

# Redundancy Allocation in an Industry using Multi-Objective Optimization

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**ABSTRACT:** In engineering, redundancy is the duplication of critical components or functions of a system thus increasing system's reliability, usually in backup or fail-safe form, or actual system performance improvement, like in the GNSS receivers' case, or multi-threaded computer processing. In either case, inventory should contain some components or subsystems to replace the failed components. Factors like budget or storage space limits the number of components in inventory can be limited by. The redundancy allocation problem is a way to maximize reliability while minimizing the cost. In this work a case study on a small scale industry is conducted to show the benefits of the using a redundant system. For this purpose a product manufactured in the industry was selected and its process of production was studied. Further the availability of the machines involved in its production is calculated and thus availability of the whole system was determined. Redundancy Allocation Number (RAN) was calculated for each and every machine involved in the production of the product. A redundant system was allotted to the machine with highest RAN. After allocation of redundant system availability of the system was calculated again and compared with the original availability of the system to measure the effect of redundancy allocation on the system.

**KEYWORDS:** Redundancy, RAN, Industry, Machines.

## I. INTRODUCTION

Reliability engineering is engineering that highlights dependability in a product's lifecycle management. Dependability, or reliability, describes the ability of a system or component to function under stated conditions for a set time period. Reliability engineering represents a branch of systems engineering. Reliability can be defined as the probability of success as the frequency of failures; or in terms of availability, as a probability based on reliability, maintainability and testability. Maintainability, testability and maintenance are often described as a part of "reliability engineering". Reliability plays an important part in deciding the cost-effectiveness of systems

In engineering, redundancy is the duplication of critical components or functions of a system thus increasing system's reliability, usually in backup or fail-safe form, or actual system performance improvement, like in the GNSS receivers case, or multi-threaded computer processing. Sometimes redundancy can decrease the reliability of system instead of increasing – it creates a more complex system which is prone to various issues, it may lead negligence of duty, and higher production demands which by overstressing the system may make it less safe.

## II. RELATED WORK

[1] Jing Wang & Mian Li proposed an analytical model describing the failure rates with failure interactions. Then a Modified Analytic Hierarchy Process (MAHP) is proposed to solve the redundancy allocation problems for systems with failure interactions. This method decomposes the system into several blocks and deals with those down-sized blocks before diving deep into the most appropriate component for redundancy allocation. Being simple and flexible, MAHP provides an intuitive way to design a complex system and complex explicit objective functions for the entire system is not required in the proposed approach. More importantly, with the help of the proposed analytical failure interaction model, MAHP can capture the effect of failure interactions. Results from case studies clearly demonstrate the applicability of the analytical model for failure interactions and MAHP for reliability design.

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Vol. 6, Issue 4, April 2017

[2] ZhigangTian, Ming J. Zuo, presented an optimization model for a multi-state series-parallel system to jointly determine the optimal component state distribution, and optimal redundancy for each stage. The relationship between component state distribution, and component cost is discussed based on an assumption on the treatment on the components. An example is used to illustrate the optimization model with its solution approach, and that the proposed reliability-redundancy allocation model is superior to the current redundancy allocation models

[3] David W. Coit and Alice E. Smith presented a review of the different optimization approaches and present a new approach, a genetic algorithm (GA) which can solve the general class of the redundancy allocation problem. The GA is demonstrated on two different problems and compared with the other techniques. The natural extension of this work is to adapt the GA to problems where the component reliability values are governed by a probability density function. Constraints would then be based on a lower bound value for system reliability or cost. This represents a more realistic model of the design process. Also, it allows for the explicit consideration of risk-averse system designers and users.

[4] Mani Sharifia, Pedram Pourkarim Guilani, Mohammad reza Shahriari dealt with a RAP with sub-systems. The structure of each sub-system is k-out-of-n and the redundancy strategy of each sub-system is active or cold-standby and is pre-defined. they presented an NSGA-II algorithm for solving MORAP for a series-parallel problem and k-out-of-n sub-systems with 3 objectives. The objectives were reliability, cost, and weight. The components were CFR and the sub-system redundancy strategy was active and cold-standby. The results of the algorithm prepared a wide range of solution for decision makers. The further studies divided in to two categories. The first category is the solving methodology and the other multi-objective meta-heuristic algorithm like NPGA, MOPSO, and MOEA that may be used for solving the problem. The other category deals with problem specification. For example, this algorithm can be used for solving the problem with multi-state components, time dependent failure rate components, and repairable components.

[5] Fulya GİZEM AYTAÇ In this study, a special type of reliability optimization problems which is called as redundancy allocation have been discussed from different perspectives based on a novel classification methodology, and latest trends in this field, in terms of models, solution methodologies etc., have been presented. The main purpose of this study is to provide researchers working in this field with a framework for future research direction.

### III. PROBLEM FORMULATION

Availability of machine individually defines the overall availability of the production system. But each machine is made of various components which can fail randomly without any warning due to many reasons. In spite of having several advantages various small scale industries are ignorant towards redundancy, in this work the benefits of providing a redundant system on the availability of the system and thus on the overall productivity of the industry is discussed.

In order to improve the availability of the system it is necessary to detect the most influencing failure and allocate an alternative to perform that task as early as possible. In order to solve this problem various methods are used but they consider basic factors like failure rate and cost. In order to provide a more efficient solution to the problems we need to consider more factors into observation.

Redundancy allocation number is used here to select the subsystem whose failure affects the most. All variables affecting the overall productivity are covered in it. These variables are as follows:

- Failure rate
- Operation time
- Number of total operations
- Repair cost of machines
- Overtime cost

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Vol. 6, Issue 4, April 2017

## IV. EXPERIMENTAL RESULTS

The study was done in Electro auto Industry, it is a leading manufacturer of the steam turbines and transformer tanks. The company is located in Govindpura Industrial area, Bhopal.

Electro auto industry employs professional having a vast experience in the engineering field and their motto is “NO compromise in quality”. This industry is dedicated to perfect its process to increase the quality of their products. Large numbers of products are manufactured at electro auto industry, for the analysis purpose pipe flange of the transformer tank assembly was selected. It is a part of transformer tanks manufactured here. Its analysis required tracing the operational flow and time consumed in machining.

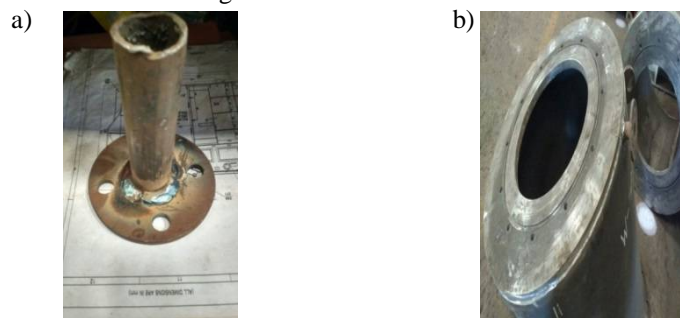


Fig 1: a) Pipe Flange b) Pipe Flange welded with transformer assembly

This product is welded to the transformer tank to provide connection to other parts of the transformer assembly. The pipe of the flange is welded to the tank while the flange is connected to other parts through nuts and bolts. It is required that the face of the flange is smooth so the connection is air tight.

Casting of the flange is not done in the industry. Only milling, grinding, drilling and welding of the product are done in house. The machining process of the product is discussed below



Fig 2: Machining Process Of The Product

### Milling Machine

In the industry a 3Hp ram turret milling machine made by PMT machines is used to perform the milling operations. It is multipurpose machine used for cutting the central hole on the flange. The part of the product to be machined is fixed on the bed of milling machine and tool is fed from above

### Grinding Machine

A 850W and 100mm angle grinder made by Kulkarni Power Tools, India is used to perform the grinding operations. This is used for smoothening of the surface of the flange and remove roughness left after machining. It consists of a grinding disk made of abrasive material which strikes the surface at a high speed and smoothenes the surface

### Drilling Machine

In the industry a drilling machine made by SMT India, requiring 1.5 HP power is used to drill holes on the flanges for the nuts and bolts. It uses a drilling tool containing cutting edges at its point.

### Welding Machine

Welding machine is used to join the pipe and flange together. It is also used to join the product to the transformer tank. The operator should be experienced as it is the most important step and error can affect the structural integrity of the product. The machine used here is a Metal arc welding machine made by Weldtronix. In this CO<sub>2</sub> gas flame is used to melt filler material in this case copper wire and the part.

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Vol. 6, Issue 4, April 2017

## V. CONCLUSION

### DATA COLLECTION

In order to validate the adopted methodology input data containing downtime, uptime and frequency of failure and operation time, number of overtime hours, number of operation performed is collected. The production cost of the part was provided by the firm.

### Failure Data

Maintenance reports and graphs of performance of each subsystem for roughly around 1 year (total time of about 6000 hours) were studied to gather failure data. From the data it can be deduced that overall availability of the machines was good and the downtime was compensated by overtime. But this statement does not stick for every firm and sometime overtime could also not help them to achieve target.

S. no	Subsystem	Down Time ( $T_{di}$ )	Failure Frequency ( $k_i$ )
1	Milling Machine	100	4
2	Grinding Machine	200	20
3	Drilling Machine	150	15
4	Welding Machine	150	18

Table 6.1: Downtime and Frequency of Failure of Each system

### Operation Time and Number of Operation

Total time for the machining of the part is calculated individually for every machine. These are tabulated below

S.no	Subsystem	Number of Operation ( $N_{ia}$ )	Operation Time ( $\tau_{ia}$ )
1	Milling Machine	1	10
2	Grinding Machine	1	10
3	Drilling Machine	4	25
4	Welding Machine	1	15

TABLE 2: REQUIRED NUMBER OF OPERATION AND TIME ON THE PIPE FLANGE

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Vol. 6, Issue 4, April 2017

### OVERTIME AND REPAIR COST

Due to failure of different machine overtime is required to compensate downtime. For overtime company has to provide overtime wage to the worker. Overtime wage of one worker is Rs 60/hour, and there were 8 workers on the shop floor. The repair cost of different machines collected from the maintenance report is tabulated below:

S. no	Subsystem	Overtime hours ( $T_{0i}$ )	Repair Cost ( $C_{Ri}$ )
1	Milling Machine	5	20000
2	Grinding Machine	1	4000
3	Drilling Machine	2	8000
4	Welding Machine	1	5000

Table 3: Overtime And Repair Cost On The Pipe Flange

### Availabilities of all Subsystem and System

Here total time of production is taken around 1000 hrs based on the data provided from the industry. Maintenance report provided by the industry is used to prepare a sheet for the availability of each subsystem. To calculate the availability of each subsystem data of downtime and failure frequency was considered. The calculated availability of the subsystem is tabulated below;

S. no	Subsystem	Down Time ( $T_{di}$ )	Failure Frequency ( $k_i$ )	Up time	MTBF	MTRR	Availability
1	Milling Machine	100	4	5900	1475	25	98.33333333
2	Grinding Machine	200	20	5800	290	10	96.66666667
3	Drilling Machine	150	15	5850	390	10	97.5
4	Welding Machine	150	18	5850	325	8.333333333	97.5
<b>SYSTEM'S AVAILABILITY</b>							90.36

Table 4: Availability of the production system

### Allocation of RAN to Each Subsystem

The steps of allocating RAN to every subsystem are discussed below

#### i. Failure Rate Ratio

The failure rate ratio of each subsystem is evaluated by calculating failure rate of each subsystem.

S. no	Subsystem	Down Time ( $T_{di}$ )	Failure Frequency ( $k_i$ )	Up time	MTBF	Failure Rate	Failure Rate Ratio
1	Milling Machine	100	4	5900	1475	0.000677966	0.069412054
2	Grinding Machine	200	20	5800	290	0.003448276	0.353044065
3	Drilling Machine	150	15	5850	390	0.002564103	0.262519946
4	Welding Machine	150	18	5850	325	0.003076923	0.315023935
<b>SYSTEM'S FAILURE RATE</b>						0.009767268	

Table 5: Failure Rate of the System

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Vol. 6, Issue 4, April 2017

## ii. Fraction of Production

In order to calculate fraction of production the number of operations performed on every subsystem are added together. The data is tabulated below.

S. no	Subsystem	Number of Operation	Production Function
1	Milling Machine	1	0.142857143
2	Grinding Machine	1	0.142857143
3	Drilling Machine	4	0.571428571
4	Welding Machine	1	0.142857143

Table 6 : Production Function of the Production System

## Production Function

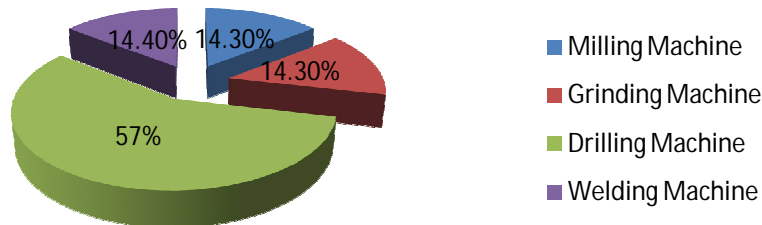


Fig 3: Production Function

## iii. Utilization Factor

It is calculated by taking the operation time in to account. The calculated value of the utilization factor is shown below

S. no	Subsystem	Operation Time	Utilization Factor
1	Milling Machine	10	0.16666667
2	Grinding Machine	10	0.16666667
3	Drilling Machine	25	0.41666667
4	Welding Machine	15	0.25
<b>Total operation time</b>		<b>60</b>	

Table 7: Utilization Factor

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Vol. 6, Issue 4, April 2017

### Impact of Failure

According to the data provided by the industry the production cost of the selected part is around Rs.75000/month. Also according to overtime cost data provided by company, it pays Rs. 100 per hour to the 10 workers individually on the production line for overtime. So the extra expenditure due to failure and thus its impact on the production is tabulated below.

S. no	Subsystem	Overtime	Overtime Cost	Repair cost	Failure Impact Ratio
1	Milling Machine	5	5000	20000	0.333333333
2	Grinding Machine	1	1000	4000	0.066666667
3	Drilling Machine	2	2000	8000	0.133333333
4	Welding Machine	1	1000	5000	0.08

Table 8: Failure Impact Ratio

In order to allocate RAN to each subsystem these factor are taken into consideration. And the RAN for each subsystem is calculated as shown below

$$RAN_i = \left( \sum_{r=1}^4 \alpha_r F_{r_i} \right) \times 1000 + \phi$$

Here  $\phi = -1000$

The calculated values are tabulated below

S. no	Subsystem	weightage of PF	weightage of FRR	weightage of PF	weight of UF	weightage of Iof	RAN
1	Milling Machine	0.285714286	0.277648214	0.285714286	0.166666667	1	730.0291664
2	Grinding Machine	0.285714286	1.412176261	0.285714286	0.166666667	0.2	1064.557214
3	Drilling Machine	1.142857143	1.050079784	1.142857143	0.416666667	0.4	2009.603593
4	Welding Machine	0.285714286	1.260095741	0.285714286	0.25	0.24	1035.810026

Table 9: Calculation of Redundancy Allocation Number

### Redundancy Allocation

When all subsystem are ranked based on their RAN it is found that the drilling machine has the highest need for allocation of a redundant system. Subsystem with their ranks and RAN value is tabulated below:

S. no	Subsystem	RAN	Ranks
1	Milling Machine	730.0291664	IV
2	Grinding Machine	1064.557214	III
3	Drilling Machine	2009.603593	I
4	Welding Machine	1035.810026	II

Table 10: Redundancy Allocation Number

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Vol. 6, Issue 4, April 2017

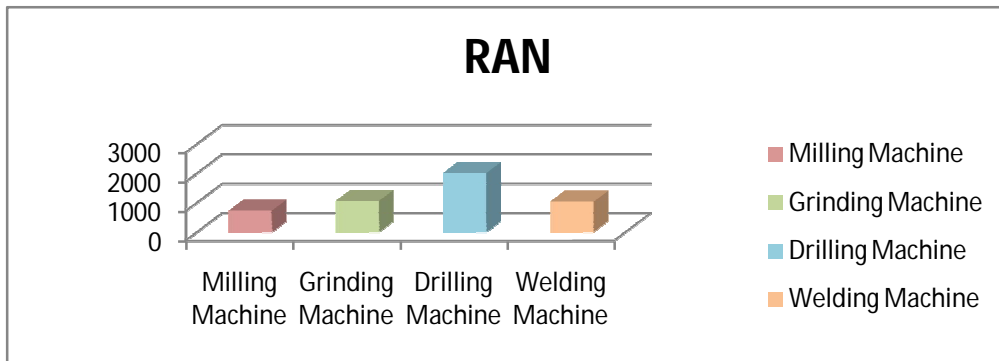


Fig 4: RAN of Each Subsystem

## Improved Subsystem and System's Availability

After allocating the redundant system to the drilling machine and improving its maintenance schedule from monthly to fortnight the availability of the machine is calculated again. This time the down time and failure frequency is changed thus improving the availability of the system.

S. no	Subsystem	Down Time ( $T_{di}$ )	Failure Frequency ( $k_i$ )	Up time	MTBF	MTTR	Availability
1	Milling Machine	100	4	5900	1475	25	98.33333333
2	Grinding Machine	200	20	5800	290	10	96.66666667
3	Drilling Machine	50	4	5950	1487.5	12.5	99.16
4	Welding Machine	150	18	5850	325	8.333333333	97.5
<b>SYSTEM'S AVAILABILITY</b>							<b>91.9</b>

Table 11: Improved Availability of the System

## Availability Increment

$$\begin{aligned} \text{Availability Increment \%} &= \frac{A_{vs}^i - A_{vs}}{A_{vs}} \times 100 \\ &= \frac{0.919 - 0.9036}{0.9036} \times 100 \\ &= 1.70\% \end{aligned}$$

## VI. RESULTS & DISCUSSION

After redundancy allocation and improving the maintenance schedule of the system its availability is found to be increased by 1.70%. In this work the redundant system was allocated to the drilling machine based on its redundancy allocation number. However there were subsystem with less availability but based on the other factors like effect on production, failure rate it had greater RAN then other. In the drilling machine all components are checked in order to allocate a redundant system, it was found that the failure mainly occurs due to failure of electrical system and tool. To overcome this redundant system was allocated for the electrical component as well as extra set of tool was also bought.



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Vol. 6, Issue 4, April 2017

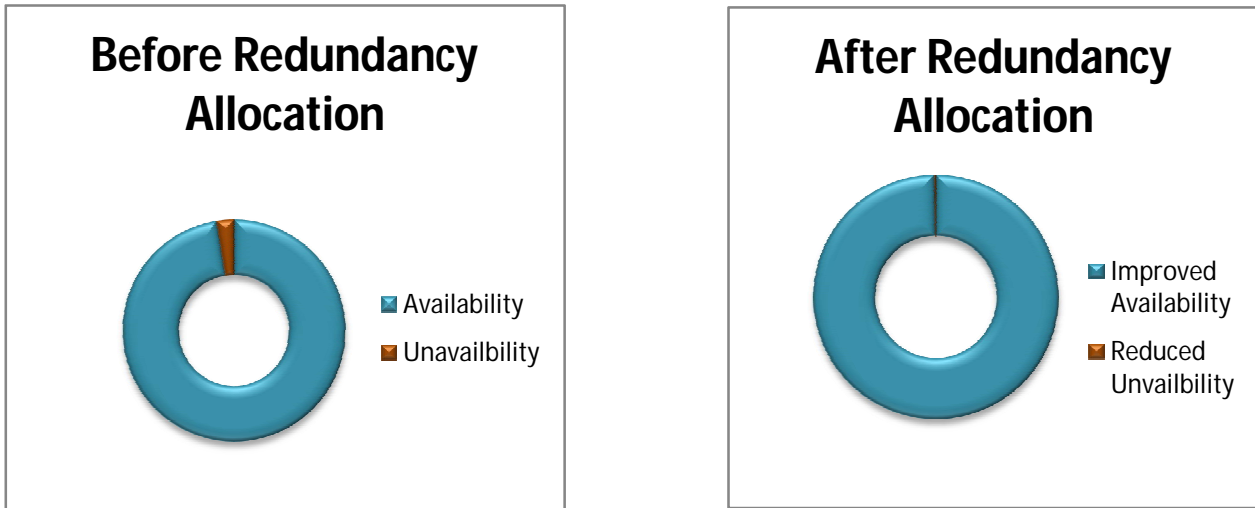


Fig 7.1: Comparison of the system Availability

The RAN of the grinding as well as welding machines was also high but redundant system was allocated to the drilling machine only as its RAN was considerably much higher than both machines. But overall availability of the system is increased not only due to allocation of the redundant system but also due to improvisation of the maintenance schedule. It can be seen that as the amount of failure decrease so is the mean time between failures is decreasing, which results in the improvement of the production rate. Now the breakdown hours of this system will be reduced thus there will be no interruption in the flow of part in the different subsystem.

In this work the subsystem have good availability so the increment in the availability of the system is not much but in the industry having low availability of the system this will be more significant and the overall system's availability would be greatly influenced.

## VII. CONCLUSION

Availability of the system is an important aspect for any firm's productivity. Allocating redundant subsystem increases the overall availability of the system and its reliability. In this work a new technique is used to specify a subsystem with series configuration to which a redundant system can be allocated thus reduce the failure rate of the system and increase its availability. This study was based on the fact that failure of a single machine can cause the breakdown of whole system. In order to allocate redundant system multi factor based redundancy allocation number is used and subsystem was selected based on this calculation.

All factors that were used to calculate the RAN had a real weightage on the productivity of the firm and they were considered based on the reports provided by the firms. At last the improvement in the overall availability of the system was checked to show the effect of redundancy allocation.

### Future Scope

This research can be optimized by various methods some of them are discussed here –

- Advanced mathematical tools can be used to optimize the presented model
- Various type of complex connection in system as well as subsystem can be handled by introducing some new factors

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