Predict Future Failures From Your Maintenance Records

Presented by:

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Crow/AMSAA Plots

- Most data fit a power law distribution which gives a straight line on log-log paper
- We had Duane plots, then Duane/AMSAA plots, and now Crow/AMSAA plots
- The methodology handles mixed failure modes and forecast future failures
- Results are simple and easy to use log-log plots of failures vs time—easy to explain, easy to make, and **easy to forecast failures**

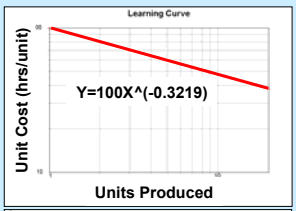
How Did This Get Started?

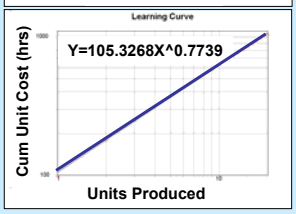
- T. P. Wright (1936) used the idea for learning curves in manufacturing
- The WWII War Production Board used Wright's techniques to forecast manpower
- James Duane of General Electric applied the concept to failure data for MTBF
- US Army Material Systems Analysis Activity wrote **MIL-HDBK-189** and published new data in **TR-652** (Growth Guide)—download a copy from **http://www.barringer1.com**

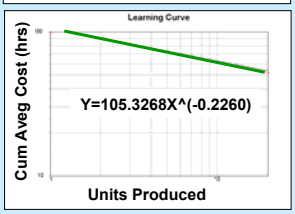
Figure 1

Unit Number	Unit Cost (hrs/unit)	Cum Total Cost (hrs)	Cum Average Cost (hrs)
1	100.00	100.00	100.00
2	80.00	180.00	90.00
3	70.21	250.21	83.40
4	64.00	314.21	78.55
5	59.56	373.77	74.75
6	56.17	429.94	71.66
7	53.44	483.38	69.06
8	51.16	534.54	66.82
9	49.29	583.89	64.88
10	47.65	631.54	63.15
11	46.21	677.75	61.61
12	44.93	722.68	60.22
13	43.79	766.47	58.96
14	42.76	809.23	57.80
15	41.82	851.05	56.74
16	40.96	892.01	55.75
17	40.17	932.18	54.83
18	39.44	971.62	53.98
19	38.76	1010.37	53.18
20	38.12	1048.49	52.42

Note the time decrease of 20% for each unit





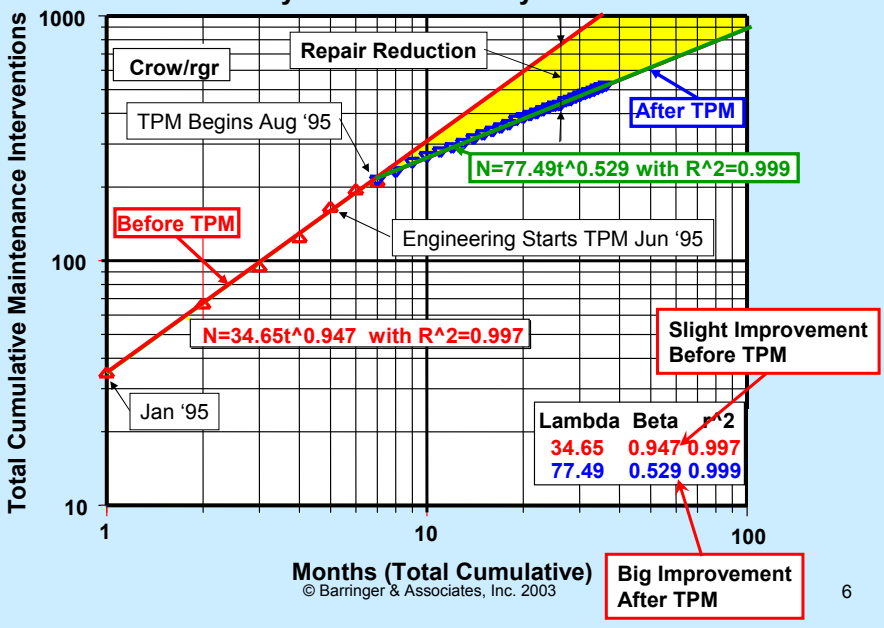


T. P. Wright's Idea For Learning Curves Which Later Drives James Duane's Idea For Reliability Growth Plots

Table 1			
Maintenance Interventions			
Month	**1995**	**1996**	**1997**
January	35	12	8
February	32	13	3
March	28	12	15
April	30	11	5
May	41	11	10
June	30	11	9
July	16	15	8
August	**18**	9	7
September	21	8	7
October	14	8	9
November	12	10	7
December	11	10	8
Total =	**288**	**130**	**96**
TPM Began August 1995			

Actual Failure Data From A Chemical Plant In Brazil

Figure 2 **Reduction Of Pump Failures In A Brazilian Monovinyl-Chloride Plant By Use Of TPM**



The Fearless Forecast Math

$N = \lambda * t^{\beta}$

N = cum number of failures
λ = y-intercept at t=1
t = cum time
β = slope of the line

β < 1 improvement
β = 1 no change
β > 1 deterioration

Before TPM
$N = 34.65 * t^{0.947}$

Forecast at t = 40 months
$N = 34.65 * 40^{0.947} = 1140$

After TPM
$N = 77.49 * t^{0.529}$

Forecast at t = 40 months
$N = 77.49 * 40^{0.529} = 545$

Δ =1140 - 545 = 595 failures avoided

The Fearless Monthly Forecast

Maintenance Interventions					
Month	**1995**	**1996**	**1997**	**'98 Fcst**	**'99 Fcst**
January	35	12	8	8	7
February	32	13	3	7	7
March	28	12	15	7	6
April	30	11	5	7	6
May	41	11	10	7	6
June	30	11	9	7	6
July	16	15	8	7	6
August	18	9	7	7	6
September	21	8	7	7	6
October	14	8	9	7	6
November	12	10	7	7	6
December	11	10	8	7	6
Total =	**288**	**130**	**96**	**85**	**74**
TPM Began August 1995					

Failures Represented By Monthly Maintenance Costs

Table 3

Petroleum Refinery Department Maintenance Cost History For One Area

	1999		2000		2001		2002	
	Cum Days	Cum $'s	Cum Days	Cum $'s	Cum Days	Cum $'s	Cum Days	Cum $'s
Jan	31	$ 210,097	396	$ 4,146,017	762	$ 8,805,297	1127	$ 13,627,145
Feb	59	$ 456,441	425	$ 4,450,893	790	$ 9,077,531	1155	$ 14,076,446
Mar	90	$ 756,350	456	$ 4,846,968	821	$ 9,435,355	1186	$ 14,275,526
Apr	120	$ 1,028,044	486	$ 5,129,931	851	$ 9,746,244	1216	$ 14,537,284
May	151	$ 1,262,368	517	$ 5,673,580	882	$ 10,135,413	1247	$ 14,937,865
Jun	181	$ 1,540,101	547	$ 6,147,311	912	$ 10,674,844	1277	***$ 14,732,077***
Jul	212	$ 1,815,380	578	$ 6,896,160	943	$ 10,957,464	1308	$ 15,075,186
Aug	243	$ 2,121,788	609	$ 7,537,645	974	$ 11,420,963	1339	$ 15,310,813
Sep	273	$ 2,769,953	639	$ 7,856,635	1004	$ 11,932,656	1369	$ 15,589,596
Oct	304	$ 3,047,065	670	$ 8,254,432	1035	$ 12,857,704	1400	$ 15,826,120
Nov	334	$ 3,360,486	700	$ 8,710,149	1065	$ 13,402,128	1430	$ 15,944,082
Dec	365	$ 3,748,406	731	***$ 8,440,050***	1096	***$ 13,214,697***	1461	$ 16,275,941

Circled Data Points Are Problems! The cumulative $'s decreases— thus do not include this data point in the regression for β & λ . However note that the $ values continue into subsequent data points.

Figure 3

Department Maintenance Data--1st Look

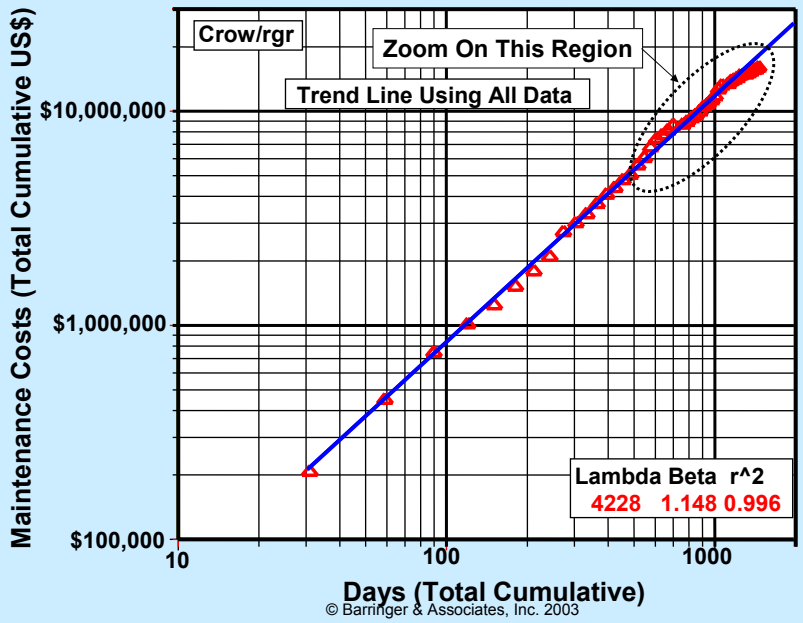


Figure 4

Department Maintenance Data-2nd Look

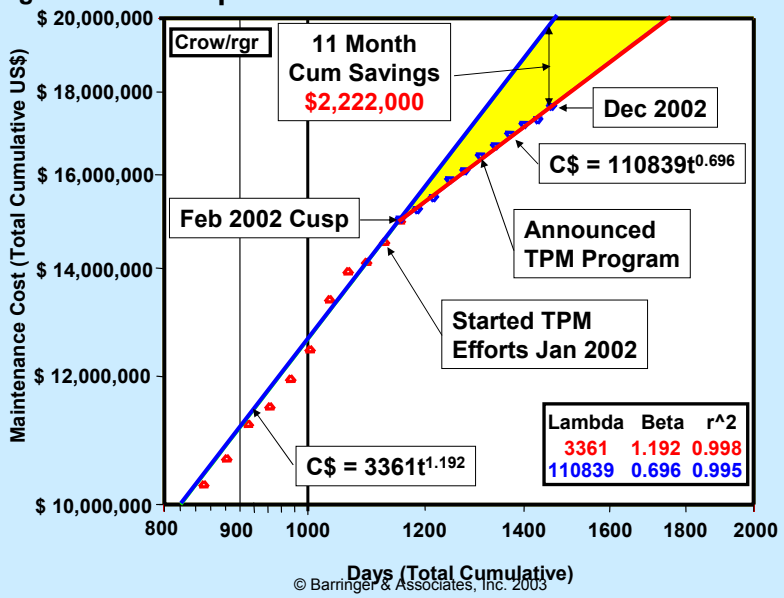


Table 4

Safety Record--Major Chemical Plant Incidents

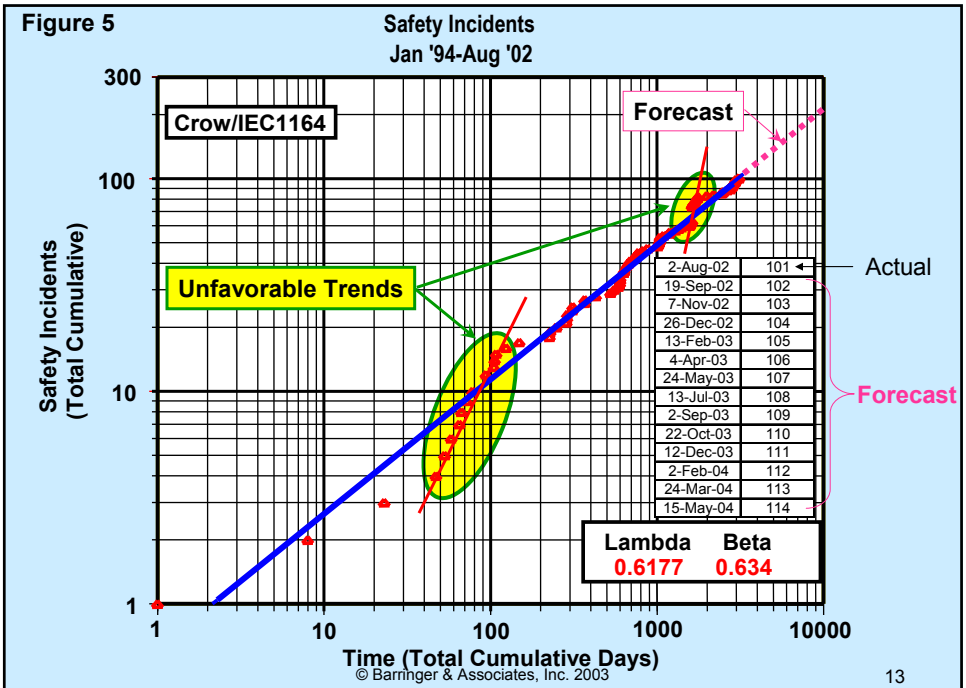
Cum Days	Cum Incidents	Cum Days	Cum Incidents	Cum Days	Cum Incidents	Cum Days	Cum Incidents
1	1	367	26	1046	53	2622	88
8	2	368	27	1096	54	2742	89
23	3	429	28	1184	55	2754	90
47	4	526	29	1195	56	2825	92
53	5	553	30	1291	57	2846	93
58	6	585	31	1345	58	2851	94
65	7	598	32	1397	59	2888	95
67	8	599	33	1565	60	2922	96
72	9	600	34	1591	61	2969	97
78	10	632	36	1598	62	2984	99
94	12	635	37	1624	63	3099	100
105	13	660	39	1626	74	3106	101
106	14	677	40	1634	75		
108	15	690	41	1655	76		
124	16	719	42	1670	77		
149	17	759	44	1692	78		
226	18	773	45	1711	79		
228	19	830	46	1753	81		
248	20	878	47	1759	82		
285	21	1009	48	1990	83		
288	22	1018	49	2186	84		
289	23	1031	50	2430	85		
310	24	1040	51	2472	86		
312	25	1044	52	2509	87		

8.5 years

Safety Incidents Are Failures!

Long term average MTBF is 3106/101 = 30.7 days/incident

Figure 5



Fearless Forecast Of Spills

Table 5

Raw Data			Crow/AMSAA Data		Forecasts	
Spill Date	Days Between Spill	Spill Events	Cum. Days	Cum. Spills	Failures Predicted By Old Method	New Method Savings
11/18/1995	35	1	35	1		
1/31/1996	74	1	109	2		
5/8/1996	98	2	207	4		
5/22/1996	14	1	221	5		
7/29/1996	68	1	289	6		
8/23/1996	25	1	314	7		
8/25/1996	2	1	316	8		
6/20/1997	299	1	615	9	18	9
2/22/1998	247	1	862	10	27	17
2/10/1999	353	1	1215	11	41	30

8 Failures In 316 Days This Is The Datum

3 Failures In 899 Days—This Is Good News!

Figure 6

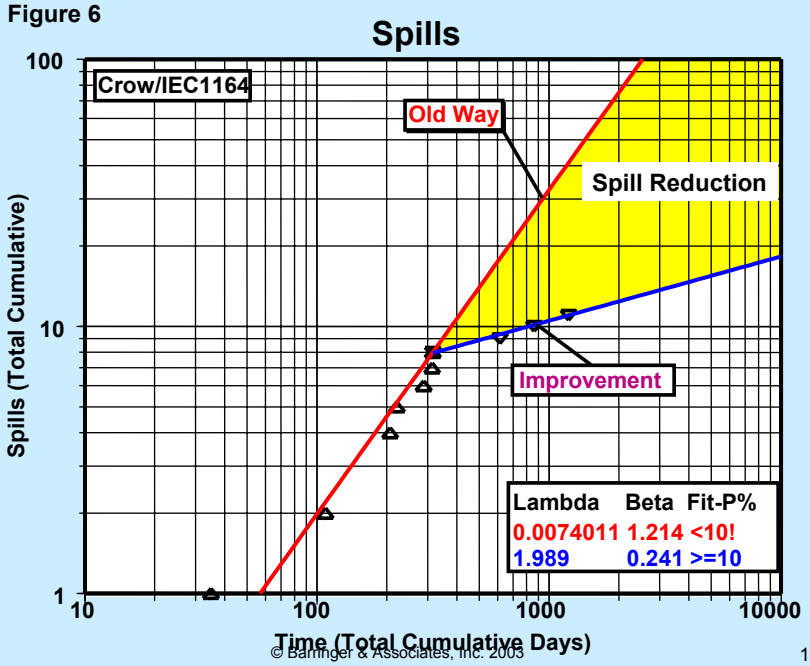


Table 6

Raw Data			Crow/AMSAA Data		Forecasted Failures		
Spill Date	Days Between Spill	Spill Events	Cum. Days	Cum. Spills	Failures Predicted By Old Method	New Method Savings	Missed Opportunities From Relapse
11/18/1995	35	1	35	1			
1/31/1996	74	1	109	2			
5/8/1996	98	2	207	4			
5/22/1996	14	1	221	5			
7/29/1996	68	1	289	6			
8/23/1996	25	1	314	7			
8/25/1996	2	1	316	8			
6/20/1997	299	1	615	9	18	9	Good News!
2/22/1998	247	1	862	10	27	17	
2/10/1999	353	1	1215	11	41	30	
8/16/1999	187	1	1402	12	Bad News! Failures Coming Faster!		1
11/7/1999	83	1	1485	13			2
2/12/2000	97	1	1582	14			2
4/29/2000	77	1	1659	15			3
11/16/2000	201	1	1860	16			4
12/25/2000	39	1	1899	17			5
3/25/2001	90	1	1989	18			5
8/1/2001	129	1	2118	19			6
10/28/2001	88	1	2206	20			7
7/10/2002	255	1	2461	21			9
7/25/2002	15	1	2476	22			9
9/6/2002	43	1	2519	23			9
2/18/2003	165	1	2684	24			11

Figure 7

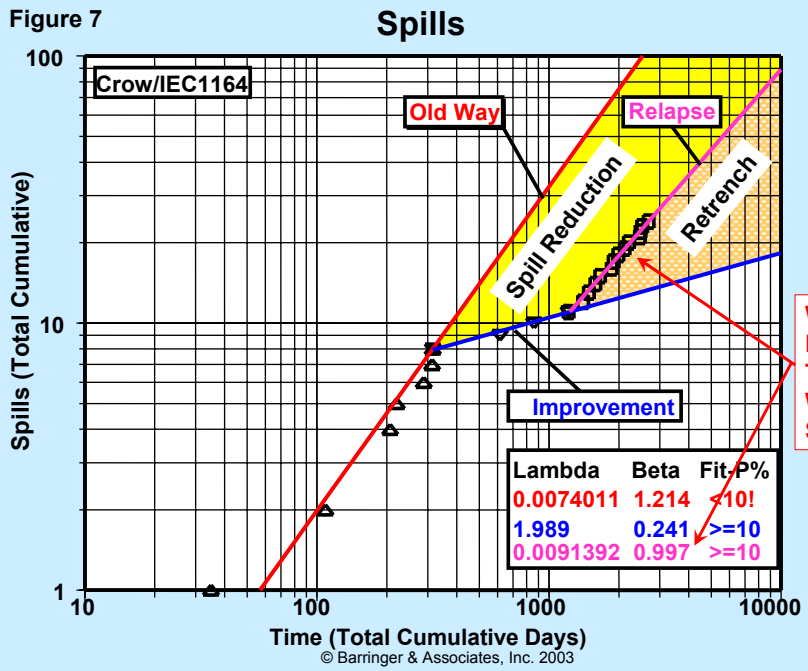


Table 7

				All Outages		Forced Outages	
Date	Event Outage	Event Description	Days Between Event	Cum. Days	Cum Failures	Cum. Days	Cum Failures
2/1/1999	Planned	Tie In	0	0	0	0	0
2/20/1999	Planned	Tie In	19	19	1		
2/24/1999	Forced	Gas Line Outage	4	23	2	23	1
5/22/1999	Forced	Animal Contact	87	110	3	110	2
7/9/1999	Planned	Interconnect Energized	48	158	4		
8/9/1999	Forced	Switching Error	31	189	5	189	3
9/13/1999	Forced	Tie Wrap Failure	35	224	6	224	4
10/13/1999	Forced	Lightning Strike	30	254	7	254	5
11/3/1999	Forced	Static Wire Short	21	275	8	275	6
11/6/1999	Forced	Switch Failed	3	278	9	278	7
11/10/1999	Forced	Not Logged	4	282	10	282	8
1/3/2000	Forced	Cable Bond Fault	54	336	11	336	9
6/12/2000	Forced	Underground Cable Fault	161	497	12	497	10
6/21/2000	Forced	Bird Contact	9	506	13	506	11
9/11/2000	Forced	Lightning Strike	82	588	14	588	12
11/7/2000	Forced	Animal Contact	57	645	15	645	13
12/2/2000	Forced	Animal Contact	25	670	16	670	14
12/12/2000	Forced	High Winds	10	680	17	680	15
4/11/2001	Forced	Not Logged	120	800	18	800	16
4/12/2001	Forced	Not Logged	1	801	19	801	17
4/19/2001	Planned	Tie In	7	808	20		
6/7/2001	Forced	Not Logged	49	857	21	857	18
8/22/2001	Forced	Pole Damage	76	933	22	933	19
9/13/2001	Forced	Interconnect Opened	22	955	23	955	20
9/16/2001	Forced	Supplemental Power Out	3	958	24	958	21
10/6/2001	Forced	Power Dip	20	978	25	978	22
10/12/2001	Forced	Control Tripped	6	984	26	984	23
10/31/2001	Forced	Power Dip	19	1003	27	1003	24
12/1/2001	Forced	Power Dip	31	1034	28	1034	25
1/1/2002	Forced	Steam Outage	31	1065	29	1065	26
4/15/2002	Forced	Switching Error	104	1169	30	1169	27
4/18/2002	Forced	Load Shedding Error	3	1172	31	1172	28
9/27/2002	Forced	Water In Switch Gear	162	1334	32	1334	29
12/6/2002	Forced	Generator Air Intake Frozen	70	1404	33	1404	30
1/3/2003	Forced	UPS Failure	28	1432	34	1432	31

Co-gen Failure Log: 31 Forced Outages In 1432 Days = 46.5 days per failure

Figure 8

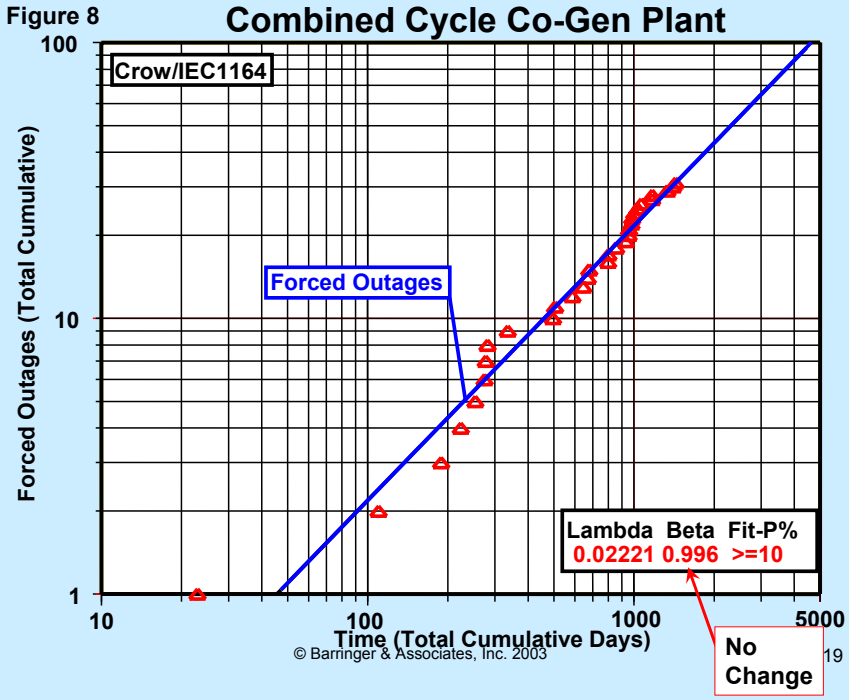


Table 7 With Failure Forecast

				All Outages		Forced Outages	
Date	Event Outage	Event Description	Days Between Event	Cum. Days	Cum Failures	Cum. Days	Cum Failures
2/1/1999	Planned	Tie In	0	0	0	0	0
2/20/1999	Planned	Tie In	19	19	1		
2/24/1999	Forced	Gas Line Outage	4	23	2	23	1
5/22/1999	Forced	Animal Contact	87	110	3	110	2
7/9/1999	Planned	Interconnect Energized					
			21	275	8	275	6
11/6/1999	Forced	Switch Failed	3	278	9	278	7
9/27/2002	Forced	Water In Switch Gear	162	1334	32	1334	29
12/6/2002	Forced	Generator Air Intake Frozen	70	1404	33	1404	30
1/3/2003	Forced	UPS Failure	28	1432	34	1432	31
2/23/2003	Forced	Predicted				1483	32
4/11/2003	Forced	Predicted				1530	33
5/27/2003	Forced	Predicted				1577	34
7/13/2003	Forced	Predicted				1623	35
8/28/2003	Forced	Predicted				1670	36
10/14/2003	Forced	Predicted				1716	37
11/29/2003	Forced	Predicted				1763	38
1/15/2004	Forced	Predicted				1809	39
3/2/2004	Forced	Predicted				1856	40
4/17/2004	Forced	Predicted				1903	41
6/3/2004	Forced	Predicted				1949	42

More Failures Predicted Into The Future From Lack Of An Improvement Program ($\beta \approx 1$)!

Summary

- Five actual datasets demonstrate **straight lines of cum failures vs cum time**
- Crow/AMSAA technology allows **failure forecast** of the mixed failure modes
- The forecast objective is to start decisive corrective action and **prevent predicted failures**
- Preventing failures requires **proactive** effort
- **Preventing future failures saves $!**