive events axiom. All mutually exclusive events are determined and those that result in system success are considered. The reliability of the system is simply the probability of the union of all mutually exclusive events that yield a system success.

The event space method is based on listing up all possible logical occurrence of system. In other words, in this method all components are considered functioning initial and then they are allowed to fail individually, two at a time, three at a time and so on. Reliability of the system is then determined by the union of all successful occurrences [4]. There are four main types of reliability one of which is parallel forms reliability used in determine the reliability of network.

Event Space method is used for determining reliability of complex system. In this method unreliability (when the component fails) is the probability of the union of all mutually exclusive event that yields system failure. In this method we construct Reliability Block Diagram for system which have various configurations of components such series, parallel and mixed structure. A block diagram that represent how the elements or component represented by blocks, are arranged and related reliability wise in larger system. Units in parallel are also referred to as redundant units. Redundancy is a very important aspect of system design and reliability in that adding redundancy is one of several methods of improving system reliability.

3.1. Calculation of system reliability by event space method of a system having four components in mixed (Series – Parallel) configuration

Configuration 1. In this mixed configuration, Units 1, Unit 2 are connected in series and Unit 3, Unit 4 also connected in series and both connected in parallel, as shown in the figure.

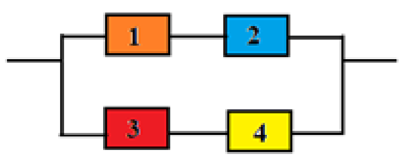


Figure 1

Let, A is the event of Unit 1 success

B is the event of Unit 2 success

C is the event of Unit 3 success

D is the event of Unit 4 success.

The mutually exclusive system events are:

$X_1 = ABCD$ – All units succeed, $X_2 = \bar{A}BCD$ – Only Unit 1 fails
$X_3 = A\bar{B}CD$ – Only Unit 2 fails, $X_4 = AB\bar{C}D$ – Only Unit 3 fails
$X_5 = ABC\bar{D}$ – Only Unit 4 fails, $X_6 = \overline{AB}CD$ – Unit 1and 2 fail
$X_7 = A\overline{BC}D$ – Unit 2 and 3 fail, $X_8 = AB\overline{CD}$ – Unit 3 and 4 fail
$X_9 = \bar{A}BC\bar{D}$ – Unit 1and 4 fail, $X_{10} = A\bar{B}C\bar{D}$ – Unit 2 and 4 fail

$X_{11} = \bar{A}B\bar{C}D$ – Unit 1 and 3 fail, $X_{12} = \overline{ABC}D$ – Unit 1, 2 and 3 fail
$X_{13} = A\overline{BCD}$ – Unit 2, 3 and 4 fail, $X_{14} = \overline{AB}C\bar{D}$ – Unit 1, 2 and 4 fail
$X_{15} = \bar{A}B\overline{CD}$ – Unit 1, 3 and 4 fail, $X_{16} = \overline{ABCD}$ – All Units fail.

System events $X_7, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}$ results in system failure. Thus the probability of failure of the system is:

$$P_f = P\left(X_7 \cup X_9 \cup X_{10} \cup X_{11} \cup X_{12} \cup X_{13} \cup X_{14} \cup X_{15} \cup X_{16}\right) \qquad (2)$$

X_i=event of success or failure of unit i
$P(X_i)$ = Probability of failure of unit i
R_s = reliability of the system.

Calculation of probability of event in which the results in system failure :

$$P(X_7) = R_1(1-R_2)(1-R_3)R_4$$

$$P(X_9) = (1-R_1)R_2R_3(1-R_4)$$

$$P(X_{10}) = R_1(1-R_2)R_3(1-R_4)$$

$$P(X_{11}) = (1-R_1)R_2(1-R_3)R_4$$

$$P(X_{12}) = (1-R_1)(1-R_2)(1-R_3)R_4$$

$$P(X_{13}) = R_1(1-R_2)(1-R_3)(1-R_4)$$

$$P(X_{14}) = (1-R_1)(1-R_2)R_3(1-R_4)$$

$$P(X_{15}) = (1-R_1)R_2(1-R_3)(1-R_4)$$

$$P(X_{16}) = (1-R_1)(1-R_2)(1-R_3)(1-R_4)$$

Combining terms, equation (1) becomes

$$\begin{aligned} P_f = \; & R_1(1-R_2)(1-R_3)R_4 + (1-R_4)R_3\left[(1-R_1)R_2 + R_1(1-R_2)\right] \\ & + (1-R_1)(1-R_3)R_4\left[R_2 + 1 - R_2\right] + (1-R_2)(1-R_4)\left[R_1(1-R_3)\right. \\ & \left. + (1-R_1)R_3\right] + (1-R_1)(1-R_3)(1-R_4)\left[R_2 + 1 - R_2\right] \end{aligned}$$

$$\begin{aligned} P_f &= (1-R_1)(1-R_3)[R_4 + 1 - R_4]R_1R_4 + (1-R_2)[R_1R_4(1-R_3) \\ &\quad +(1-R_4)(R_1 + R_3 - 2R_1R_3)] + R_3(1-R_4)(R_1 + R_2 - 2R_1R_2) \\ &= (1-R_1)(1-R_3) + (1-R_2)(R_1 + R_3 - 2R_1R_3 - R_3R_4 + R_1R_3R_4) \\ &\quad +(R_3 - R_3R_4)(R_1 + R_2 - 2R_1R_2) \\ &= 1 - R_3R_4 - R_1R_2 + R_1R_2R_3R_4 \end{aligned}$$

Reliability of the system = 1 – Probability of event of system failure, i.e

$$R_s = 1 - P_f$$
$$R_s = R_3R_4 + R_1R_2 - R_1R_2R_3R_4.$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98%, subsystem 3 has a reliability of 97% and subsystem 4 has reliability of 96%, i.e.

$$R_1 = 95\%, \;\; R_2 = 98\% \;\; R_3 = 97\% \;\; R_4 = 96\%.$$

Since the reliabilities of the subsystems are specified for 100 hours (assume), the reliability of the system for a 100-hour mission is simply: then we will find the value of system's reliability as

$$R_s = 0.9312 + 0.931 - 0.867 = 0.9952$$

Configuration 2. In this mixed (series – parallel) configuration, subsystem 1 and subsystem 2 are connected in parallel and subsystem 2 is connected in series with parallel combination of subsystem 3 and subsystem 4 i.e. subsystem 3 and subsystem 4 are connected in parallel with subsystem 2 is in series as shown in the figure.

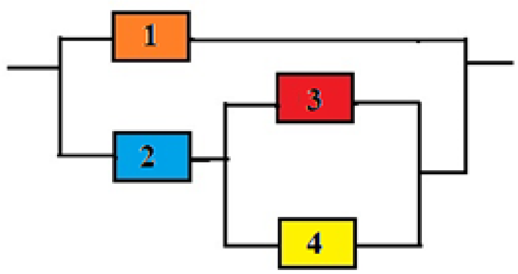


Figure 2

$X_6 = \overline{AB}CD, \;\; X_{12} = \overline{ABC}D, \;\; X_{14} = \overline{AB}C\bar{D}, \;\; X_{15} = \bar{A}B\overline{CD}$
$X_{16} = \overline{ABCD}.$

System events $X_6, X_{12}, X_{14}, X_{15}, X_{16}$ results in system failure.

Thus the probability of failure of the system is

$P\left(X_6\right) = \left(1 - R_1\right)\left(1 - R_2\right) R_3 R_4$

$P\left(X_{12}\right) = \left(1 - R_1\right)\left(1 - R_2\right)\left(1 - R_3\right) R_4$

$P\left(X_{14}\right) = \left(1 - R_1\right)\left(1 - R_2\right) R_3 \left(1 - R_4\right)$

$P\left(X_{15}\right) = \left(1 - R_1\right) R_2 \left(1 - R_3\right)\left(1 - R_4\right)$

$P\left(X_{16}\right) = \left(1 - R_1\right)\left(1 - R_2\right)\left(1 - R_3\right)\left(1 - R_4\right)$

$P_f = P\left(X_6\right) + P\left(X_{12}\right) + P\left(X_{14}\right) + P\left(X_{15}\right) + P\left(X_{16}\right)$

$$\begin{aligned} P_f &= (1-R_1)(1-R_2)R_4[R_3+1-R_3] + (1-R_1)(1-R_2)(1-R_4)[R_3 \\ &\qquad +1-R_3] + (1-R_1)(1-R_3)(1-R_4)R_2 \\ &= (1-R_1)(1-R_2)R_4 + (1-R_1)(1-R_2)(1-R_4) + (1-R_1)(1-R_3) \\ &\quad (1-R_4)R_2 \\ &= (1-R_1)(1-R_2) + (1-R_1)(1-R_3)(1-R_4)R_2 \\ &= (1-R_1)[1-R_2+(1-R_3)(R_2-R_2R_4)] \\ &= (1-R_1)(1-R_2R_4-R_2R_3+R_2R_3R_4) \\ &= 1-R_2R_4-R_2R_3+R_2R_3R_4-R_1+R_1R_2R_4+R_1R_2R_3-R_1R_2R_3R_4 \end{aligned}$$

$$R_s = 1 - P_f$$
$$R_s = R_1 + R_2R_4 + R_2R_3 - R_1R_2R_3 - R_2R_3R_4 - R_1R_2R_4 + R_1R_2R_3R_4$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98%, subsystem 3 has a reliability of 97% and subsystem 4 has reliability of 96%, i.e.

$$R_1 = 0.95, \;\; R_2 = 0.98 \;\; R_3 = 0.97, \;\; R_4 = 0.96$$

then we will find the value of system's reliability

$$\begin{aligned} R_s = 0.95 + 0.9408 + 0.9506 - 0.9030 - 0.9126 - 0.8938 + 0.8669 \\ = 0.9989 \\ = 0.9719 \end{aligned}$$

Configuration 3. In this mixed (series – parallel) configuration, subsystem 1, subsystem 2, subsystem 3 are connected in parallel with subsystem 3 and subsystem 4 are connected in series as shown in figure :

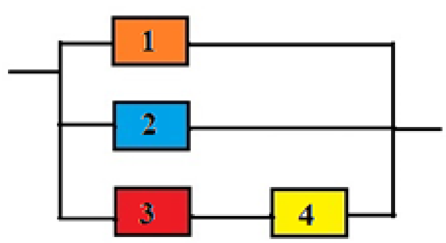


Figure 3

$$X_{12} = \overline{ABC}D, \qquad X_{14} = \overline{AB}C\bar{D}, \qquad X_{16} = \overline{ABCD}.$$

System events X_{12}, X_{14}, X_{16} results in system failure.

Thus the probability of failure of the system is

$$P(X_{12}) = (1-R_1)(1-R_2)(1-R_3)R_4$$

$$P(X_{14}) = (1 - R_1)(1 - R_2) R_3 (1 - R_4)$$

$$P(X_{16}) = (1 - R_1)(1 - R_2)(1 - R_3)(1 - R_4)$$

$$\begin{aligned} P_f &= P(X_{12}) + P(X_{14}) + P(X_{16}) \\ &= (1 - R_1)(1 - R_2)[(1 - R_3) R_4 + 1 - R_4] \\ &= (1 - R_1)(1 - R_2)(1 - R_3 R_4) \\ &= 1 - R_3R_4 - R_2 + R_2R_3R_4 - R_1 + R_1R_3R_4 + R_1R_2 - R_1R_2R_3R_4 \\ &= 1 - R_1 - R_2 + R_1R_2 - R_3R_4 + R_2R_3R_4 + R_1R_3R_4 - R_1R_2R_3R_4 \end{aligned}$$

$$R_s = 1 - P_f$$

$$R_s = R_1 + R_2 - R_1R_2 + R_3R_4 - R_2R_3R_4 - R_1R_3R_4 + R_1R_2R_3R_4$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98%, subsystem 3 has a reliability of 97% and subsystem 4 has reliability of 96 %, i.e.

$$R_1 = 0.95, \ \ R_2 = 0.98 \ \ R_3 = 0.97, \ \ R_4 = 0.96$$

then we will find the value of system's reliability

$$R_s = 0.95 + 0.98 - 0.931 + 0.931 - 0.913 - 0.885 + 0.8669 = 0.9989$$

3.2. Calculation of system reliability by event space method of a system having three components in mixed (Series – Parallel) configuration

Configuration 1. In this mixed (series – parallel) configuration, subsystem 1 and subsystem 2 are connected in parallel and subsystem 3 is connected in series with the first two as shown in figure:

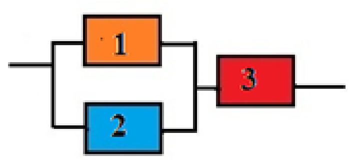


Figure 4

$$X_1 = ABC, \ \ X_2 = \bar{A}BC, \ \ X_3 = A\bar{B}C, \ \ X_4 = AB\bar{C}, \ \ X_5 = \overline{AB}C,$$
$$X_6 = A\overline{BC}, \ \ X_7 = \bar{A}B\bar{C}, \ \ X_8 = \overline{ABC}.$$

System events X_4, X_5, X_6, X_7, X_8 results in system failure.

Thus the probability of system failure of the system is

$$P_f = P(X_4 \cup X_5 \cup X_6 \cup X_7 \cup X_8).$$

Since events are mutually exclusive $P(X_4) = R_1R_2(1 - R_3)$

$$P(X_5) = (1 - R_1)(1 - R_2) R_3$$

$P(X_6) = R_1(1-R_2)(1-R_3)$

$P(X_7) = (1-R_1)R_2(1-R_3)$

$P(X_8) = (1-R_1)(1-R_2)(1-R_3)$

Combining terms

$$\begin{aligned} P_f &= R_1R_2(1-R_3) + (1-R_2)\left[(1-R_1)R_3 + R_1(1-R_3)\right] \\ &\quad + (1-R_1)(1-R_3)\left[R_2 + 1 - R_2\right] \\ &= (1-R_3)\left[R_1R_2 + 1 - R_2\right] + (1-R_2)(R_1 + R_3 - 2R_1R_3) \\ P_f &= 1 - R_1R_3 - R_2R_3 + R_1R_2R_3 \end{aligned}$$

Since

$$R_s = 1 - P_f$$
$$R_s = R_1R_3 + R_2R_3 - R_1R_2R_3$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98% and subsystem 3 has a reliability of 97% i.e.

$$R_1 = 0.95, \quad R_2 = 0.98 \quad R_3 = 0.97,$$

then we will find the value of system's reliability

$$R_s = 0.9215 + 0.9506 - 0.90307 = 0.96903$$

Configuration 2. In this mixed (series – parallel) configuration, subsystem 1 and subsystem 2 are connected in series and subsystem 3 is connected in parallel with the first two as shown in figure :

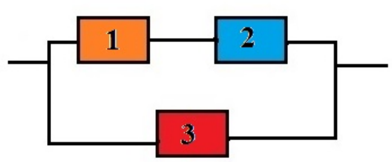


Figure 5

$X_6 = A\overline{BC}, \qquad X_7 = \bar{A}B\bar{C}, \qquad X_8 = \overline{ABC}.$

System events X_6, X_7 and X_8 results in system failure.

Thus the probability of system failure of the system is

$P_f = P(X_6 \cup X_7 \cup X_8)$

$P(X_6) = R_1(1-R_2)(1-R_3)$

$P(X_7) = (1-R_1)R_2(1-R_3)$

$P(X_8) = (1-R_1)(1-R_2)(1-R_3)$

Combining terms

$$P_f = 1 - R_1R_2 - R_3 + R_1R_2R_3.$$

Since

$$R_s = 1 - P_f$$
$$R_s = R_3 + R_1R_2 - R_1R_2R_3.$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98% and subsystem 3 has a reliability of 97% i.e.

$$R_1 = 0.95, \qquad R_2 = 0.98 \qquad R_3 = 0.97,$$

then

$$R_s = 0.998.$$

3.3. Calculation of system reliability by event space method of a system having two components in Parallel configuration

In this parallel configuration, subsystem 1 and subsystem 2 are connected in parallel as shown in figure :

Let, A is the event of Unit 1 success
B is the event of Unit 2 success

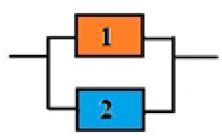


Figure 6

$$X_1 = AB, \qquad X_2 = \bar{A}B, \qquad X_3 = A\bar{B}, \qquad X_4 = \overline{AB}.$$

System events X_4 results in system failure.

$$\begin{aligned} P(X_4) &= (1 - R_1)(1 - R_2) \\ P_f &= 1 - R_1 - R_2 + R_1R_2 \\ R_s &= R_1 + R_2 - R_1R_2 \end{aligned}$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98% i.e

$$R_1 = 0.95, \qquad R_2 = 0.98$$

then , value of system's reliability

$$R_s = 0.95 + 0.98 - 0.931 = 0.999$$

3.4. Calculation of system reliability by event space method of a system having two components in series configuration

In this parallel configuration, subsystem 1 and subsystem 2 are connected in parallel as shown in figure :

Let, A is the event of Unit 1 success
B is the event of Unit 2 success

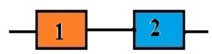


Figure 7

$$R_s = R_1.R_2.$$

If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98% i.e.

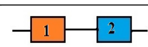
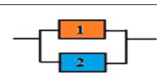
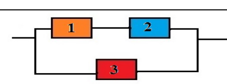
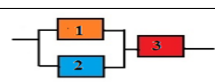
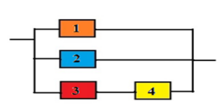
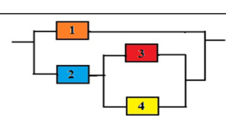
$$R_1 = 0.95, \qquad R_2 = 0.98$$

then, value of system's reliability

$$R_s = R_1.R_2$$
$$R_s = 0.95 * 0.98 = 0.931 = 93.1\%.$$

The following table shows the system configurations and their system reliability.

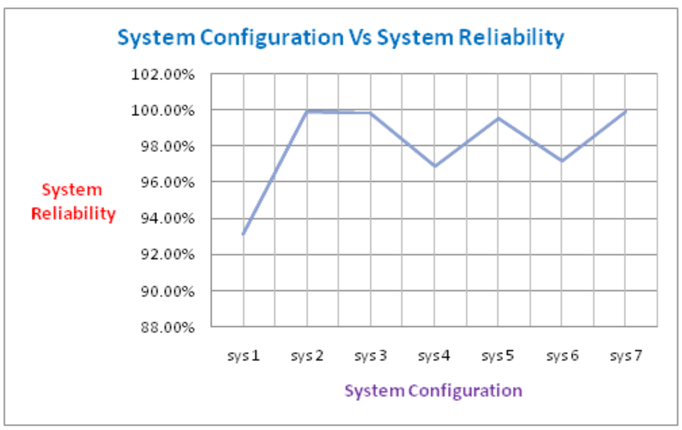
Table 1

S.N	System Configuration	System Reliability
1.		93.1%
2.		99.9%
3.		99.8%
4.		96.9%
5.		99.52%
6.		97.19%

7.		99.89%

4. Graphical Representation

In this study, we consider four components, three components and two components arranged reliability wise in mixed configuration, series and parallel configuration, where $R_1 = 95\%$, $R_2 = 98\%$, $R_3 = 97\%$, $R_4 = 96\%$ for a given time. In the table 1, we can examine system reliability of the system having different configuration based on above components reliability. We consider seven different configuration system and calculate their corresponding system reliability. The result obtained can also be illustrated graphically, as shown in the following graph 1.



Graph 1

In table 1, we can examine the effect of each component's reliability on the overall system reliability on system of different configuration.

Now If we take, Subsystem 1 has a reliability of 95%, subsystem 2 has a reliability of 98%, subsystem 3 has a reliability of 97% and subsystem 4 has reliability of 96%, i.e.

$$R_1 = 0.95, \qquad R_2 = 0.98, \qquad R_3 = 0.97, \qquad R_4 = 0.96.$$

The computation of the system reliability is given in column 2 as system reliability 1.

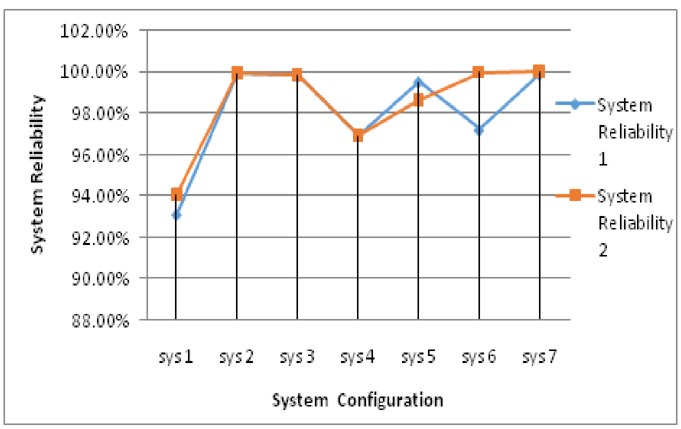
Now If we increase reliability of subsystem 1 by 1% then, Subsystem 1 has a reliability of 96%, and all other subsystem has no change (i.e. constant), then, subsystem 2 has a reliability of 98%, subsystem 3 has a reliability of 97% and subsystem 4 has reliability of 96%, i.e.

$$R_1 = 96\%, \qquad R_2 = 98\%, \qquad R_3 = 97\%, \qquad R_4 = 96\%.$$

The computation of the system reliability is given in column 3 as system reliability 2.

System Configuration	System Reliability 1	System Reliability 2
sys 1	93.10%	94.08%
sys 2	99.90%	99.92%
sys 3	99.80%	99.83%
sys 4	96.90%	96.93%
sys 5	99.52%	98.64%
sys 6	97.19%	99.95%
sys 7	99.89%	100.00%

The result obtained for different configuration system with reliability of components can also be illustrated graphically, as shown in the following graph 2. We see that if we improve the reliability of subsystem 1, then system reliability of systems increase. Similar result can also discussed with improvement in other subsystems or components.



Graph 2

5. Discussion

The comparison of system reliability of all the system having different configuration of components and their structure is given in Table 1 and Table 2. These systems are evaluated according to their structure as series, parallel, series - parallel, parallel - series and mixed configuration (i.e. all RBD configurations).

6. Conclusion

In this paper, we evaluate system reliability of the system having different configuration such as series, parallel and mixed. We see that if we increase redundancy of the system, the system reliability increased. The graphical representation of these different configuration systems is also discussed. Clearly, the reliability of a system can be improved by adding redundancy. However, it must be noted that doing so is usually costly in terms of additional components or increase redundancy. Also parallel redundancy increase system reliability.

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