### 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 (*CLOUd Risk* Assessment and Management) studied in detail as follows in Fig.2. NS will denote non-stochastic simulation.

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)

l	🛓 Sy	stem Application				
ſ	File	Simulation Graphs	Print Help			
	- Pro	Stochastic Simulation	L	- System Load Parame	eters	
		Simulate System	Submit	Constant Load		
	C	Input Values		O Percent Load		Add Loads
	Pro	Result Values	Delete			Add to Range
	Wei	bull Shape: 1	Exp Dist	Variable Load		Delete Range
	F	ailure Rate: .01 (	🔾 Wei Dist	Multiplier:	1.0	Multiply Range
	R	epair Rate: .02		Startup Failure	0.0000001	Modify Range
				Startup Delay	0	

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.

le Simulation Graphs P	rint Help		
Producers	System Load Parameters		
Group: 1	Submit II	Haistance Crows	240 Standard
Components: 1	🔬 Stochastic Simulation	ARIAN INVITATION	and Count
Product Value: 1	Producer Distribution		
Veibull Shape: 1	Failure	Repair	1
Failure Rate: 01 G			10
Repair Rate: .02	Bayesian Gamma	Bayesian Gamma	11
Nopul Nutre .vz	C: Ksi:	d: Eta:	12
	-	Ctu.	13
	a: Xt	b: Yt:	14
Group: 1			15
Components: 4	Uniform	Uniform	16
Weibull Shape: 1.0			17
Failure Rate: 0.028	Lower: Upper:	Lower: Upper:	18
Repair Rate: 0.0552	O None	O None	
Capacity value: 340	U none	U Noire	Update
	Link Distribution		
Group: 2			
Components: 6	Failure	Repair	1
Weibull Shape: 1.0 Failure Rate: 0.013	% of Producer : 10	S of Producer: 10	10
Repair Rate: 0.013	NOIPIOUUCEI.		11
Capacity value: 300	Bayesian Gamma	Bayesian Gamma	12
oupering funct. ove	<ul> <li>Bayesian Gamma</li> </ul>	<ul> <li>Bayesian Gamma</li> </ul>	13
Group: 3	C: Ksi:	d: Fta:	14
Components: 8		U Etd	15
Weibull Shape: 1.0	a: Xt:	b: Yt:	16
Failure Rate: 0.406	d AL	U. 1.	17
Repair Rate: 0.517			18
Capacity value: 300	O Uniform	O Uniform	19
Group: 4	Lower: Upper:	Lower: Upper:	2
Components: 8	Lower: Upper:	Lower: Upper:	20
Weibull Shape: 1.0			24
Failure Rate: 0.0050	None	None	Update
Repair Rate: 0.0283			
Capacity value: 210	Load Distribution		
		en 1.0nz 0.n	
Group: 5		🖲 Normal 🔾 Uniform 🔾 None	
Components: 1			
Weibull Shape: 1.0	-	Mean: 9729.6680 Std Dev: 1557.5737	

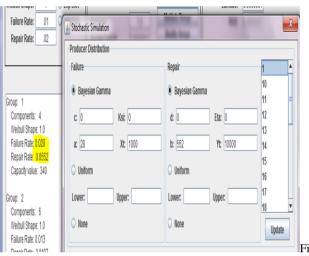
Figure 3. The initial screen to start the Stochastic Simulation.

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

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## 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.



gure 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.

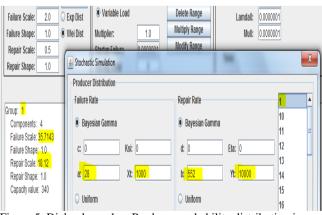


Figure 5. Dialog box when Producer probability distribution is in Weibull.

## 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.

Failure Scale: 2.0 O Exp Dist	Link Distribution		
Failure Shape: 1.0   Wei Dist	Failure Rate	Repair Rate	1 1
Repair Scale:         0.5           Repair Shape:         1.0	% of Producer : 10 💌	% of Producer : 10 💌	10 11
	O Bayesian Gamma	🔘 Bayesian Gamma	12 13 <sup>≡</sup>
Group: 1 Components: 4	C: Ksi:	d: Eta:	14 15
Failure Scale: 35.7143 Failure Shape: 1.0	a: Xt:	b: Yt:	16 17
Repair Scale: 18.12 Repair Shape: 1.0 Capacity value: 340	Uniform	Uniform	18 19
Group: 2	Lower: 0.0277 Upper: 0.0339	Lower: 0.0546 Upper: 0.0668	2 20
Components: 6 Failure Scale: 76.92 Failure Shape: 1.0	O None	○ None	Update

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

Failure Kate:01 V Repair Rate:02	Stochastic Simulation	hall, loop	x
	Failure Rate	Repair Rate	1
Group: 1	O Bayesian Gamma	Bayesian Gamma	10 11 =
Components: 4	C: Ksi:	d: Eta:	12
Weibull Shape: 1.0			13
Failure Rate: 0.028	a: Xt:	b: Yt:	14
Repair Rate: 0.0552			15
Capacity value: 340	Uniform	Uniform	16
			17
Group: 2	Lower: 0.0252 Upper: 0.0308	Lower <mark>: 0.0497 Uppe</mark> r: 0.0607	
Components: 6			18 💌
Weibull Shape: 1.0	<ul> <li>None</li> </ul>	None	Update
Failure Rate: 0.013			opulie
Repair Rate: 0.0187	II		

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

Producer Distribution		
Failure Rate	Repair Rate	15
		16
Bayesian Gamma	Bayesian Gamma	17
c: 0 Ksi: 0	d: 0 Eta: 0	18
		19
a: 43 Xt: 10000	b: 23 Yt: 1000	20
Uniform	<ul> <li>Uniform</li> </ul>	22
Lower: Upper:	Lower: Upper:	23
		24
None	O None	Update
ink Distribution		
Failure Rate	Repair Rate	
		12
% of Producer: 0 💌	% of Producer : 0	▼ 13 14
Bayesian Gamma	Bayesian Gamma	14
Bayesian Gamma	Bayesian Gamma	16
c: 0 Ksi: 0	d: 0 Eta: 0	17
		18
a: 43 Xt: 10000	b: 23 Yt: 1000	) 19 20
Uniform	O Uniform	21
-		22
Lower: Upper:	Lower: Upper:	23
		24
None	<ul> <li>None</li> </ul>	Update
.oad Distribution		
01	ormal 🔾 Uniform 💿 None	
Mean:	Std Dev:	
Mean:	Stu Dev.	
	Simulate Cancel	

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<sub>t</sub>' 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<sub>t</sub>' = 10000. "d" and " $\eta$ " (eta) are set to zero. See Fig. 9 for input data and Fig. 10 for output results.

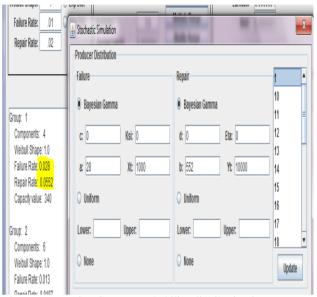


Figure 9. Bayesian Gamma probability distribution input template for Stochastic Simulation

Cloud Assess

Producers			r System Load Para	meters			neters		
Group: Components: Product Value:	25 6 300	Submit	Constant Load		Add Loads Add to Range	Maintance Crews Total Cycles (TC) Simulations:	348		q 2.3408 M 1.5765
Failure Scale: Failure Shape:	76.92	© Exp Dist	Variable Load  Multiplier:	10	Delete Range Multiply Range	Lamdaû:	0.0000001 0.0000001	U U MIACU	O Up  O Dov Values
Repair Scale: Repair Shape:	53.47 1.0		Startup Failure Startup Delay	0.0000001	Modify Range		hr 3min 13s		Graph Density
Simulation Syste Repair Crews: 3 Component Gro Total number of Total installed ca Load Applied: Va Production Unit	48 ups: 24 componeri apacity: 209 ritable	t 348 150		Frequency of loa Standard Deviat Total cycles of L Load Surplus Pr Expected Surplu	Flyl n of load surpluses: s = 2 ad surpluses: n = 314 ion = 112 53100650 aad Surplus Eiperded LS mobability. LSP = LSE/TC = us Production Units. ESPL out surplus or deficiency	≡ 1E = n * s = 8265 : 0.9434 J = 42600414 Gigaw	X fixit Herage Duration of K Frequency of load del Standard Deviation = Total cycles of Loss of Loss of load probabil Expected Unserved P Total cycles without s	iciencies: f = 314 102.53180659 Xf Load Expected: I ity: LOLP = LOLE/ roduction Units: E	LOLE = f * d = 495 FC = 0.0566 UPU = 711936 Gig

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.

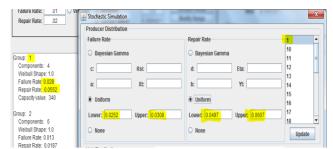


Figure 11. If uniform is used, default values are +10% of corresponding rates for lower and upper.

Producers-			System Load Para	meters			neters			IT NB Para	ameters-
Group:	25	Submit	C Constant Load			Maintance Crews	348	🔾 Standar	d 🖲 Exp	q	2.2630
Components:	6				Add Loads	Total Cycles (TC)	8760	Power	() Weibull	М	1.5465
Product Value:	300	Delete	O Percent Load		Add to Range	Simulations:	1000	O Cyber	() Mixed	Ø	© E
Weibull Shape:	1	Exp Dist	Variable Load		Delete Range	Lamda0:	0.0000001			OUp	🖲 Down
Failure Rate:	.01	O Wei Dist	Multiplier:	1.0	Multiply Range	Mult	0.0000001			1	Values
Repair Rate:	.02		Startup Failure	0.0000001	Modify Range						Graph
			Startup Delay	0		Time:	) hr 5 min 8	15		0	Density
				yf(y)	F(y)	s(y) _	X	f(x)	F(x)	S(x)	
Simulation Syste Repair Crews: 34 Component Grou Total number of c Total installed ca Load Applied: Va Production Unit (	18 ps: 24 componer pacity: 201 tiable	t 348 150	* III	Frequency of loa Standard Deviati Total cycles of Lo Load Surplus Pri Expected Surplus	i of load surpluses; s = d surpluses; n = 325 on = 109.96186726 tad Surplus Expected: obability: LSP = LSE/TC s Production Units: ESI out surplus or deficienc	LSE = n * s = 8257 C = 0.9425 PU = 42365103 Gigaw	Frequency Standard I Total cycle Loss of loc Expected I	of load deficie Deviation = 10 s of Loss Of L ad probability: Jnserved Proc	d deficiencies: c encies: f = 325 9.96186726 .cad Expected: LOLP = LOLE/ duction Units: E olus or deficien	LOLE = f* IC = 0.057 UPU = 711	d = 503 15 7190 Gigai

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.

Coud Assessment File Simulation Graphs Print Help		2 12 A.	<u> </u>		
Producers Group 25 Submit Components 1 Delete Webul Shape 1 Exp Dist Failure Rate 01 O We Dist Repair Rate 02	System Load Parameters           C constant Load           Percent Load           @ Variable Load           Multiplier:         10           Startup Failure         0.000001           Startup Delay         0	Add Loads Total C	vcles (TC) 8760 ( nulations: 500 ( Lamdath: 0.000001 Muth: 0.000001	9 Standard () Exp Power () Weibull () Cyber () Mixed	r NB Parameters q 2.0488 M 1.4622
Simulation Bystem Results Repart Creans 346 Component Groups 24 Trial number of component 348 Trial installer Aquadri, 20050 Land Aprilet Viralitate Production Uhit Capach, "Cycle	Frequency of load Standard Deviation Total cycles of Loa Load Surplus Prot Expected Surplus		Frequency of Standard Dev 8389 Total cycles o Loss of load 13 Expected Uns	find fliad deficiencies: d licad deficiencies: f = 254 licad deficiencies: f = 254 lication = 83.38232996 fLoss OfLoad Expected: L probability: LOLP = LOLEIT served Production Units: EL ithout surplus or deficienc	.OLE = f * d = 371 C = 0.0424 JPU = 500665

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.

Producers Group: 1 Submit Components: 1 Product Value: 1 Delete Weibull Shape: 1 © Exp Dist Failure Rate: .01 O Wei Dist Repair Rate: .02	System Load Parame Constant Load Percent Load Variable Load Multiplier: Startup Failure Startup Delay	1.0 0.0000001
There are no groups. A stochastic simulation can not be performed		

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.

Stochastic Simulation		X
Producer Distribution Failure  Bayesian Gamma  C:  Ks  Vt:   Uniform  Failure  Failure Failure Failure  Failure Failure  Failure  Failure  Failure  Failure  Failure  Failure  Failure  Failure  Failure  Failure  Failure Fail	1 10 11 12 13 14 15 16	
Lower:     Upper:     Lower:     Upper:       O     None     None	17 18 Update	•

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

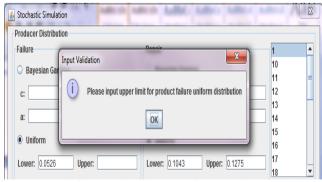


Figure 16. Red-flag warning when user forgets to input required data for a given distribution.

# 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.

Producers			System Load Param	eters		- Environment Param	neters			nr NB Par	ameters-
Group:	28	Submit	Constant Load			Maintance Crews	364	Standari	d 🖲 Exp	q	2.4513
Components:	1			-	Add Loads	Total Cycles (TC)	8760	Power	() Weibull	M	1.6186
Product Value:	1	Delete	O Percent Load		Add to Range	Simulations:	1000	O Cyber	() Mixed	0 đ	ΟE
Weibull Shape:	1	Exp Dist	Variable Load		Delete Range	Lamda0:	0.0000001			O Up	Down
Failure Rate:	.01	🔾 Wei Dist	Multiplier:	1.0	Multiply Range	Mu0:	0.0000001				Values
Repair Rate:	.02		Startup Failure	0.0000001	Modify Range						Graph
			Startup Delay	0		Time: 0	) hr 3 min 3	4 S			Density
				fly)	F(y)	S(y)	x1	(x)	F(x)	S(x)	
Simulation Syste Repair Crews: 36 Component Grou Total number of c Total installed ca Load Applied: Va Production Unit 1	4 ps: 27 omponen pacity: 213 iable	t 364 846		Frequency of load Standard Deviatio Total cycles of Lo Load Surplus Pro Expected Surplus	of load surpluses; s = d surpluses; n = 439 on = 128.66652498 ad Surplus Expected; L sbability: LSP = LSE/TC Production Units; ESP out surplus or deficiency	= SE = n * s = 8049 = 0.9188 U = 38666917 Gigaw	Frequency Standard D Total cycle Loss of loa Expected L	of load deficie leviation = 12i s of Loss Of L id probability: I Inserved Prod	l deficiencies: d encies: f = 439 8.65652498 oad Expected: l LOLP = LOLE/7 fuction Units: E lus or deficienc	LOLE = f " IC = 0.081 UPU = 10	d = 711

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.

Cloud Assessment			
File Simulation Graphs Print Help			
Producers Group: 23 Submit Components: 1 Product Value: 1 Delete Webull Sape: 1 Exp Dist Failure Rate: 01 © Wei Dist Repair Rate: 02	Percent Load     A     Variable Load     D Mutiplier:     1.0	Add Loads Add Loads Total Cycles (TC) 2750 © Stand Total Cycles (TC) 2750 © Cyber Simulations: 100 © Cyber Landel: 0.000001 Molt 0.000001 Time: 0 hr 6 min 38 s	-
Simulation System Results Repair Circups: 384 Component Groups: 27 Total involter of component 364 Total Installed capacity 21346 Load Applica Variable Vaduction Unit: Capacht <sup>1</sup> Circle	Frequency of load surpli Standard Deviation = 11 Total cycles of Load Sur Load Surplus Probabilit Expected Surplus Produ	uses: n = 429 e Fequency of load def 6:77750366 plus Expected: LSE = n * s = 8140 y: LSP = LSETC = 0.9292 uction Units: ESPU = 40054237 Gigan Expected Unsered Ph	

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].

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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 "Cvber-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

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	 				_					_
	Average Dur	ation of load	euroluese	s = 43.2194		Average Dura	tion of load	doficioneio	o: d = 2.5102	<b></b>
Simulation System Depute	-				=	-				
Simulation System Results	Frequency o					Frequency of				
Repair Crews: 348	Standard De	Hallon Tee	•		Standard Dev	Tation Tee				
Component Groups: 24				ed: LSE = n * s = 8279					ed: LOLE = f * d = 481	
Total number of component: 348				E/TC = 0.9451					LE/TC = 0.0549	
Total installed capacity: 20950				ESPU = 42551294					s: EUPU = 617091	
Load Applied: Variable	Total cycles	iency (ties): 0		Total cycles v	vithout surpl	us or defic	iency (ties): 0			
Production Unit: Capacity * Cycle										
	q2: 237.399	3				q1: 5.0798				
	theta2: 0.998	58				theta1: 0.803	1			=
	alpha2: 0.18	28				alpha1: 0.615	53			
Component Summary										
	y	f(y)	F(y)	S(y)		х	f(x)	F(x)	S(x)	
	Avg. Up	Density	Cum.	Survival		Avg. Down	Density	Cum.	Survival	
Group Name: 1	Duration		Density			Duration		Density		
Component: 1 Capacity: 340	Cycles					Cycles				
Produced an average of 5836 out of 8760 cycles,	Ľ.					Ľ.				
resulting in an average of 1984240 production units.	1	0.1821	0.1821	0.8179		1	0.4942	0.4942	0.5058	-
	2	0.0906	0.2727	0.7273		2	0.1984	0.6926	0.3074	
Not produced 2924 out of 8760 cycles.	3	0.0602	0.3329	0.6671		3	0.1063	0.7988	0.2012	
Average cycles not produced due to repair: 2924	4	0.0449	0.3778	0.6222		4	0.0640	0.8629	0.1371	
Average cycles not produced due to wait: 0.	5	0.0358	0.4136	0.5864		5	0.0411	0.9040	0.0960	
Average cycles not produced due to startup faliure: 0.	6	0.0297	0.4433	0.5567		6	0.0275	0.9315	0.0685	
Availability: 0.6662	7	0.0254	0.4687	0.5313		7	0.0189	0.9504	0.0496	
Unavailability: 0.3338	8	0.0221	0.4908	0.5092		8	0.0133	0.9638	0.0362	
Failure rate: 0.0280	9	0.0221	0.5103	0.4897		9	0.0095	0.9733	0.0362	
Repair rate: 0.0552	10	0.0130	0.5105	0.4721		10	0.0069	0.9801	0.0199	
repair rate. 0.0002	10	0.0170	0.5218	0.4721		10	0.0009	0.0001	0.0100	

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

🛃 Clou	d Assessm	ent			-	
File Si	imulation	Graphs	Print Help			
Produ	cers			- System Load Para	ameters	
	Group:	25	Submit	Constant Loa	d	
Com	ponents:	6				Add Loads
Produ	ct Value:	300	Delete	Percent Load		Add to Range
Failu	re Scale:	76.92	C Exp Dist	Variable Load	1	Delete Range
Failur	e Shape:	1.0	Wei Dist	Multiplier:	1.0	Multiply Range
Repa	ir Scale:	53.47		Startup Failure	0.000000	1 Modify Range
Repai	ir Shape:	1.0		Startup Delay	0	
				•		
				-		
	ure Scale:			<u> </u>	Load Values	7750.0000
	ure Shape bair Scale:				2	7359.0000
	air Shape				3	6870.0000
	acity value				4	6722.0000
	acity value				5	6284.0000
Group:	22				6	6226.0000
	nponents:	40			7	6233.0000
	ure Scale:				8	6046.0000
Fail	ure Shape	: 1.0			9	6090.0000
Rep	air Scale:	42.017			10	6387.0000
Rep	air Shape	: 1.0			11	6726.0000
Cap	oacity value	e: 33			12	7090.0000
					13	7368.0000
Group:	23				14	7483.0000
	nponents:				15	7496.0000
	ure Scale:				16	7678.0000
	ure Shape				17	8548.0000
	pair Scale:				18	9505.0000
	air Shape				19 20	9482.0000
Cap	pacity value	e: 22			20	9372.0000
Crown	24				21	9169.0000 8940.0000
Group:	. ∠4 nponents:	121			22	8667.0000
	ure Scale:				23	7814.0000
	ure Scale. ure Shape				25	7231.0000
	air Scale:				26	6866.0000
	air Shape				27	6665.0000
	acity value				28	6570.0000
	,				29	6707.0000
1				-	30	6803 0000
Jiguro	10 Waibu	ll input fail	ire and renair rates	for 1005		

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

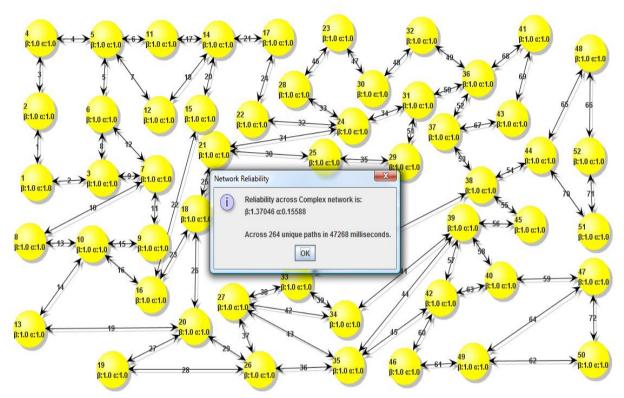


Figure 20. A sample complex Telecom grid with 52 Weibull ( $\alpha$ =1,  $\beta$ =1) units and perfectly reliable links; Output: Weibull<sub>1-52</sub> ( $\alpha$ =1.37,  $\beta$ =0.16).

Number States         10         Multipler:         Multiple:         Multiple:         Multiple:         Multiple:         Multiple:         Multiple:         Multiple:	2 Cloud Assessment	-	_	-			-	-					- 0 -
Group:         22         Submit         Constant Load           Components:         6         Delete         Add Loads         Product Value:         8760         Power @: Welbust           Failure Scale:         75.92         Exp Dist         Mittiple:         Add to Range         Delete Range         Mittiple:         0.0000001         Cyber         Mittige           Repair Scale:         75.32         Exp Dist         Mittiple:         0.0000001         Mittiple:         0.0000001         Time:         0.0000001         Wittee         Up         Down         Values         Graph           Repair Scale:         75.47         Time:         0.00         Not         Nittee         Up         Down         Values         Graph         Density         Calues         Graph         Densof dof dof	ile Simulation Graphs Print Help												
Average Duration of load surpluses: s = 25 4207         Frequency of load surpluses: n = 325         Average Duration of load surpluses: n = 325         Average Duration of load Surpluses: n = 325         Standard beviaton = 110.0703586           Component Groups: 24         Total cycles of Load Surpluse Stype etclet LSE = n * s = 8250         Standard beviaton = 110.0703586         Total cycles of Load Surpluse Stype etclet LSE = n * s = 8250           Load Applied: Variable         Production Unit: Capacity * Cycle         Total cycles without surplus or deficiency (ties): 0         Total cycles without surplus or deficiency (ties): 0           Production Unit: Capacity * Cycle         Total cycles without surplus or deficiency (ties): 0         Total cycles without surplus or deficiency (ties): 0           Group Name: 1         Component 1 Gapacity 340         Production units:         Surplus Expected Unserved Production Units: EVPU = 1232809 Gigav           Total cycles and robability: 0.6728         Y         F(y)         S(y)           Y         f(y)         F(y)         S(y)           Average cycles not produced due to repair: 2935         Average cycles not produced due to startup failure: 0.         Not produced 2933 out of 8760 cycles, resulting in average of 1981180 production units.         So 00390         0.6814         0.6818         0.0736         0.3727         0.6243         0.0312         0.9724         0.2765         5< 0.0124	Group: 25 Submit Components: 6 Product Value: 300 Delete Failure Scale: 76.92 Exp Dist Failure Shape: 1.0 @ Wei Dist Repair Scale: 53.47 Startup Failu	t Load Load Load Ire	1.0 0.0000001	Ad De Mu	ld to Range lete Range ltiply Range	• •	Naintance Crev Total Cycles (T Simulation Lamda Mu	vs C) s: 0: 0:	348 8760 1000 0.0000001 0.0000001	Power Cyber	Weibu	q ₩ M @ d ○ Up	2.3223 1.5694 © E © Down /alues Graph
Average Duration of load surpluses: s = 25.4207         Average Duration of load deficiencies: d = 1.5694           Simulation System Results         Frequency of load surpluses: n = 325         Standard Deviation = 101.06703586           Component Groups: 24         Load Surplus Probability: LSP = LSE/TC = 0.9418         Expected Surplus Probability: LSP = LSE/TC = 0.9418           Card Applied: Variable         Production Unit: Capacity * Cycle         Total cycles of Load Surplus surplus or deficiency (ties): 0           Q2: 123.4148         Theta?: 0.9919         alpha2: 0.2077           Component 1         Capacity: 340         Production units.           Produced an average of 5827 out of 8760 cycles, resulting in an average of 1981180 production units.         Y         f(y)         F(y)         S(y)           Average cycles not produced due to varia 0.         Average cycles not produced due to repair: 2935         4         0.0503         0.4298         0.0512         7         0.0286         0.0134         0.0568         0.6758         0.3242         2         0.1924         0.8822         0.1318         2         0.1924         0.8628         0.1318         2         0.1924         0.8822         0.1318         2         0.1924         0.8628         0.1314           Average cycles not produced due to varia 0.         Average cycles not produced due to varia 0.         0.0057			y f(y)		F(y)	S(y	) [.		x f(x	()	F(x)	S(x)	
y         f(y)         F(y)         S(y)         Xx         f(x)         F(x)         S(x)           Group Name: 1 Component: 1         Capacity: 340         Density         Density         Density         Density         Density         Curm.         Survival         Duration         Durstion         Cycles           1         0.2060         0.2060         0.7940         2         0.1924         0.8682         0.3242           2         0.1022         0.3081         0.6919         3         0.0730         0.9412         0.0588           Average cycles not produced due to repair: 2935         4         0.0503         0.4259         0.5741         4         0.0312         0.9740           Average cycles not produced due to vait: 0.         5         0.0339         0.4658         0.5342         5         0.0142         0.9866         0.0134           Average cycles not produced due to startup faliure: 0.         6         0.0330         0.4988         0.5012         6         0.0067         0.9934         0.0066           Availability: 0.6652         7         0.0280         0.5268         0.4732         7         0.0033         0.9966         0.0034           Unavailability: 0.348         8         0.0214	Repair Crews: 348 Component Groups: 24 Total number of component: 348 Total installed capacity: 20950 Load Applied: Variable Production Unit: Capacity * Cycle		Frequency of los Standard Devial Total cycles of L Load Surplus P Expected Surplu Total cycles with q2: 123.4148 theta2: 0.9919	ad surplu tion = 101 .oad Surp robability: us Produc	ses: n = 32 1.06703586 Ilus Expecte : LSP = LSE ction Units:	5 ed: LSE = :/TC = 0.9 ESPU = 4	n * s = 8250 418 2260637 Gigav		Frequency of Standard De Total cycles Loss of load Expected Un Total cycles q1: 2.3223 theta1: 0.569	f load deficie viation = 101 of Loss Of Lo probability: I served Prod without surpl	ncies: f = 32 1.06703586 bad Expecte LOLP = LOL uction Units	25 ed: LOLE = f * .E/TC = 0.058 s: EUPU = 72	2
Instruction	Group Name: 1 Component: 1 Capacity: 340		Duration		Cum.		I		Duration		Cum.		
	resulting in an average of 1981180 production units. Not produced 2933 out of 8760 cycles. Average cycles not produced due to repair: 2935 Average cycles not produced due to wait: 0. Average cycles not produced due to startup faliure: 0. Availability: 0.6652 Unavailability: 0.3348 Failure Scale: 35.7143 Failure Shape: 1.0000		2 3 4 5 6 7 8 9 10 11 12	0.1022 0.0676 0.0503 0.0399 0.0330 0.0280 0.0243 0.0214 0.0214 0.0191 0.0173	0.3081 0.3757 0.4259 0.4658 0.4988 0.5268 0.5511 0.5726 0.5917 0.6090	0.6919 0.6243 0.5741 0.5342 0.5012 0.4732 0.4489 0.4274 0.4083 0.3910		•	2 3 4 5 6 7 8 9 10 11 12	0.1924 0.0730 0.0312 0.0142 0.0067 0.0033 0.0016 0.0008 0.0004 0.0002	0.8682 0.9412 0.9724 0.9866 0.9934 0.9966 0.9983 0.9991 0.9995 0.9998	0.1318 0.0588 0.0276 0.0134 0.0066 0.0034 0.0017 0.0009 0.0005 0.0005	

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