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## Cascade reliability of stress-strength system for the new Rayleigh-Pareto Distribution

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### Abstract

In This paper we present the estimation of stress strength model by considering cascade stress strength model. The system survives if and only if the strength is greater than stress, otherwise fails. The statistical model is derived to study the cascade and system reliability. Here we assume that all the components are independents and follow the New Rayleigh-Pareto strength stress distribution. The first four cascade reliabilities are obtained for various values of strength-stress parameters. The statistical variation in cascade and system reliability is shown graphically.

**Keywords:** Cascade reliability, new rayleigh pareto distribution, stress-strength model, probability density function

### Introduction

Cascade reliability model is a special type of Stress-Strength model. Reliability may be used as a measure of the system's success in providing its function properly. Mathematically, reliability  $R(t)$  is that a system will be successful in the interval  $(0, t)$ . If  $R(t) = P(T > t)$

for  $t \geq 0$ , where  $T$  is a random variable denoting the failure time.

Cascade systems were first proposed and studied by [1] they have studied an n-cascade reliability for exponential distribution. They evaluate reliability values for a two-cascade system with gamma and normal stress and strength distribution [2]. studied the reliability of a cascade system with normal stress and strength distribution [3]. Rekha and Shyam Sundar have derived an expression of the reliability of an n-cascade system by considering attenuation factor with the same parameter value. For their study, they considered exponential strength and gamma stress distribution [4]. has done a case study of cascade reliability using Weibull distribution [5], has done a case study of cascade reliability with Rayleigh distribution [6] have studied cascade reliability of stress-strength system considering strength follows mixed exponential distribution [7]. has done comparison of an n-cascade system by considering normal stress and exponential strength distribution [8]. studied the reliability analysis of a redundant cascade system by using Markovian approach assuming n-components which are arranged in the hierarchical order. The n-cascade system survive with loss of m components by k number of attacks [9]. studied about estimation of reliability for stress-strength cascade model by comparison between estimators made using data obtained through simulation experiment [9-12] has done a cascade and system reliability for Exponential distribution.

In this paper we determined a statistical model of New Rayleigh-Pareto strength-stress distribution which are considered for computations of marginal and system reliabilities supported by reliability computations with numerical and graphical study along with various values.

### Statistical Model

Let us consider the New Rayleigh Pareto distribution with probability density function (pdf)

$$g(x) = \frac{1}{2\sigma^2} \frac{\lambda}{\alpha} x^{\lambda-1} e^{-\frac{1}{2\sigma^2} \left(\frac{x}{\alpha}\right)^2} \quad \text{Where } 0 < x < \infty, \lambda > 0, \alpha > 0, \sigma > 0 \quad (1)$$

The cumulative distribution function (cdf) of the NRPD is given by

$$G(x) = 1 - e^{-\frac{1}{2\sigma^2}\left(\frac{x}{\alpha}\right)^\lambda} \quad \text{Where } 0 < x < \infty, \lambda > 0, \alpha > 0, \sigma > 0 \tag{2}$$

Where  $\alpha > 0, \sigma > 0$  is a scale parameters and  $\lambda > 0$  is the shape parameter

The hazard function is

$$h(x) = \frac{1}{2\sigma^2} \frac{\lambda}{\alpha} x^{\lambda-1}$$

Time to failure is given by

$$F(t) = 1 - \exp\left[-\frac{1}{2\sigma^2} \int_0^t h(x) dx\right]$$

$$= 1 - \exp\left[-\int_0^t \frac{1}{2\sigma^2} \frac{\lambda}{\alpha} x^{\lambda-1} dx\right]$$

By integrating we get

$$F(t) = 1 - e^{-\frac{1}{2\sigma^2}\left(\frac{t}{\alpha}\right)^\lambda}$$

Let  $X$  denotes the strength and  $Y$  denotes the stress. The reliability of the component is given by

$$R = P(X > Y) = \int_0^\infty \left( \int_y^\infty g(x) dx \right) f(y) dy$$

$$= \int_0^\infty \bar{G}(y) f(y) dy \tag{3}$$

Where  $g(x)$  and  $f(y)$  are probability density functions of  $X$  and  $Y$  respectively.  $G(y)$  be the distribution function of  $Y$  and

$$\bar{G}(y) = 1 - G(y).$$

Let  $X_1, X_2, X_3, \dots, X_n$  be the strength of the  $n$  components arranged in order of activation respectively, having probability density function. Let another random variable  $Y$  is the stress imposed on the  $n$  components, having probability density function. The system survives up to failure of first  $(n - 1)$  components i.e.,  $X_i < Y ; i = 1, 2, 3, \dots, (n - 1)$  and  $X_n > Y$ , The system reliability  $R_s(n)$  is given by

$$R_s(n) = R_1 + R_2 + R_3 + R_4 + \dots + R_n \tag{4}$$

The marginal reliability  $R_n$  is the reliability of the system for the  $n^{\text{th}}$  component is given by

$$R_n = P(X_1 < Y, X_2 < Y, X_3 < Y, X_4 < Y, \dots, X_{n-1} < Y, X_n > Y) \tag{5}$$

$$R_n = \int_0^\infty \left[ \int_0^y g_1(x_1) dx_1 \times \int_0^y g_2(x_2) dx_2 \times \int_0^y g_3(x_3) dx_3 \times \int_0^y g_4(x_4) dx_4 \dots \times \int_0^y g_{n-1}(x_{n-1}) dx_{n-1} \times \int_0^y g_n(x_n) dx_n \right] f(y) dy$$

$$R_n = \int_0^{\infty} G_1(y)G_2(y)\dots G_n(y)\overline{G}(y)f(y)dy \quad (6)$$

Where,

$$G_i(y) = \int_0^y g_i(x_i)dx_i, i = 1, 2, 3, \dots, n$$

and

$$\overline{G}_i(y) = 1 - G_i(y)$$

### 3. Reliability Computation

Let us consider the New Rayleigh Pareto distribution with probability density functions (pdf's)

of  $X$  and  $Y$ .

Let  $X$  represents the strength of an component with density function

$$g(x) = \frac{1}{2\sigma_1^2} \frac{\lambda_1}{\alpha^{\lambda_1}} x^{\lambda_1-1} e^{-\frac{1}{2\sigma_1^2}\left(\frac{x}{\alpha}\right)^{\lambda_1}}, 0 < x < \infty, \lambda_1 > 0, \alpha > 0, \sigma_1 > 0 \quad (7)$$

Where  $\alpha, \sigma_1$  are the scale parameters and  $\lambda_1$  is the shape parameter and its distribution function is given by

$$G(x) = 1 - e^{-\frac{1}{2\sigma_1^2}\left(\frac{x}{\alpha}\right)^{\lambda_1}} \quad \text{Where } 0 < x < \infty, \lambda_1 > 0, \alpha > 0, \sigma_1 > 0 \quad (8)$$

and the probability density function of stress  $Y$  is given by

$$f(y) = \frac{1}{2\sigma_2^2} \frac{\lambda_2}{\alpha^{\lambda_2}} y^{\lambda_2-1} e^{-\frac{1}{2\sigma_2^2}\left(\frac{y}{\alpha}\right)^{\lambda_2}}, 0 < y < \infty, \lambda_2 > 0, \alpha > 0, \sigma_2 > 0 \quad (9)$$

Where  $\lambda_2$  and  $\alpha, \sigma_2$  are the shape parameter and scale parameters respectively. and its probability distribution function is given by

$$F(y) = 1 - e^{-\frac{1}{2\sigma_2^2}\left(\frac{y}{\alpha}\right)^{\lambda_2}}, 0 < y < \infty, \lambda_2 > 0, \alpha > 0, \sigma_2 > 0 \quad (10)$$

Then from (6), we evaluate cascade reliability.

a) 1-cascade reliability,

$$\begin{aligned} R_1 &= P(X_1 > Y) = \int_0^{\infty} \overline{G}_1(y) f(y) dy \\ &= \int_0^{\infty} e^{-\frac{1}{2\sigma_1^2}\left(\frac{y}{\alpha}\right)^{\lambda_1}} \frac{1}{2\sigma_2^2} \frac{\lambda_2}{\alpha^{\lambda_2}} y^{\lambda_2-1} e^{-\frac{1}{2\sigma_2^2}\left(\frac{y}{\alpha}\right)^{\lambda_2}} dy \\ &= \frac{\lambda_2 \sigma_1^2}{\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2} \end{aligned}$$

b) 2-cascade reliability,

$$R_2 = P(X_1 > Y, X_2 > Y) = \int_0^\infty G_1(y) \bar{G}_2(y) f(y) dy$$

$$= \int_0^\infty \left( 1 - e^{-\frac{1}{2\sigma_1^2} \left(\frac{y}{\alpha}\right)^{\lambda_1}} \right) e^{-\frac{1}{2\sigma_2^2} \left(\frac{y}{\alpha}\right)^{\lambda_2}} \frac{1}{2\sigma_2^2} \frac{\lambda_2}{\alpha^{\lambda_2}} y^{\lambda_2-1} e^{-\left(\frac{y}{\alpha}\right)^{\lambda_2}} dy$$

$$= \frac{\lambda_1 \sigma_2^2 \lambda_2 \sigma_1^2}{(\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)(2\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)}$$

Similarly,

c) 3- cascade reliability,

$$R_3 = \frac{2\lambda_1^2 (\sigma_2^2)^2 \lambda_2 \sigma_1^2}{(\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)(2\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)(3\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)}$$

d) 4- cascade reliability,

$$R_4 = \frac{6\lambda_1^3 (\sigma_2^2)^3 \lambda_2 \sigma_1^2}{(\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)(2\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)(3\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)(4\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)}$$

In general an n- cascade reliability,

$$R_n = \frac{(n-1)! \lambda_1^{n-1} (\sigma_2^2)^{n-1} \lambda_2 \sigma_1^2}{\prod_{i=1}^n (i\lambda_1 \sigma_2^2 + \lambda_2 \sigma_1^2)} \tag{11}$$

**4. Simulation and Graphical Study**

In this section, the simulation work and graphical presentation by determining cascade and system reliability is carried out. In the table 1 strength parameter is constant i.e., 4 and stress parameter is steadily increasing it from 1 to 7.5. In the table 2 stress parameter is constant i.e., 4 and the strength parameter steadily increasing it from 1 to 7.5. In the table 3 strength parameter is increasing it from 1 to 7.5 and stress parameter decreasing it from 7.5 to 1. In table 4 stress parameter is increasing it from 1 to 7.5 and strength parameter is decreasing it from 7.5 to 1. In table 5 stress parameter increasing it from 1 to 7.5 and by taking scale parameters  $\sigma_1 = 0.1581, \sigma_2 = 0.25$  strength parameter is steadily increasing from 1 to 7.5. In table 6 strength parameter is constant and by taking scale parameters  $\sigma_1 = 0.5, \sigma_2 = 0.25$  stress parameter is increasing from 1 to 7.5. Now we determine the cascade reliability by using (11) and then next compute the system reliability using (4). Next we plot the graphs by taking the progressive values of strength and stress against cascade and system reliability respectively.

**Table 1:** Cascade and system reliability

$\lambda_1$	$\lambda_2$	$\sigma_1^2$	$\sigma_2^2$	<b>R<sub>1</sub></b>	<b>R<sub>2</sub></b>	<b>R<sub>3</sub></b>	<b>R<sub>4</sub></b>	<b>R<sub>s</sub></b>
4	1	1	1	0.2	0.088889	0.054701	0.038612	0.38220211
4	1.25	1	1	0.238095	0.10296	0.062165	0.043245	0.44646486
4	1.5	1	1	0.272727	0.114833	0.068049	0.046662	0.50227083
4	1.75	1	1	0.304348	0.124861	0.072646	0.049113	0.55096759
4	2	1	1	0.333333	0.133333	0.07619	0.050794	0.59365079
4	2.25	1	1	0.36	0.140488	0.07887	0.05186	0.63121811
4	2.5	1	1	0.384615	0.14652	0.080839	0.052436	0.66441015
4	3	1	1	0.428571	0.155844	0.083117	0.052495	0.72002734
4	3.5	1	1	0.466667	0.162319	0.083777	0.051555	0.76431834
4	4	1	1	0.5	0.166667	0.083333	0.05	0.8

4	4.5	1	1	0.529412	0.169412	0.082139	0.048081	0.82904395
4	5	1	1	0.555556	0.17094	0.080442	0.045967	0.85290526
4	5.5	1	1	0.578947	0.17154	0.078418	0.043768	0.87267393
4	6	1	1	0.6	0.171429	0.07619	0.041558	0.88917749
4	6.5	1	1	0.619048	0.170772	0.073847	0.039385	0.90305182
4	7	1	1	0.636364	0.169697	0.071451	0.037279	0.91479093
4	7.5	1	1	0.652174	0.168303	0.069047	0.035258	0.92478245

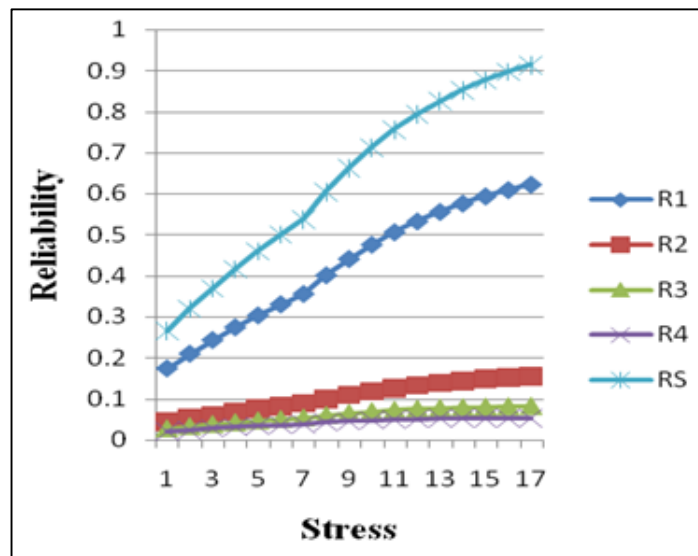


Fig 1: Cascade and system reliability (for constant strength parameter ' $\lambda_1$ ')

Table 2: Cascade and system reliability

$\lambda_1$	$\lambda_2$	$\sigma_1^2$	$\sigma_2^2$	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$
1	4	1	1	0.8	0.133333	0.038095	0.014286	0.98571429
1.25	4	1	1	0.761905	0.14652	0.047265	0.019694	0.97538304
1.5	4	1	1	0.727273	0.155844	0.055004	0.024752	0.96287242
1.75	4	1	1	0.695652	0.162319	0.061418	0.029313	0.94870206
2	4	1	1	0.666667	0.166667	0.066667	0.033333	0.93333333
2.25	4	1	1	0.64	0.169412	0.070917	0.036822	0.91715037
2.5	4	1	1	0.615385	0.17094	0.074322	0.039815	0.90046186
3	4	1	1	0.571429	0.171429	0.079121	0.044505	0.86648352
3.5	4	1	1	0.533333	0.169697	0.081923	0.047788	0.83274121
4	4	1	1	0.5	0.166667	0.083333	0.05	0.8
4.5	4	1	1	0.470588	0.162896	0.083775	0.051407	0.76866663
5	4	1	1	0.444444	0.15873	0.083542	0.052214	0.73893066
5.5	4	1	1	0.421053	0.154386	0.082841	0.052572	0.71085218
6	4	1	1	0.4	0.15	0.081818	0.052597	0.68441558
6.5	4	1	1	0.380952	0.145658	0.080577	0.052375	0.65956255
7	4	1	1	0.363636	0.141414	0.079192	0.05197	0.63621212
7.5	4	1	1	0.347826	0.1373	0.077717	0.05143	0.61427298

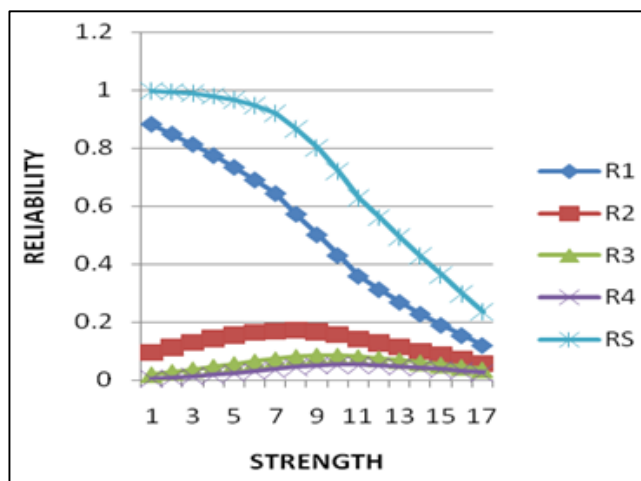
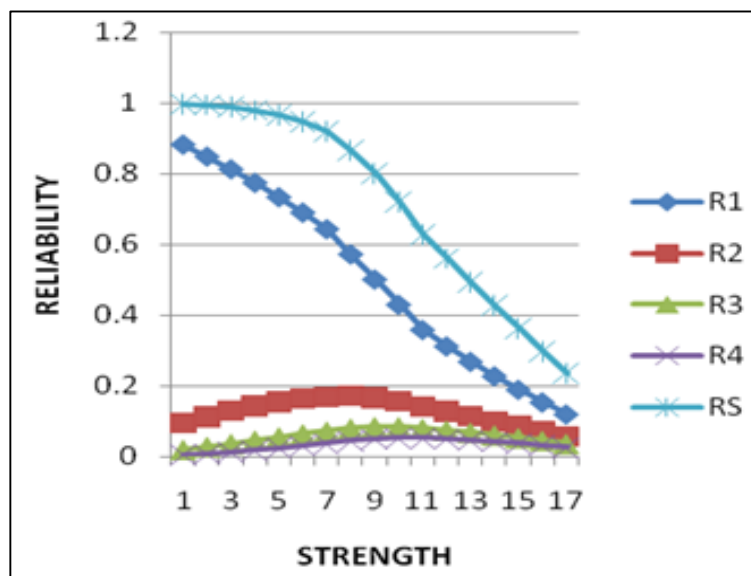


Fig 2: Cascade and system reliability (for constant stress parameter ' $\lambda_2$ ')

**Table 3:** Cascade and system reliability

$\lambda_1$	$\lambda_2$	$\sigma_1^2$	$\sigma_2^2$	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$
1	7.5	1	1	0.882353	0.09288	0.017691	0.00462	0.99754
1.25	7	1	1	0.848485	0.11164	0.025963	0.00811	0.9942
1.5	6.5	1	1	0.8125	0.12829	0.034988	0.0126	0.98837
1.75	6	1	1	0.774194	0.14261	0.044369	0.01792	0.9791
2	5.5	1	1	0.733333	0.15439	0.053699	0.02387	0.96529
2.25	5	1	1	0.689655	0.16334	0.062556	0.03016	0.94571
2.5	4.5	1	1	0.642857	0.16917	0.070489	0.03646	0.91898
3	4	1	1	0.571429	0.17143	0.079121	0.04451	0.86648
3.5	3.5	1	1	0.5	0.16667	0.083333	0.05	0.8
4	3	1	1	0.428571	0.15584	0.083117	0.05249	0.72003
4.5	2.5	1	1	0.357143	0.13975	0.07861	0.05177	0.62727
5	2.25	1	1	0.310345	0.12667	0.073433	0.04951	0.55995
5.5	2	1	1	0.266667	0.11282	0.067082	0.04612	0.49269
6	1.75	1	1	0.225806	0.09853	0.059869	0.04185	0.42606
6.5	1.5	1	1	0.1875	0.08405	0.052032	0.0369	0.36048
7	1.25	1	1	0.151515	0.06955	0.043761	0.03142	0.29624
7.5	1	1	1	0.117647	0.05515	0.0352	0.02555	0.23354



**Fig 3:** Cascade and system reliability (for increasing strength parameter ' $\lambda_1$ ')

**Table 4:** Cascade and system reliability

$\lambda_1$	$\lambda_2$	$\sigma_1^2$	$\sigma_2^2$	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$
7.5	1	1	1	0.117647	0.055147	0.0352	0.025549	0.23354294
7	1.25	1	1	0.151515	0.069548	0.043761	0.031418	0.29624139
6.5	1.5	1	1	0.1875	0.084052	0.052032	0.036895	0.36047918
6	1.75	1	1	0.225806	0.098534	0.059869	0.04185	0.42605866
5.5	2	1	1	0.266667	0.112821	0.067082	0.046119	0.49268884
5	2.25	1	1	0.310345	0.126671	0.073433	0.049505	0.55995403
4.5	2.5	1	1	0.357143	0.139752	0.07861	0.051768	0.62727238
4	3	1	1	0.428571	0.155844	0.083117	0.052495	0.72002734
3.5	3.5	1	1	0.5	0.166667	0.083333	0.05	0.8
3	4	1	1	0.571429	0.171429	0.079121	0.044505	0.86648352
2.5	4.5	1	1	0.642857	0.169173	0.070489	0.03646	0.91897848
2.25	5	1	1	0.689655	0.163339	0.062556	0.030161	0.94571076
2	5.5	1	1	0.733333	0.154386	0.053699	0.023866	0.96528519
1.75	6	1	1	0.774194	0.142615	0.044369	0.017918	0.97909538
1.5	6.5	1	1	0.8125	0.128289	0.034988	0.012596	0.98837321
1.25	7	1	1	0.848485	0.111643	0.025963	0.008114	0.99420459
1	7.5	1	1	0.882353	0.092879	0.017691	0.004615	0.9975386

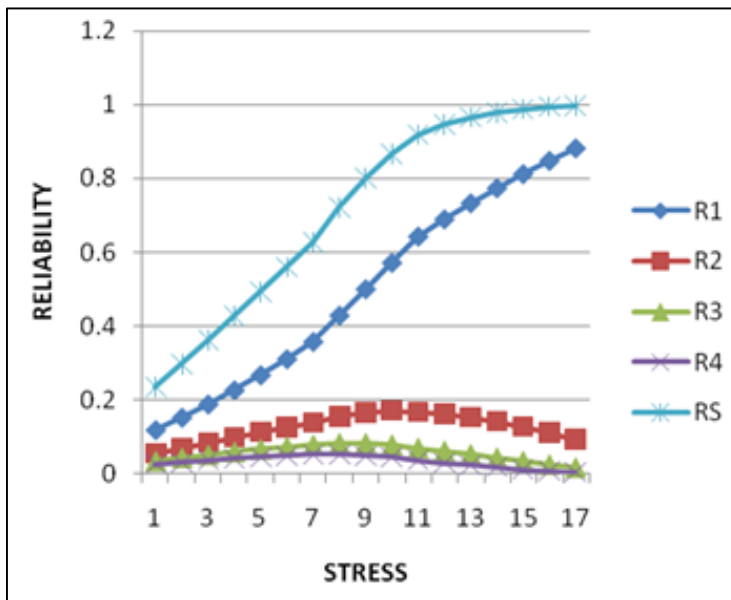


Fig 4: Cascade and system reliability (for increasing stress parameter ' $\lambda_2$ ')

Table 5: Cascade and system reliability

$\lambda_1$	$\lambda_2$	$\sigma_1^2$	$\sigma_2^2$	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>	R <sub>4</sub>	R <sub>s</sub>
4	1	0.025	0.0625	0.090909	0.04329	0.027929	0.0204	0.18256
4	1.25	0.025	0.0625	0.111111	0.05229	0.033464	0.0243	0.2212
4	1.5	0.025	0.0625	0.130435	0.06067	0.038519	0.0278	0.25747
4	1.75	0.025	0.0625	0.148936	0.06848	0.043135	0.031	0.29154
4	2	0.025	0.0625	0.166667	0.07576	0.047348	0.0338	0.32359
4	2.25	0.025	0.0625	0.183673	0.08255	0.051194	0.0364	0.35377
4	2.5	0.025	0.0625	0.2	0.08889	0.054701	0.0386	0.3822
4	3	0.025	0.0625	0.230769	0.10033	0.060809	0.0424	0.43434
4	3.5	0.025	0.0625	0.259259	0.11032	0.065865	0.0454	0.48087
4	4	0.025	0.0625	0.285714	0.11905	0.070028	0.0477	0.52254
4	4.5	0.025	0.0625	0.310345	0.12667	0.073433	0.0495	0.55995
4	5	0.025	0.0625	0.333333	0.13333	0.07619	0.0508	0.59365
4	5.5	0.025	0.0625	0.354839	0.13915	0.078396	0.0517	0.62408
4	6	0.025	0.0625	0.375	0.14423	0.080128	0.0523	0.65162
4	6.5	0.025	0.0625	0.393939	0.14866	0.081456	0.0526	0.6766
4	7	0.025	0.0625	0.411765	0.15251	0.082435	0.0526	0.69932
4	7.5	0.025	0.0625	0.428571	0.15584	0.083117	0.0525	0.72003

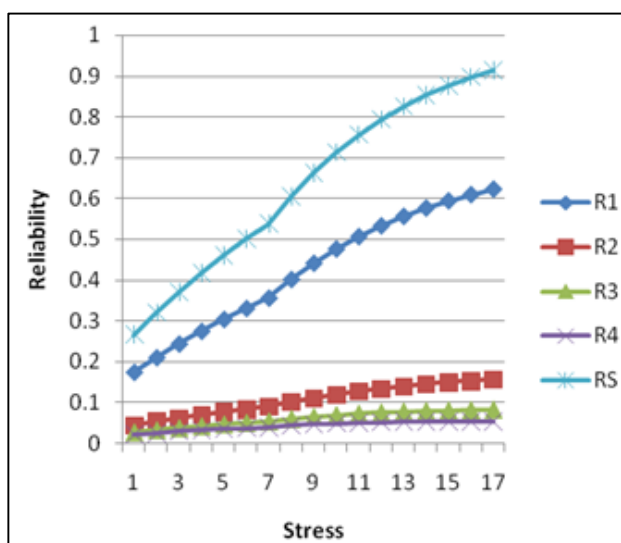
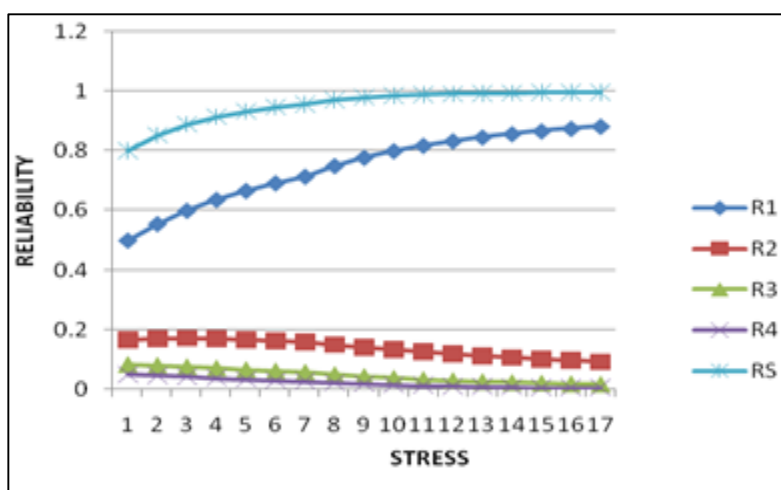


Fig 5: Cascade and system reliability (for increasing stress parameter ' $\lambda_2$ ' and scale parameters  $\sigma_1 = 0.1581$  and  $\sigma_2 = 0.25$ )

**Table 6:** Cascade and system reliability

$\lambda_1$	$\lambda_2$	$\sigma_1^2$	$\sigma_2^2$	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$
4	1	0.25	0.0625	0.5	0.16667	0.083333	0.05	0.8
4	1.25	0.25	0.0625	0.555556	0.17094	0.080442	0.04597	0.85291
4	1.5	0.25	0.0625	0.6	0.17143	0.07619	0.04156	0.88918
4	1.75	0.25	0.0625	0.636364	0.1697	0.071451	0.03728	0.91479
4	2	0.25	0.0625	0.666667	0.16667	0.066667	0.03333	0.93333
4	2.25	0.25	0.0625	0.692308	0.1629	0.062056	0.02979	0.94705
4	2.5	0.25	0.0625	0.714286	0.15873	0.05772	0.02664	0.95738
4	3	0.25	0.0625	0.75	0.15	0.05	0.02143	0.97143
4	3.5	0.25	0.0625	0.777778	0.14141	0.043512	0.0174	0.98011
4	4	0.25	0.0625	0.8	0.13333	0.038095	0.01429	0.98571
4	4.5	0.25	0.0625	0.818182	0.12587	0.033566	0.01185	0.98947
4	5	0.25	0.0625	0.833333	0.11905	0.029762	0.00992	0.99206
4	5.5	0.25	0.0625	0.846154	0.11282	0.026546	0.00838	0.9939
4	6	0.25	0.0625	0.857143	0.10714	0.02381	0.00714	0.99524
4	6.5	0.25	0.0625	0.866667	0.10196	0.021465	0.00613	0.99623
4	7	0.25	0.0625	0.875	0.09722	0.019444	0.0053	0.99697
4	7.5	0.25	0.0625	0.882353	0.09288	0.017691	0.00462	0.99754



**Fig 6:** Cascade and system reliability (for constant strength parameter ' $\lambda_1$ ' and Scale parameters  $\sigma_1 = 0.5$  and  $\sigma_2 = 0.25$ )

**Conclusion**

In this paper the reliability formulae for an n-cascade system using new rayleigh-pareto strength-stress distribution is found out. We observe that the system reliability  $R_s$  reaches to 0.99 i.e., unity (one) if we choose strength parameter constant and stress parameter steadily increasing. In addition, if we increase strength parameter and decrease stress parameter the cascade reliability little bit increases and then decreases but the system reliability steadily increases and reaches to unity (one). Hence we conclude that the cascade and system reliability is found to be constant if strength and stress parameters are steadily increasing.

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