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INTRODUCTION

REVIEW OF LITERATURE

NEED/IMPORTANCE OF THE STUDY

STATEMENT OF THE PROBLEM

OBJECTIVES

HYPOTHESES

RESEARCH METHODOLOGY

RESULTS & DISCUSSION

FINDINGS

RECOMMENDATIONS/SUGGESTIONS

CONCLUSIONS

SCOPE FOR FURTHER RESEARCH

ACKNOWLEDGMENTS

REFERENCES

APPENDIX/ANNEXURE

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- Bowersox, Donald J., Closs, David J., (1996), "Logistical Management." Tata McGraw, Hill, New Delhi.
- Hunker, H.L. and A.J. Wright (1963), "Factors of Industrial Location in Ohio" Ohio State University, Nigeria.

CONTRIBUTIONS TO BOOKS

- Sharma T., Kwatra, G. (2008) Effectiveness of Social Advertising: A Study of Selected Campaigns, Corporate Social Responsibility, Edited by David Crowther & Nicholas Capaldi, Ashgate Research Companion to Corporate Social Responsibility, Chapter 15, pp 287-303.

JOURNAL AND OTHER ARTICLES

- Schemenner, R.W., Huber, J.C. and Cook, R.L. (1987), "Geographic Differences and the Location of New Manufacturing Facilities," Journal of Urban Economics, Vol. 21, No. 1, pp. 83-104.

CONFERENCE PAPERS

- Garg, Sambhav (2011): "Business Ethics" Paper presented at the Annual International Conference for the All India Management Association, New Delhi, India, 19–22 June.

UNPUBLISHED DISSERTATIONS AND THESES

- Kumar S. (2011): "Customer Value: A Comparative Study of Rural and Urban Customers," Thesis, Kurukshetra University, Kurukshetra.

ONLINE RESOURCES

- Always indicate the date that the source was accessed, as online resources are frequently updated or removed.

WEBSITE

- Garg, Bhavet (2011): Towards a New Natural Gas Policy, Political Weekly, Viewed on January 01, 2012 http://epw.in/user/viewabstract.jsp

INTEGRATED RELIABILITY MODEL AND FAILURE MODES EFFECTS & CRITICALITY ANALYSIS FOR OPTIMUM RELIABILITY

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ABSTRACT
The present research work is on Integrated Reliability Models for Redundant Systems. All most all the models that are reported primarily considered Cost as the basic constraint. In this scenario, the Authors proposed a class of Integrated Reliability Models for Redundant Systems with multiple constraints as a novel beginning in the mentioned area of research and initiated the optimizing the System Reliability for the said model under two different approaches and the results reported in the work is highly useful for the Reliability / Design Engineers for successful implementation which helps to produce highly Reliable and quality goods and the models are established for the Series – Parallel Reliable Configuration Systems. These model can also be further investigated for different mathematical functions of interest and also can be applied for Parallel – Series Configuration Systems, where the application of these models for such systems will be feasible only when the cost of the system is very low. The Authors is of the opinion that the stated problem can be investigated under the scope of study. The Lagrangean Approach has given the Reliability of three stage system is 0.8512 where the number of components are real, which has been increased to 0.937 (10%) by just rounding off the number of components to the nearest integer, since the number of components cannot be real numbers. The system reliability has gone to 0.9113 when calculated scientifically by using Dynamic Programming which has taken care of Cost, Weight, Volume and the number of components is integers.

KEYWORDS
Integrated reliability models, redundant systems.

INTRODUCTION
Reliability Engineering has been extensively developed over the years with a significant contribution by defense personnel, which resulted in developing much more reliable products / services. It is easy to manufacture Cost effective Systems that perform better by blending Reliability concepts in all phases of the product life cycle from proposal to manufacture. The Reliability of a System can be maximized subject to the resource constraint to determine the optimum number of redundant Components for each stage when the Reliability of each Component is known. In other situation, the Reliability of the System can be maximized subject to the resource constraint to determine the Reliabilities of the Components in the System when the number of redundant units in each stage is known. Literature survey reveals the available techniques to solve the problems in these two situations. K.B.MISRA [1972] developed a simple algorithm for the solution of redundant optimization problem. The literature regarding optimization of Integrated Reliability Models for Redundant Systems with Multiple Constraints is scanty in nature, that a few authors in recent times mentioned in their work, that the system could be optimized with multiple constraints like Weight, Volume, Size etc., apart from the basic Cost constraint. One of the pioneers, R. GORDON [1957] expressed the view that the redundant Reliability of a system can be maximized by treating Volume, Weight, and Size etc., as constraints apart from the basic Cost constraint. So far as the literature on maximization of System Reliability problems are concerned, the researchers opined that optimization problems can be handled with multiple constraints also but to the best of the knowledge of the authors, the optimization of Integrated Reliability Models for Redundant Systems with Multiple Constraints are not reported. In this scenario, the authors want to make an attempt to optimize the Reliability of Integrated Reliability Model with multiple constraints, reinforced with Failure Mode Effect & Criticality Analysis.

To study and optimize, the Integrated Reliability Model for Redundant Systems with multiple constraints is considered with Cost, Weight and Volume as constraints, for the given known mathematical function $r_j = \left[\frac{c_j}{b_j}\right]^{\frac{1}{d_j}}$. To establish the results for the above specified mathematical function, Lagrangean Multiplier Method is applied to calculate the number of Components in each stage, Components Reliability and corresponding stage Reliability in real value numbers. Since the number of components in each stage cannot be rounded off to nearest integer due to variation in Cost and Reliability and further to optimize the Integrated Reliability Models for Redundant Systems with Multiple Constraints, the authors used Dynamic Programming. Finally the result of this work supports the researchers' statement of the problem concurring that these Models are particularly of high application value for any Series – Parallel Redundant Systems with multiple constraints.

STATEMENT OF THE PROBLEM
The problem considers the component reliabilities and the no. of components in each stage are unknowns for the given constraints to maximize the System Reliability. The authors in this work make an attempt to negotiate the impact of Weight and Volume as constraints in optimizing the Redundant Systems under consideration for the selected above mathematical function. Though Cost has direct relation in maximizing System Reliability, the indirect impact of Weight and Volume as constraints in optimizing the Reliability of a redundant system presents a novel beginning in the mentioned area of research. The Series – Parallel Systems are considered with Cost, Weight and Volume as constraints to maximize the Reliability of a redundant system as its objective function.

ASSUMPTIONS OF THE MODEL
- ♣ All the components in each stage are assumed to be identical.
- ♣ The components are assumed to be statistically independent i.e. failure of one component does not affect the performance of the other components in the system.
- ♣ A component is either in working condition or non-working condition

MATHEMATICAL MODEL

The objective function and the constraints of the model are

$$\text{Max } R_s = \prod_{j=1}^{n} R_j = \prod_{j=1}^{n} [\,1 - (\,1 - r_j\,)^{x_j}\,]$$

Subjected to

$$\sum_{j=1}^{n} c_j \,.\, x_j \le C_o \qquad \text{.... 1}$$

$$\sum_{j=1}^{n} w_j \,.\, x_j \le W_o \qquad \text{....2}$$

$$\sum_{j=1}^{n} v_j \,.\, x_j \le V_o \qquad \text{....3}$$

Non negativity restriction x_j is an integer and r_j , $R_j > 0$

Where R_s = System Reliability

R_j = Stage Reliability j $0 < Rj < 1$

r_j = Reliability of each component in stage j, $0 < rj < 1$

x_j = No. of components in stage j

c_j = Cost coefficient of each component in stage j

w_j = Weight coefficient of each component in stage j

v_j = Volume coefficient of each component in stage j

C_0 = Maximum allowable System Cost

W_0 = Maximum allowable System Weight

V_0 = Maximum allowable System Volume

System Reliability for the given Cost function is

$$R_s = \prod_{j=1}^{n} R_j$$

Cost coefficient of each component in stage j is derived from the following relationship between Cost and Reliability

$r_j = [\, c_j / b_j \,]^{(1/dj)}$

$c_j = b_j \,.\, r_j^{dj}$ .... Cost Constraint

Similarly using the same relationship Weight and Volume Constraints are

$w_j = p_j \,.\, r_j^{qj}$ .... Weight Constraint

$v_j = k_j \,.\, r_j^{lj}$ .... Volume Constraint

Since Cost constraint is linear in x_j, substituting cj, wj, vj in the respective equations and after simplification the Lagrangean function is formulated as follows

$$F = R_S + \lambda_1\left[\sum_{j=1}^{n}\left\{\left(b_j.r_j^{d_j}\right).\frac{\ln(1-R_j)}{\ln(1-r_j)}\right\} - C_0\right] + \lambda_2\left[\sum_{j=1}^{n}\left\{\left(p_j.r_j^{q_j}\right).\frac{\ln(1-R_j)}{\ln(1-r_j)}\right\} - W_0\right] +$$

$$\lambda_3\left[\sum_{j=1}^{n}\left\{\left(k_j.r_j^{l_j}\right).\frac{\ln(1-R_j)}{\ln(1-r_j)}\right\} - V_0\right]$$

The stationery point can be obtained by differentiating the Lagrangean function with respect to R_j , r_j , λ_1 , λ_2 , and λ_3 and the problem can be re written after simplification.

$$\frac{\partial F}{\partial r_j} = \lambda_1\left[\left\{\sum_{j=1}^{n} b_j.\ln(1-Rj)\left(\ln(1-rj).dj.rj^{d_{j-1}} + \frac{rj^{d_j}}{(1-r_j)}\right)\right\}\right] +$$

$$\lambda_2\left[\left\{\sum_{j=1}^{n} p_j.\ln(1-Rj)\left(\ln(1-rj).pj.rj^{q_{j-1}} + \frac{rj^{q_j}}{(1-r_j)}\right)\right\}\right] + \lambda_3\left[\left\{\sum_{j=1}^{n} k_j.\ln(1-Rj)\left(\ln(1-rj).lj.rj^{l_{j-1}} + \frac{rj^{l_j}}{(1-r_j)}\right)\right\}\right] = 0$$

$$\frac{\partial F}{\partial R_j} = 1 - \lambda_1\left[\sum_{j=1}^{n}\frac{b_j.r_j^{d_j}}{\ln(1-rj)}.\frac{1}{(1-R_j)}\right] - \lambda_2\left[\sum_{j=1}^{n}\frac{p_j.r_j^{q_j}}{\ln(1-rj)}.\frac{1}{(1-R_j)}\right] - \lambda_3\left[\sum_{j=1}^{n}\frac{k_j.r_j^{l_j}}{\ln(1-rj)}.\frac{1}{(1-R_j)}\right] = 0$$

$$\frac{\partial F}{\partial \lambda_1} = \left\{\sum_{j=1}^{n} b_j.rj^{d_j}.\frac{\ln(1-R_j)}{\ln(1-r_j)}\right\} - C_0 = 0$$

$$\frac{\partial F}{\partial \lambda_2} = \left\{ \sum_{j=1}^{n} p_j r_j^{q_j} . \frac{\ln(1-R_j)}{\ln(1-r_j)} \right\} - W_0 = 0$$

$$\frac{\partial F}{\partial \lambda_3} = \left\{ \sum_{j=1}^{n} k_j r_j^{l_j} . \frac{\ln(1-R_j)}{\ln(1-r_j)} \right\} - V_0 = 0$$

CASE

Consider the case of a Mechanical system with three stages for which the component Reliability is given by the equation: : $r_j = \left[\frac{c_j}{b_j} \right]^{\frac{1}{d_j}}$. To determine the optimum Component Reliability (r_j), Stage Reliability (R_j), Number of Components in each stage (x_j), and the System Reliability (R_s) not to exceed the system Cost Rs.200, Weight of the system 400 Kgs and Volume of the system 600 cm^3. The Component Reliabilities, Stage Reliabilities, Number of Components in each stage and the System Reliability are determined by solving the above mathematical function using MATLAB are presented in the following Tables.

COST, WEIGHT & VOLUME AS CONSTRAINTS

Reliability Design relating to Cost, Weight and Volume is shown in the following tables.

STAGE	r_j	R_j	x_j	c_j	$c_j.x_j$
01	0.7875	0.9046	1.52	62.02	94
02	0.7707	0.9664	2.30	22.89	53
03	0.8162	0.9737	2.15	24.40	53
T0TAL COST					200

STAGE	r_j	R_j	x_j	w_j	$x_j.w_j$
01	0.7875	0.9046	1.52	62.02	094
02	0.7707	0.9664	2.30	68.67	158
03	0.8162	0.9737	2.15	68.78	148
T0TAL WEIGHT					400
STAGE	r_j	R_j	x_j	v_j	$x_j.v_j$
01	0.7875	0.9046	1.52	186.04	283
02	0.7707	0.9664	2.30	68.67	158
03	0.8162	0.9737	2.15	73.23	159
T0TAL VOLUME					600

SYSTEM RELIABILITY: Rs= 0.8512

COST, WEIGHT & VOLUME WITH x_j ROUNDING OFF

The Reliability Design is reestablished by considering the values of x_j to be integers (by rounding off the value of x_j to the nearest integer) and the relevant results relating to Cost, Weight and Volume are presented in the following table, further calculated the variation due to Cost, Weight, Volume and System Reliability.

STAGE	r_j	R_j	x_j	c_j	$c_j.x_j$
01	0.7875	0.9548	2	62.02	124
02	0.7707	0.9879	3	22.89	069
03	0.8162	0.9937	3	24.40	073
T0TAL COST					266

System Reliability: Rs = 0.937

STAGE	r_j	R_j	x_j	w_j	$x_j.w_j$
01	0.7875	0.9548	2	62.02	124
02	0.7707	0.9879	3	68.67	206
03	0.8162	0.9937	3	68.78	206
T0TAL WEIGHT					536

STAGE	r_j	R_j	x_j	v_j	$x_j.v_j$
01	0.7875	0.9548	2	186.04	372
02	0.7707	0.9879	3	68.67	206
03	0.8162	0.9937	3	73.23	220
T0TAL VOLUME					798

Variation in Total Cost= 33.0%
Variation in Total Weight = 34.0%
Variation in Total Volume = 33.0 %
Variation in System Reliability = 10.1 %

DYNAMIC PROGRAMMING

To optimize the design by using Dynamic Programming the same case problem discussed in the preceding chapter has been considered by taking the values of Component Reliabilities (r_j), the number of components in each stage (x_j), Stage Reliabilities (R_j) and the System Reliability (R_s) as inputs. This Approach is particularly useful in optimizing the design with the values of x_j's to be integers, which are highly appreciated for practical implementation to real life problems. The necessary program is developed in C Language with inputs taking from the Lagrangean Method. The number of components, which was taken as a real number has been changed to an integer. The output has come in two stages with corresponding Stage Reliability.

DYNAMIC PROGRAMMING – STAGE 1

Number of Components - x_j	Stage Reliability - R_j
01	0.7875
02	0.9548
03	0.9904
04	0.9979
05	0.9995
06	0.9999

DYNAMIC PROGRAMMING – STAGE 2

x_j	STAGE RELIABILITY					
	R_j					
02	0.60					
03	0.73	0.74				
04	0.76	0.90	0.77			
05	0.76	0.93	0.93	0.78		
06	0.77	0.94	0.97	0.95	0.78	
07	0.70	0.94	0.98	0.98	0.95	0.78

DYNAMIC PROGRAMMING – STAGE 3

x_j	STAGE RELIABILITY					
	R_j					
3	0.49					
4	0.60	0.58				
5	0.73	0.72	0.61			
6	0.76	0.87	0.74	0.61		
7	0.79	**0.90**	0.90	0.75	0.61	
8	0.81	0.94	0.93	0.91	0.75	0.61

RELIABILITY DESIGN- COST

From the Dynamic Programming tables the maximum System Reliability is 0.9113 with a total COST of Rs. 242 and the corresponding optimal values are as shown below.

STAGE	r_j	R_j	x_j	c_j	$c_j.x_j$
01	0.7875	0.9548	2	62.02	124
02	0.7707	0.9879	3	22.89	069
03	0.8162	0.9662	2	24.40	049
TOTAL COST					242

RELIABILITY DESIGN - WEIGHT

From the Dynamic Programming tables the maximum System Reliability is 0.9113 with a total WEIGHT of 468 and the corresponding optimal values are as shown below.

STAGE	r_j	R_j	x_j	w_j	$x_j.w_j$
01	0.7875	0.9548	2	62.02	124
02	0.7707	0.9879	3	68.67	206
03	0.8162	0.9662	2	68.78	138
TOTAL WEIGHT					468

RELIABILITY DESIGN -VOLUME

From the Dynamic Programming tables the maximum System Reliability is 0.9113 with a total VOLUME of 725 and the corresponding optimal values are as shown below.

STAGE	r_j	R_j	x_j	v_j	$x_j.v_j$
01	0.7875	0.9548	2	186.1	372
02	0.7707	0.9879	3	68.67	206
03	0.8162	0.9662	2	73.23	147
TOTAL VOLUME					725

System Reliability	=	0.9113
Variation in Total Cost	=	21.0%
Variation in Total Weight	=	17.0%
Variation in Total Volume	=	21.0 %
Variation in System Reliability	=	7.06 %

FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS

Failure Modes Effects & Criticality Analysis is a Novel method of identifying primary functional failures, their related failure modes or states, the effect of the failure modes on the operation of the system and the criticality associated with the failure mode as a function of impact likelihood [5]. This effective tool improves the management of failure modes or enables the removal of failure modes, through application of advanced maintenance techniques, redesign or redundancy.
The total impact of failure of each subsystem in a plant is calculated using the relation:-
Total impact weightage of failure:
$F_{TW} = (A + B + C)^x$
Where
A = Possible effects of failure
B = Criticality of such failure
C = Inverse of the reliability of detection / control mechanism

x = Frequency of failure occurrence

Criticality of each equipment / system / subsystems is decided, based on the total weightage obtained. This is an analysis, which should be implemented during the design phase, to have maximum influence and impact on the final design.

The Failure Modes Effects & Criticality Analysis supports safety engineering effects in analysis such as the FAULT TREE ANALYSIS. The failure modes with their assigned criticality would be seen as basic events. As part of the maintainability analysis, Failure Modes Effects & Criticality Analysis is the importance that detection and isolation is accurately reflected in the overall mean time to repair calculations. This analysis would support the design engineering effort to ensure that programme design requirements are taken care of, which could be in the support of requirements like as no single points of failure.

The Failure Modes Effects & Criticality Analysis & Criticality Analysis can be implemented as a functional analysis and or physical analysis. Functional analysis approach would be taken earlier in a design process. With improved definition of the design and as more details are firmed up then this will permit a physical analysis to be implemented. The analysis effectively provides a contribution to final system configuration, with regards to reliability performance characteristics, during the actual design phase.

It is to be noted that Reliability centered Maintenance treats the symptom while this analysis finds and corrects the cause. That means to say that the purpose of the analysis is to uncover the underlying reasons (root causes) why an event is occurring so that the necessary steps can be taken to eliminate the event in its entirety by analyzing the modes.

CRITICALITY ANALYSIS / CRITICALITY MATRIX:

Once the failure mode is identified in the Failure Modes Effects Analysis, then the purpose of Criticality Analysis is to rank each failures mode according to the severity and the probability of occurrence of the same. This results in a Criticality Matrix.

The failure mode criticality number (C_n) is calculated by using the relation:-

$C_n = \alpha \beta \lambda_p t$

Where,

α = Failure mode ratio

β = Conditional probability of failure effect

λ_p = Part failure rate per million hours

t = Operation time in hours

The criticality number of each system is calculated per each severity category. The criticality number is the sum of the specific failure mode criticality numbers related to the particular severity category.

That is,

$$Cm = \sum_{i=1}^{m} Cn$$

$$= \sum_{i=1}^{m} \alpha \ \beta \ \lambda \mathbf{p} \ t$$

Where, m = Number of models at the particular severity category.

The next step is to divide the criticality scale into a number of sections according to the probability of occurrence to represent Z axis of the criticality matrix.

Level 1, Frequent: The probability which is greater than or equal to 0.2 ($\geq 20\%$) of the overall system probability of failure.

Level 2, Moderate: The probability which is between 0.1 and 0.2 (10 to 20 %) of the overall system probability of failure.

Level 3, Occasional: The probability between 0.01 and 0.1 (1 to 10%) of the overall system probability of failure.

Level 4, Remote: The probability between 0.001 and 0.01 (0.1 to 1%) of the overall system probability of failure.

Level 5, Very unlikely: The probability which is less than 0.001 ($<$ 0.1%) of the overall system probability of failure.

The next step is to calculate the severity classification as follows:

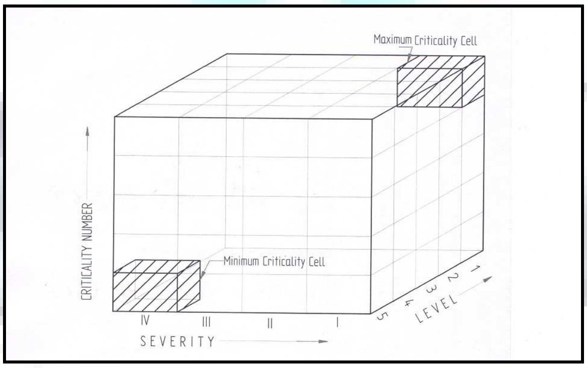
Category I, Catastrophic: A failure that may cause death or total system loss (that is, aircraft, vehicle, missile, ship, Train etc).

Category II, Critical: A failure that may cause severe injury, major property damage, or major system damage, which results in considerable loss.

Category III, Marginal: A failure that may cause minor injury, minor property damage or minor system damage, which results in a delay or degradation.

Category IV, Minor: A failure which is not serious enough to cause injury, property damage or system damage, which results in unscheduled repair or maintenance.

The criticality matrix is constructed as follows:



CONCLUSIONS

Till date not much of work is reported on Integrated Reliability Models for Redundant Systems. All most all the models that are reported primarily considered Cost as the basic constraint. In this scenario, the Authors proposed a class of Integrated Reliability Models for Redundant Systems with multiple constraints as a novel beginning in the mentioned area of research and initiated the optimizing the System Reliability for the said model under two different approaches and the results reported in the work is highly useful for the Reliability / Design Engineers for successful implementation which helps to produce highly Reliable and quality goods and the models are established for the Series – Parallel Reliable Configuration Systems. These model can also be further investigated for different mathematical functions of interest and also can be applied for Parallel – Series Configuration Systems, where the application of these models for such systems will be feasible only when the cost of the system is very low. The Authors is of the opinion that the stated problem can be investigated under the scope of study. The Lagrangean Approach has given the Reliability of three stage system is 0.8512 where the number of components are real, which has been increased to 0.937 (10%) by just rounding off the number of components to the nearest integer, since the number of components cannot be real numbers. The system reliability has gone to 0.9113 when calculated scientifically by using Dynamic Programming which has taken care of Cost, Weight, Volume and the number of components is integers.

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