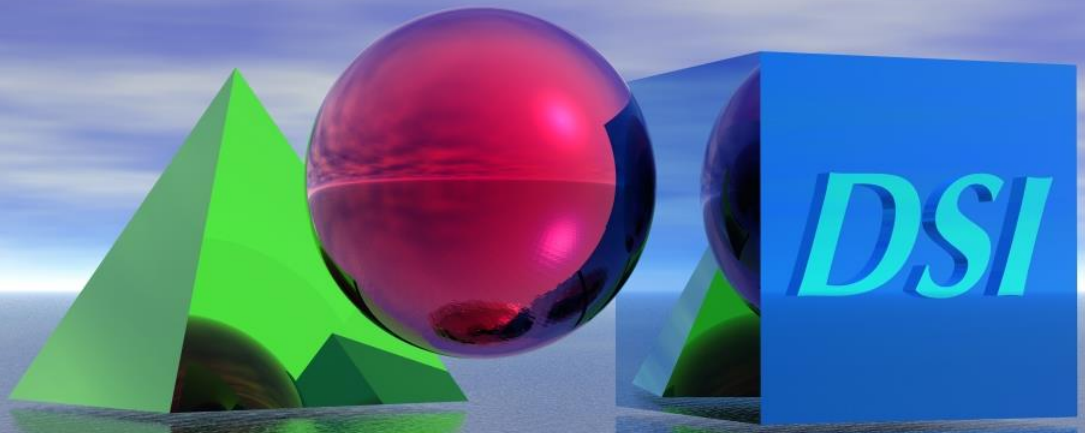
An Brief Introduction to:

Unique Isolation of Failures, or “FUI”



DSI International, Inc.

April, 2015

Fault Detection & Isolation in *eXpress*

Detection Order Report

Summary

Total Detection Tests: 17
Total Functions Detected: 92.68%
Total Probability Detected: 97.34%

Aggregate Failure Rate: 34634.054901
Mean Time Between Failures (MTBF): 28.87 hours

Beginning with a system that has a 97% Fault Detection…

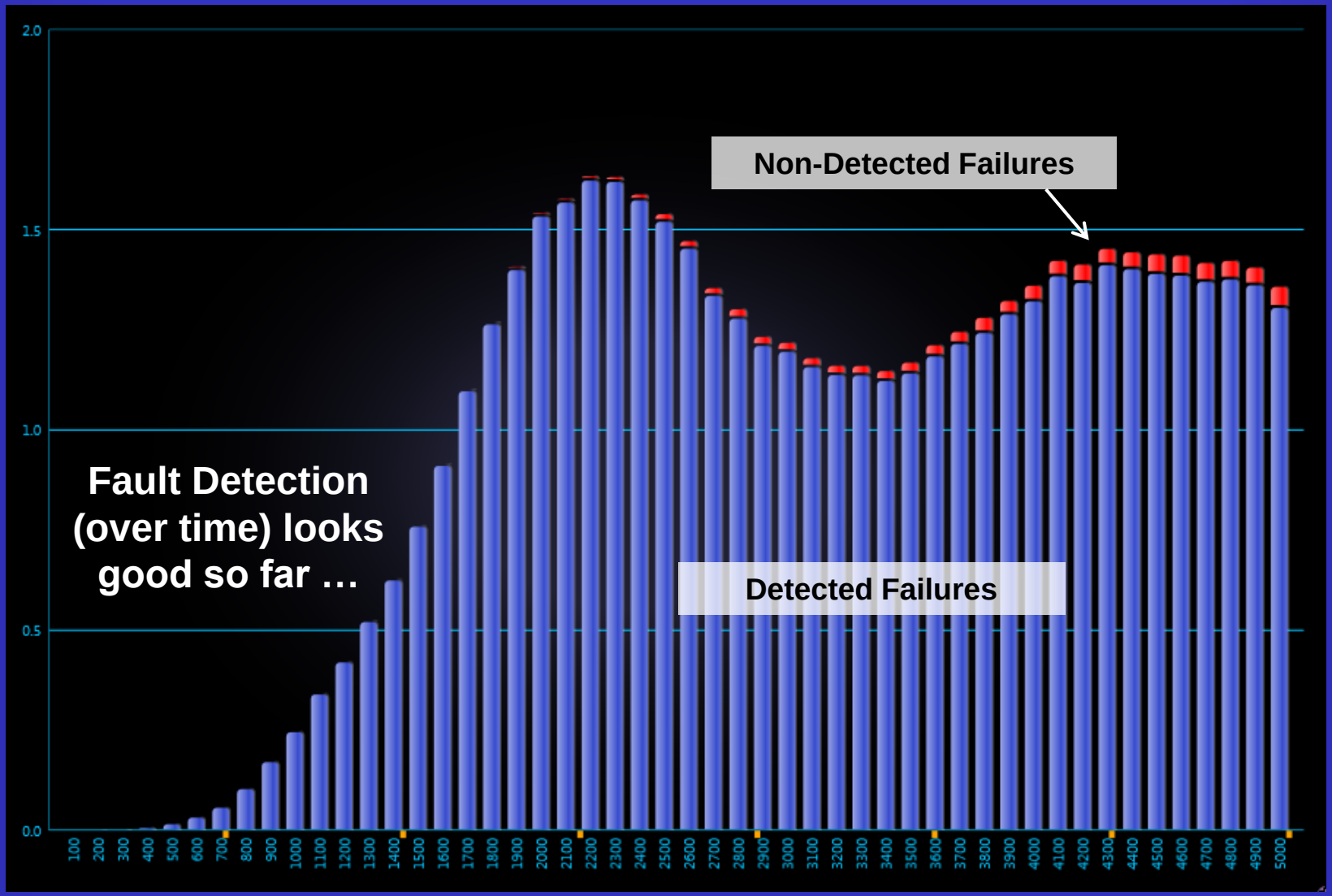
… and 92% Fault Isolation to a group of one item …

Fault Isolation Report

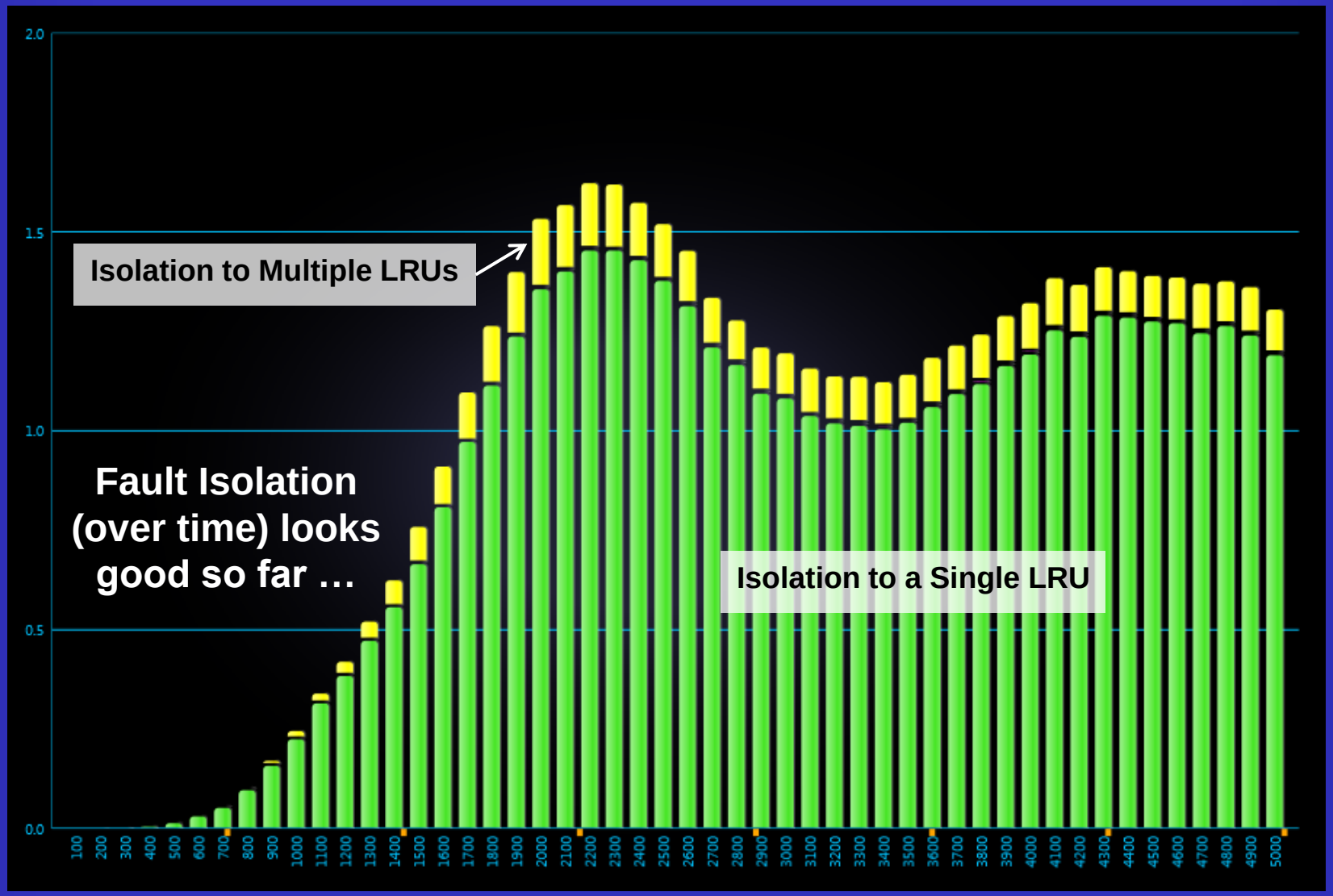
Multiple Failure
Fault Group Size Statistics

	Isolation Percentages Using Testing Only			Isolation Probabilities Using Testing Only		Resolution Probabilities Using Lambda Search	
Size	Qty	%	Cum %	%	Cum %	%	Cum %
1	77	78.57	78.57	81.04	81.04	92.72	92.72
2	11	11.22	89.80	8.97	90.00	3.37	96.09
3	0	0.00	89.80	0.00	90.00	2.01	98.10
4	0	0.00	89.80	0.00	90.00	1.29	99.39
5	2	2.04	91.84	7.22	97.22	0.57	99.96
6	0	0.00	91.84	0.00	97.22	0.03	99.98
7	7	7.14	98.98	2.16	99.38	0.01	99.99
8	1	1.02	100.00	0.62	100.00	< 0.01	100.00

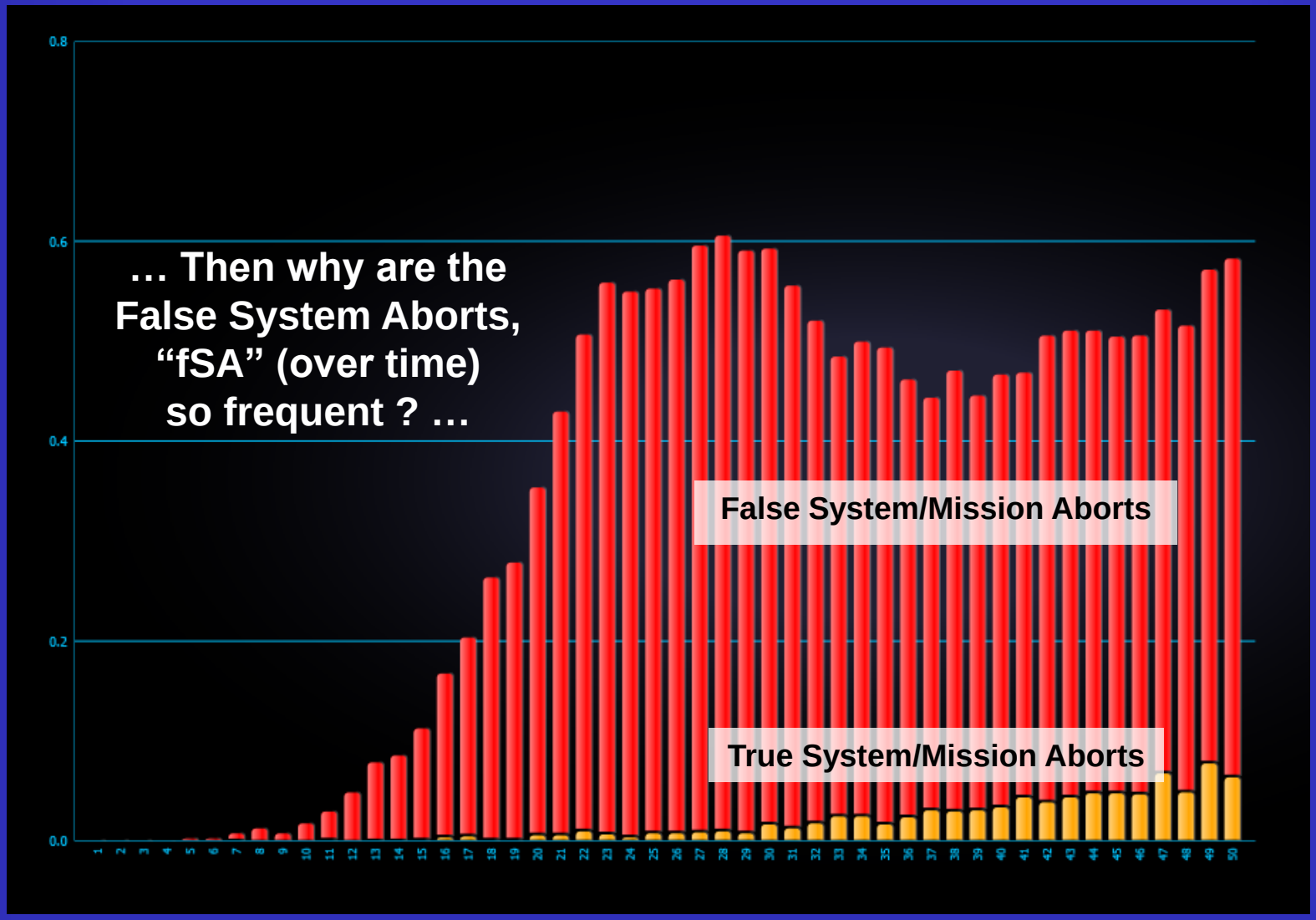
Fault Detection in STAGE



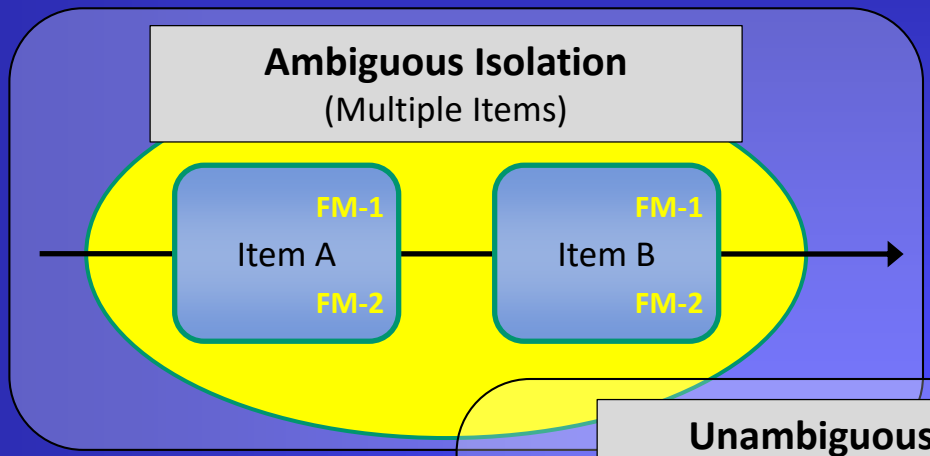
Fault Isolation in STAGE



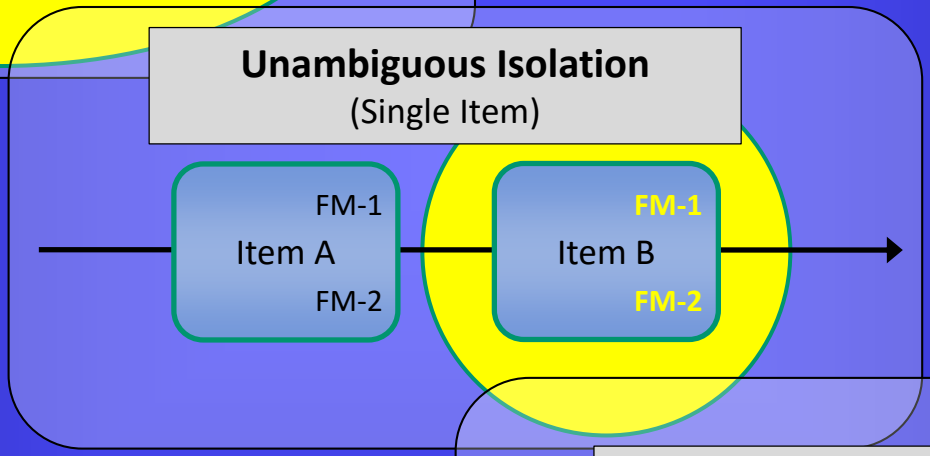
System/Mission Aborts in STAGE



Unambiguous vs. Unique Isolation



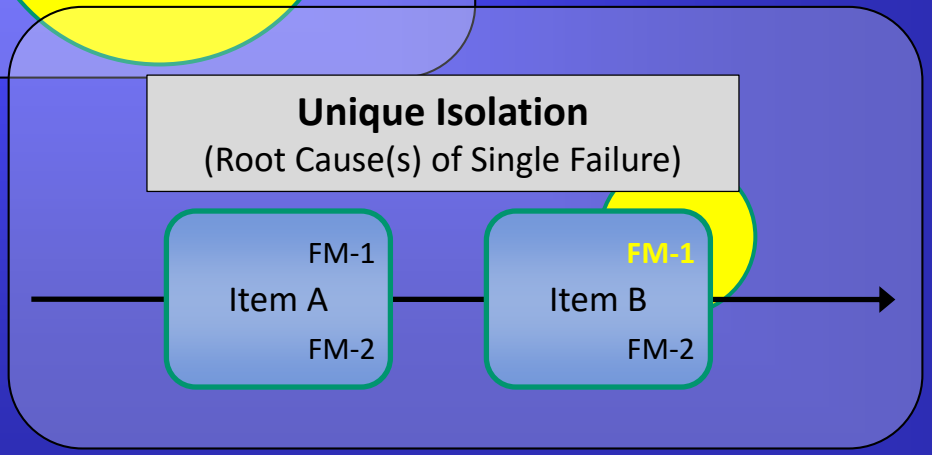
… The Fault Isolation was 97% to 1 item… But the fSA's were still unacceptable …



… Fault Isolation between the unique failures on the items remains unassessed

Failures Uniquely Isolated, "FUI" could have different severities…

Causing…
Different corrective actions and obfuscates sustainment decision-making

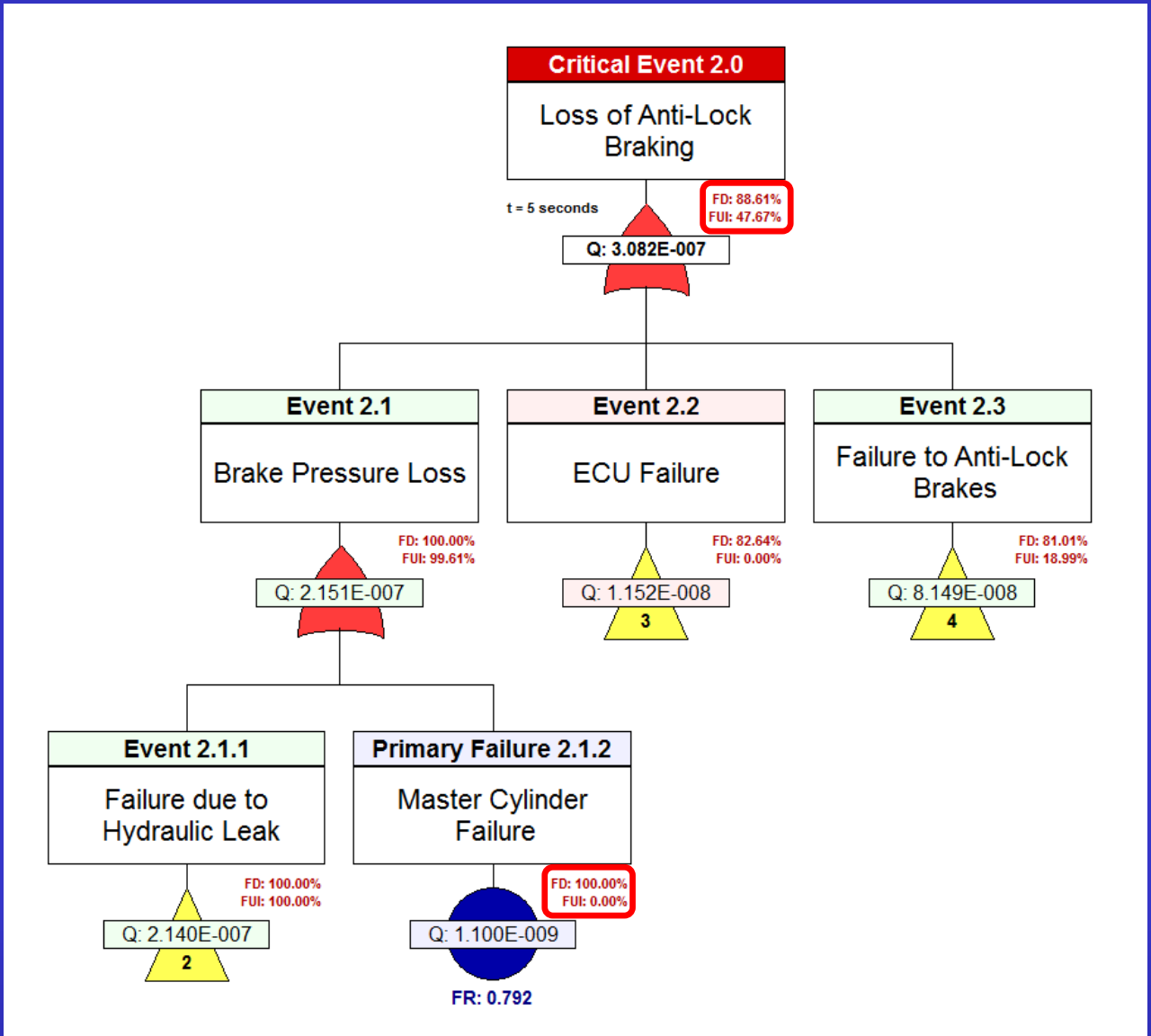


FMECA Plus: Critical Failure Diagnosis Chart

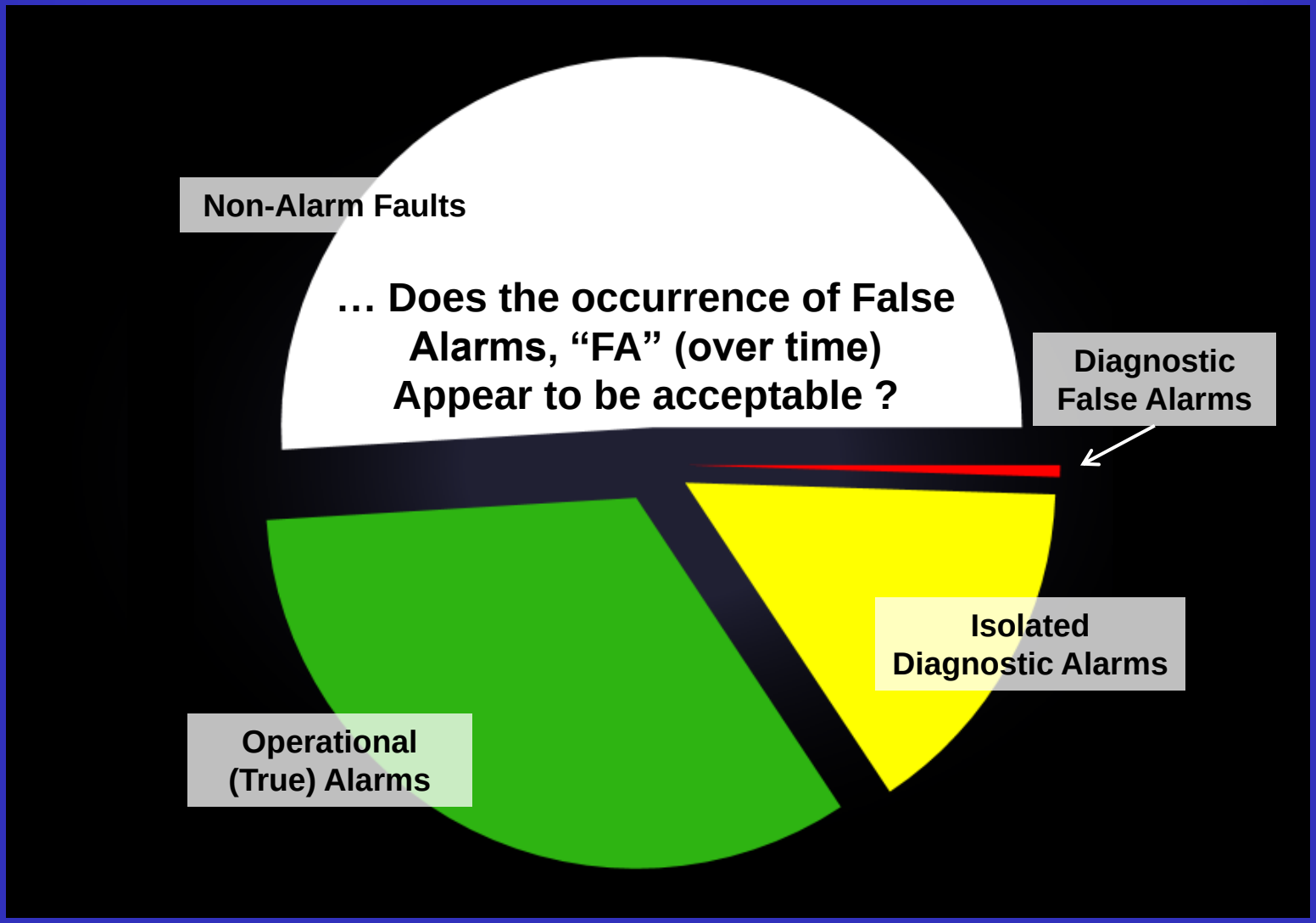
Failure	Item	Failure Rate	Severity Class	Relative Criticality	Diagnostic Coverage				
					Failure Detected	Fault Isolation			
						Uniquely Isolated	Number of Root FMs in Fault Groups	Fault Groups	Fault Group Sizes (Number of Items)
Hydraulic Leak	FS Line	38.026486	Loss of Life	38.0265	Yes	Yes	1	Fault Group # 88	1
Hydraulic Leak	FR Line	38.026486	Loss of Life	38.0265	Yes	Yes	1	Fault Group # 89	1
Forward Pump Failure	Front Pump	19.013243	Loss of Life	19.0132	No	N/A	N/A	N/A	N/A
Rear Pump Failure	Rear Pump	19.012853	Loss of Life	19.0129	No	N/A	N/A	N/A	N/A
L Brake Light Bulb Failure	L Brake Bulb	87.751628	Degraded Performance	17.5503	Yes	Yes	1	Fault Group # 82	1
R Brake Light Bulb Failure	R Brake Bulb	87.751628	Degraded Performance	17.5503	Yes	Yes	1	Fault Group # 84	1
W Brake Light Bulb Failure	RW Brake Bulb	87.751628	Degraded Performance	17.5503	Yes	Yes	1	Fault Group # 85	1
Battery dead	BATTERY	41.639002	Loss of Operation	16.6556	Yes	No	2	Fault Group # 0	1
Solenoid Control Relay Coil Open	Solenoid Relay	11.573041	Loss of Life	11.5730	No	N/A	N/A	N/A	N/A
Battery Fuse Blown	Fuse	11.407946	Loss of Life	11.4079	Yes	Yes	1	Fault Group # 1	1
Pump Relay Cotact Stuck Open	Pump Relay	11.129475	Loss of Life	11.1295	Yes	Yes	1	Fault Group # 23	1
Brake Light Switch Stuck Open	Brake Light SW	9.919749	Loss of Life	9.9197	Yes	No	2	Fault Group # 83	1
Pad1 Wear Beyond Limit	LR Disc Assy:PADS	9.393689	Loss of Life	9.3937	Yes	No	4	Fault Group # 105	1
Pad1 Wear Beyond Limit	LF Disc Assy:PADS	9.393689	Loss of Life	9.3937	Yes	No	4	Fault Group # 102	1
Pad1 Wear Beyond Limit	RR Disc Assy:PADS	9.393689	Loss of Life	9.3937	Yes	No	4	Fault Group # 104	1
Pad1 Wear Beyond Limit	RF Disc Assy:PADS	9.393689	Loss of Life	9.3937	Yes	No	4	Fault Group # 103	1
Tread Worn	LR Tire	45.000000	Degraded Performance	9.0000	No	N/A	N/A	N/A	N/A
Worn Tread	RF Tire	45.000000	Degraded Performance	9.0000	No	N/A	N/A	N/A	N/A
Worn Tread	LF Tire	45.000000	Degraded Performance	9.0000	No	N/A	N/A	N/A	N/A
Worn Tread	RR Tire	45.000000	Degraded Performance	9.0000	No	N/A	N/A	N/A	N/A
Pedal Linkage Failure	Brake Pedal	8.577227	Loss of Life	8.5772	Yes	Yes	1	Fault Group # 3	1
Ignition Switch Stuck Open	Ignition Switch	8.415525	Loss of Life	8.4155	Yes	Yes	1	Fault Group # 2	1
Solenoid Control Relay Ccontact stuck ATCM	Solenoid Relay	7.661896	Loss of Life	7.6619	Yes	Yes	1	Fault Group # 81	1
Solenoid Control Relay Ccontact stuck GND	Solenoid Relay	7.661896	Loss of Life	7.6619	Yes	Yes	1	Fault Group # 80	1
Hydraulic Leak	RS Line	38.027272	Degraded Performance	7.6055	Yes	Yes	1	Fault Group # 86	1
Hydraulic Leak	RR Line	38.027272	Degraded Performance	7.6055	Yes	Yes	1	Fault Group # 87	1

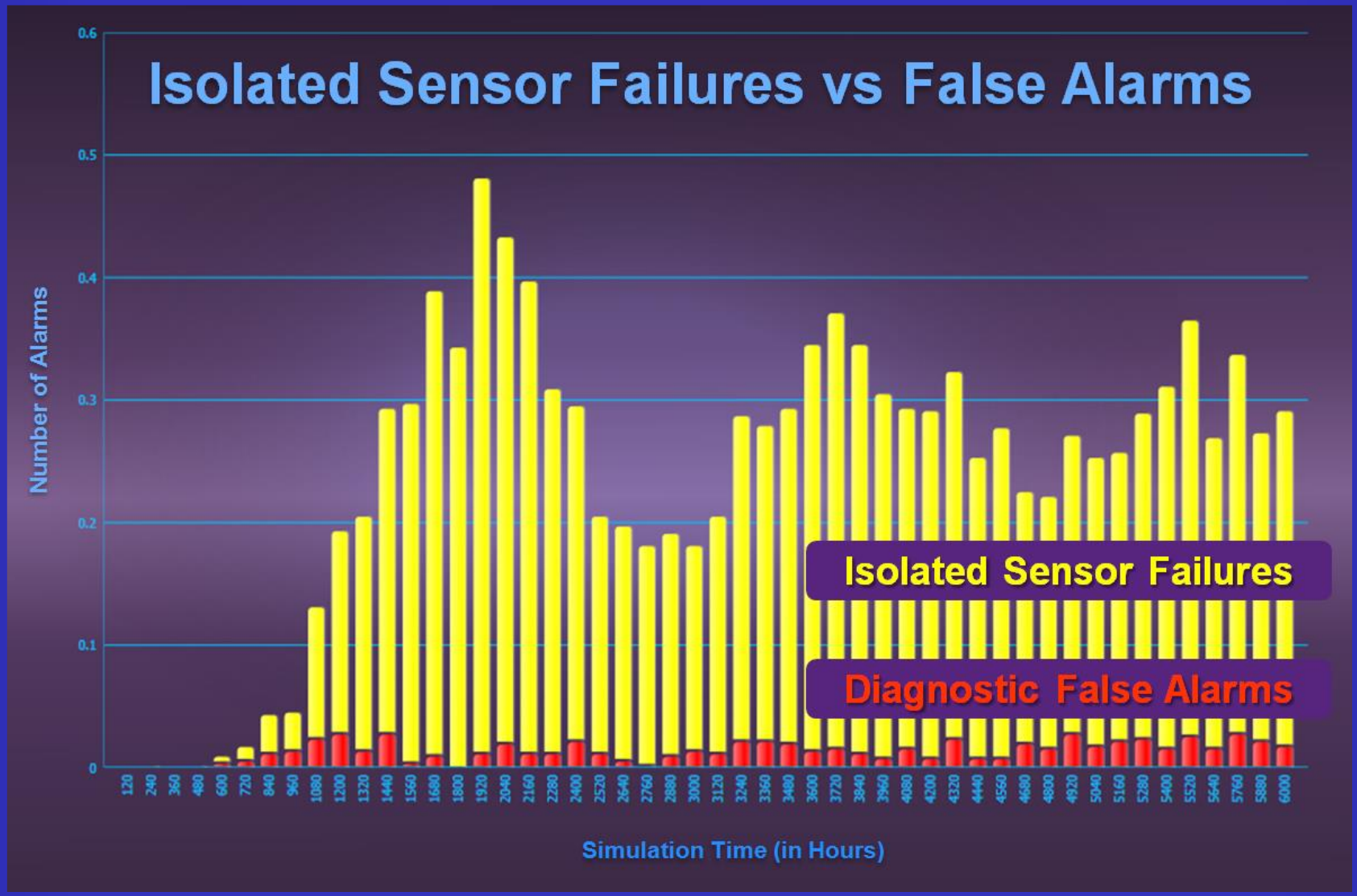
The “Uniquely Isolated” column indicates whether the fault group that is isolated for this failure contains only root causes of the given failure. If the fault group contains any failure modes that are not a root cause of that failure, then the failure has not been uniquely isolated by the diagnostics. The non-unique isolation of critical failures is a primary driver of false alarms and unnecessary system or mission aborts.

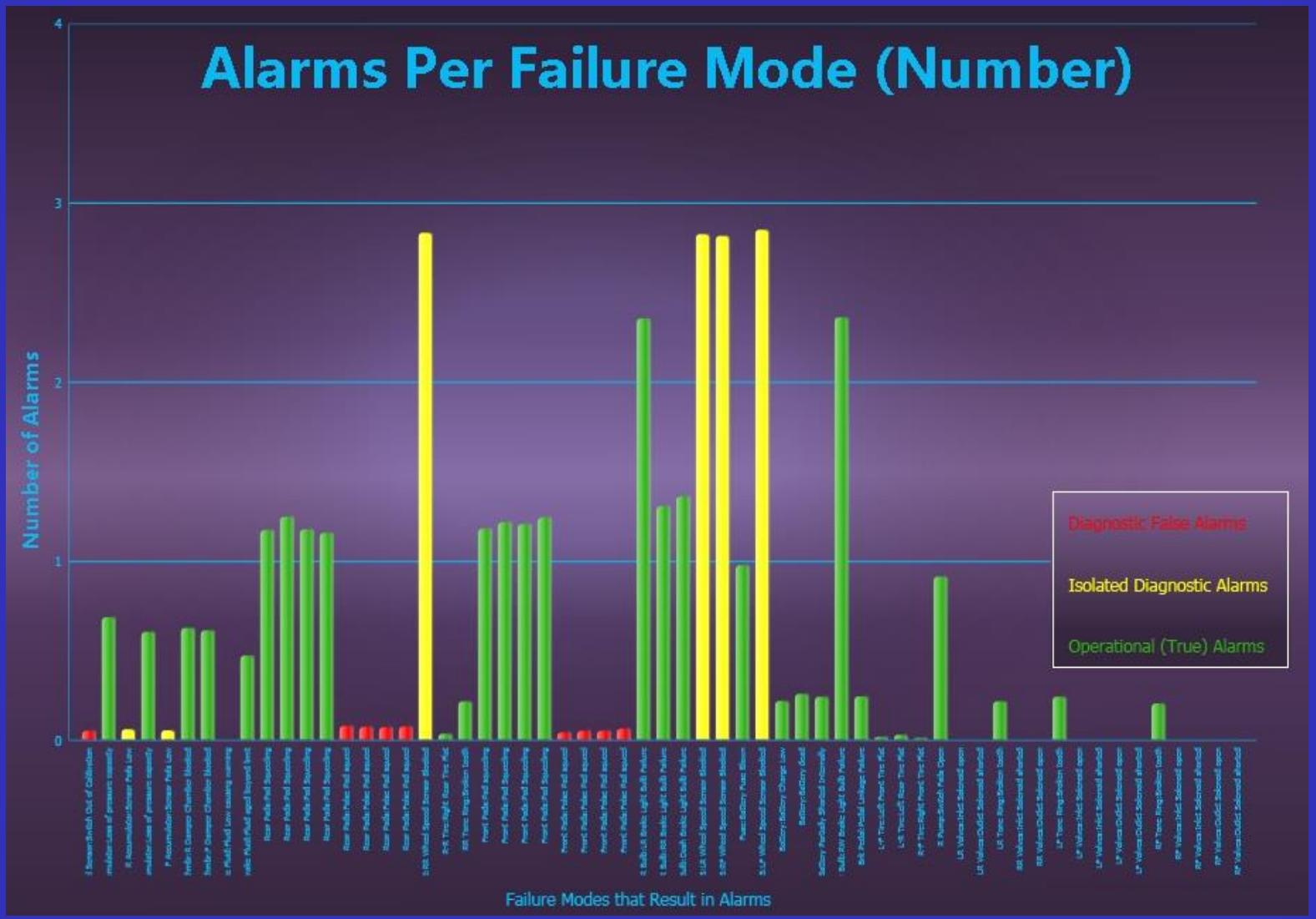
eXpress FTA Module: Fault Tree with FD/FUI



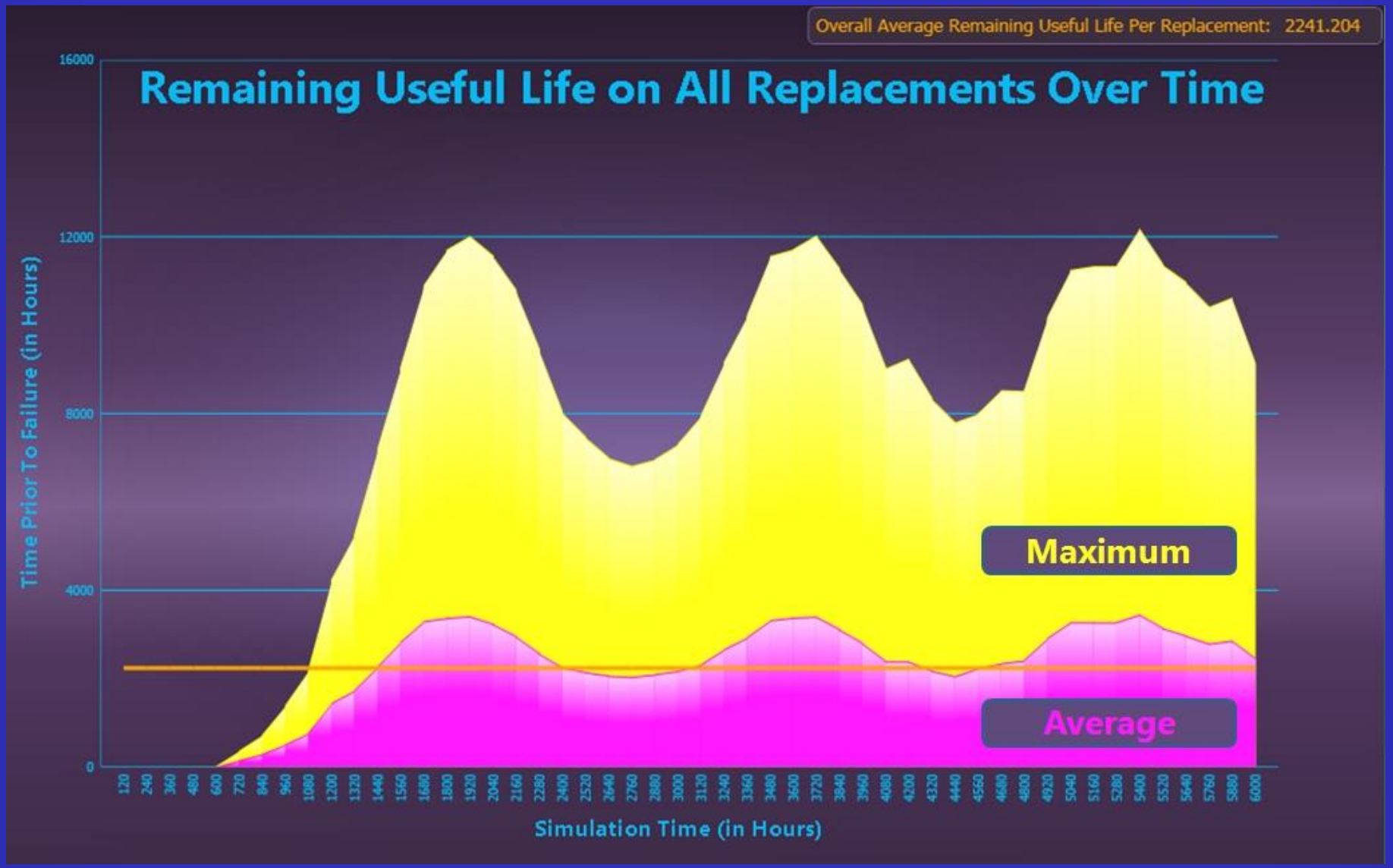
False Alarms in STAGE




Isolated Sensor Failures vs False Alarms
Number of Alarms
0.6
0.5
0.4
0.3
0.2
0.1
0
120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800 1920 2040 2160 2280 2400 2520 2640 2760 2880 3000 3120 3240 3360 3480 3600 3720 3840 3960 4080 4200 4320 4440 4560 4680 4800 4920 5040 5160 5280 5400 5520 5640 5760 5880 6000
Simulation Time (in Hours)
Isolated Sensor Failures
Diagnostic False Alarms


Alarms Per Failure Mode (Number)
Number of Alarms
0
1
2
3
4
Diagnostic False Alarms
Isolated Diagnostic Alarms
Operational (True) Alarms
Failure Modes that Result in Alarms


False Removals Over Time (Number)
Number of Replaced Items
1.2
0.9
0.6
0.3
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
1920
2040
2160
2280
2400
2520
2640
2760
2880
3000
3120
3240
3360
3480
3600
3720
3840
3960
4080
4200
4320
4440
4560
4680
4800
4920
5040
5160
5280
5400
5520
5640
5760
5880
6000
Simulation Time (in Hours)

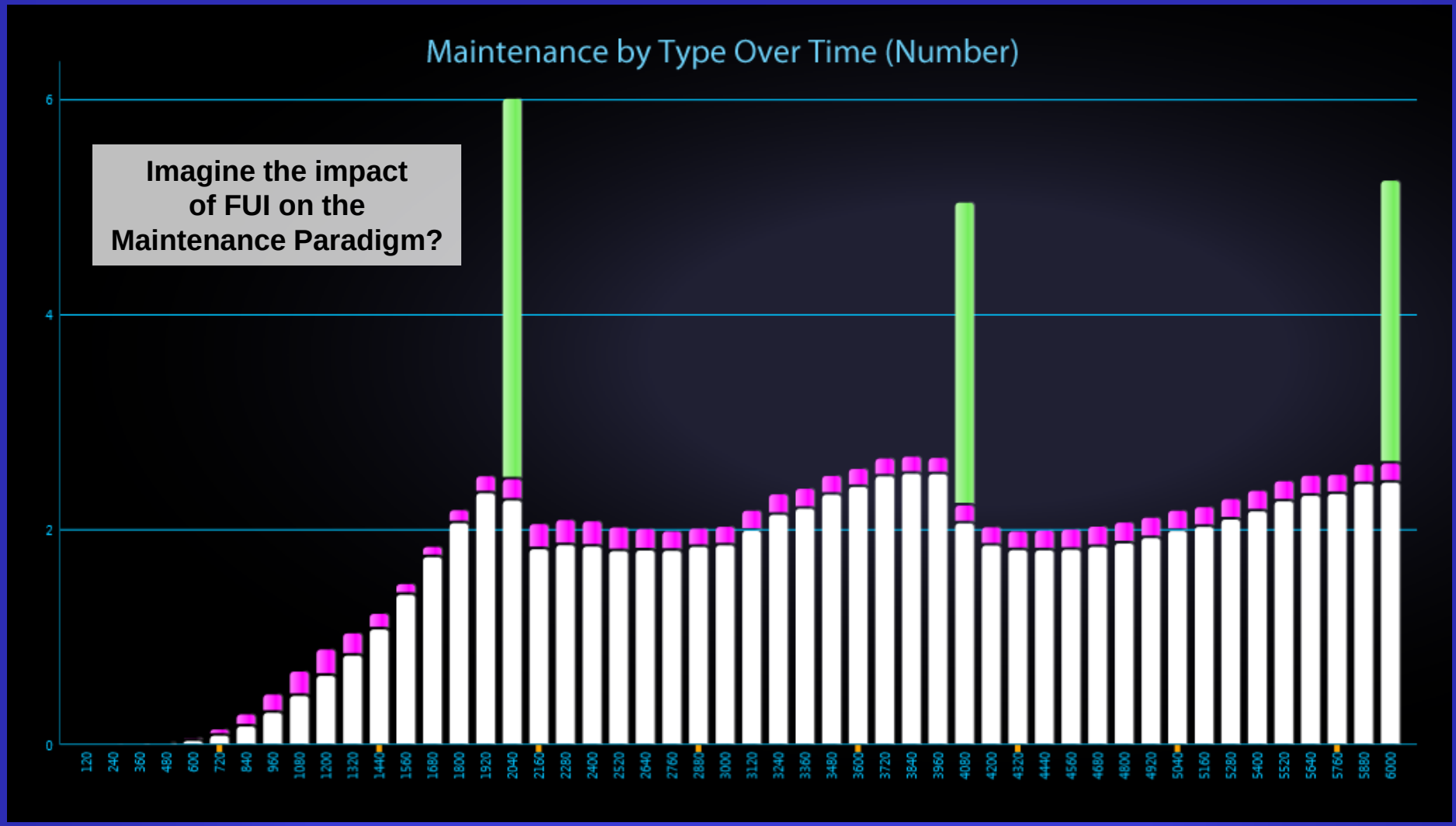

Overall Average Remaining Useful Life Per Replacement: 2241.204
Remaining Useful Life on All Replacements Over Time
Time Prior To Failure (in Hours)
16000
12000
8000
4000
0
Maximum
Average
120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800 1920 2040 2160 2280 2400 2520 2640 2760 2880 3000 3120 3240 3360 3480 3600 3720 3840 3960 4080 4200 4320 4440 4560 4680 4800 4920 5040 5160 5280 5400 5520 5640 5760 5880 6000
Simulation Time (in Hours)

Simulation Summary Report

Simulation:	Run to Failure	Sched. Maint. (tight)	Sched. Maint. (loose)	Prognostics
Failure Statistics				
Likelihood of Loss of Operation	100% at 1,280 hours	100% at 1,360 hours	100% at 1,680 hours	100% at 1,520 hours
Likelihood of Loss of Equipment	100% at 1,440 hours	100% at 1,760 hours	100% at 2,000 hours	100% at 1,920 hours
Likelihood of Loss of Life	62.098% at 4,000 hours	61.537% at 4,000 hours	62.612% at 4,000 hours	61.904% at 4,000 hours
Prognostic Statistics				
Critical Failures Prognosed	N/A	N/A	N/A	4.787 (27.007%)
Critical Failures Not Prognosed: Loss of Operation	2.780 (15.694%)	2.828 (20.004%)	2.800 (26.677%)	2.787 (15.721%)
Critical Failures Not Prognosed: Loss of Equipment	14.255 (80.486%)	10.622 (75.143%)	7.015 (66.830%)	9.480 (53.484%)
Critical Failures Not Prognosed: Loss of Life	0.677 (3.820%)	0.686 (4.853%)	0.682 (6.493%)	0.672 (3.788%)
Maintenance Statistics				
Corrective Maintenance	54.646 (100.000%)	51.753 (87.637%)	46.943 (72.724%)	50.747 (90.984%)
Scheduled Maintenance	N/A	7.301 (12.363%)	17.607 (27.276%)	N/A
Maintenance due to Prognostics	N/A	N/A	N/A	5.029 (9.016%)
Replacement Statistics				
Replacements due to Item Failure	42.157 (77.146%)	39.143 (66.283%)	34.320 (53.168%)	38.130 (68.362%)
Replacements due to Diagnostic Ambiguity	12.489 (22.854%)	12.611 (21.354%)	12.623 (19.556%)	12.618 (22.622%)
Replacements due to Prognostics	N/A	N/A	N/A	5.029 (9.016%)
Replacements due to Scheduled Maintenance	N/A	7.301 (12.363%)	17.607 (27.276%)	N/A
Remaining Useful Life Per Replacement	1,392.812 hours (3.164%)	1,507.617 hours (5.347%)	1,634.176 hours (9.279%)	1,480.756 hours (6.409%)
Remaining Useful Life Per Early Replacement	2,222.812 hours (4.791%)	2,322.021 hours (7.652%)	2,418.948 hours (12.072%)	2,287.480 hours (9.290%)
Cost-Related Statistics				
Wasted Item Cost	274.53	680.85	1,162.97	392.29
Wasted Item Cost due to False Removals	274.53 (100.000%)	279.49 (41.050%)	276.79 (23.800%)	279.03 (71.130%)
Wasted Item Cost due to Prognostics	N/A	N/A	N/A	113.25 (28.870%)
Wasted Item Cost due to Scheduled Maintenance	N/A	401.36 (58.950%)	886.18 (76.200%)	N/A
Cost of Extra Replacements	105.24	399.31	694.67	133.24
Cost of Extra Replacements due to False Removals	105.24 (100.000%)	109.74 (27.483%)	105.26 (15.152%)	110.55 (82.965%)
Cost of Extra Replacements due to Prognostics	N/A	N/A	N/A	22.70 (17.035%)
Cost of Extra Replacements due to Scheduled Maintenance	N/A	289.57 (72.517%)	589.41 (84.848%)	N/A

Simulation Summary Report

Simulation:	3000 hours (w/o Prev. Maint.)	5000 hours (w/o Prev. Maint.)	8000 hours (w/o Prev. Maint.)
RAM-T Metrics			
Reliability	0.97681	0.96994	0.96584
Mission Length (for Reliability)	2.50 hours	2.50 hours	2.50 hours
Inherent Availability	0.98858	0.98464	0.98144
Operational Availability	0.86473	0.81982	0.78728
Mean Logistics Delay Time (MLDT)	24.00 hours	24.00 hours	24.00 hours
Mean Time to Repair (MTTR)	106.369 minutes	104.042 minutes	103.988 minutes
Mean Time to Replace (MTTR)	75.854 minutes	72.613 minutes	71.774 minutes
Mean Time to Isolate (MTTI)	30.515 minutes	31.428 minutes	32.214 minutes
Fault Detection	96.70%	94.72%	94.26%
Fault Isolation to 1 Item	92.50%	92.30%	92.18%
Fault Isolation to 2 Items or less	92.51%	92.30%	92.19%
Fault Isolation to 3 Items or less	92.51%	92.30%	92.19%
False Alarm Rate (from diagnostics)	0.959%	0.829%	1.035%
Failure Statistics			
Failures	28.358	61.306	111.532
Unique Failures	26.690	43.852	57.350
Total Percentage of Possible Failures	12.187%	20.024%	26.187%
Diagnostic Statistics			
Detected Faults	27.422 (96.699%)	58.070 (94.722%)	105.134 (94.264%)
Non-Detected Faults	0.936 (3.301%)	3.236 (5.278%)	6.398 (5.736%)
Faults Isolated to Fault Group of Size 1	25.366 (92.502%)	53.596 (92.296%)	96.914 (92.181%)
Faults Isolated to Fault Group of Size 2	0.002 (0.007%)	N/A	0.004 (0.004%)
Faults Isolated to Fault Group of Size 4 or Greater	2.054 (7.490%)	4.474 (7.704%)	8.216 (7.815%)
Diagnostic False Alarms	0.272 (0.959%)	0.508 (0.829%)	1.154 (1.035%)
Replacement Statistics			
Removals	35.044	74.700	135.462
True Removals	27.422 (78.250%)	58.070 (77.738%)	105.134 (77.611%)
False Removals	7.622 (21.750%)	16.630 (22.262%)	30.328 (22.389%)



Scheduled Maintenance (RCM)
Conditioned Based Maintenance (CBM)
Corrective Maintenance (CM)