Reliability Optimization Using Heuristic Algorithm In Pharmaceutical Plant

Tripti Dahiya[1], Deepika Garg[2] and Sarita Devi[4]

•

[1,2,4]G D Goenka University, Gurgaon – 122103, Haryana, India
Tripti.dahiya@gdgu.org, deepika.garg@gdgoenka.ac.in,Sarita.fame@gmail.com

Rakesh Kumar[3]

•

[3]Department of Mathematics and Statistics, Namibia University of Science and Technology, Windhoek
rkumar@nust.na

Abstract

In this paper, reliability of the liquid medicine manufacturing system of pharmaceutical plant named as Yaris Pharmaceuticals is enhanced on solving a redundancy allocation problem with the help of three algorithms HA_{SL1} (Heuristic algorithm with selection factor 1), HA_{SL2} (Heuristic Algorithm with Selection factor 2) and HA_{SL3} (Heuristic Algorithm with Selection factor 3). It is ensured that redundancy is allocated within given cost constraints to maximize system reliability. Post allocation of redundancy the results of these algorithms are analyzed with the help of graphs, it has been found that the reliability of the system is optimized.

Keywords: redundancy, optimization, heuristic method, system reliability

I. Introduction

In the present scenario, there is a massive growth in the industrialization due to advancement in the technology. In order to achieve the desired output, production process and machinery system has become bit complex. It is very essential that during their expected life span machines work in an effective and efficient manner. That is why concept of reliability comes into play. With the advancement of technology and growing complexity of an industrial system, it has become imperative for all production systems to perform satisfactorily during their expected life span. However, it must also be understood that failure is an inherent phenomenon that is likely to occur in most of the machines. Concept of reliability engineering aims to achieve the required and desired levels of reliability in the complex system during planning, testing and designing procedures. Reliability Redundancy Allocation Problem (RRAP) aims to maximize the system reliability under the several constraints like cost, weight and volume. A system structure achieves higher levels of reliability using minimum cost either by exchanging the existing components with more reliable components or by using redundant components in parallel. But exchanging the existing component stops the regular functioning of the system that affects the man power working on the system, their health, safety and also production & delivery services. That is why solving cost constraint redundancy allocation in complex system has become quite popular to maximize its reliability and enhance the quality after imposition of cost related constraints. Various objective optimization techniques like heuristic algorithm, Meta-heuristic algorithms, nonlinear programming, fuzzy method etc. are used while solving a large variety of problems.

Shi method [14] used to solve constrained RAP in complex systems and the performance of this method was also compared with the existing heuristic methods. Hwan and Bong [9] proposed a heuristic method to solve constrained RAP in complex systems that allows digression over bounded infeasible region and reduces the risk of being stuck at local optimum. Garg et al. [7] introduced three heuristic algorithms for the optimization of constrained redundancy allocation problem in pharmaceutical plant and compared them to find best optimal solution. A-G method [1] formed on penalty function used to solve constrained RAP was identified and explored its feasible and infeasible regions to find optimal solution. Kumar et al. [10] analysed profit of an edible oil refinery containing four independent subsystems with the help of fuzzy logic in order to deduce that output capacity of a unit is dependent on failure and repair rates of selected independent subsystems. Kumari and Kumar [11] studied various categories of conjunctions and visual graphs to investigate conjunctions uses and effects in Mathematics writings. Kumar and Singh [12] developed a method to analyse fuzzy reliability and handle the vagueness & incompleteness of defined rough intuitionistic fuzzy set. Garg and Kumar [4] developed a mathematical model and solved differential equations with the help of Markov birth- death process and matrix method respectively, also developed C-program in order to study the variation of reliability with respect to time. Garg et al. [5] developed a mathematical model with the help of Markov birth-death process and solved differential equations based on probabilistic approach with the help of transition diagram for steady state in tab manufacturing plant. Devi and Garg [2] introduced a heuristic algorithm and constrained optimization genetic algorithm in cost constrained RAP to find best optimal solutions and compared their results in order to know which one is better algorithm. Kumar et al.[13] used Regenerative Point Graphical Technique in order to study behavioural changes happening in washing unit of a paper factory. Hsieh [8] solved nonlinear redundancy allocation problems that are multiple linear constrained with the help of introduced a two-phase linear programming approach. Tyagi et al. [15] evaluated a reliability function of renewable energy-based system by using Universal Generating Function technique and tail signature, signature, expected cost rate, expected life time and Barlow-Proschan index were found. Garg and Sharma [6] introduced a particle swarm optimization algorithm to solve a non linear constrained redundancy allocation problem in order to get best optimal solution. Devi and Garg [3] solved a constrained redundancy allocation problem with the help of fault tree analysis in manufacturing plant in order to get best optimal solution.

Further in section 2, proposed problem of the system for the manufacturing of liquid medicines in Yaris Pharmaceutical plant is given. In section 3, methodology to enhance system's reliability is described. In section 4, results of redundancy allocation of the proposed problem to increase system reliability is discussed.

II. Problem Formulation

I. System Description

The Yaris Pharmaceuticals consists of various units viz. Stirrer, colloid mill and twin head volumetric filling machine, that are placed in series for the manufacturing of liquid medicines. In the manufacturing process, there exist certain inherent factors (such as temperature, mixing time, shear rate, speed etc.) as shown in figure 1 which affect the functioning of the units of a system. Manufacturing process of liquid medicines undergoes the following procedure:

Initially required composition of raw materials is placed into a tank with stirrer machine connected to it that makes liquid solution by mixing the raw materials at required temperature and time. Liquid solution is then transferred to colloid mill machine in order to reduce the size of particles at required shear rate and size of droplet in the liquid suspension.

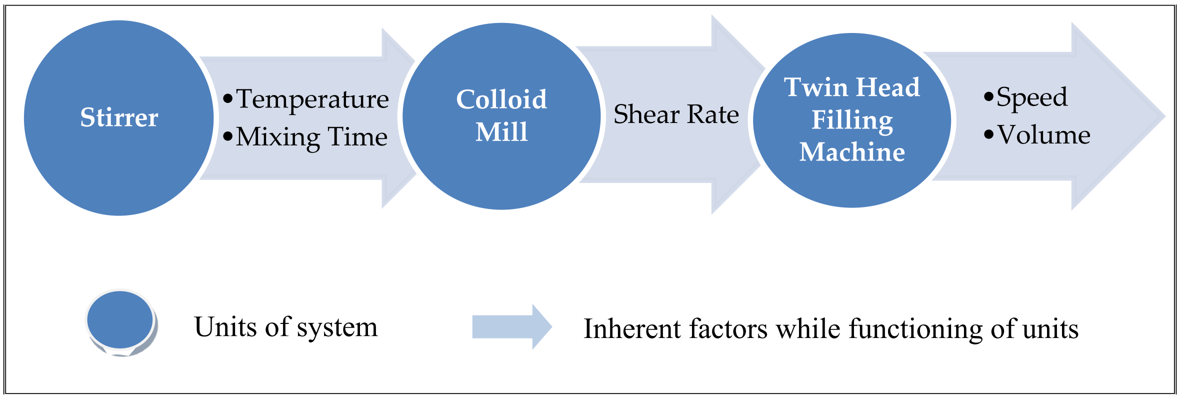

Figure 1: *Units & Respective inherent Factors*

Finally, twin head volumetric filling machine/ sealing machine is used to transfer prepared liquid for further packaging with specific speed and volume. Units of liquid medicines manufacturing system are shown in figure 2 that are connected in series.

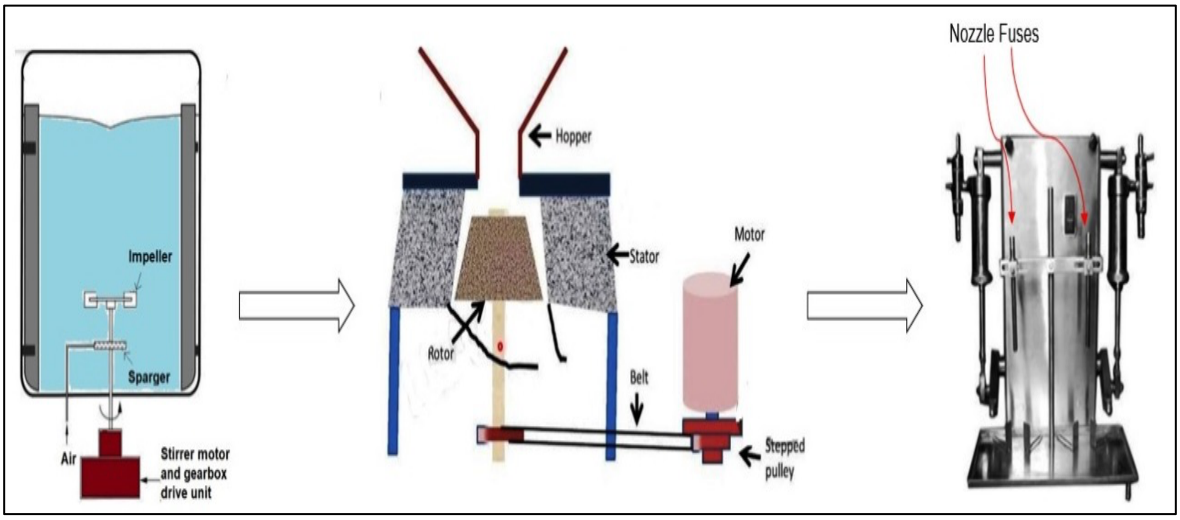

Figure 2: *Subsystems of Liquid Medicine Manufacturing Plant*

II. Assumptions

Assumptions made in this paper are as follows:

1. Coherence: A property of a system or components, as defined by Kim, Yum [9].
2. Path set: A set of components such that, if all components in the set operate, the system is guaranteed to operate.
3. Structure of total number of subsystems in system that are other than coherence is not restricted.

4. Minimal path set: A path set such that, if any subsystem is removed from the set, remaining components no longer form a path set.
5. Redundant components are not crossing the boundaries of unit in system.

III. Notations

t_i	i^{th} Subsystem/Component of system
$R_i(t_i)$, $Q_i(t_i)$	Reliability, unreliability of subsystem- t_i
$R_s(t)$	System reliability
α_i	Number of i^{th} subsystems
t	$(t_1,........,t_\alpha)$
t^*	$(\alpha_1, \alpha_2, \alpha_3)$ is optimal solution
ΔR_i	Difference in reliability of i^{th} subsystem by adding one more redundant subsystem
$f^j(t_i)$	j^{th} resource- consumed by i^{th} subsystem
M_j	Maximum of resource-j
N_k	Minimal path set of the system
α	Number of subsystems
β	Number of constraints
γ	Number of minimal path sets
x(.)	A function that yields the system reliability, based on unique subsystems, and which depends on the configuration of the subsystems
H_i	Selection factor

IV. Redundancy Allocation Problem in Yaris Pharmaceuticals

In Yaris Pharmaceuticals, problem is to maximize the reliability with cost constraint.
Considering cost constraint M_1=Rs. 335000 and $R_s(t)$= 0.7734 (here number of constraints is one that is β=1, hence j=1)
Problem is to maximize

$$R_s(t) = g(R_1(t_1), R_2(t_2), \dots\dots\dots\dots\dots\dots\dots, R_\alpha(t_\alpha)) = \prod_{i=1}^{\alpha} R_i(t_i) \quad (1)$$

Subject to:

$$\sum_{i=1}^{\alpha} f^1(t_i) * \alpha_i \leq 335000 \quad (2)$$

Where $f^1(t_i)$ is cost of i^{th} subsystem and α_i is total number of subsystems of i^{th} subsystem.
Reliability and cost of each subsystem is given by Yaris pharmaceuticals management are:

Table 1: *Reliability and cost of each component of Yaris pharmaceuticals*

Subsystem	t_1	t_2	t_3
Reliability of subsystem $R_i(t_i)$	0.9652	0.8261	0.97
Cost of subsystem $f^1(t_i)$	22444	85000	118000

III. Methods

Heuristic algorithm is one of the faster, accurate and feasible approach to solve a problem as compared to traditional methods. Here, three different heuristic algorithms have been designed to solve a problem effectively in order to get accurate and feasible solution. Also, comparison of these algorithms suggests the best one among them.

I. HA$_{SL1}$(Heuristic Algorithm with Selection factor 1)

Here selection factor (H$_i$) is defined as minimum stage reliability. Taking into account this selection factor, redundancy allocation problem is solved as follows.

Algorithm 1

Step 1
Initialize XX=0, X=0, E(0)=0
Step 2
Initialize α_i=1 for 1≤i≤α
Step 3
Find reliability of each component

$$\left[R_i(t_i) = \left(1 - \left(Q_i(t_i)\right)^{\alpha_i}\right)\right]$$

Step 4
Identify the subsystem with minimum reliability

- Find j such that

$$R_j(t_j) = min\{(R_i(t_i))\ 1 \le i \le \alpha, i \ne E(XX) forall\ 0 \le XX \le X\}$$

- If j_1 and j_2 are such that

$$R_{j_1}(t_{j_1}) = R_{j_2}(t_{j_2}) = min\{(R_i(t_i))\ 1 \le i \le \alpha, i \ne E(XX) forall\ 0 \le XX \le X\}$$

Then check
If $f^1(t_{j_1}) < f^1(t_{j_2})$
Then take $j = j_1$ otherwise $j = j_2$
Step 5
Check for violation of the constrained on addition of additional redundant component in jth component

$$\sum_{\substack{i=1 \\ i \ne j}}^{\alpha} \alpha_i f^1(t_i) + (\alpha_j + 1) f^1(t_j) > M_1$$

- If violation of constrained occurred, remove this subsystem from selection list $[X = X + 1, E[X] = J]$ and go to step 6
- If violation of constrained is not occurred then check whether on addition of this subsystem reliability is improving up to desired limit i.e. $\Delta R_j > 0.0001$
- If on addition of this subsystem reliability improved up to desired limit i.e. $\Delta R_j > 0.0001$, increase that number of subsystem by one i.e. $\alpha_j = \alpha_j + 1$ and go to step 3
- If on addition, this subsystem reliability does not improve to desired limit i.e. $\Delta R_j \le 0.0001$. Remove this subsystem from further selection process i.e. X=X+1, E[X]=J and go to step 6

Step 6

- If all components are removed from further selection then $t^* = (\alpha_1, \alpha_2, \alpha_3)$ is the optimal solution
- Else go to step 3

Step 7

At the end calculate system reliability i.e. $R_s(t^*)$ using equation (1).

II. HA_{SL2}(Heuristic Algorithm with Selection factor 2)

In this algorithm selection factor (H_i) is defined as given below

$$H_i = h_i(t_i) = \frac{subsystemreliability}{percentageofresourcesconsumed} = \frac{R_i(t_i)}{\left(f^1(t_i)/_{M_1}\right)}$$

Applying this selection factor, algorithm is as follows

Algorithm 2

Step 1

Initialize XX=0, X=0, E(0)=0

Step 2

Initialize α_i=1 for 1≤i≤α

Step 3

- Find reliability of each component

$$\left[R_i(t_i) = \left(1 - \left(Q_i(t_i)\right)^{\alpha_i}\right)\right]$$

- Calculate selection factor of each component

$$H_i = h_i(t_i) = \frac{R_i(t_i)}{\left(f^1(t_i)/_{M_1}\right)}$$

Step 4

Identify the subsystem with minimum reliability

- Find j such that

$$h_j(t_j) = max\{(h_i(t_i))\ 1 \le i \le \alpha, \quad i \ne E(XX) forall\ 0 \le XX \le X\}$$

- If $j_1$and j_2 are such that

$$h_{j_1}(t_{j_1}) = h_{j_2}(t_{j_2}) = min\{(h_i(t_i))\ 1 \le i \le \alpha, i \ne E(XX) forall\ 0 \le XX \le X\}$$

Then check

If $f^1(t_{j_1}) < f^1(t_{j_2})$

Then take $j = j_1$ otherwise $j = j_2$

Step 5

Check for violation of the constrained on addition of additional redundant component in j[th] component

$$\sum_{\substack{i=1 \\ i \ne j}}^{\alpha} \alpha_i f^1(t_i) + (\alpha_j + 1) f^1(t_j) > M_1$$

- If violation of constrained occurred, remove this subsystem from selection list $[X = X + 1, E[X] = J]$ and go to step 6
- If violation of constrained is not occurred then check whether on addition of this subsystem reliability is improving up to desired limit i.e. $\Delta R_j > 0.0001$
- If on addition of this subsystem reliability improved up to desired limit i.e. $\Delta R_j > 0.0001$, increase that number of subsystem by one i.e. $\alpha_j = \alpha_j + 1$ and go to step 3
- If on addition, this subsystem reliability does not improve to desired limit i.e. $\Delta R_j \le 0.0001$. Remove this subsystem from further selection process i.e. X=X+1, E[X]=J and go to step 6

Step 6

- If all components are removed from further selection then $t^* = (\alpha_1, \alpha_2, \alpha_3)$ is the optimal solution.

- Else go to step 3

Step 7

At the end calculate system reliability i.e. $R_s(t^*)$ using equation (1).

III. HA$_{SL3}$ (Heuristic Algorithm with selection factor 3)

In this algorithm selection factor (H_i) is defined as given below

$$H_i = h_i(t_i) = \frac{Changeinsubsystemreliability}{percentageofresourcesconsumed} = \frac{\Delta R_i}{\left(f^1(t_i)/_{M_1}\right)}$$

Where $\Delta R_i = (1 - Q_i(t_i)^{\alpha_i+1}) - R_i(t_i)$

Algorithm 3

Step 1

Initialize XX=0, X=0, E(0)=0

Step 2

Initialize α_i=1 for 1≤i≤α

Step 3

- Find reliability of each component

$$\left[R_i(t_i) = \left(1 - \left(Q_i(t_i)\right)^{\alpha_i}\right)\right]$$

- Calculate selection factor of each component

$$H_i = h_i(t_i) = \frac{\Delta R_i}{\left(f^1(t_i)/_{M_1}\right)}$$

Step 4

Identify the subsystem with minimum reliability

- Find j such that

$$h_j(t_j) = max\{(h_i(t_i))\ 1 \le i \le \alpha, \quad i \ne E(XX) forall\ 0 \le XX \le X\}$$

- If j_1 and j_2 are such that

$$h_{j_1}(t_{j_1}) = h_{j_2}(t_{j_2}) = min\{(h_i(t_i))\ 1 \le i \le \alpha, i \ne E(XX) forall\ 0 \le XX \le X\}$$

Then check

If $f^1(t_{j_1}) < f^1(t_{j_2})$

Then take $j = j_1$ otherwise $j = j_2$

Step 5

Check for violation of the constrained on addition of additional redundant component in j[th] component

$$\sum_{\substack{i=1 \\ i \ne j}}^{\alpha} \alpha_i f^1(t_i) + (\alpha_j + 1) f^1(t_j) > M_1$$

- If violation of constrained occurred, remove this subsystem from selection list $[X = X + 1, E[X] = J]$ and go to step 6
- If violation of constrained is not occurred then check whether on addition of this subsystem reliability is improving up to desired limit i.e. $\Delta R_j > 0.0001$
- If on addition of this subsystem reliability improved up to desired limit i.e. $\Delta R_j > 0.0001$, increase that number of subsystem by one i.e. $\alpha_j = \alpha_j + 1$ and go to step 3
- If on addition, this subsystem reliability does not improves to desired limit i.e. $\Delta R_j \le 0.0001$. Remove this subsystem from further selection process i.e. X=X+1, E[X]=J and go to step 6

Step 6

- If all components are removed from further selection then $t^* = (\alpha_1, \alpha_2, \alpha_3)$ is the optimal solution
- Else go to step 3

Step 7

At the end calculate system reliability i.e. $R_s(t^*)$ using equation (1).

IV. Results & Discussions

In this section, application of above mentioned methodologies are discussed on the data collected from Yaris Pharmaceuticals.

I. Application of HA_{SL1}

After applying HA_{SL1} on proposed problem, following result is obtained.

Table 2: *Result of HA_{SL1}*

S. No.	Number of components in each subsystem			Consumed Resources	Subsystem Selection factor		
	$\alpha_1\alpha_2\alpha_3$			$\sum_{i=1}^{\alpha} f^1(t_i) * \alpha_i$	H_1	H_2	H_3
1.	1	1	1	225444	0.9652	0.8261	0.97
2.	1	2	1	310444	0.9652	0.9697	0.97
3.	2	2	1	332888	0.9987	0.9697	0.97
4.	2	3	1	**417888?**	0.9987	!	0.97
5.	2	2	2	**450888?**	0.9987	!	!
6.	3	2	1	**355332?**	!	!	!
7.	2	2	1	332888	Algorithm stops here		

! denote 'this subsystem is removed from further selection process due to cost constraint violation'.
? denote 'the cost constraint is violated'.
Here, cost constraint is violated at 4th iteration and the optimal solution for proposed problem from table 2 is $t^* = (2,2,1)$ and system reliability is $R_s(t^*) = 0.9405$

II. Application of HA_{SL2}

After applying HA_{SL2} on proposed problem, following result is obtained

Table 3: *Result of HA_{SL2}*

S. No.	Number of components in each subsystem			Consumed Resources	Subsystem Selection factor		
	$\alpha_1\alpha_2\alpha_3$			$\sum_{i=1}^{\alpha} f^1(t_i) * \alpha_i$	H1	H2	H3
1.	1	1	1	225444	14.4071	3.2558	2.7538
2.	2	1	1	247888	7.4533	3.2558	2.7538
3.	3	1	1	**270332#**	#	3.2558	2.7538
4.	2	2	1	332888	#	1.9108	2.7538
5.	2	2	2	**450888?**	#	1.9108	**!**
6.	2	3	1	**417888?**	#	**!**	**!**
7.	2	2	1	332888	Algorithm stops here		

! denote 'this subsystem is removed from further selection process due to cost constraint violation'.
? denote 'the cost constraint is violated'
denote 'this subsystem is removed from further selection process due to violation of ΔR_i desired limit'.
Here, cost constraint is violated at 5th iteration and the optimal solution for proposed problem from table 3 is $t^* = (2,2,1)$ and system reliability is $R_s(t^*) = 0.9394$.

III. Application of HA_{SL3}

After applying HA_{SL3} on proposed problem, following result is obtained

Table 4: *Result of HA_{SL3}*

S. No.	Number of components in each subsystem			Consumed Resources	Subsystem Selection factor		
	$\alpha_1\alpha_2\alpha_3$			$\sum_{i=1}^{\alpha} f^1(t_i) * \alpha_i$	H1	H2	H3
1.	1	1	1	225444	0.5051	0.5563	0.0826
2.	1	2	1	310444	0.5051	0.6646	0.0826
3.	1	3	1	**395444?**	0.5051	**!**	0.0826
4.	2	2	1	332888	0.5188	**!**	0.0826

5.	3	2	1	**355332?**		!	!	0.0826
6.	2	2	2	**450888?**	!	!	!	
7.	2	2	1	332888		Algorithm stops here		

Here, cost constraint is violated at 3rd iteration and the optimal solution for proposed problem from table 4 is $t^* = (2,2,1)$ and system reliability is $R_s(t^*) = 0.9676$.

Discussion

On applying HA_{SL1}, HA_{SL2}& HA_{SL3} on proposed problem, redundancy allocation is done in order to improve system's reliability under given cost constrained. As a result, redundancy obtained is same i.e. (2, 2, 1) for subsystems in all the three cases that are shown in figure 3 as a common illustration for them.

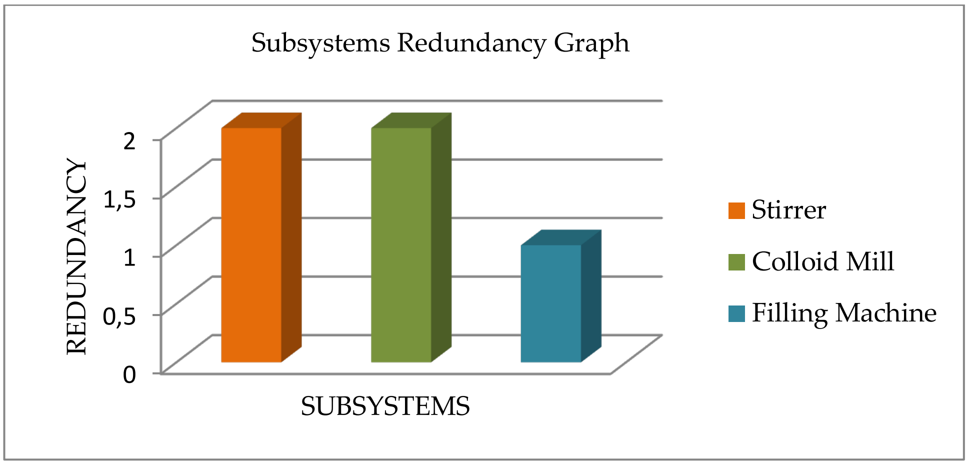

Figure 3: *Redundancy allocated to subsystems by HA_{SL1}, HA_{SL2}& HA_{SL3}*

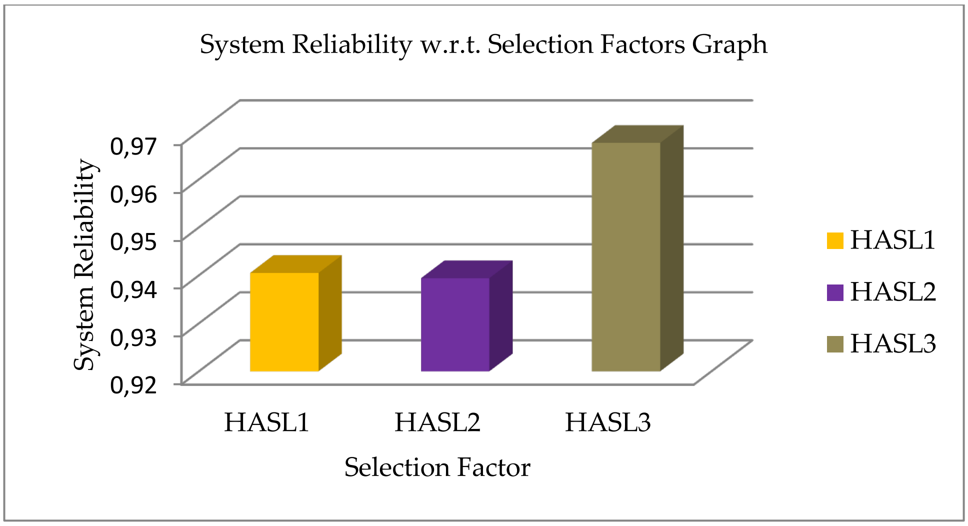

Figure 4: *Systems reliability w.r.t. selection factors of HA_{SL1}, HA_{SL2}& HA_{SL3}*

Even after getting same redundancy in case of HA_{SL1}, HA_{SL2}& HA_{SL3}, system's reliability varies in all the three cases as shown in figure 4 that is due the selection factors of HA_{SL1}, HA_{SL2} and HA_{SL3} in this paper. It clearly states that not only redundancy allocation but selection factors also plays important role in the variation of reliability of a system.

V. Conclusion

Solving a redundancy allocation problem of pharmaceutical plant (Yaris Pharmaceuticals) using described three algorithms, reliability of the liquid medicine manufacturing system is enhanced under the given cost constrained. Before applying algorithms system reliability was 0.7734, after the application of HA_{SL1}, HA_{SL2} and HA_{SL3} reliability of liquid medicine manufacturing system is improved by 20.06%.

References

[1] Agarwal, M. and Gupta, R. (2005). Penalty function approach in heuristic algorithms for constrained redundancy reliability optimization.*Institute of Electrical and Electronics Engineers (IEEE) Trans. Reliab.*, 54(3):549-558.

[2] Devi, S. and Garg, D. (2017). Redundancy-Allocation in Neel Metal Products Limited. *Indian Journal of Science and Technology*, 10(30).

[3] Devi, S. and Garg, D. (2019). Reliability Analysis of Manufacturing Plant via Fault Tree Analysis.*Journalof Advances and Scholarly Researches in Allied Education (JASRAE)*, 16(5):256-259.

[4] Garg, D. and Kumar, K. (2009). Matrix- Based System Reliability Method and its Application to Rice plant.*The IUP Journal of Computational Mathematics*, 2(4):17-29.

[5] Garg, D., Kumar, K. and Sigh, J. (2010). Decision support system of a tab manufacturing plant. *Journal of Mechanical Engineering*, 41(1):71-79.

[6] Garg, H., Sharma, S. P. (2013). Reliability–redundancy allocation problem of pharmaceutical plant. *Journal of Engineering Science and Technology,* 8(2):190 – 198

[7] Garg, D., Kumar, K., Pahuja, G. L. (2010). Redundancy-allocation in pharmaceutical plant. *International Journal of Engineering Science and Technology*, 2(5):1088–97.

[8] Hsieh, Y.-C. (2002). A two-phase linear programming approach for redundancy allocation problems. *Yugoslav journal of Operation Research*, 12(2): 227-236.

[9] Hwan, J. K. and Bong, J. Y. (1993). A heuristic method for solving redundancy-optimization problems in complex systems. *Institute of Electrical and Electronics Engineers (IEEE) transaction on reliability*, 42(4):572-578.

[10] Kumar, A., Garg, D. and Goel, P. (2017). Mathematical Modeling and Profit Analysis of An Edible Oil Refinery Industry. *Airo International Research journal*, (13) ISSN 2320-3714: 1-14.

[11] Kumari, A. and Kumar, D. (2019). Conjunction as cohesive devices in the writing of Mathematicians. *The International Organization of Scientific Research Journal of Mathematics (IOSR-JM)*, 15(5):17-22.

[12] Kumar, D. and Singh, S. B. (2014). Evaluating fuzzy reliability using rough intuitionistic fuzzy set. *Innovative Application of Computational Intelligence on Power, Energy and controls with their impact on humanity , Institute of Electrical and Electronics Engineers Xplore*, 138-142.

[13] Kumar, A., Garg, D. and Goel, P. (2019). Mathematical modeling and behavioral analysis of a washing unit in paper mill. *International Journal of System Assurance Engineering and Management*, 10:1639-1645.

[14] Shi, D. H. (1987). A New heuristic Algorithm for constrained redundancy-optimization in complex systems. *Institute of Electrical and Electronics Engineers (IEEE) Transaction on reliability*, 36(5):621-623.

[15] Tyagi, S., Kumar, A., Bhandari, A. S. and Ram, M. (2020). Signature reliability evaluation of renewable energy system. *Yugoslav journal of operation research*, 20(20).