# Stochastic System Simulation for Cyber and Power CLOUDS

Mehmet Sahinoglu and Preethi Vasudev

***Abstract*—Generally in Cyber and/or Power Grid modeling and simulations; failure rate, repair rate, and capacity of servers or generators and transmission lines or links, load (demand) on grid and count of repair crew are collected as deterministic constants from external sources. CLOURAM is a risk assessment and management application that has been used to emulate a grid, where simulation is applied using failure and repair rates for a given group whose assigned failure and repair rate data and load remain constant across iterations. In this modified version of CLOURAM through Stochastic Simulation of CLOUD parameters such as failure and repair rates and the load cycle for a Power Grid scenario, the CLOUD metrics are compared favorably to those employing deterministic data. Further, grid producer and link scenarios will be studied.**

***Index Terms*— Bayesian Gamma, CLOUD, LOLP, Monte Carlo, Stochastic Simulation**

## I. Introduction and Methodology

For a Power or Cyber Grid scenario, the following features are provided; that is, one is expected to:

- Specify generator or server (both producers) and transmission line (or link) failure and repair rates separately.
- Study effect of different load distributions using stochastic simulation. Load probability distributions supported are Normal and Uniform probability densities.
- Study effect of different failure distributions using stochastic simulation. Failure probability distributions supported are Gamma (Bayesian) and Uniform alternatively upon choice.
- Study effect of different repair distributions using stochastic simulation. Repair probability distributions supported are similarly Gamma and Uniform.

In the following studies, the large power or cyber CLOUD system of 348 units (data95.txt) will be taken as an example as in Fig.1. in the APPENDIX to follow and compare with.

A new menu item 'Stochastic Simulation' (SS) is added to 'Simulation' menu in CLOURAM (*CLOU*d *R*isk *A*ssessment and *M*anagement) studied in detail as follows in Fig.2. NS will denote non-stochastic simulation.

Manuscript received October 10, 2014; revised January 15, 2015; accepted March 20, 2015.

Mehmet Sahinoglu and Preethi Vasudev are both with the Informatics Institute, Cybersystems and Information Security, Auburn University Montgomery, Montgomery, AL, USA 36117. (email: msahinog@aum.edu; preegrad@gmail.com)

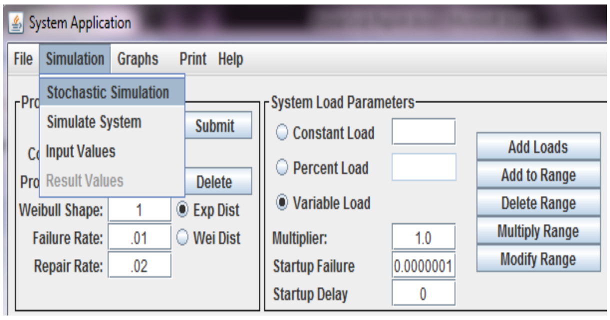


Fig. 2. The appending of Stochastic Simulation to CLOURAM as a new icon to choose from.

User inputs normally collected grid data in one of the following ways:

1. Input wizard.
2. Manual entry for each group.
3. Import data that was saved earlier in CLOURAM required format.

The following Fig. 3 displays the initial screen when user clicks Stochastic Simulation after importing data.

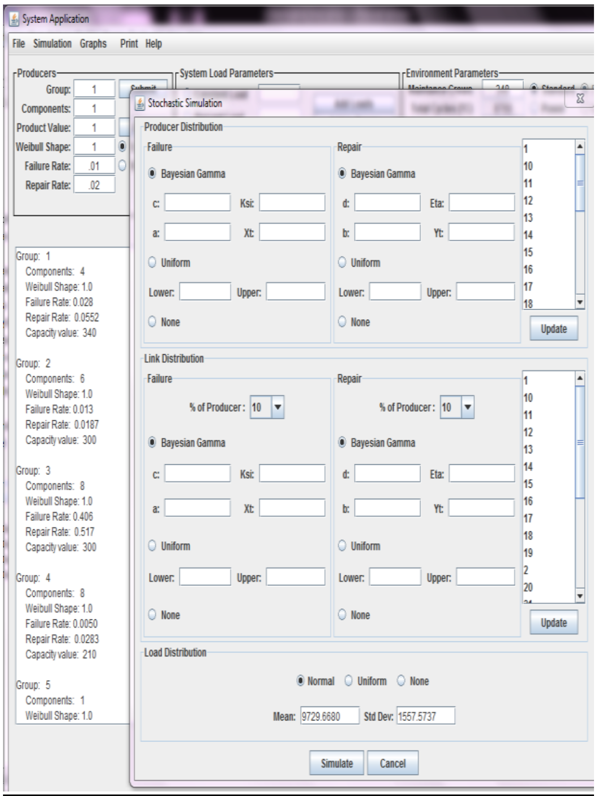


Figure 3. The initial screen to start the Stochastic Simulation.

Now, the article will study different cases of input data for executing Stochastic Simulation.

*A. Producer Distributions (when data is in Negative Exponential)*

For producer group 1 with failure rate = 0.028 and repair rate = 0.0552, flat (non-informative) parameters are c = ksi= d = eta = 0, a = 28, $X_t$ = 1000, b = 552 and $Y_t$ = 10000. This data is inspired from large CLOUD input (data95.txt) in Ref. [1, Fig. 17, p.63]. To generate random failure and repair rates, the empirical Bayesian Gamma distribution is used [2, Chap. 5]. See Fig. 4.

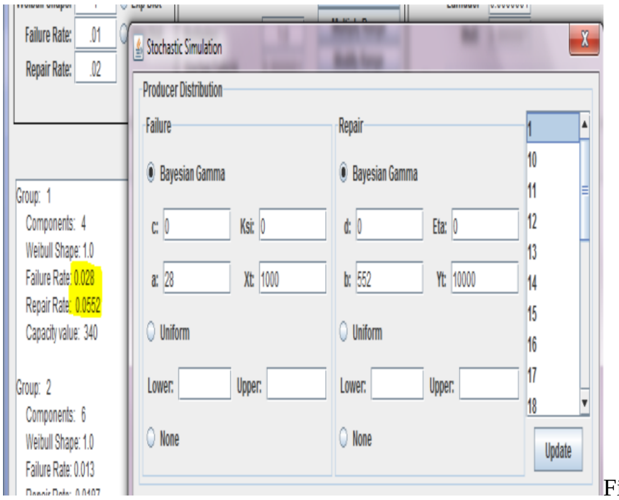


Figure 4. Dialog box when Producer probability distribution is Negative Exponential.

*C. Producer Distributions (when data is in Weibull)*

For Producer Group 1 with failure scale = 35.714 and repair scale = 18.12, where both shapes =1 (special case) for neg. exponential, parameters are c = ksi= d = eta = 0, a = 28, $X_t$ = 1000, b = 552 and $Y_t$ = 10000. See Fig. 5.

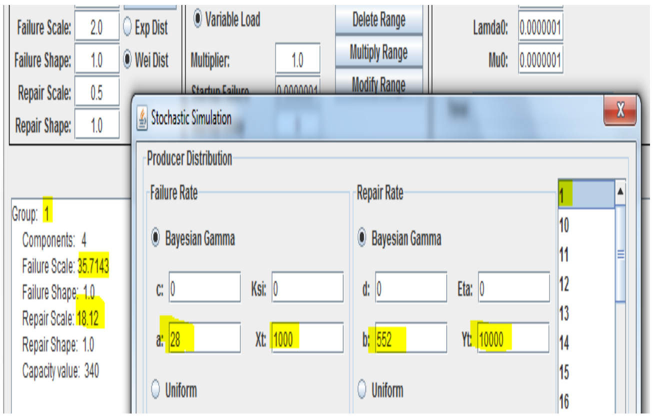


Figure 5. Dialog box when Producer probability distribution is in Weibull.

*D. Link Distributions (when data is Negative Exponential or Weibull) with Uniform and Bayesian Gamma applied*

First, transmission failures and repair rates are computed by applying rules when the producer data is in Weibull or Neg. Exponential. Then link failure rate = +10% of the producer failure rate and repair rate = +10% of the producer repair rate as an initiating example. Other parameters follow the same rules as above. See Fig. 6 and 7 and 8.

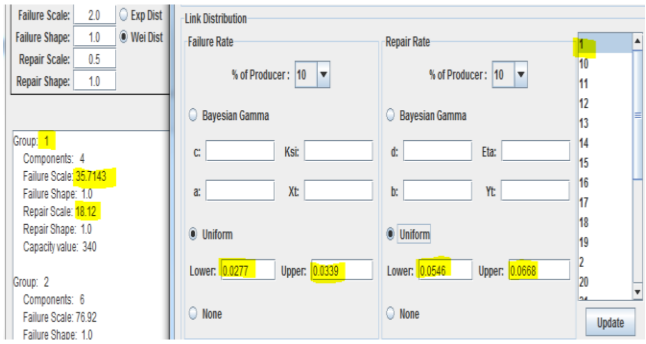


Figure 6. Dialog box when Producer probability distribution is in Weibull and link probability distribution is in Uniform.

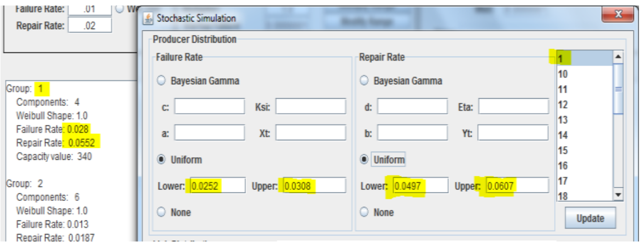


Figure 7. If uniform is used, default values are +/- 10% of corresponding rates for lower and upper with Producer probability distribution in Negative Exponential.

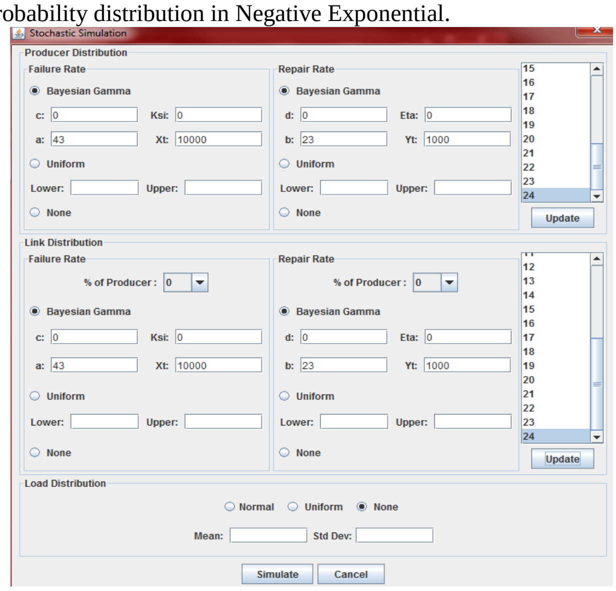


Figure 8. Links are Bayesian Gamma same as Producers.

## II. Numerical Applications for Stochastic Simulation to Verify Nonstochastic

*A. Stochastic Simulation with Bayesian Gamma Input for Producers and Normal for Load with perfect links*

Taking the same example as in I-A the first step is to express the rate as a ratio; e.g., failure rate 0.028 is identical to 28/1000. Now, a numerator is assigned to 'a' and a denominator is assigned to ‘$X_t$’ and also the prior parameters “c” and “ksi” are set to zero. Along the same line, the repair rate 0.0552 is 552 / 10000 => ‘b’ = 552; ‘$Y_t$’ = 10000. “d” and “**η**” (eta) are set to zero. See Fig. 9 for input data and Fig. 10 for output results.

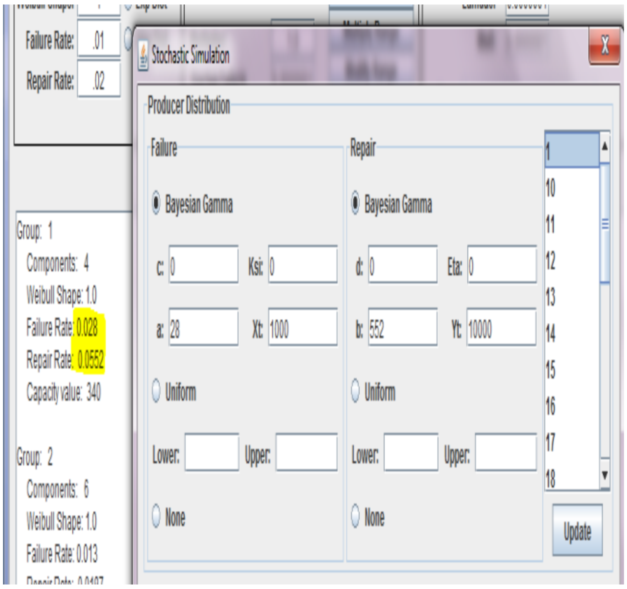

Figure 9. Bayesian Gamma probability distribution input template for Stochastic Simulation

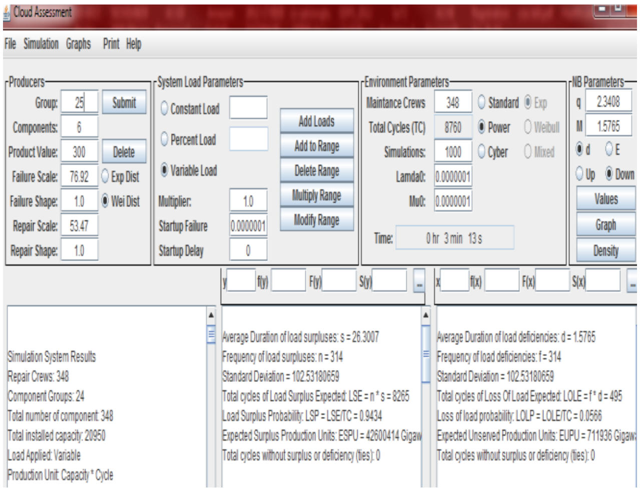

Figure 10. The SS LOLP = 5.66% and NS LOLP= 5.49% for 348-unit system with Load random; Result: Outputs nearly same

*B. Stochastic Simulation with equal Failure & Repair Uniform variation for Links and Normal for Load when Producer data is in Neg. Exponential*

Let’s see the effect of varying link (transmission line in case of a Power or Cyber Grid) failure and repair rates using the Negative Exponential. So, taking link failure and repair rates identical as +10% and LOAD mean = 9729.67, and LOAD standard deviation = 1557.5; we get an output not much changed due to 10% increases in failure and repair rates offsetting each other. See Fig. 11 and 12.

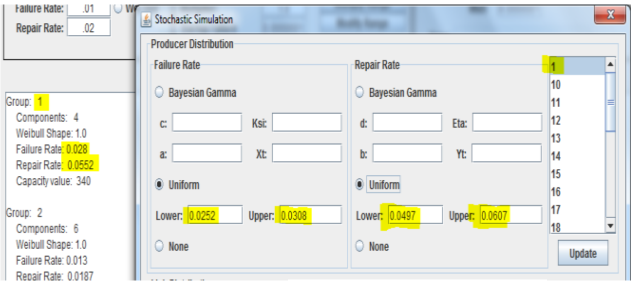

Figure 11. If uniform is used, default values are +10% of corresponding rates for lower and upper.

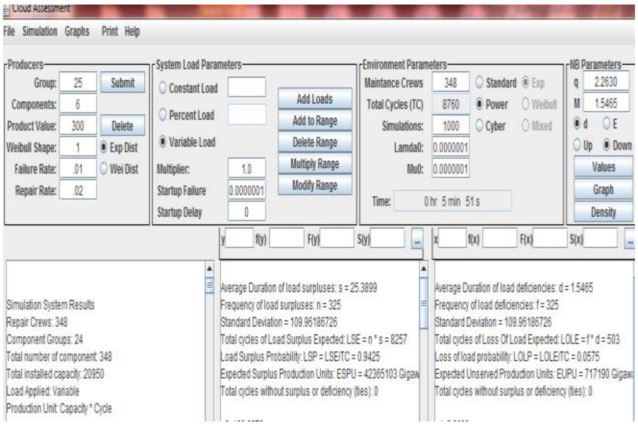

Figure 12. LOLP=5.75%, not much changed from %5.49 when Figure’s 11 stochastic input data applied to links with else same.

LOLP (Loss of Load Probability) as in Fig. 12 revolves around the same; 5.75% as in the original non-stochastic (NS) result of 5.49% since increased failure rate of links has been offset by an equal increase in their repair rates.

*C. Stochastic Simulation with unequal Failure & Repair Rates Uniform variation for Links with all else the same*

LOLP (Loss of Load Probability) as expected decreases to 4.24% from 5.49 due to 20% increase in the repair rates (better maintenance) compared to 10% in the failure rates. See Fig.13.

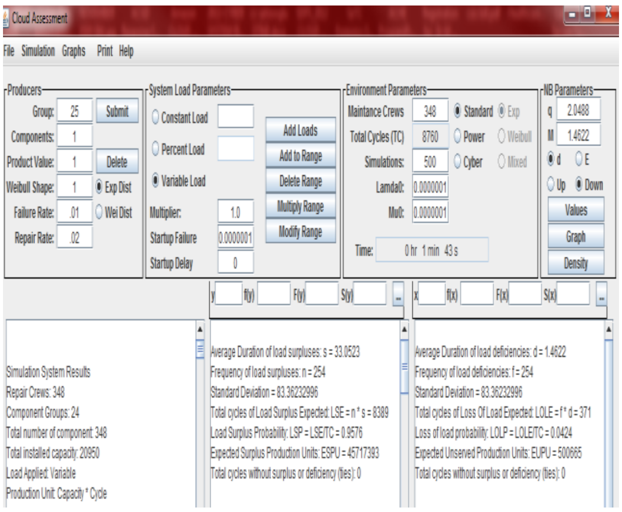

Figure 13. LOLP=4.24%. i.e. around 20% improved from %5.49 when both changes were identical =10%.

## III. Error Checking or Flagging for Stochastic Simulation Runs

Error checks are made at every stage of stochastic simulation. Error condition could be one such that user clicks Stochastic Distribution before loading groups' production and load data, or one clicks update button without inputting both values required for given distribution or selecting group from right-hand list first, and similar.

### *A. When and If Groups and Load Are Not Defined*

We will get a warning sign that says, "A Stochastic Simulation cannot be performed". See Fig. 14.

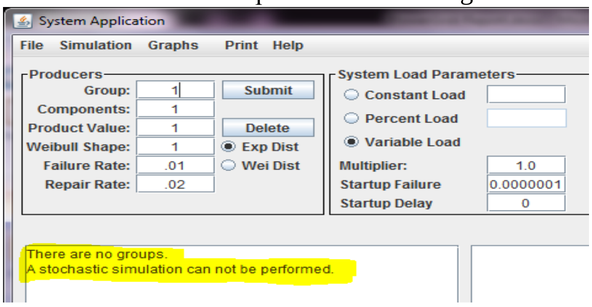


Figure 14. Red-flag warning if groups are not defined.

### *B. When and If Groups and Load Are Not Defined*

We will get a warning sign that says, "Please make a selection from the list". See Fig. 15.

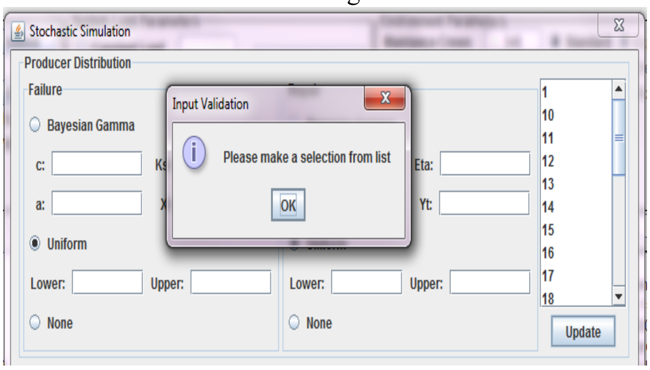


Figure 15. Red-flag warning when user fails to update the group whose data is being modified.

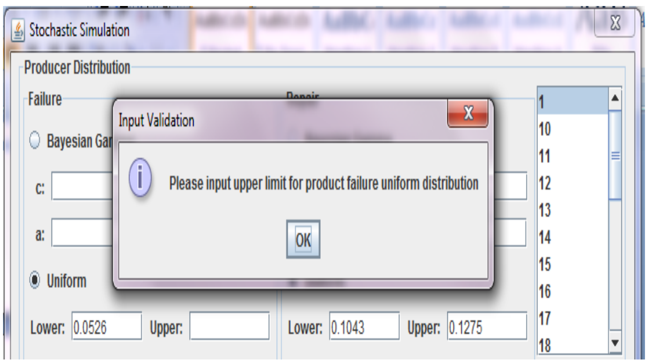


Figure 16. Red-flag warning when user forgets to input required data for a given distribution.

### *C. When User Forgets to Input Required Values for a Given Distribution Updating*

We will get a warning sign that says, "Please input upper limit for product failure uniform distribution". See Fig. 16.

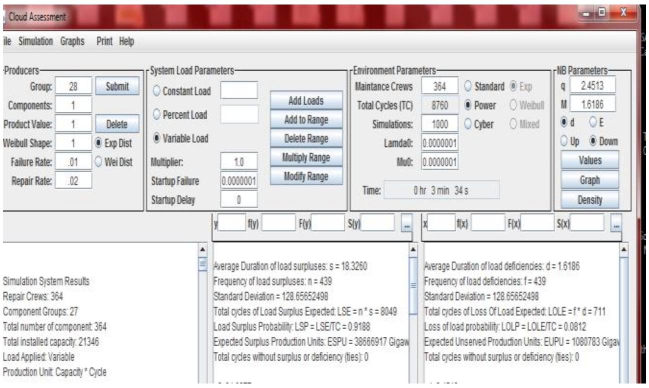

Figure 17. The 1996.txt LOLP (.0812 = 8.12%) for 1000 years without Stochastic Simulation (only non-SS).

## IV. Stochastic Simulation Applied to a Power Grid

### *A) With Negative Exponential input for failure and repair rates.*

After the verification processes in Sections I and II, where the Stochastic and NS (non-Stochastic) outputs led to almost identical results, we need to work on Power Grid scenarios this time for estimation of system performance other than verification purpose.

Let's suppose an electric power generation grid (data1996.txt) comprising 364 generating units of 28 groups composed of different variety of power plants [3]. See Fig. 17 outputs for 1000 years of simulation if for 364 units, prompt maintenance attention with 364 repair crews is available. The unavailability or LOLP (Loss of Load Probability) is 0.0812 or 8.12% for an average year over 1000 years.

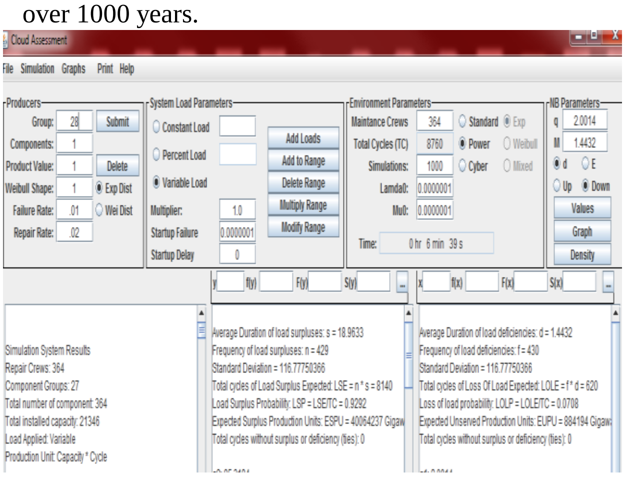

Figure 18. The LOLP increased to 7.08% from 5.49 with links activated having same failure and repair rates as the generating units.

We have earlier substantiated that when we randomize the producer parameters as well as load, we verify to obtain the original results in a controlled experimental status (except for the scenario that repair rates were 10% higher than those of failure rates). Therefore now with more changes, otherwise to reflect the grid input data, we will reach a stochastically (purely random) scenario. The output of Fig. 3 or 4 is not a grid analysis; i.e. without any transmission lines (or links) and from purely generation-based data. However in power grid scenarios, each generating unit is attached to a link to transmit the power generated by the units.

Let's assume then that each power generating unit has failure and repair rates as identical inspired by the producer's data given for each group. Also assume that each unit is linked to its entire perimeter in supplying the generated energy specified by the identical failure and repair rates of the generating unit on the average. This is different than assuming 10% increase on the failure rates or 10% on the repair rates for an alternative "uniform distribution" study we presented in Fig. 8. It has dropped to 7.08% from 8.12% due to now link in effect, i.e. links not being perfectly reliable, thus averaging 1000 years of non-stochastic simulation.

*B) With the Weibull input for failure and repair rates.*

This time, the product failure and repair rate distributions are Weibull rather than the Neg. Exponential where the input dialogue box is as follows for a different data1995.txt (same as the data in Sections I and II).The output for LOLP is approximately the same (=0.057) as the usual neg. exponential assumption (=0.055) since shape parameters for both failure and repair are 1.0 for Weibull [2]. See Fig. 19 in the APPENDIX.

Let's imagine a sample Power or Cyber or Telecom Grid with links connected to the entire set of generating units to possess the same lump-sum failure and repair rates as the units did assuming Weibull distributed failure and repair rates such as follows in a simulated sample topology. See Fig. 20 in the APPENDIX.

As a result of 1000 years of Stochastic Simulation, while we assumed 348 generating units with the Weibull distributed failure and repair rates and the identical data for the links connected to each unit as a lump-sum; we obtained an unavailability metric of LOLP (=.0582) or 5.82 %, i.e. worse than the expected 5.49% in Fig.1. See Fig. 21 in the APPENDIX. This was expected since the links worked with no more perfect availability, but carried certain failure and repair rates.

## V. Discussions and Conclusions

Traditionally, in Cyber or Power Grid modeling, data regarding failure rate, repair rate, and servers' or generators' nominal capacity and transmission lines or links, as well as load (demand) supplied by the power (or cyber) grid and count of repair crews for maintenance are sampled and estimated as deterministic constants from external data collection sources. CLOURAM is a risk assessment and management tool that simulates and manages the entire generation grid. Through what is termed as Stochastic (Random) Simulation of CLOUD parameters such as failure and repair rates of power generators or cyber servers and the demand (load) cycle, we verify the non-stochastic CLOURAM so that SS runs are accurate.

First, we verify the conventional results through test runs by conducting Stochastic Simulation (SS). Once the verification process is carried out successfully, i.e. the CLOUD non-SS metrics are compared favorably to those employing deterministic data; grid producer and link scenarios will be studied such as in the event of the links no more being perfectly reliable, but operating with specified values through uniform, or negative exponential input data assumptions. These were executed in the examples of Section III. This innovative research illustrates that we can include lump-sum the grid transmission (link) data as an averaging effect in the simulation of cyber or power CLOUD performance. Additionally, this algorithm can be used for any other stochastic (random) data entry for the producers as well as the links. The versatility of the algorithm stems from a wide area of usage by leveraging the Weibull distribution (whose default is neg. exponential and used extensively for failures). In the event of the non-existence of sophisticated data such as Weibull or similar, the analyst may use uniform deviations with percentages as shown in the examples of Section IV. For further research, the authors will seek the power grid data from industry to compare results [4-6].

## References


[1] M. Sahinoglu, L. Cueva-Parra, "CLOUD Computing," *Invited Author (Advanced Review) for Wiley Interdisciplinary Reviews: Computational Statistics*; New Jersey, Ed.-in-Chief: E. Wegman, Yasmin H. Said, **Vol. 3**, Number 1, pp. 47-68, Jan/Feb. 2011. http://authorservices.wiley.com/bauthor/onlineLibraryTPS.asp?DOI=10.1002/wics.139&ArticleID=771921, 2011.

[2] M. Sahinoglu, Trustworthy Computing: Analytical and Quantitative Engineering Evaluation (Book), John Wiley & Sons, Inc., Hoboken, NJ, USA, 2007.

[3] Dan Marghitu, M. Sahinoglu, "Computing Reliability in a Complex Electric Power Generation Grid using the Analytical Overlap and CLOUD Simulation Techniques for Directional and Non-directional System Topologies," *Proc. of tthe Conference of Society of Design &Process Science (SDPS), Session X1 Cloud Computing: Security and Reliability*, Berlin, Germany, June 2012.

[4] M. Sahinoglu, Scott Morton, "Cloud Risk-O-Meter: An Algorithm for Cloud Risk Assessment and Management," *Proc of the Conference of Society of Design & Process Science (SDPS), Session X1 Cloud Computing: Security and Reliability*, 1:30-3:15pm, Berlin, Germany, June 2012.

[5] Luis Cueva-Parra, M. Sahinoglu, Susan Simmons, "Reliability Testing before Releasing CLOUD using a

sequential Stopping Rule with Logistic-Growth Compound Poisson Modeling", *Proc. of the Conference of Society of Design & Process Science, Session X1 Cloud Computing: Security and Reliability, Berlin, Germany*, June 2012.

[6] M. Sahinoglu, Luis Cueva-Parra, D. Ang, "Game-theoretic computing in risk analysis", *WIREs Computational Statistics*, doi:10.1002/wics. http://authorservices.wiley.com/bauthor/onlineLibraryTPS.asp?DOI=10.1002/wics.1205&ArticleID=961931, 2012.

**Mehmet Sahinoglu** is the founder Director of the Informatics Institute, and the Cybersystems and Information Security (CSIS) graduate program in Auburn University at Montgomery since 2008. He obtained his Ph.D. from Texas A&M (1981) and his MS from UMIST, England (1975) both in EE. Following his 20 year-long tenure at METU (his alma mater with BS-ECE 1969-73) in Ankara as an Assistant-Associate-Full Professor, he served as the founding dean and chair in the College of Sciences at DEU in Izmir (1992-97). He taught at TAMU (1978-81) and Purdue (1989-90, 1997-98) and Case Western Reserve (1998-99), as a Fulbright and NATO research scholar, later at Troy as Eminent Scholar. An IEEE Senior member and a Fellow of the SDPS www.sdpsnet.org and an elected member of International Statistical Institute, ISI, he authored 130 conference proceedings, 50 journal articles and a textbook, 'Trustworthy Computing' by Wiley (2007), managed 15 grant projects. He was one of 14 awardees for Microsoft's 'Trustworthy Curriculum' grant in the world (2006). His new book "Cyber-Risk Informatics" will be published in 2015 Spring by Wiley and Sons Inc.

**Preethi Vasudev** has been a part-time graduate research assistant at AUM (Auburn University Montgomery) since 2013 January. She graduated from AUM's CSIS graduate program with a Master's degree (Sum Cum Laude) in August 2014. She holds a B.E. in Computer Science from Bangalore University, India. Preethi has worked in investment banking domain as senior consultant with Blackrock Inc. in London, England from 2008 to 2012. Her software expertise and skill set, as a first-rate JAVA programmer, is her best asset both in educational and corporate world, including Cybersecurity and finance area.

## APPENDIX

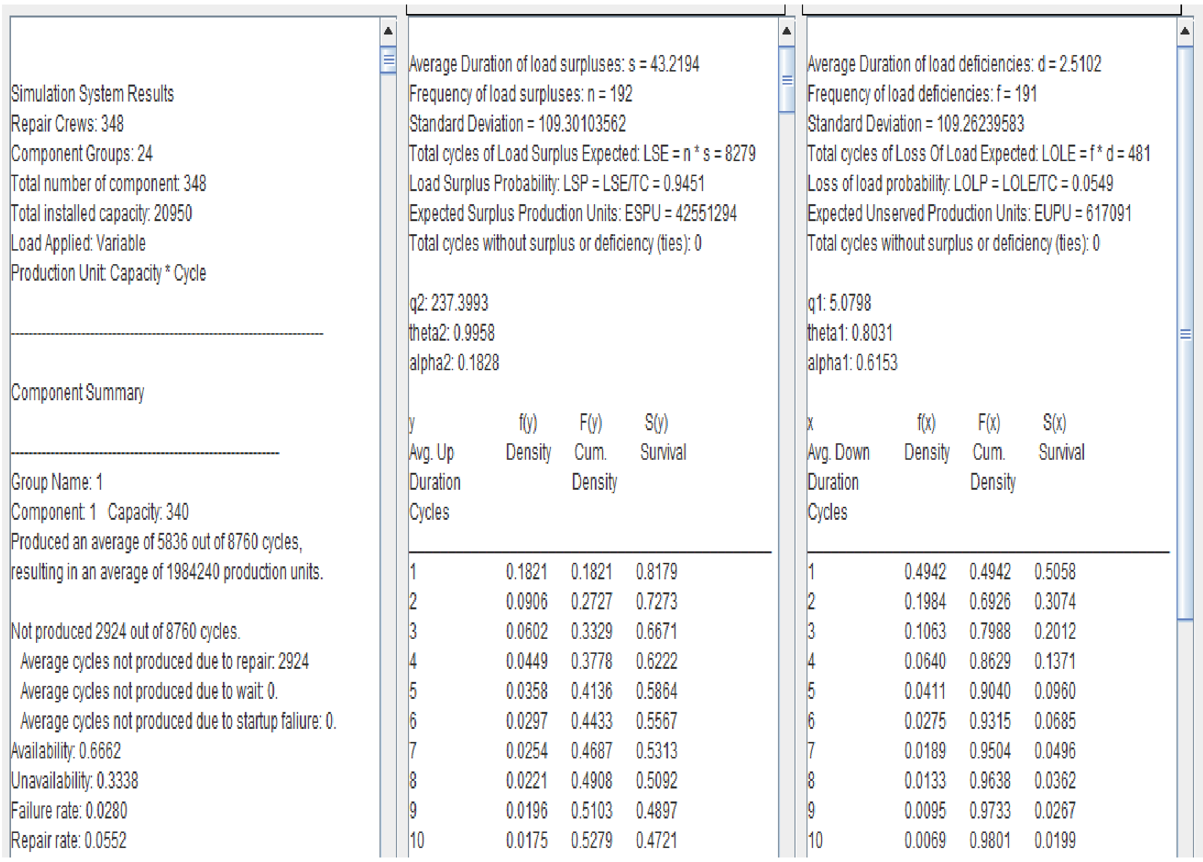


Fig. 1. The LOLP=5.49% outcome for the 348 units system with full maintenance, not applying Stochastic Simulation (SS) .

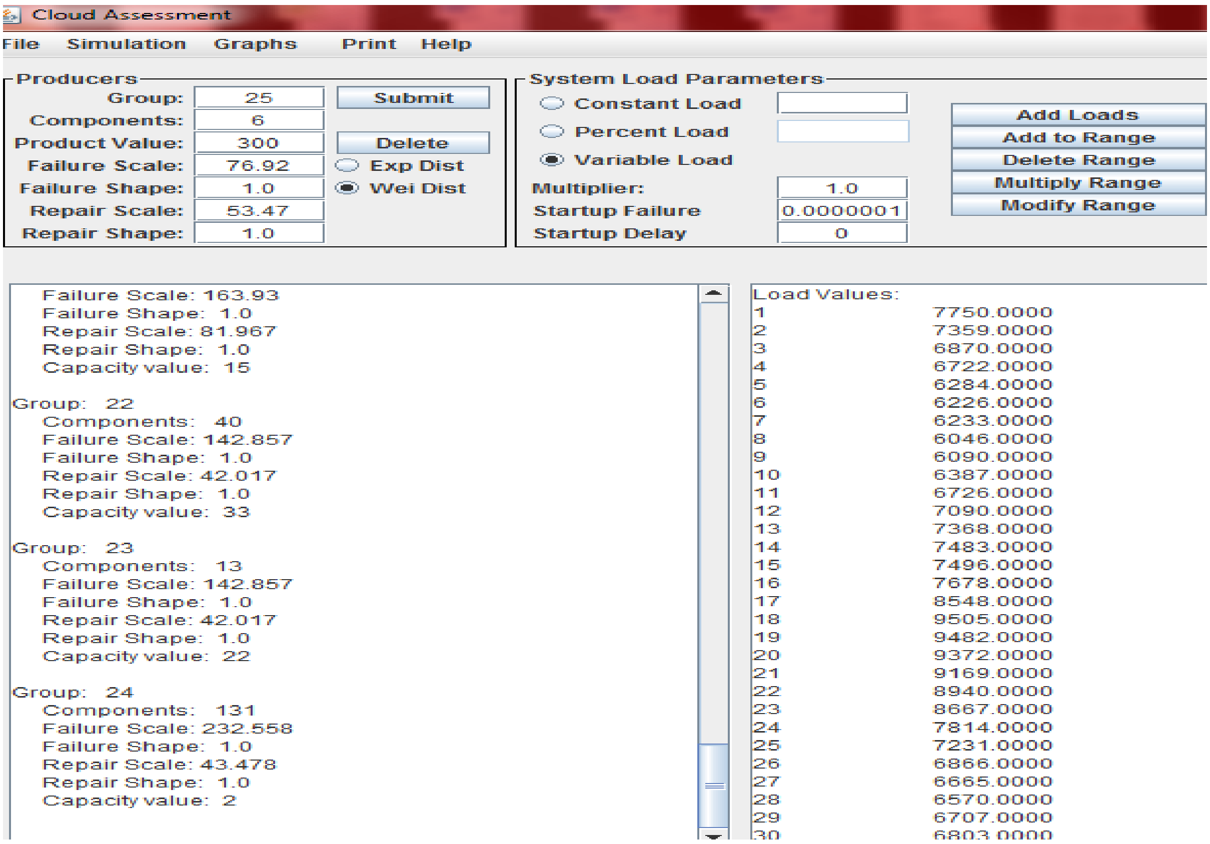


Figure 19. Weibull input failure and repair rates for 1995.

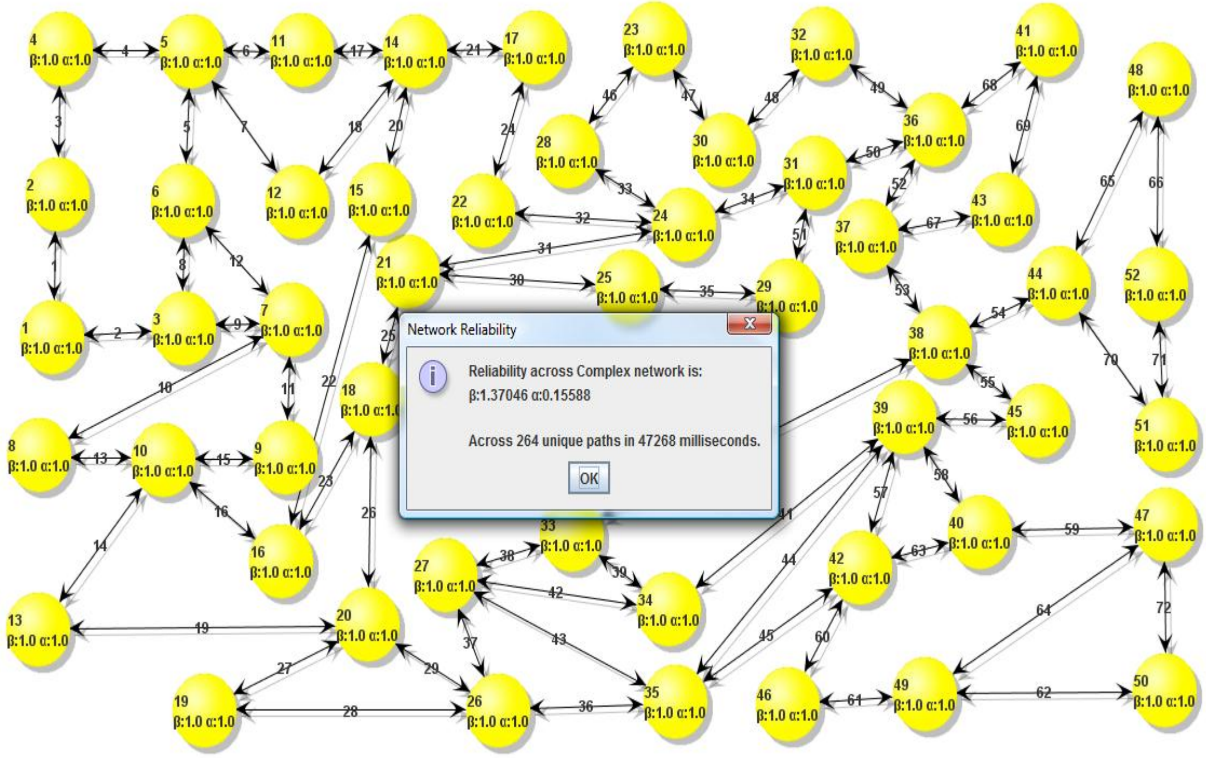


Figure 20. A sample complex Telecom grid with 52 Weibull (α=1, β=1) units and perfectly reliable links; Output: $\text{Weibull}_{1\text{-}52}$ (α=1.37, β=0.16).

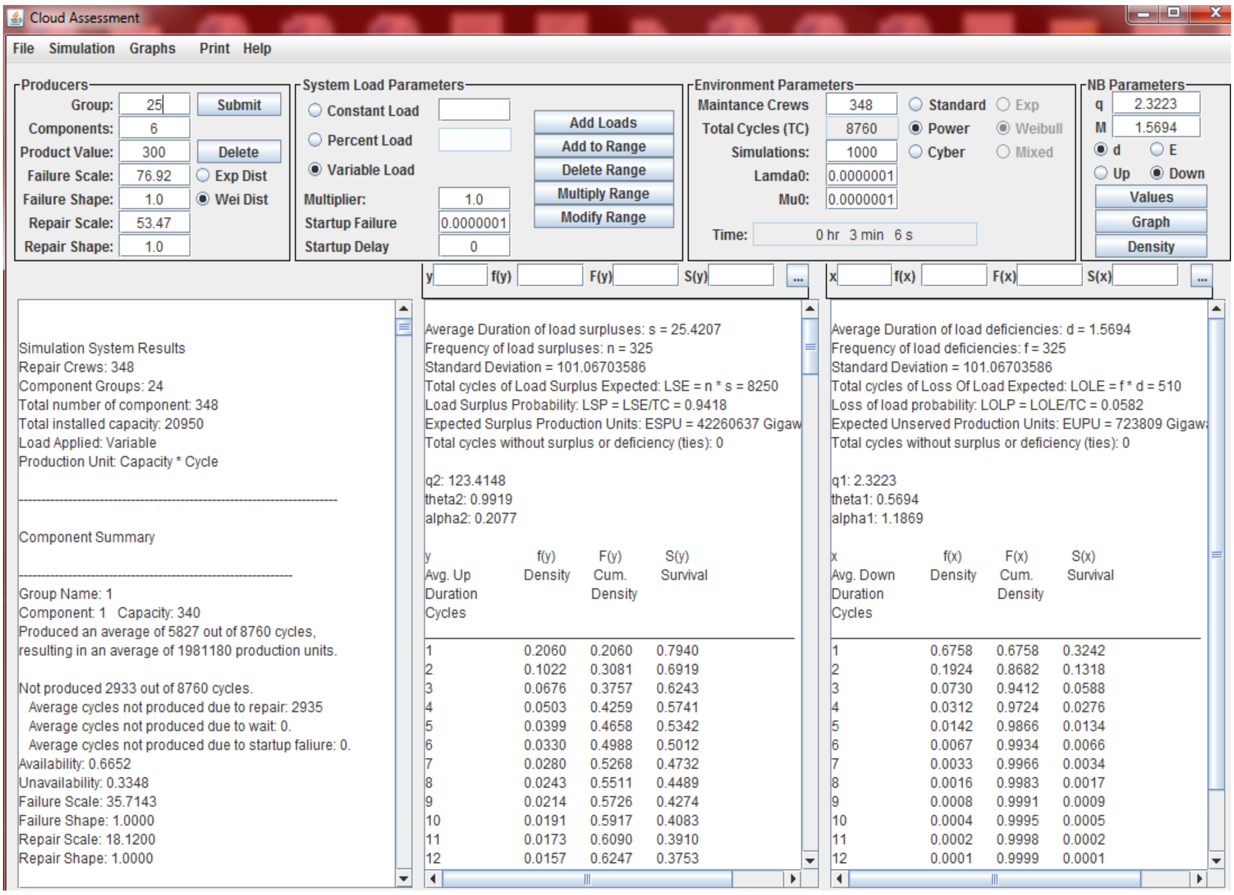


Figure 21. LOLP (=.0582=5.82%) for data95.txt for Power Grid with Weibull parameters applied to both generating units and link.