LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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LIGO
DATA ACQUISITION SYSTEM
RELIABILITY PREDICTION REPORT

LIGO Systems Engineering

This is an internal working note
of the LIGO Project.

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TABLE OF CONTENTS

ABSTRACT 4
1.0 INTRODUCTION 5
2.0 ACRONYMS 6
3.0 APPLICABLE DOCUMENTS 7
4.0 RELIABILITY REQUIREMENTS 8
5.0 RELIABILITY ANALYSES 10
5.1 RELIABILITY MODELING 10
5.2 RELIABILITY PREDICTION 11
5.3 AVAILABILITY PREDICTION 11
6.0 CONCLUSIONS 16
APPENDIX A:
DAQ AVAILABILITY PREDICTION,
HANFORD, WA A-17
APPENDIX B:
DAQ AVAILABILITY PREDICTION,
LIVINGSTON, LA B-46
APPENDIX C:
LIGO 3X
DAQ AVAILABILITY PREDICTION C-65
APPENDIX D:
LIGO 2X
DAQ AVAILABILITY PREDICTION D-67
APPENDIX E:
LIGO 1X
DAQ AVAILABILITY PREDICTION E-69
APPENDIX F:
DEMYSTIFYING
TAPE RELIABILITY F-71

LIST OF TABLES

Table 1: Project Documents 7
Table 2: Reliability Standards and Handbooks. 7
Table 3: Reliability Software 7
Table 4: LIGO System Reliability Requirements. 8
Table 5: Subsystem Availability Allocations 9
Table 6: Reliability Data Sources 15
Table 7: Interferometer DAQ Availability Prediction Results 16
Table 8: DAQ Availability Predictions For The LIGO Operating Modes 16

LIST OF FIGURES

Figure 1: DAQ Reliability Block Diagram For The LIGO 3X Operating Mode 12
Figure 2: DAQ Reliability Block Diagram For The LIGO 2X Operating Mode 13
Figure 3: DAQ Reliability Block Diagram For The LIGO 1X Operating Mode 14

ABSTRACT

A reliability prediction was performed on the LIGO Data Acquisition System (DAQ). Vendor data was the primary source of reliability values for the various equipments comprising the DAQ. Where vendor data was not available, engineering estimates were made based upon equipment complexity, NPRD-95 data and vendor data on similar equipment.

The manufacturer and configurations for the DAQ Short Term Storage System, Long Term Storage System and Servers were not defined at the time of this report. A RAID Disk Drive Storage System was being considered for the Short Term Storage System and Magnetic Tape and recordable CD ROM was under evaluation for the Long Term Storage System. SUN Workstations are being considered for the Servers. Research on the RAID Disk Drive Systems and the Magnetic Tape Systems showed that numerous configurations are available with various levels of redundancy. The redundancy includes such things as redundant disk drives, redundant power supplies, redundant data recording, redundant tape robots, etc. It is assumed that there will also be some level of redundancy designed into the final configuration of the Servers. Based upon the information presented in Appendix F, it was determined that the Short Term Storage, Long Term Storage, and Server systems would be Availability Class 5 systems. Availability Class 5 systems have an availability of 99.999%. Therefore, a fixed availability value of 0.99999 was assigned to the Short Term Storage System, the Long Term Storage System and the Server System.

The DAQ consists primarily of computer type equipment and rack mounted modular electronic assemblies. On-line diagnostics capabilities and fault indications have been designed into the DAQ to ease the fault detection, fault localization and fault isolation process. It is assumed that a sufficient electronic module spares inventory will be available at each observatory. Taking into consideration the on-line diagnostics capability, the modular design concept and the availability of spares, the MDT associated with a DAQ repair action should be minimal. Therefore, a DAQ MDT value of 8.0 hours was used for the availability predictions.

A fault tree was developed and an Availability prediction was performed on the DAQ at the Washington Observatory. The Washington Observatory DAQ consists of the HIF1 DAQ, the HIF2 DAQ, the HCMN DAQ and the HPEM DAQ. A fault tree was also developed and an Availability prediction was also performed on the DAQ at the Louisiana Observatory. The DAQ at the Louisiana Observatory consists of the LIF1 DAQ.

The fault tree and detailed calculations for the HIF1 DAQ, the HIF2 DAQ, the HCMN DAQ and the HPEM DAQ are provided in Appendix A. The fault tree and detailed calculations for the LIF1 DAQ are provided in Appendix B. Availability predictions were then performed for the three LIGO operating modes. The fault trees and Availability predictions for the three LIGO operating modes are provided in Appendices C through E. The results of the DAQ availability predictions for each of the LIGO operating modes are summarized in the table below.

DAQ Availability Predictions For The LIGO Operating Modes

Mode of Operation	*Allocated Annual Availability*	*Predicted Annual Availability*
3X	0.9959	0.9714
2X	0.9980	0.9862
1X	1.0000	1.0000

1.0 INTRODUCTION

Reliability, repair time and availability calculations were performed on the Data Acquisition System (DAQ) of the Laser Interferometer Gravitational Wave Observatory (LIGO). Failure rate data was obtained from the following sources:

- Vendor data
- "Non-Electronic Parts Reliability Data 1995," NPRD-95, Reliability Analysis Center
- Engineering estimates predicated upon experience with equipments of similar complexity.

The calculations were predicated upon the design information available at the time this report was prepared. This report will be updated to reflect the current design if the differences in design or material/part selection are likely to significantly impact reliability or availability.

2.0 ACRONYMS

A	Operational Availability
ADC	Analog/Digital Converter
ASC	Alignment Sensing and Control
Assy	Assembly
CMN	Common
DAQ	Data Acquisition
DCU	Data Collection Unit
FB	Frame Builder
FPMH	Failures Per Million Hours
FTA	Fault Tree Analysis
GPS	Global Positioning System
H	Hanford, Washington site
IFODS	Interferometer Diagnostics System
IF1	Interferometer, 4 km long
IF2	Interferometer, 2 km long
L	Livingston, Louisiana site
LIGO	Laser Interferometer Gravitational Wave Observatory
LSC	Length Sensing and Control
MDT	Mean Down Time
MSD	Mass Storage Devices
MTBF	Mean Time Between Failure (λ^{-1})
N/A	Not Applicable
NDCU	Network Data Collection Unit
OSB	Operational Support Building
PEM	Physics Environment Monitoring
PSL	Pre-Stabilized Laser
Q	Operational Unavailability (1 - A)
RTDD	Real Time Data Distribution
SUS	Suspension System
λ	Failure Rate

3.0 APPLICABLE DOCUMENTS

The documents containing Data Acquisition System (DAQ) design requirements, DAQ design, LIGO reliability requirements and guidelines, reliability modeling and prediction methods, and the software used to perform the reliability predictions and availability calculations are listed in the tables below.

Table 1: Project Documents

LIGO-E960099-B-E	LIGO Reliability Program Plan
LIGO-T960009-A-C	LIGO Data Acquisition System Design Requirements
LIGO-T970136-00-C	CDS Data Acquisition Preliminary Design
LIGO-G960000-00-M	LIGO Data Acquisition Preliminary Design Review
LIGO - E950018-02-E	LIGO Science Requirements Document

Table 2: Reliability Standards and Handbooks

MIL-STD-785	Reliability Program for Systems and Equipment Development and Prediction
MIL-STD-756	Reliability Modeling and Prediction
MIL-HDBK-217F	Reliability Prediction For Electronic Equipment
NRPD-95	Non-Electronic Parts Reliability Data 1995, Reliability Analysis Center

Table 3: Reliability Software

RELEX 217	Reliability prediction software; hardware failure rate calculations.
ITEM Software FaultTree+	Fault tree analysis software; Availability calculations

4.0 RELIABILITY REQUIREMENTS

The LIGO top level system availability requirements are summarized in Table 4 below:

Table 4: LIGO System Reliability Requirements

Mode of Operation	*Annual Availability*	*Minimum Continuous Operating Period*
3X	75%	100 hours
2X	85%	100 hours
1X	90%	40 hours

The Modes of Operation are defined as:

a. Triple Operations Mode (3X): All three interferometers are operational.

b. Double Operations Mode (2X): At least two interferometers are operational. One of which must be the Louisiana interferometer.

c. Single Operations Mode (1X): At least one of the three interferometers is operational.

As described in the LIGO Reliability Program Plan, the allocated subsystem availability requirements were derived from the observatory availability requirements for the 3X mode of operation. With respect to availability, the 3X mode of operation represents the worst case operating scenario. For the reader's convenience, the subsystem availability requirements are presented in Table 5 on page 9. The DAQ availability requirements are highlighted. In the process of allocating the subsystem availability requirements, it was assumed that the 4 km and the 2 km interferometers were of equal complexity. Therefore, since there are two interferometers at the Washington Observatory, the subsystems at the Washington Observatory were assumed to be twice as complex as the respective subsystems at the Louisiana Observatory. As a result, the Washington Observatory subsystem Mean-Time-Between-Mission-Critical-Failure (MTBMCF) values are half of the respective subsystem MTBMCF values at the Louisiana Observatory. The Beam Tube, Facilities Monitoring and Control System, Heating, Ventilation and Air Conditioning, and Electrical Power are exceptions to this rule. These four subsystems were considered to be of equal complexity at each observatory.

MTBMCF is the mean time between subsystem failures which would jeopardize the collection and validation of science data. The MTBMCF takes into consideration equipment redundancies which might be present within the subsystem.

Table 5: Subsystem Availability Allocations

SUBSYSTEM	*OBSERVATORY*					
	LOUISIANA			*WASHINGTON*		
	MTBMCF *(Op. Hours)*	*MDT* *(Hours)*	*A*	*MTBMCF* *(Op. Hours)*	*MDT* *(Hours)*	*A*
CDS C&M	17, 600	24	0.9986	8, 800	24	0.9973
CDS DAQ	**17, 600**	**24**	**0.9986**	**8, 800**	**24**	**0.9973**
CDS Infrastructure	17, 600	24	0.9986	8, 800	24	0.9973
VCMS	17, 600	24	0.9986	8, 800	24	0.9973
ASC	20, 000	72	0.9964	10, 000	72	0.9929
LSC	20, 000	72	0.9964	10, 000	72	0.9929
COC	26, 000	72	0.9972	13, 000	72	0.9945
COS	24, 000	72	0.9970	12, 000	72	0.9940
IOO	10, 000	72	0.9929	5, 000	72	0.9858
PSL	5, 000	72	0.9858	2, 500	72	0.9720
SEI	13, 000	72	0.9945	6, 500	72	0.9890
SUS	13, 000	72	0.9945	6, 500	72	0.9890
PEM	17, 600	24	0.9986	8, 800	24	0.9973
BT	35, 000	1, 460	0.9600	35, 000	1, 460	0.9600
FMCS	17, 600	24	0.9986	17, 600	24	0.9986
HVAC	17, 600	72	0.9959	17, 600	72	0.9959
ELEC. PWR.	8, 800	24	0.9973	8, 800	24	0.9973
VE	8, 800	72	0.9919	4, 400	72	0.9839

Mean-Down-Time (MDT) is the total preventive and corrective maintenance time divided by the total number of preventive and corrective maintenance actions for a given subsystem. Logistic delays are included in the calculation of preventive and corrective maintenance times. The subsystem MDT requirements are based upon subsystem. size, complexity, and the fact that some subsystems may require a bake-out following maintenance actions. The MDT requirement should be used as a guide in the development of on-site spares and maintenance support policies.

Availability is defined as the ability of an item, under the combined aspects of its reliability and maintenance, to perform its required function over a given period of time. Mathematically, Availability is approximated as:

$$A = \frac{MTBMCF}{MTBMCF + MDT}$$

Therefore, since availability allows for trade-offs between reliability (MTBMCF) and maintenance (MDT), the subsystem availability allocations are the design constraints which must be met in order to achieve the desired level of observatory availability.

5.0 RELIABILITY ANALYSES

DAQ reliability was assessed by means of:

- Reliability Modeling
- Reliability and Availability Predictions
- Fault Tree Analysis

5.1 RELIABILITY MODELING

The DAQ Reliability Block Diagram for the LIGO 3X Operating Mode is shown in Figure 1. The Reliability Block Diagram depicts a series model in which it is necessary for the DAQ at both of the observatories to be operational for successful LIGO 3X operation. At the Hanford Observatory, DAQ equipments collect science data peculiar to the 4km Interferometer (HIF1 DAQ) and science data peculiar to the 2km Interferometer (HIF2 DAQ). In addition, there are DAQ equipments which are common to the collection of science data from both interferometers (HCMN DAQ) as well as equipments which collect physics environment monitoring data (HPEM DAQ). At the Livingston Observatory, DAQ equipments collect science data from a 4km Interferometer as well as the physics environment monitoring data associated with the 4km Interferometer (LIF1 DAQ).

The DAQ Reliability Model for the LIGO 2X Operating Mode is shown in Figure 2. The combination series/parallel model illustrates that at least the HIF1 DAQ or the HIF2 DAQ must be operational along with the HCMN DAQ, the HPEM DAQ and the LIF1 DAQ for successful LIGO 2X operation.

The DAQ Reliability Model for the LIGO 1X Operating Mode is shown in Figure 3. This combination series/parallel model depicts that one, or more, of the following conditions must be met for successful LIGO 1X operation:

- HIF1 DAQ “AND” HCMN DAQ “AND” HPEM DAQ
- HIF2 DAQ “AND” HCMN DAQ “AND” HPEM DAQ
- LIFI DAQ

5.2 RELIABILITY PREDICTION

A reliability prediction was performed on the DAQ. Vendor data was the primary source of reliability values for the various equipments comprising the DAQ. Where vendor data was not available, engineering estimates were made based upon equipment complexity, NPRD-95 data and vendor data on similar equipment. Table 6 on page 15 identifies the various DAQ equipments, the equipment MTBFs and the source of the MTBF values.

The manufacturer and configurations for the DAQ Short Term Storage System, Long Term Storage System and Servers were not defined at the time of this report. A RAID Disk Drive Storage System was being considered for the Short Term Storage System and Magnetic Tape and writable CD ROM was under evaluation for the Long Term Storage System. SUN Workstations are being considered for the Servers. Research on the RAID Disk Drive Systems and the Magnetic Tape Systems showed that there are configurations available with various levels of redundancy. The redundancy includes such things as redundant disk drives, redundant power supplies, redundant data recording, redundant tape robots, etc. It is assumed that there will also be some level of redundancy designed into the final configuration of the Servers. Based upon the information presented in Appendix F, it was determined that the Short Term Storage, Long Term Storage, and Server systems would be Availability Class 5 systems. Availability Class 5 systems have an availability of 99.999%. Therefore, a fixed availability value of 0.99999 was assigned to the Short Term Storage System, the Long Term Storage System and the Server System.

5.3 AVAILABILITY PREDICTION

Availability predictions were performed by developing fault trees using the FaultTree+ software. A fault tree was developed and an Availability prediction was performed on the DAQ at the Washington Observatory. The Washington Observatory DAQ consists of the HIF1 DAQ, the HIF2 DAQ, the HCMN DAQ and the HPEM DAQ. A fault tree was also developed and an Availability prediction was also performed on the DAQ at the Louisiana Observatory. The DAQ at the Louisiana Observatory consists of the LIF1 DAQ.

The DAQ consists primarily of computer type equipment and rack mounted modular electronic assemblies. On-line diagnostics capabilities and fault indications have been designed into the DAQ to ease the fault detection, fault localization and fault isolation process. It is assumed that a sufficient electronic module spares inventory will be available at each observatory. Taking into consideration the on-line diagnostics capability, the modular design concept and the availability of spares, the MDT associated with a DAQ repair action should be minimal. Therefore, a DAQ MDT value of 8.0 hours was used for the availability predictions rather than the previously allocated MDT of 24.0 hours.

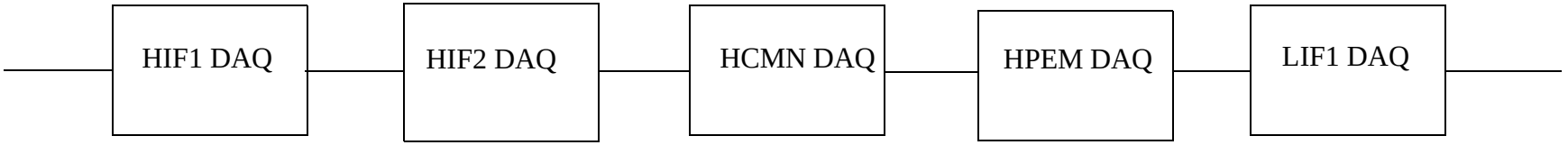


Figure 1: DAQ Reliability Block Diagram For The LIGO 3X Operating Mode

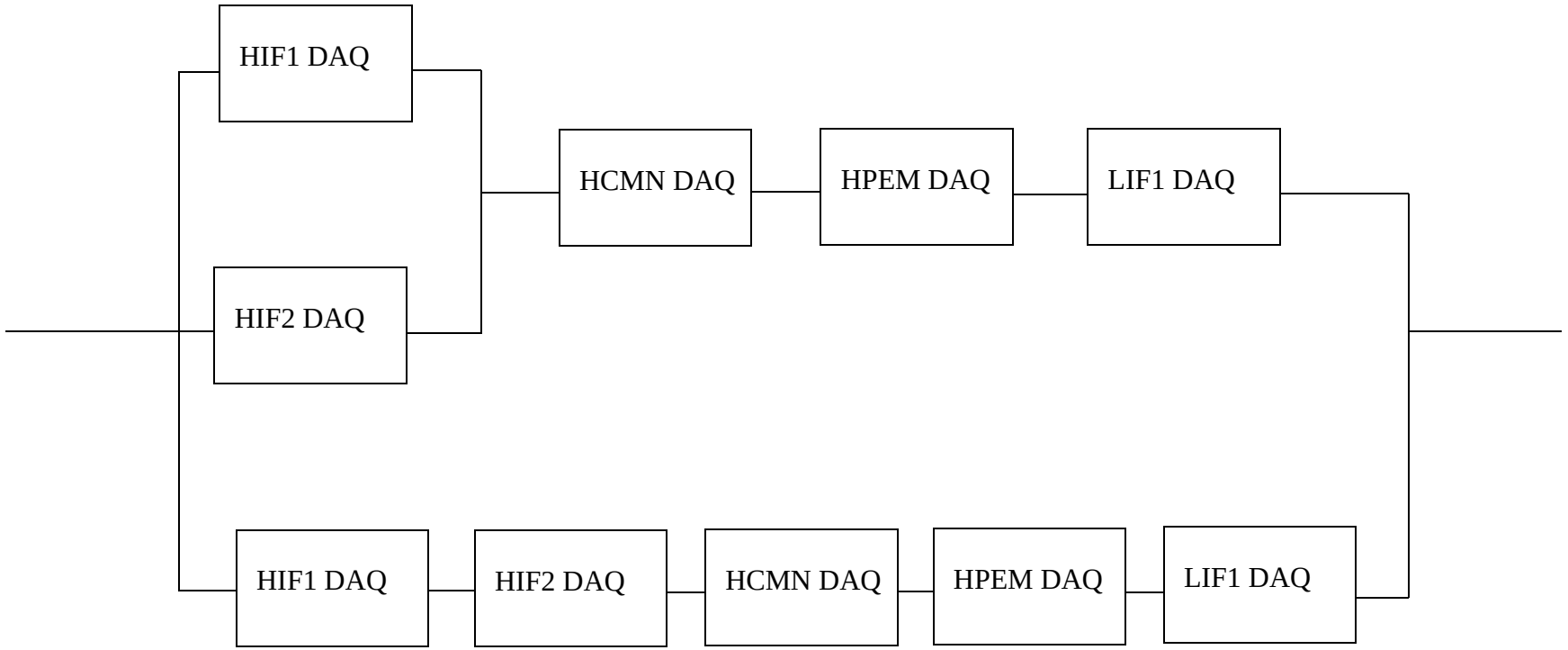


Figure 2: DAQ Reliability Block Diagram For The LIGO 2X Operating Mode

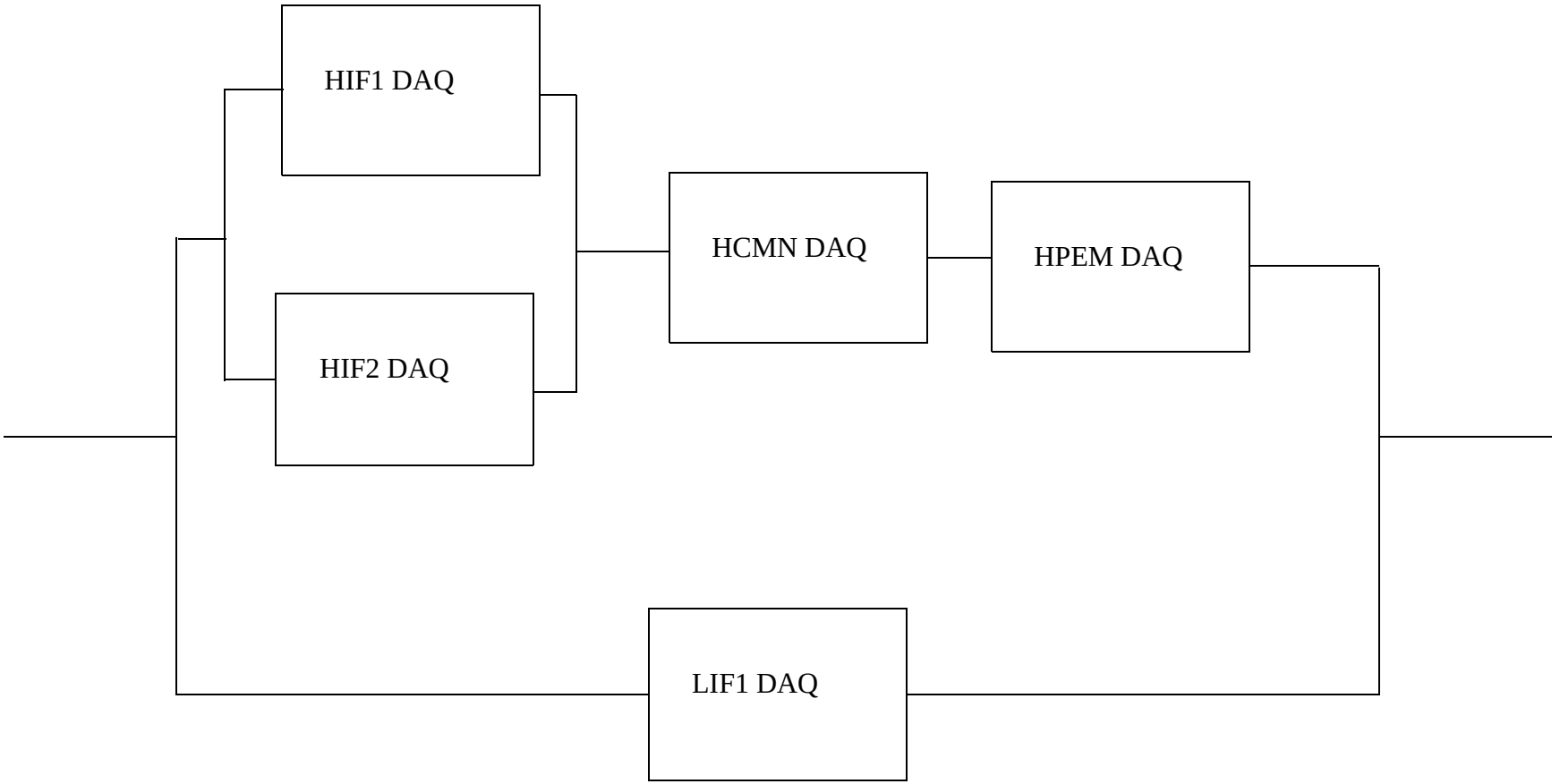


Figure 3: DAQ Reliability Block Diagram For The LIGO 1X Operating Mode

Table 6: Reliability Data Sources

Description	*Failure Rate (λ) (FPMH)*	*MTBF (Hours)*	*Source*
Baja 4700 CPU Module	2.8454	351, 448	Vendor
Xycom 212 Binary Input Module	10.0000	100, 000	Vendor
Motorola MVME-162 CPU Module	5.2491	190, 509	Vendor
Reflective Memory Module	11.3630	88, 005	Vendor
Single/Multi-Mode Converter Module	2.7871	358, 800	Vendor
ICS-110B ADC Module	23.8095	42, 000	Vendor
Optical Bypass Switching Module	2.3004	434, 700	Vendor
Brandywine GPS Module	20.0000	50, 000	Engineering Estimate
Slow Clock / ADC Trigger Module	10.0000	100, 000	Engineering Estimate
Power Supply, DCU	20.0000	50, 000	Engineering Estimate
Power Supply, FB	20.0000	50, 000	Engineering Estimate
Short Term Disk Storage System	Q = 1.0000e-5	A = 0.99999	Engineering Estimate
Long Term Magnetic Tape Storage System	Q = 1.0000e-5	A = 0.99999	Engineering Estimate
Server	Q = 1.0000e-5	A = 0.99999	Engineering Estimate

The fault tree and detailed calculations for the HIF1 DAQ, the HIF2 DAQ, the HCMN DAQ and the HPEM DAQ are provided in Appendix A. The fault tree and detailed calculations for the LIF1 DAQ are provided in Appendix B. A summary of the results is shown in Table 7 below:

Table 7: Interferometer DAQ Availability Prediction Results

DAQ	*Unavailability (Q)*	*Availability (A = 1-Q)*
HIF1	7.534e-3	0.9925
HIF2	7.534e-3	0.9925
HCMN	1.532e-3	0.9985
HPEM	1.605e-3	0.9984
LIF1	1.065e-2	0.9894

Availability predictions were then performed for the three LIGO operating modes. Fault trees for the three LIGO operating modes were developed using the results of the HIF1 DAQ, HIF2 DAQ, HCMN DAQ, HPEM DAQ and the LIF1 DAQ availability predictions. The fault trees and Availability predictions for the three LIGO operating modes are provided in Appendices C through E. The results of the DAQ availability predictions for each of the LIGO operating modes are summarized in Table 8 below.

Table 8: DAQ Availability Predictions For The LIGO Operating Modes

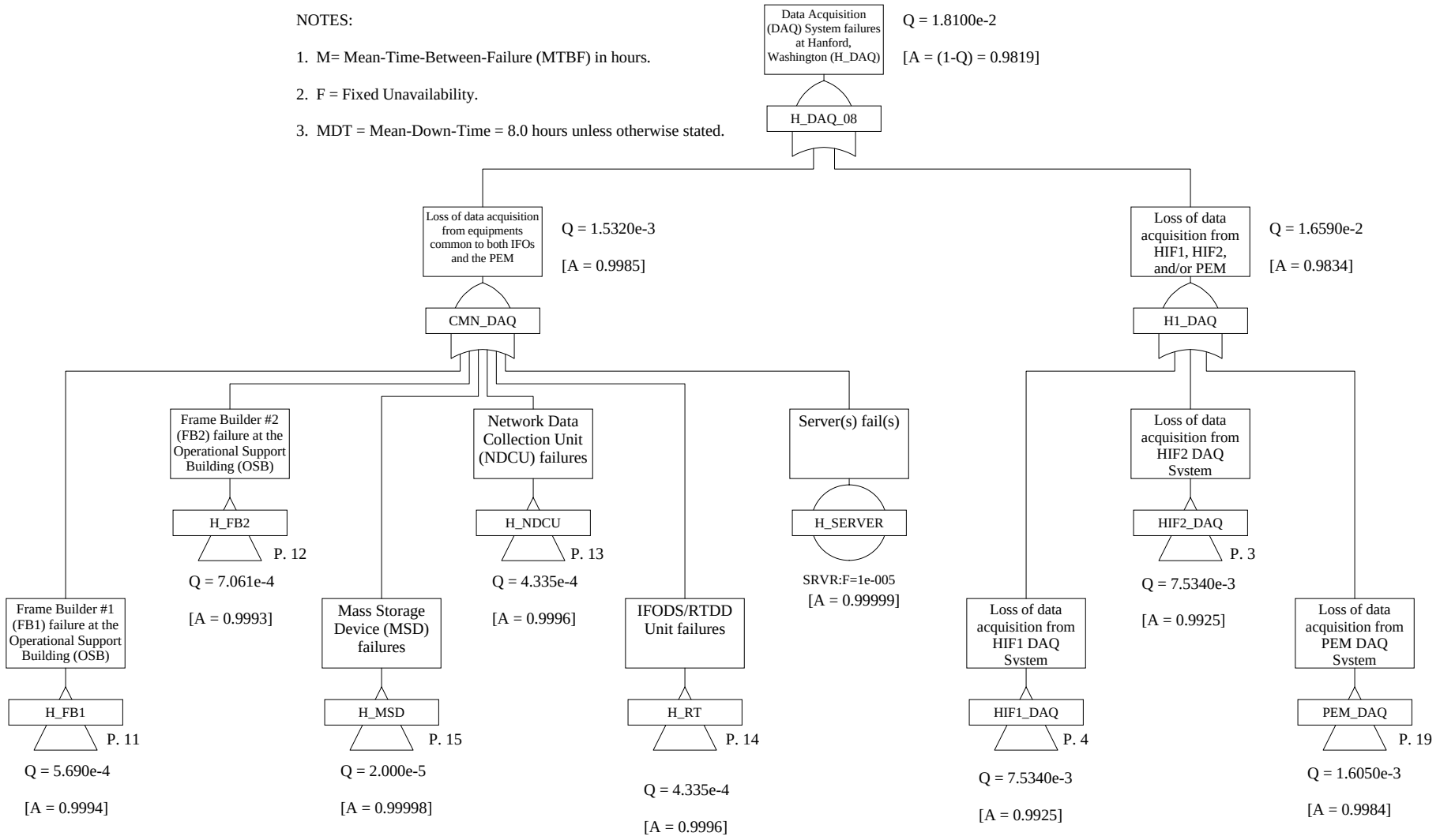
Mode of Operation	*Allocated Annual Availability*	*Predicted Annual Availability*
3X	0.9959	0.9714
2X	0.9980	0.9862
1X	1.0000	1.0000

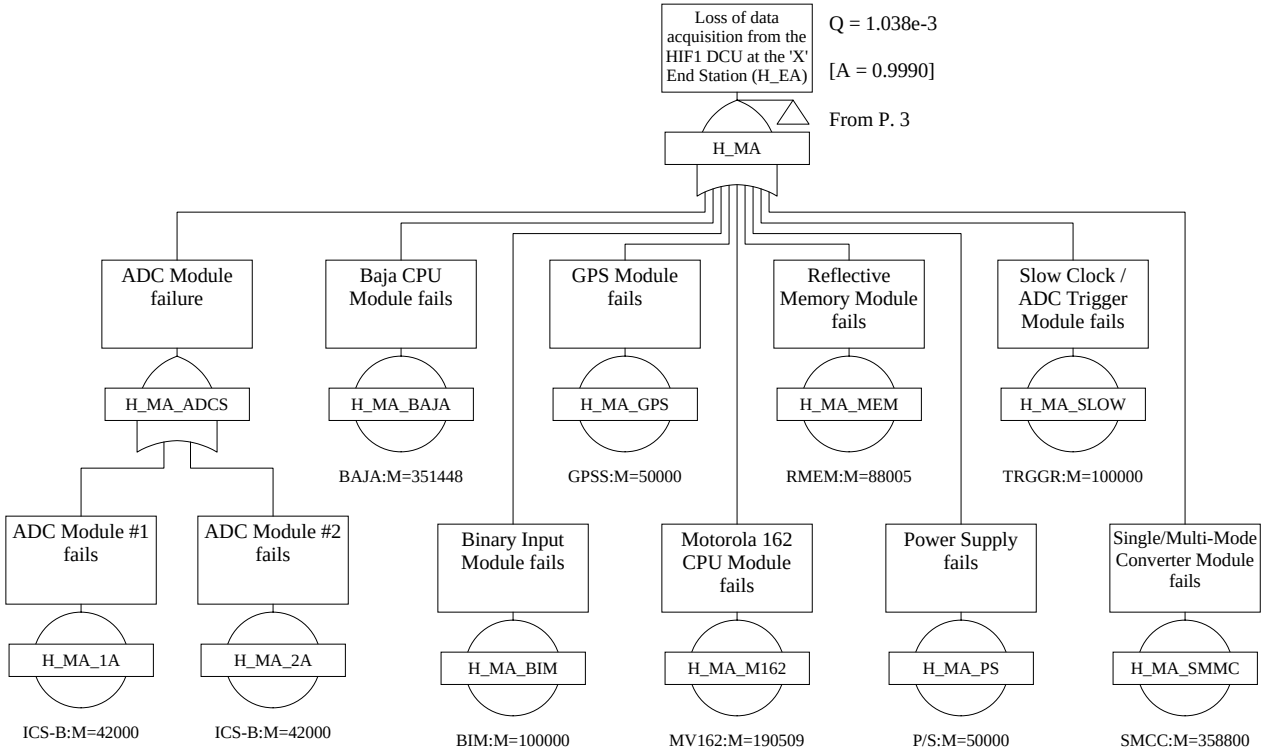
6.0 CONCLUSIONS

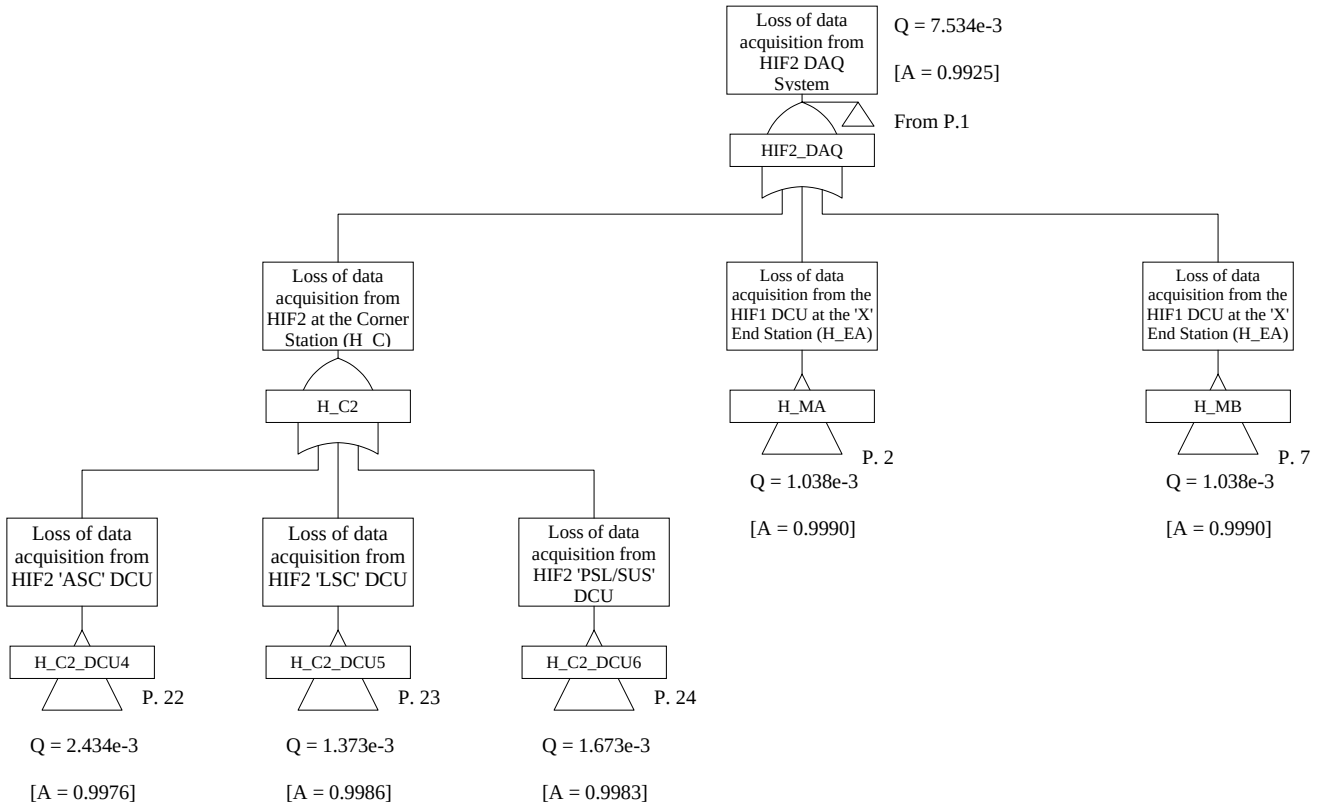
The DAQ predicted availability for the LIGO operating modes is less than the DAQ allocated availability. The significance of this can not be fully evaluated until availability predictions have been performed on all of the LIGO subsystems. As the maintenance and spares policy becomes more defined and as additional vendor reliability data becomes available, refinements to this analysis will be made which should help raise the overall DAQ availability.

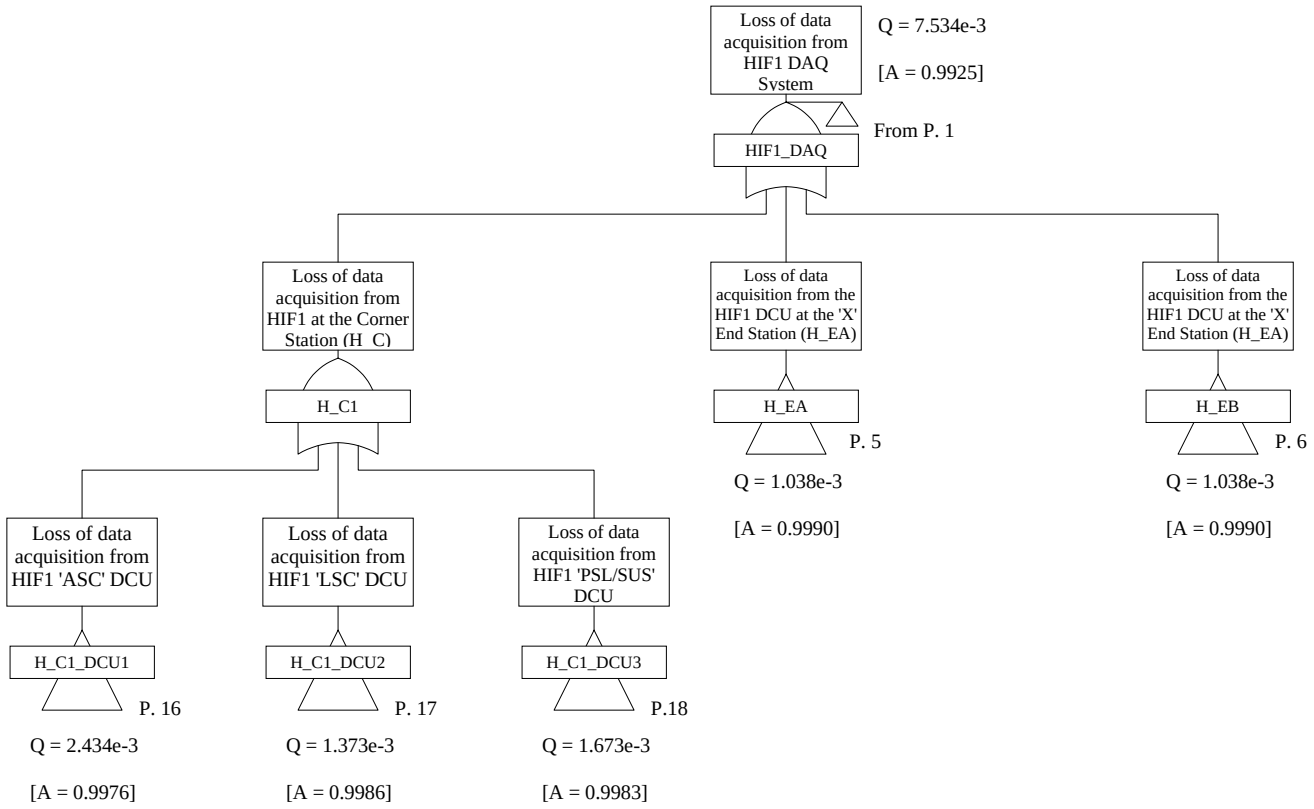
In addition, a DAQ prototype has been operating at the 40M Model since March 1997. The DAQ prototype has been operating 24 hours per day and has not experienced a hardware failure. The prototype is very similar to the DAQ to be deployed at the observatories with the primary difference being that the prototype uses a scaled down disk and tape drive storage system. The feasibility of incorporating DAQ prototype test data into the reliability/availability analyses will be evaluated. Utilization of test data, in the determination of equipment and module MTBF values, may result in a more accurate reliability/availability assessment of the DAQ.

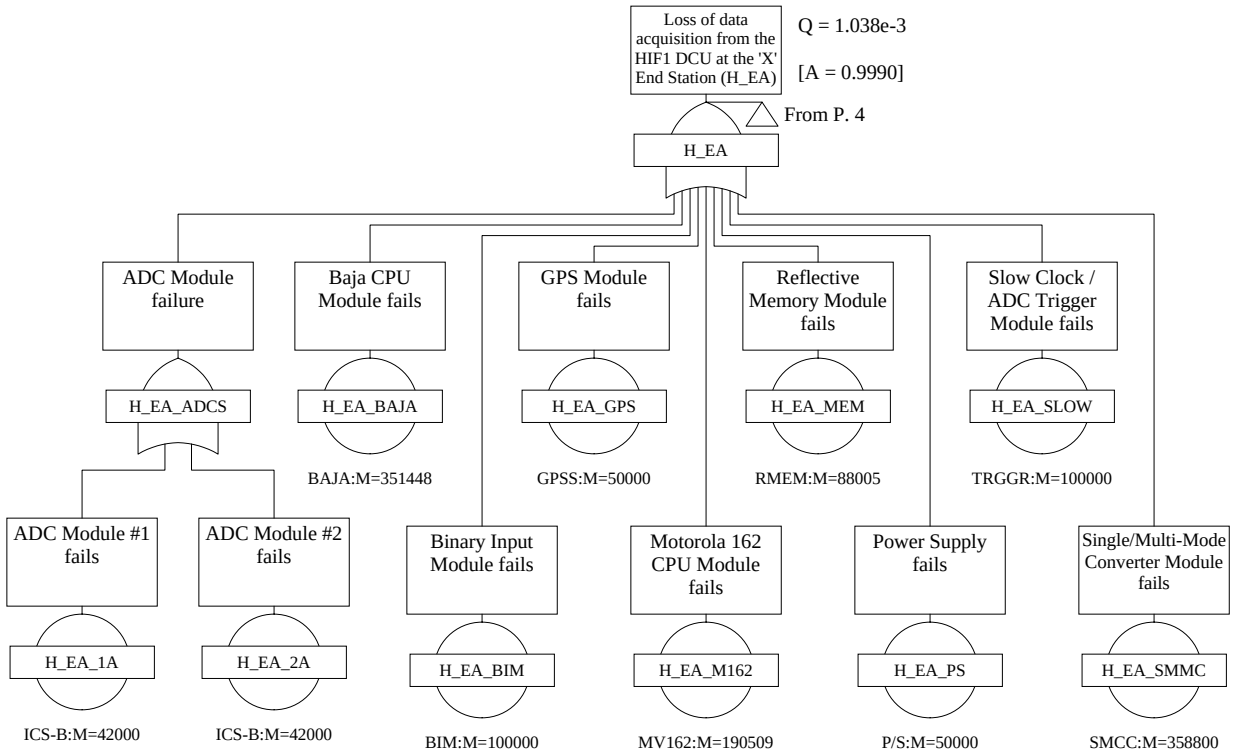
APPENDIX A:
DAQ AVAILABILITY PREDICTION, HANFORD, WA

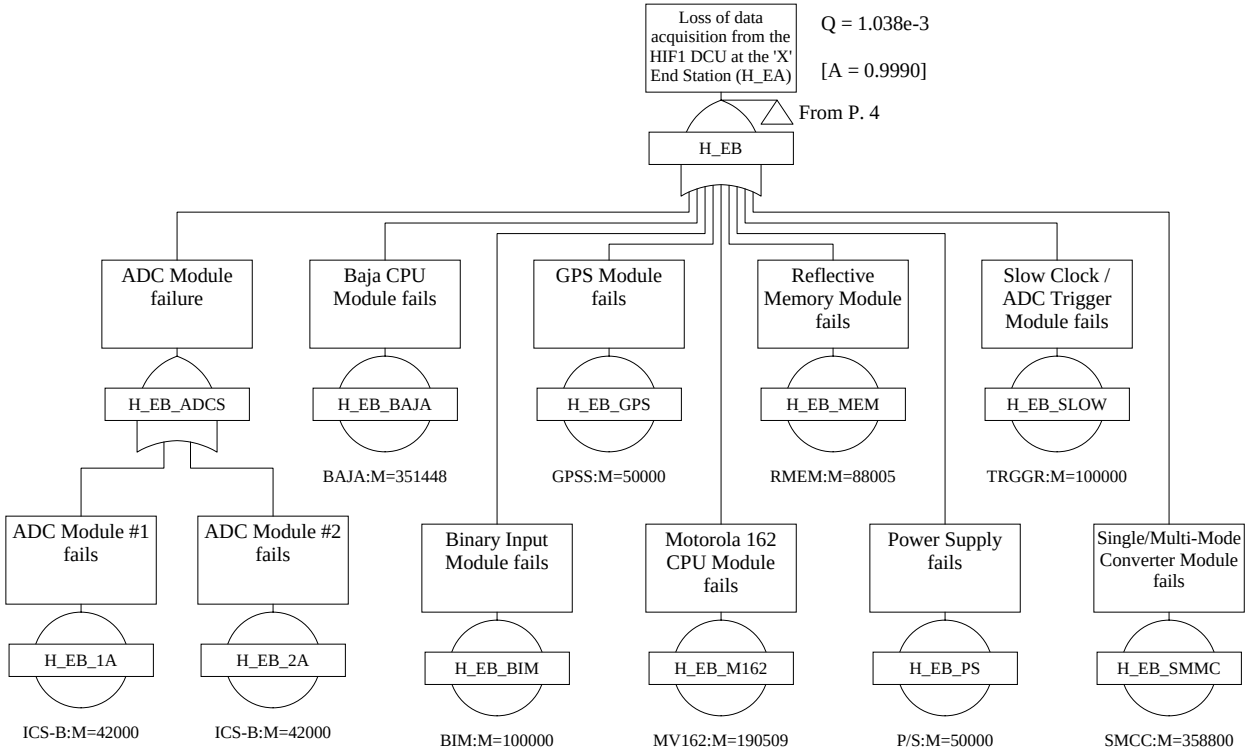

NOTES:
1. M= Mean-Time-Between-Failure (MTBF) in hours.
2. F = Fixed Unavailability.
3. MDT = Mean-Down-Time = 8.0 hours unless otherwise stated.
Data Acquisition (DAQ) System failures at Hanford, Washington (H_DAQ)
Q = 1.8100e-2
[A = (1-Q) = 0.9819]
H_DAQ_08
Loss of data acquisition from equipments common to both IFOs and the PEM
Q = 1.5320e-3
[A = 0.9985]
CMN_DAQ
Loss of data acquisition from HIF1, HIF2, and/or PEM
Q = 1.6590e-2
[A = 0.9834]
H1_DAQ
Frame Builder #2 (FB2) failure at the Operational Support Building (OSB)
H_FB2
P. 12
Q = 7.061e-4
[A = 0.9993]
Network Data Collection Unit (NDCU) failures
H_NDCU
P. 13
Q = 4.335e-4
[A = 0.9996]
Server(s) fail(s)
H_SERVER
SRVR:F=1e-005
[A = 0.99999]
Loss of data acquisition from HIF2 DAQ System
HIF2_DAQ
P. 3
Q = 7.5340e-3
[A = 0.9925]
Frame Builder #1 (FB1) failure at the Operational Support Building (OSB)
H_FB1
P. 11
Q = 5.690e-4
[A = 0.9994]
Mass Storage Device (MSD) failures
H_MSD
P. 15
Q = 2.000e-5
[A = 0.99998]
IFODS/RTDD Unit failures
H_RT
P. 14
Q = 4.335e-4
[A = 0.9996]
Loss of data acquisition from HIF1 DAQ System
HIF1_DAQ
P. 4
Q = 7.5340e-3
[A = 0.9925]
Loss of data acquisition from PEM DAQ System
PEM_DAQ
P. 19
Q = 1.6050e-3
[A = 0.9984]

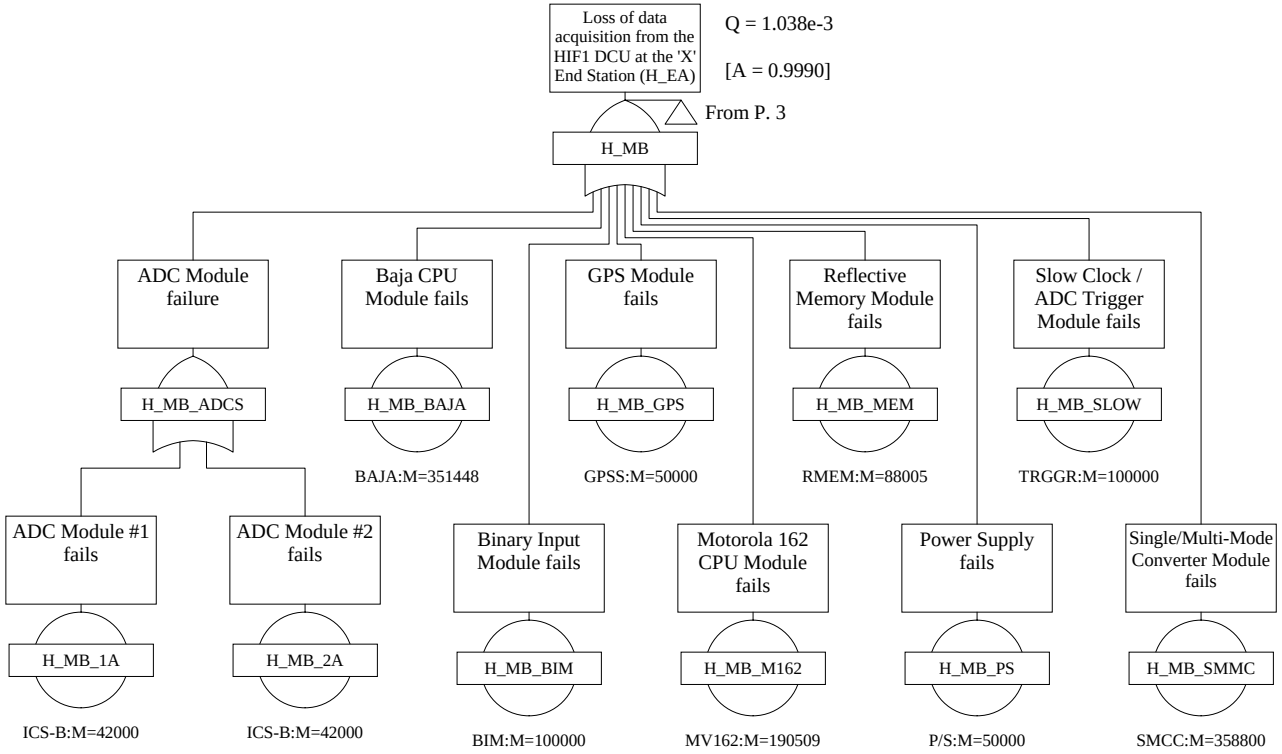

Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
Q = 1.038e-3
[A = 0.9990]
From P. 3
H_MA
ADC Module failure
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
H_MA_ADCS
H_MA_BAJA
H_MA_GPS
H_MA_MEM
H_MA_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
ADC Module #1 fails
ADC Module #2 fails
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Single/Multi-Mode Converter Module fails
H_MA_1A
H_MA_2A
H_MA_BIM
H_MA_M162
H_MA_PS
H_MA_SMMC
ICS-B:M=42000
ICS-B:M=42000
BIM:M=100000
MV162:M=190509
P/S:M=50000
SMCC:M=358800

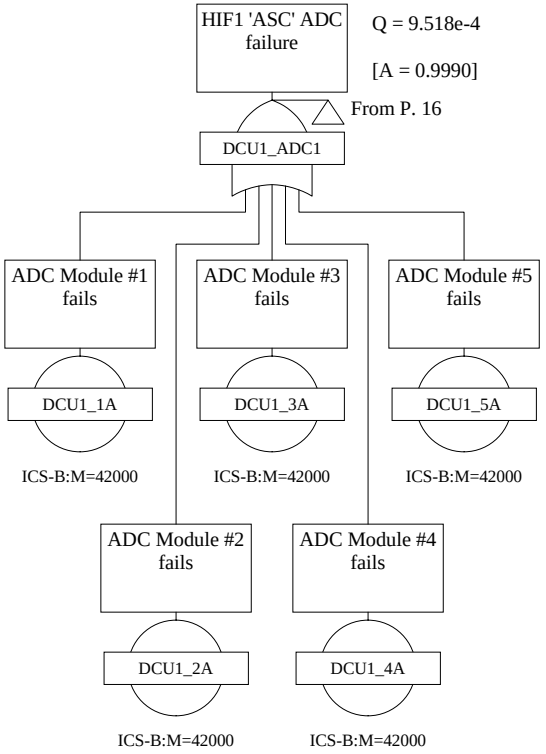

Loss of data acquisition from HIF2 DAQ System
Q = 7.534e-3
[A = 0.9925]
From P.1
HIF2_DAQ
Loss of data acquisition from HIF2 at the Corner Station (H_C)
Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
H_C2
H_MA
H_MB
P. 2
Q = 1.038e-3
[A = 0.9990]
P. 7
Q = 1.038e-3
[A = 0.9990]
Loss of data acquisition from HIF2 'ASC' DCU
Loss of data acquisition from HIF2 'LSC' DCU
Loss of data acquisition from HIF2 'PSL/SUS' DCU
H_C2_DCU4
H_C2_DCU5
H_C2_DCU6
P. 22
Q = 2.434e-3
[A = 0.9976]
P. 23
Q = 1.373e-3
[A = 0.9986]
P. 24
Q = 1.673e-3
[A = 0.9983]

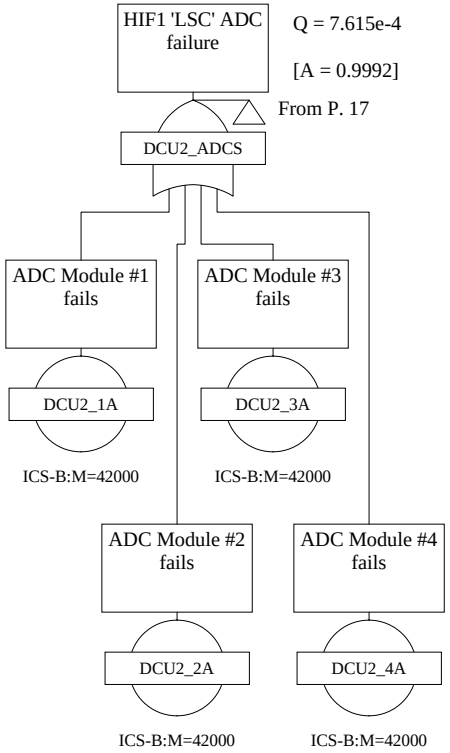

Loss of data acquisition from HIF1 DAQ System
Q = 7.534e-3
[A = 0.9925]
From P. 1
HIF1_DAQ
Loss of data acquisition from HIF1 at the Corner Station (H_C)
Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
H_C1
H_EA
H_EB
P. 5
P. 6
Q = 1.038e-3
[A = 0.9990]
Q = 1.038e-3
[A = 0.9990]
Loss of data acquisition from HIF1 'ASC' DCU
Loss of data acquisition from HIF1 'LSC' DCU
Loss of data acquisition from HIF1 'PSL/SUS' DCU
H_C1_DCU1
H_C1_DCU2
H_C1_DCU3
P. 16
P. 17
P.18
Q = 2.434e-3
[A = 0.9976]
Q = 1.373e-3
[A = 0.9986]
Q = 1.673e-3
[A = 0.9983]

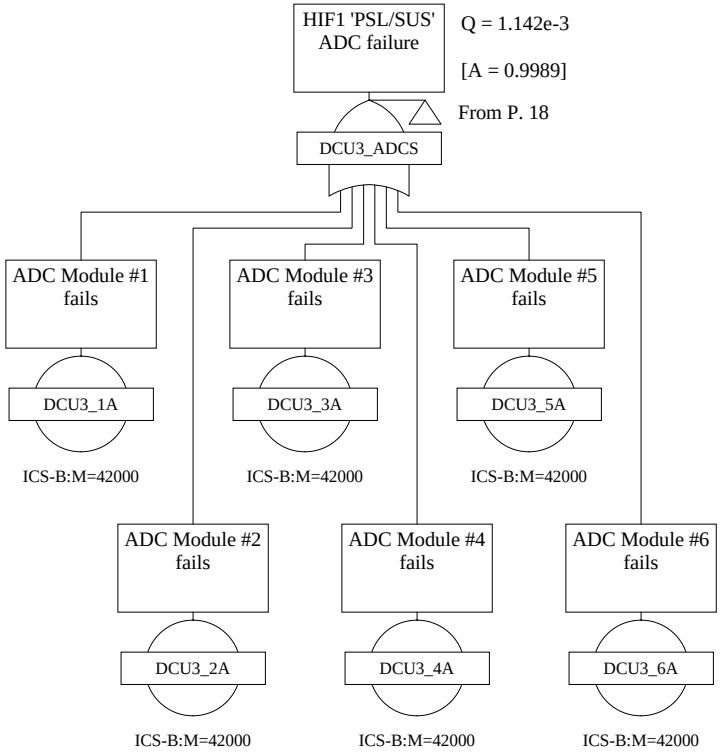

Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
Q = 1.038e-3
[A = 0.9990]
From P. 4
H_EA
ADC Module failure
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
H_EA_ADCS
H_EA_BAJA
H_EA_GPS
H_EA_MEM
H_EA_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
ADC Module #1 fails
ADC Module #2 fails
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Single/Multi-Mode Converter Module fails
H_EA_1A
H_EA_2A
H_EA_BIM
H_EA_M162
H_EA_PS
H_EA_SMMC
ICS-B:M=42000
ICS-B:M=42000
BIM:M=100000
MV162:M=190509
P/S:M=50000
SMCC:M=358800

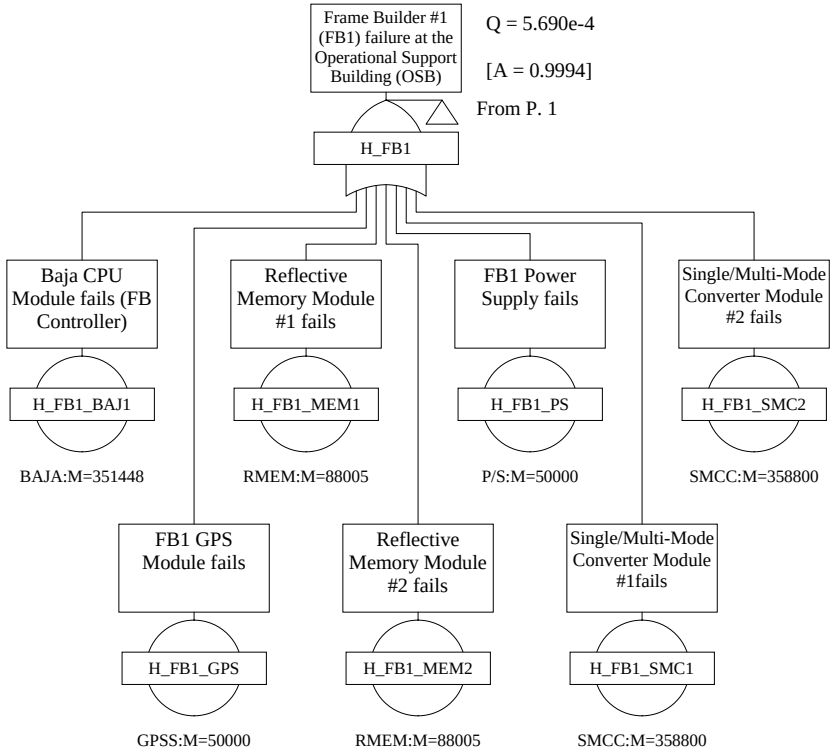

Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
Q = 1.038e-3
[A = 0.9990]
From P. 4
H_EB
ADC Module failure
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
H_EB_ADCS
H_EB_BAJA
H_EB_GPS
H_EB_MEM
H_EB_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
ADC Module #1 fails
ADC Module #2 fails
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Single/Multi-Mode Converter Module fails
H_EB_1A
H_EB_2A
H_EB_BIM
H_EB_M162
H_EB_PS
H_EB_SMMC
ICS-B:M=42000
ICS-B:M=42000
BIM:M=100000
MV162:M=190509
P/S:M=50000
SMCC:M=358800

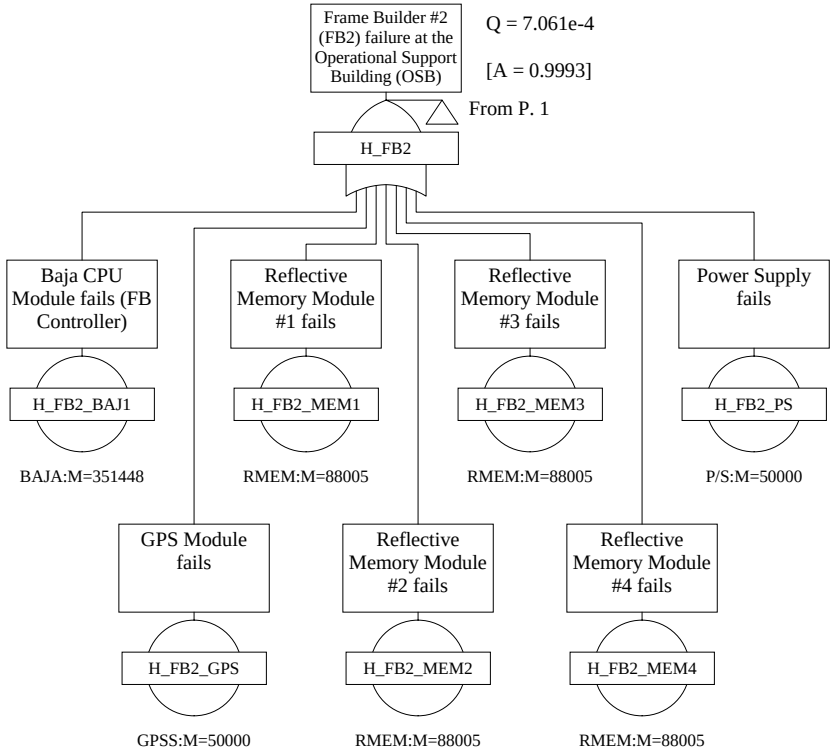

Loss of data acquisition from the HIF1 DCU at the 'X' End Station (H_EA)
Q = 1.038e-3
[A = 0.9990]
From P. 3
H_MB
ADC Module failure
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
H_MB_ADCS
H_MB_BAJA
H_MB_GPS
H_MB_MEM
H_MB_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
ADC Module #1 fails
ADC Module #2 fails
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Single/Multi-Mode Converter Module fails
H_MB_1A
H_MB_2A
H_MB_BIM
H_MB_M162
H_MB_PS
H_MB_SMMC
ICS-B:M=42000
ICS-B:M=42000
BIM:M=100000
MV162:M=190509
P/S:M=50000
SMCC:M=358800

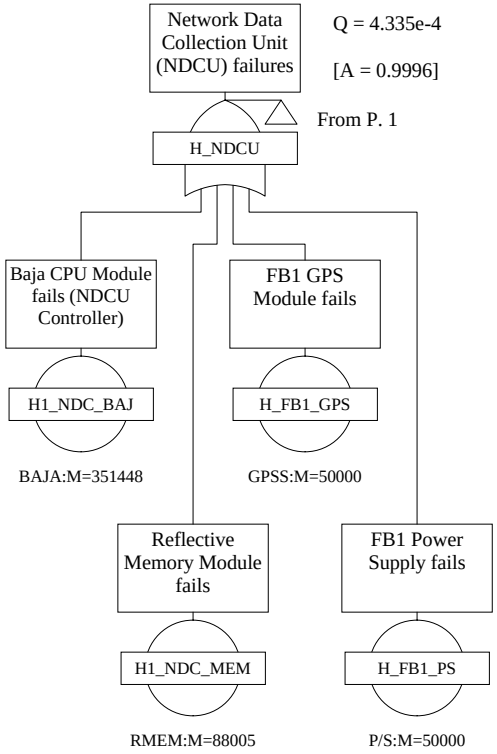

HIF1 'ASC' ADC failure
Q = 9.518e-4
[A = 0.9990]
From P. 16
DCU1_ADC1
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
DCU1_1A
DCU1_3A
DCU1_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
DCU1_2A
DCU1_4A
ICS-B:M=42000
ICS-B:M=42000

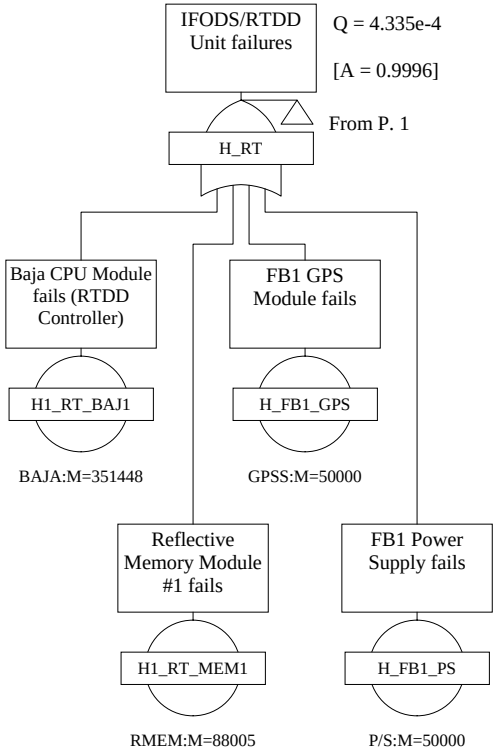

HIF1 'LSC' ADC failure
Q = 7.615e-4
[A = 0.9992]
From P. 17
DCU2_ADCS
ADC Module #1 fails
ADC Module #3 fails
DCU2_1A
DCU2_3A
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
DCU2_2A
DCU2_4A
ICS-B:M=42000
ICS-B:M=42000

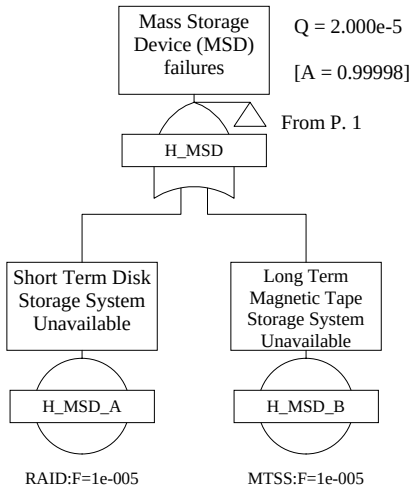

HIF1 'PSL/SUS' ADC failure
Q = 1.142e-3
[A = 0.9989]
From P. 18
DCU3_ADCS
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
DCU3_1A
DCU3_3A
DCU3_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
ADC Module #6 fails
DCU3_2A
DCU3_4A
DCU3_6A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000

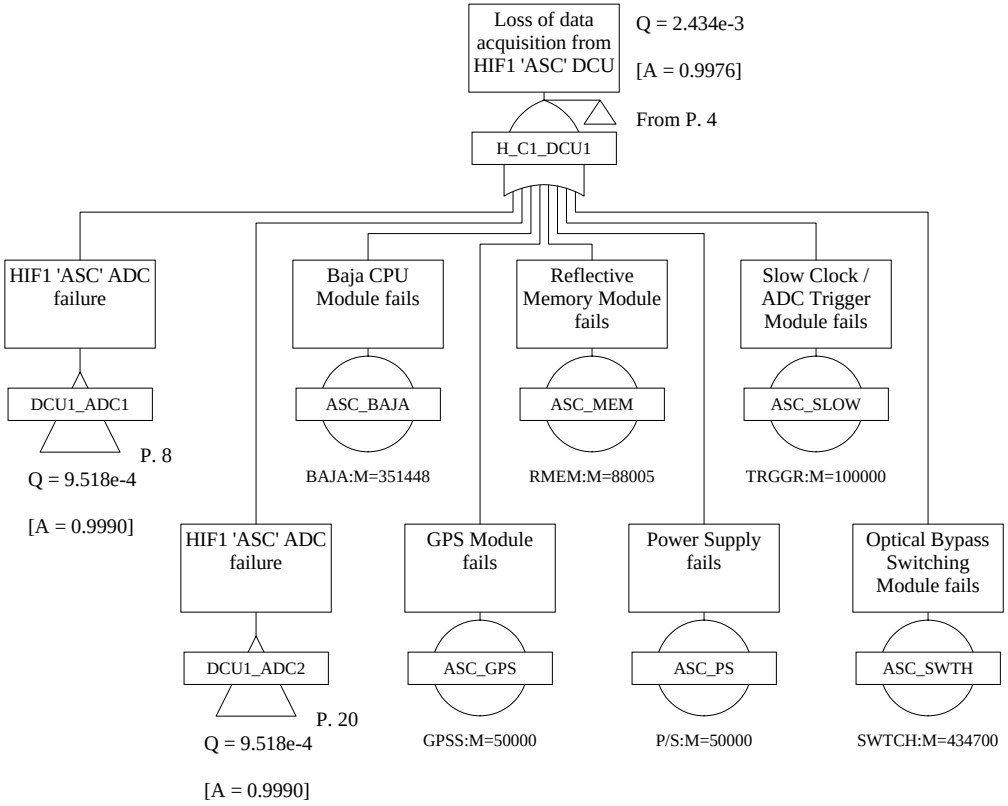

Frame Builder #1 (FB1) failure at the Operational Support Building (OSB)
Q = 5.690e-4
[A = 0.9994]
From P. 1
H_FB1
Baja CPU Module fails (FB Controller)
Reflective Memory Module #1 fails
FB1 Power Supply fails
Single/Multi-Mode Converter Module #2 fails
H_FB1_BAJ1
H_FB1_MEM1
H_FB1_PS
H_FB1_SMC2
BAJA:M=351448
RMEM:M=88005
P/S:M=50000
SMCC:M=358800
FB1 GPS Module fails
Reflective Memory Module #2 fails
Single/Multi-Mode Converter Module #1fails
H_FB1_GPS
H_FB1_MEM2
H_FB1_SMC1
GPSS:M=50000
RMEM:M=88005
SMCC:M=358800

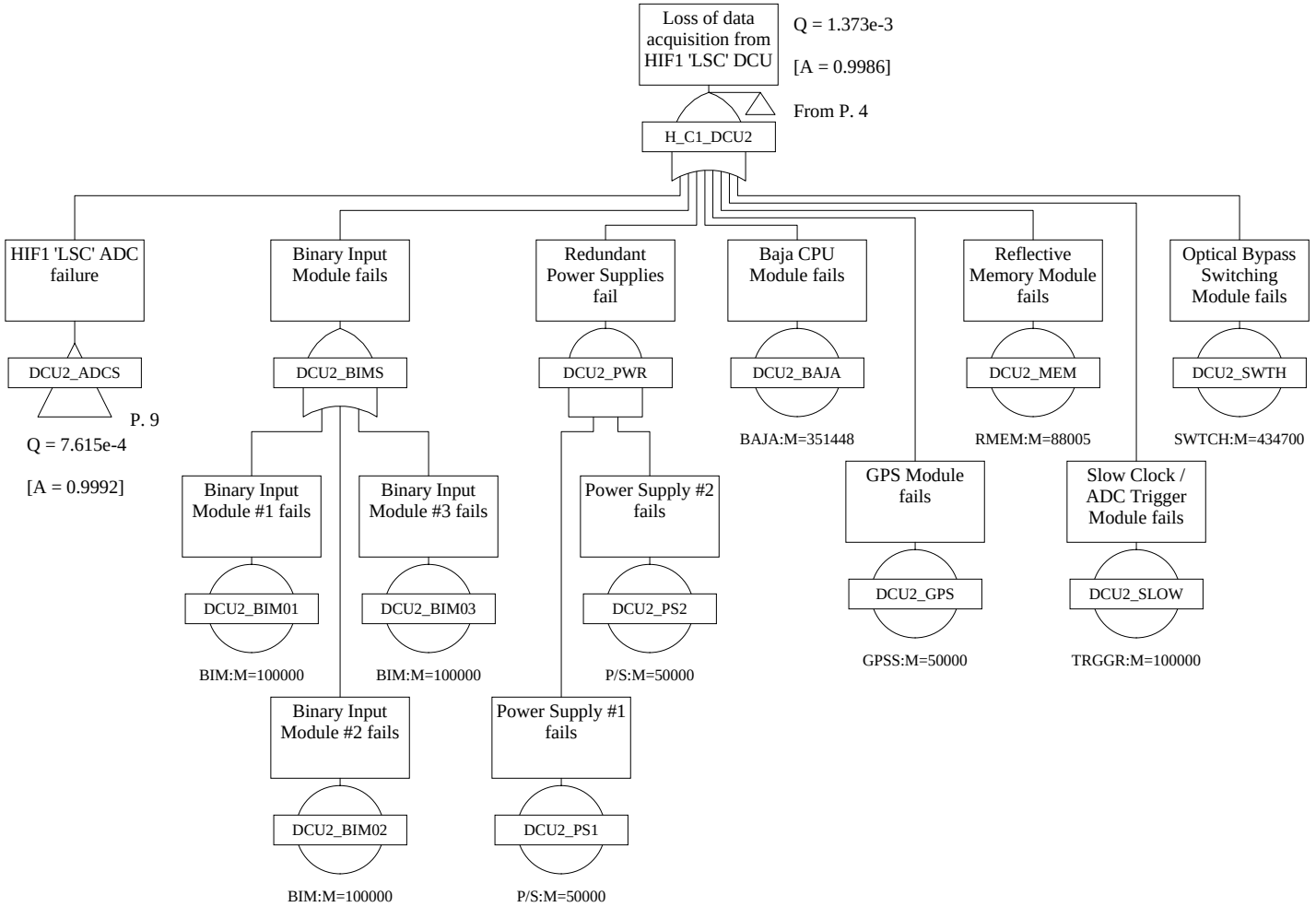

Frame Builder #2 (FB2) failure at the Operational Support Building (OSB)
Q = 7.061e-4
[A = 0.9993]
From P. 1
H_FB2
Baja CPU Module fails (FB Controller)
Reflective Memory Module #1 fails
Reflective Memory Module #3 fails
Power Supply fails
H_FB2_BAJ1
H_FB2_MEM1
H_FB2_MEM3
H_FB2_PS
BAJA:M=351448
RMEM:M=88005
RMEM:M=88005
P/S:M=50000
GPS Module fails
Reflective Memory Module #2 fails
Reflective Memory Module #4 fails
H_FB2_GPS
H_FB2_MEM2
H_FB2_MEM4
GPSS:M=50000
RMEM:M=88005
RMEM:M=88005

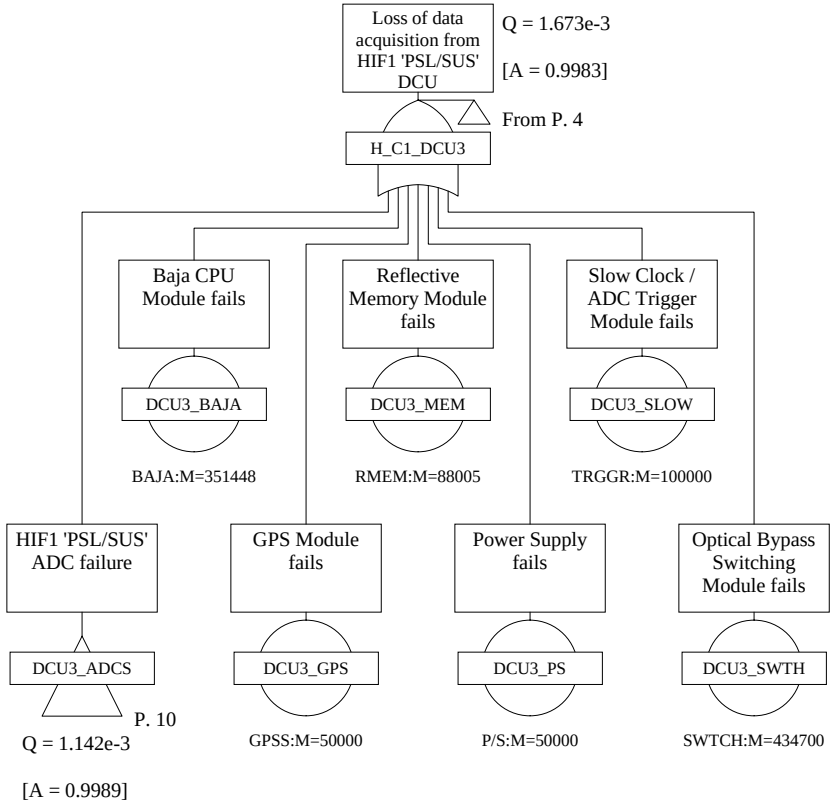

Network Data Collection Unit (NDCU) failures
Q = 4.335e-4
[A = 0.9996]
From P. 1
H_NDCU
Baja CPU Module fails (NDCU Controller)
FB1 GPS Module fails
H1_NDC_BAJ
H_FB1_GPS
BAJA:M=351448
GPSS:M=50000
Reflective Memory Module fails
FB1 Power Supply fails
H1_NDC_MEM
H_FB1_PS
RMEM:M=88005
P/S:M=50000

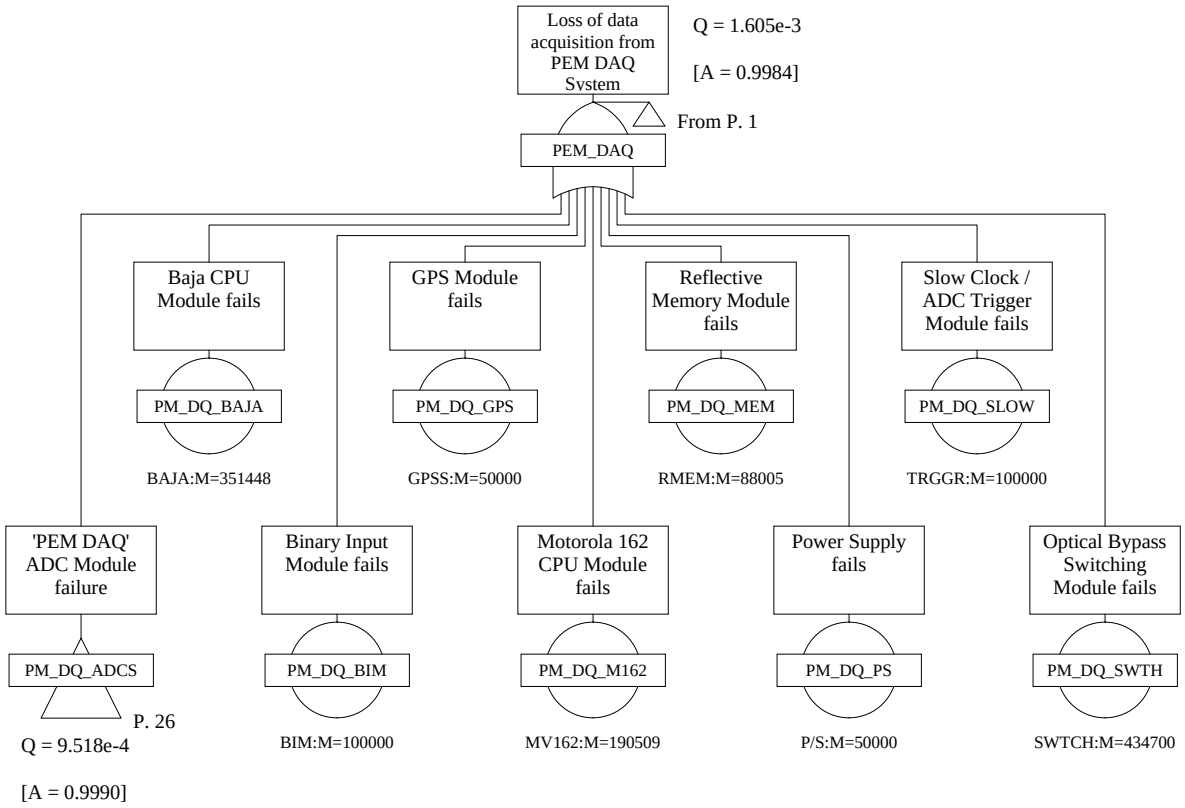

IFODS/RTDD
Unit failures
Q = 4.335e-4
[A = 0.9996]
From P. 1
H_RT
Baja CPU Module
fails (RTDD
Controller)
FB1 GPS
Module fails
H1_RT_BAJ1
H_FB1_GPS
BAJA:M=351448
GPSS:M=50000
Reflective
Memory Module
#1 fails
FB1 Power
Supply fails
H1_RT_MEM1
H_FB1_PS
RMEM:M=88005
P/S:M=50000

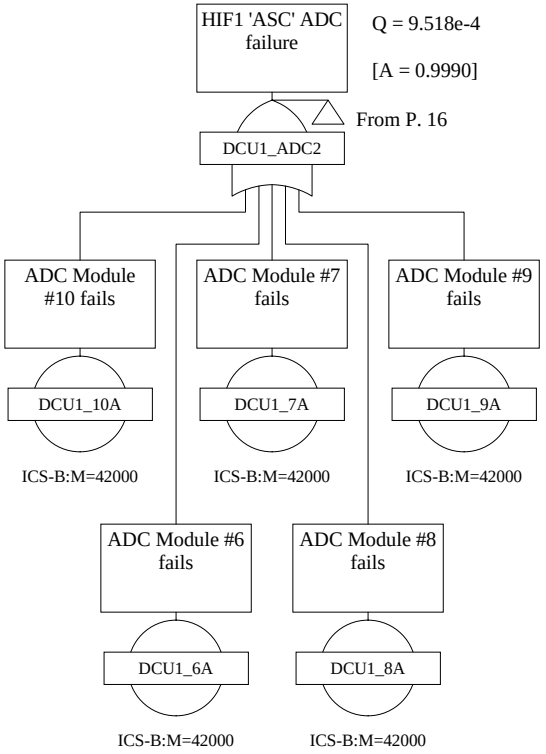

Mass Storage Device (MSD) failures
Q = 2.000e-5
[A = 0.99998]
From P. 1
H_MSD
Short Term Disk Storage System Unavailable
Long Term Magnetic Tape Storage System Unavailable
H_MSD_A
H_MSD_B
RAID:F=1e-005
MTSS:F=1e-005

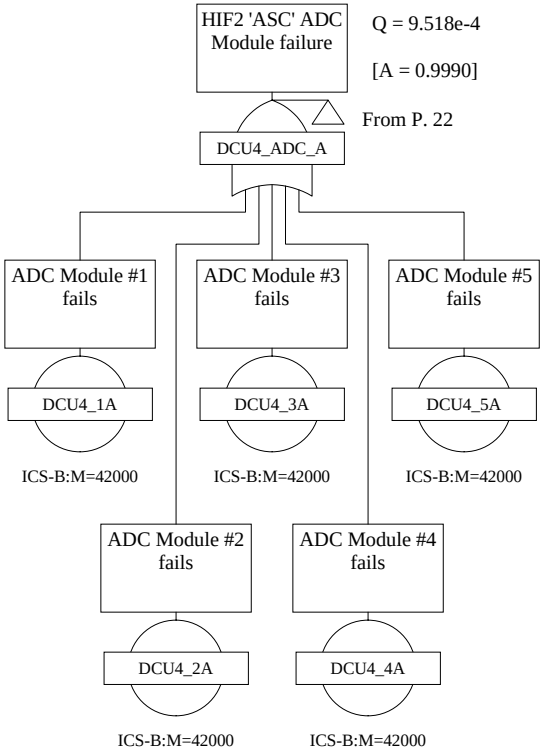

Loss of data acquisition from HIF1 'ASC' DCU
Q = 2.434e-3
[A = 0.9976]
From P. 4
H_C1_DCU1
HIF1 'ASC' ADC failure
DCU1_ADC1
P. 8
Q = 9.518e-4
[A = 0.9990]
Baja CPU Module fails
ASC_BAJA
BAJA:M=351448
Reflective Memory Module fails
ASC_MEM
RMEM:M=88005
Slow Clock / ADC Trigger Module fails
ASC_SLOW
TRGGR:M=100000
HIF1 'ASC' ADC failure
DCU1_ADC2
P. 20
Q = 9.518e-4
[A = 0.9990]
GPS Module fails
ASC_GPS
GPSS:M=50000
Power Supply fails
ASC_PS
P/S:M=50000
Optical Bypass Switching Module fails
ASC_SWTH
SWTCH:M=434700

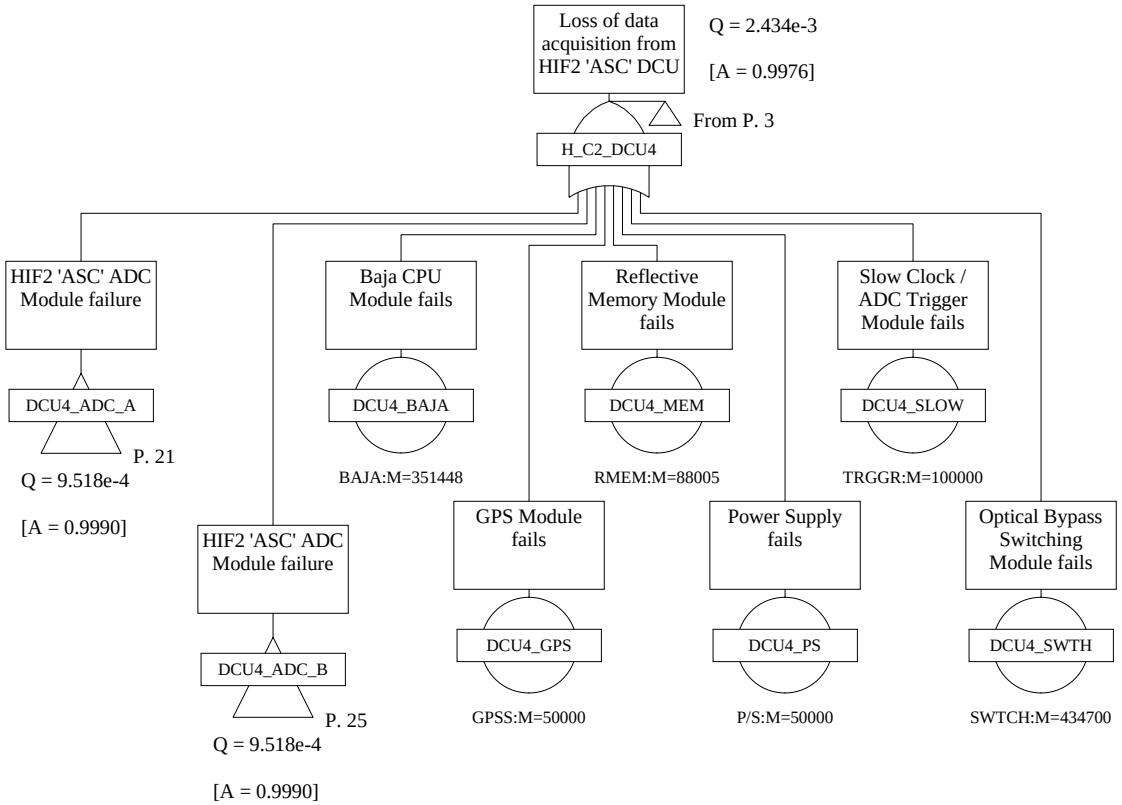

Loss of data acquisition from HIF1 'LSC' DCU
Q = 1.373e-3
[A = 0.9986]
From P. 4
H_C1_DCU2
HIF1 'LSC' ADC failure
DCU2_ADCS
P. 9
Q = 7.615e-4
[A = 0.9992]
Binary Input Module fails
DCU2_BIMS
Redundant Power Supplies fail
DCU2_PWR
Baja CPU Module fails
DCU2_BAJA
BAJA:M=351448
Reflective Memory Module fails
DCU2_MEM
RMEM:M=88005
Optical Bypass Switching Module fails
DCU2_SWTH
SWTCH:M=434700
Binary Input Module #1 fails
DCU2_BIM01
BIM:M=100000
Binary Input Module #3 fails
DCU2_BIM03
BIM:M=100000
Power Supply #2 fails
DCU2_PS2
P/S:M=50000
GPS Module fails
DCU2_GPS
GPSS:M=50000
Slow Clock / ADC Trigger Module fails
DCU2_SLOW
TRGGR:M=100000
Binary Input Module #2 fails
DCU2_BIM02
BIM:M=100000
Power Supply #1 fails
DCU2_PS1
P/S:M=50000

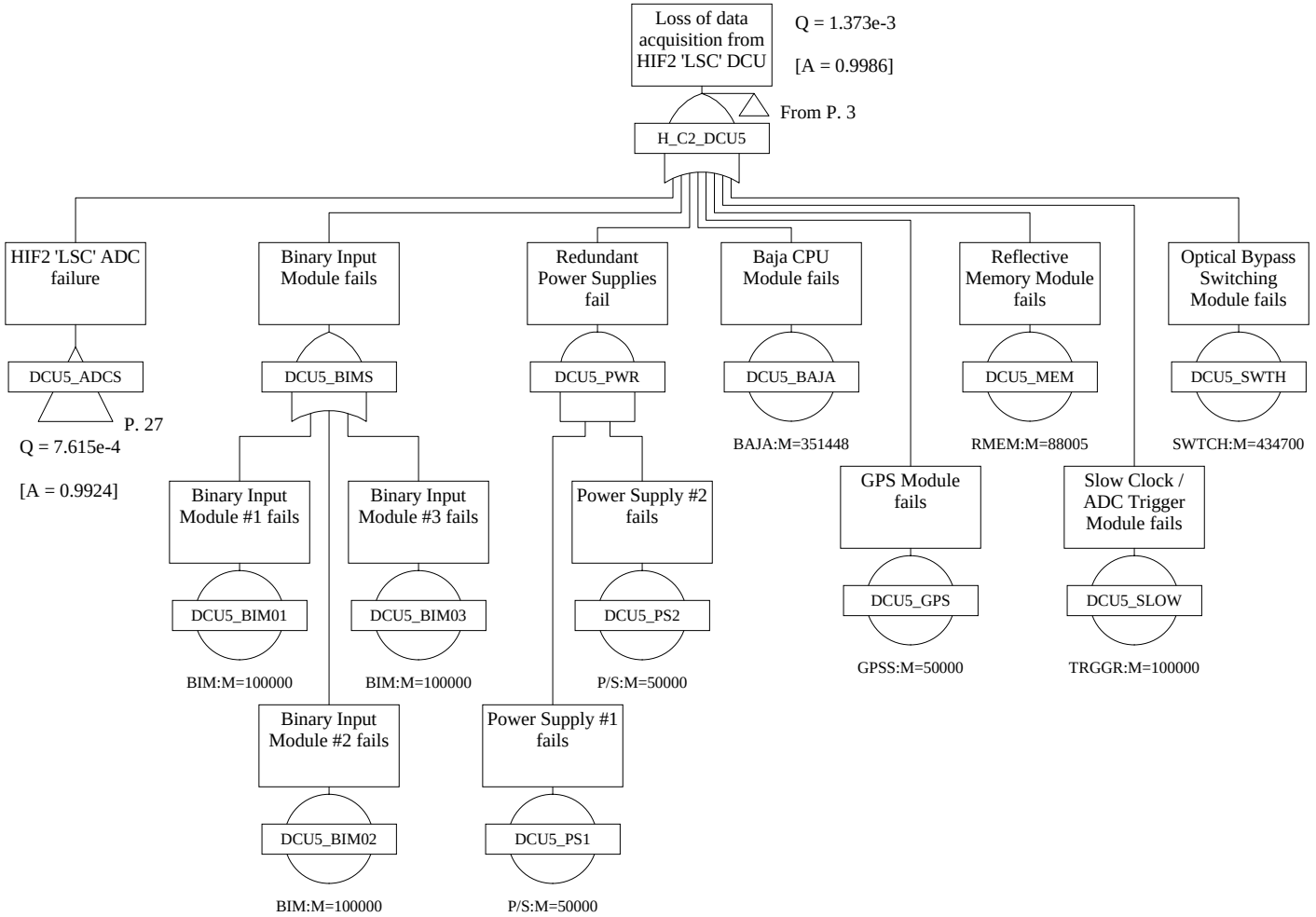

Loss of data acquisition from HIF1 'PSL/SUS' DCU
Q = 1.673e-3
[A = 0.9983]
From P. 4
H_C1_DCU3
Baja CPU Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
DCU3_BAJA
DCU3_MEM
DCU3_SLOW
BAJA:M=351448
RMEM:M=88005
TRGGR:M=100000
HIF1 'PSL/SUS' ADC failure
GPS Module fails
Power Supply fails
Optical Bypass Switching Module fails
DCU3_ADCS
DCU3_GPS
DCU3_PS
DCU3_SWTH
P. 10
Q = 1.142e-3
[A = 0.9989]
GPSS:M=50000
P/S:M=50000
SWTCH:M=434700

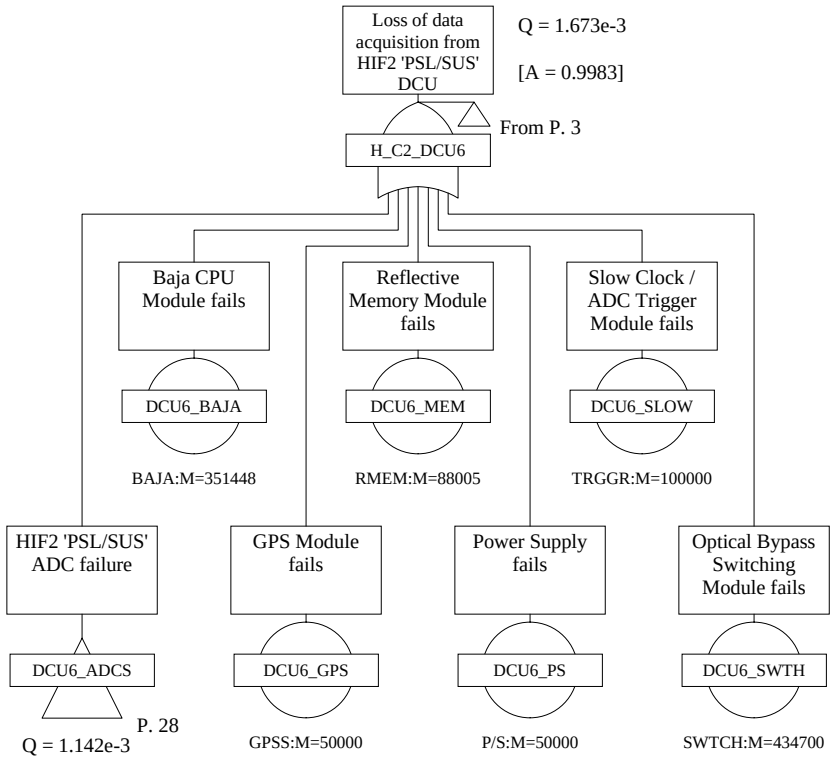

Loss of data acquisition from PEM DAQ System
Q = 1.605e-3
[A = 0.9984]
From P. 1
PEM_DAQ
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
PM_DQ_BAJA
PM_DQ_GPS
PM_DQ_MEM
PM_DQ_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
'PEM DAQ' ADC Module failure
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Optical Bypass Switching Module fails
PM_DQ_ADCS
PM_DQ_BIM
PM_DQ_M162
PM_DQ_PS
PM_DQ_SWTH
P. 26
Q = 9.518e-4
[A = 0.9990]
BIM:M=100000
MV162:M=190509
P/S:M=50000
SWTCH:M=434700

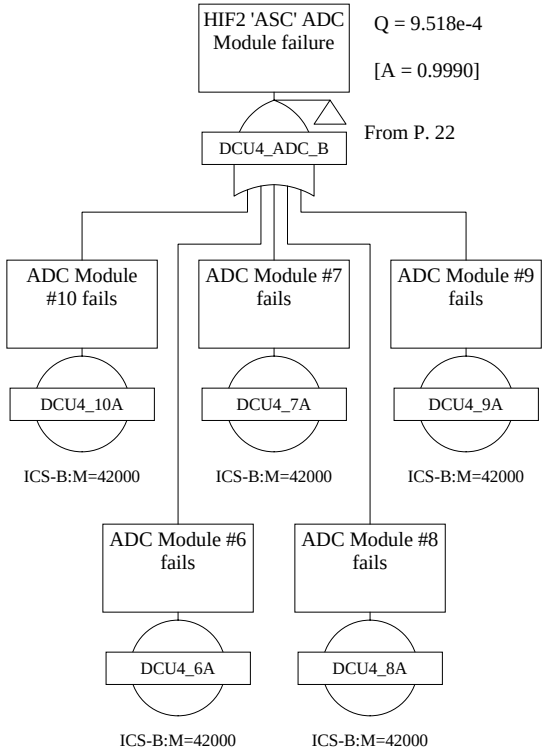

HIF1 'ASC' ADC failure
Q = 9.518e-4
[A = 0.9990]
From P. 16
DCU1_ADC2
ADC Module #10 fails
ADC Module #7 fails
ADC Module #9 fails
DCU1_10A
DCU1_7A
DCU1_9A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #6 fails
ADC Module #8 fails
DCU1_6A
DCU1_8A
ICS-B:M=42000
ICS-B:M=42000

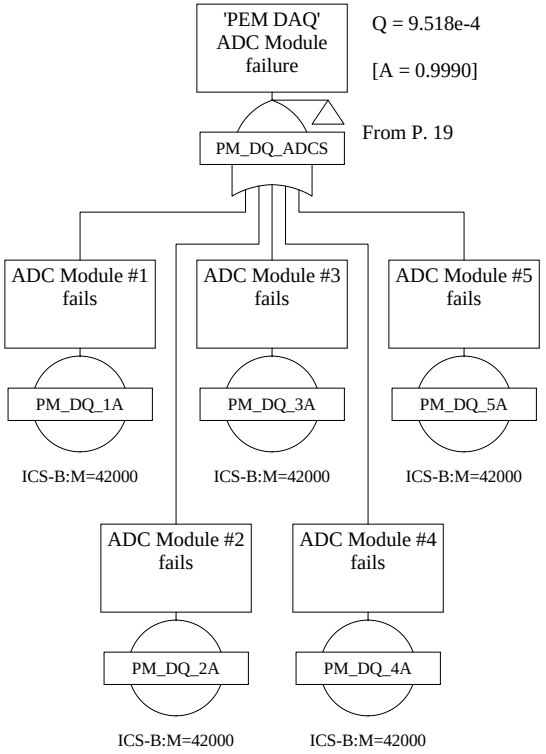

HIF2 'ASC' ADC Module failure
Q = 9.518e-4
[A = 0.9990]
From P. 22
DCU4_ADC_A
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
DCU4_1A
DCU4_3A
DCU4_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
DCU4_2A
DCU4_4A
ICS-B:M=42000
ICS-B:M=42000

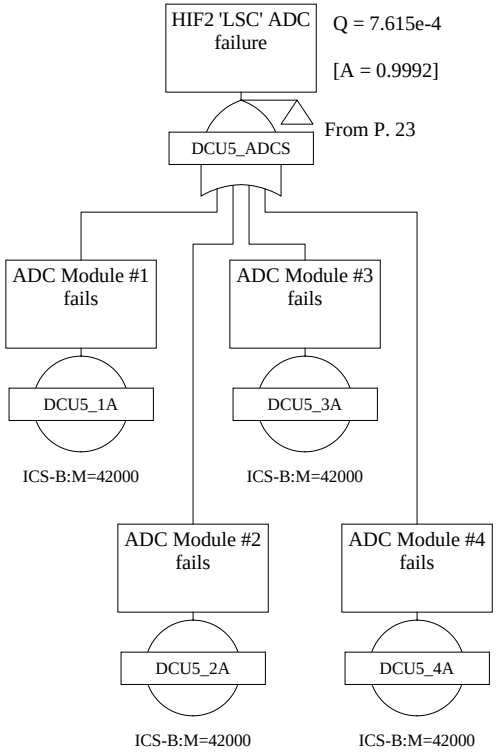

Loss of data acquisition from HIF2 'ASC' DCU
Q = 2.434e-3
[A = 0.9976]
From P. 3
H_C2_DCU4
HIF2 'ASC' ADC Module failure
DCU4_ADC_A
P. 21
Q = 9.518e-4
[A = 0.9990]
Baja CPU Module fails
DCU4_BAJA
BAJA:M=351448
Reflective Memory Module fails
DCU4_MEM
RMEM:M=88005
Slow Clock / ADC Trigger Module fails
DCU4_SLOW
TRGGR:M=100000
HIF2 'ASC' ADC Module failure
DCU4_ADC_B
P. 25
Q = 9.518e-4
[A = 0.9990]
GPS Module fails
DCU4_GPS
GPSS:M=50000
Power Supply fails
DCU4_PS
P/S:M=50000
Optical Bypass Switching Module fails
DCU4_SWTH
SWTCH:M=434700

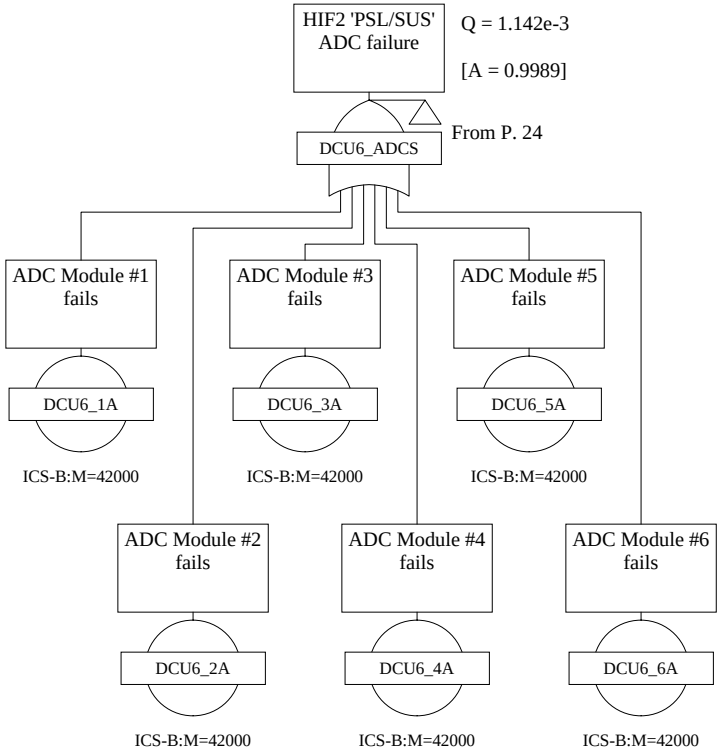

Loss of data acquisition from HIF2 'LSC' DCU
Q = 1.373e-3
[A = 0.9986]
From P. 3
H_C2_DCU5
HIF2 'LSC' ADC failure
DCU5_ADCS
P. 27
Q = 7.615e-4
[A = 0.9924]
Binary Input Module fails
DCU5_BIMS
Binary Input Module #1 fails
DCU5_BIM01
BIM:M=100000
Binary Input Module #3 fails
DCU5_BIM03
BIM:M=100000
Binary Input Module #2 fails
DCU5_BIM02
BIM:M=100000
Redundant Power Supplies fail
DCU5_PWR
Power Supply #2 fails
DCU5_PS2
P/S:M=50000
Power Supply #1 fails
DCU5_PS1
P/S:M=50000
Baja CPU Module fails
DCU5_BAJA
BAJA:M=351448
GPS Module fails
DCU5_GPS
GPSS:M=50000
Reflective Memory Module fails
DCU5_MEM
RMEM:M=88005
Slow Clock / ADC Trigger Module fails
DCU5_SLOW
TRGGR:M=100000
Optical Bypass Switching Module fails
DCU5_SWTH
SWTCH:M=434700


Loss of data acquisition from HIF2 'PSL/SUS' DCU
Q = 1.673e-3
[A = 0.9983]
From P. 3
H_C2_DCU6
Baja CPU Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
DCU6_BAJA
DCU6_MEM
DCU6_SLOW
BAJA:M=351448
RMEM:M=88005
TRGGR:M=100000
HIF2 'PSL/SUS' ADC failure
GPS Module fails
Power Supply fails
Optical Bypass Switching Module fails
DCU6_ADCS
DCU6_GPS
DCU6_PS
DCU6_SWTH
P. 28
Q = 1.142e-3
[A = 0.9989]
GPSS:M=50000
P/S:M=50000
SWTCH:M=434700


HIF2 'ASC' ADC Module failure
Q = 9.518e-4
[A = 0.9990]
From P. 22
DCU4_ADC_B
ADC Module #10 fails
ADC Module #7 fails
ADC Module #9 fails
DCU4_10A
DCU4_7A
DCU4_9A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #6 fails
ADC Module #8 fails
DCU4_6A
DCU4_8A
ICS-B:M=42000
ICS-B:M=42000


'PEM DAQ' ADC Module failure
Q = 9.518e-4
[A = 0.9990]
From P. 19
PM_DQ_ADCS
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
PM_DQ_1A
PM_DQ_3A
PM_DQ_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
PM_DQ_2A
PM_DQ_4A
ICS-B:M=42000
ICS-B:M=42000

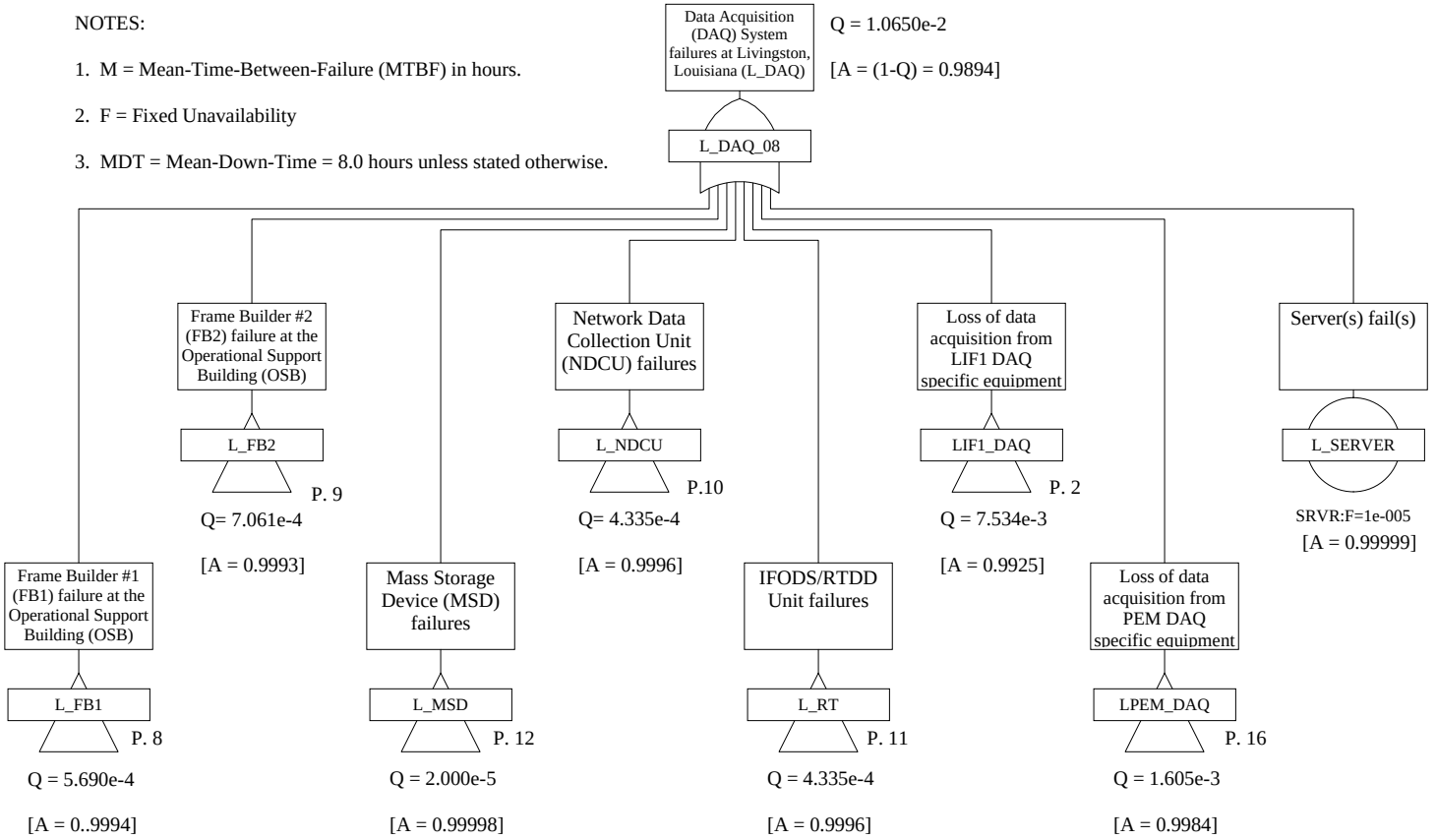

HIF2 'LSC' ADC failure
Q = 7.615e-4
[A = 0.9992]
From P. 23
DCU5_ADCS
ADC Module #1 fails
ADC Module #3 fails
DCU5_1A
DCU5_3A
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
DCU5_2A
DCU5_4A
ICS-B:M=42000
ICS-B:M=42000

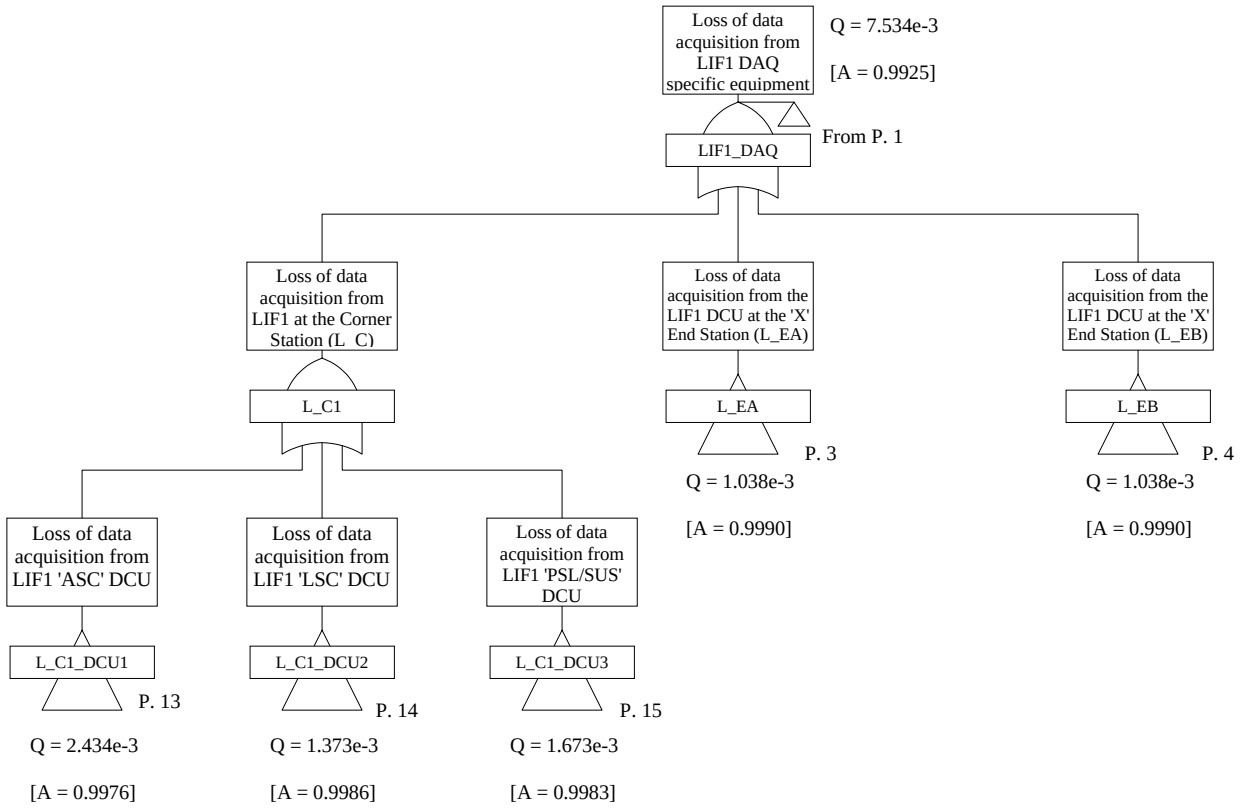

HIF2 'PSL/SUS' ADC failure
Q = 1.142e-3
[A = 0.9989]
From P. 24
DCU6_ADCS
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
DCU6_1A
DCU6_3A
DCU6_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
ADC Module #6 fails
DCU6_2A
DCU6_4A
DCU6_6A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000

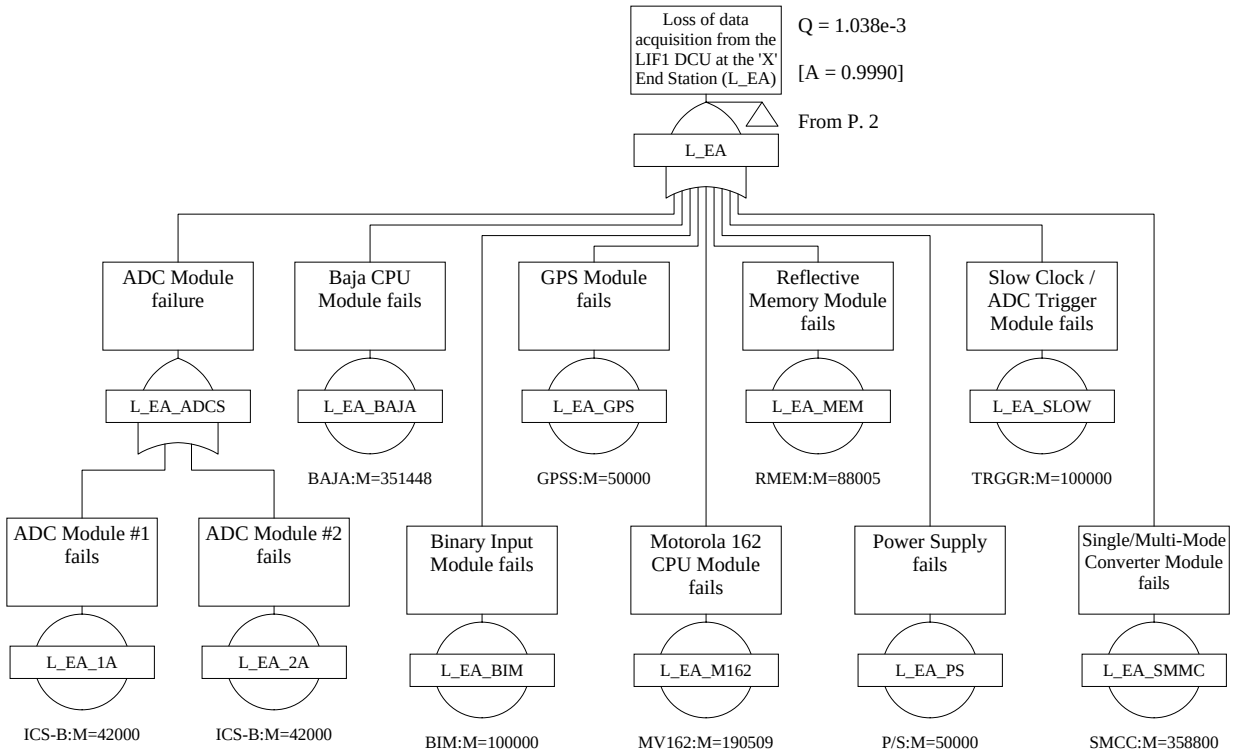
APPENDIX B:
DAQ AVAILABILITY PREDICTION, LIVINGSTON, LA

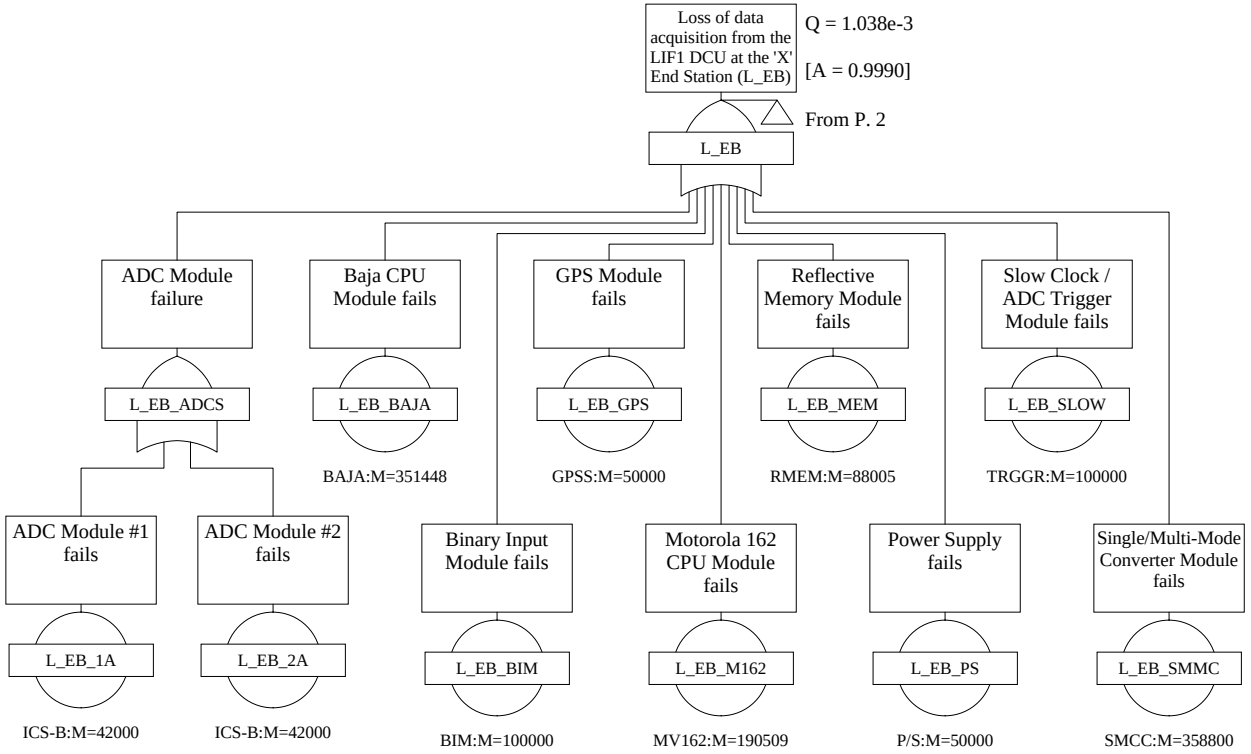
NOTES:

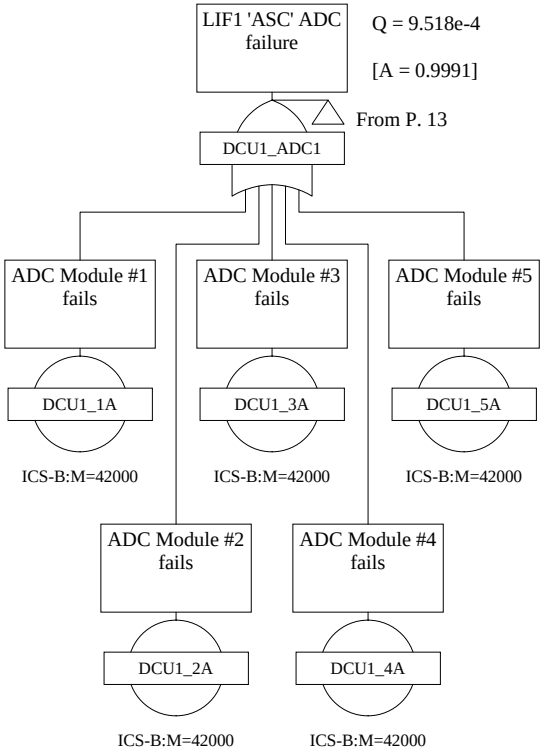
1. M = Mean-Time-Between-Failure (MTBF) in hours.
2. F = Fixed Unavailability
3. MDT = Mean-Down-Time = 8.0 hours unless stated otherwise.

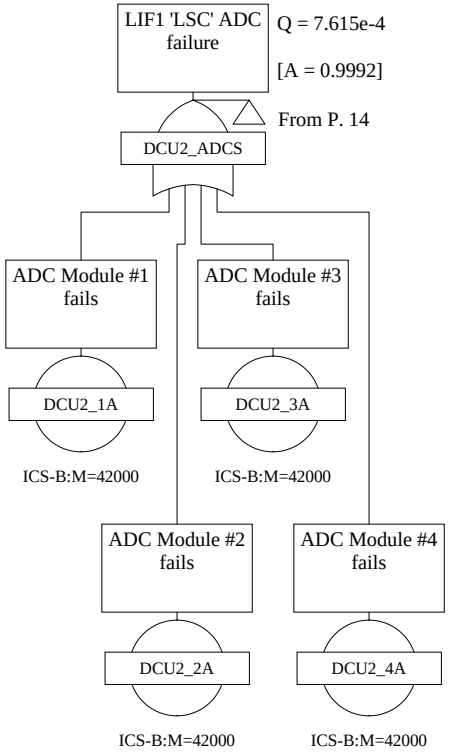


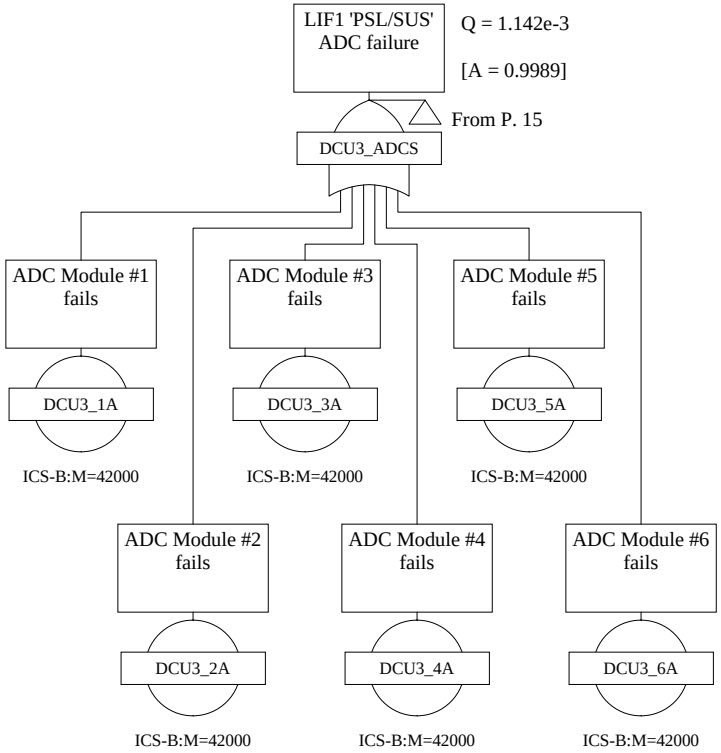

Loss of data acquisition from LIF1 DAQ specific equipment
Q = 7.534e-3
[A = 0.9925]
LIF1_DAQ
From P. 1
Loss of data acquisition from LIF1 at the Corner Station (L_C)
Loss of data acquisition from the LIF1 DCU at the 'X' End Station (L_EA)
Loss of data acquisition from the LIF1 DCU at the 'X' End Station (L_EB)
L_C1
L_EA
L_EB
P. 3
P. 4
Q = 1.038e-3
[A = 0.9990]
Q = 1.038e-3
[A = 0.9990]
Loss of data acquisition from LIF1 'ASC' DCU
Loss of data acquisition from LIF1 'LSC' DCU
Loss of data acquisition from LIF1 'PSL/SUS' DCU
L_C1_DCU1
L_C1_DCU2
L_C1_DCU3
P. 13
P. 14
P. 15
Q = 2.434e-3
[A = 0.9976]
Q = 1.373e-3
[A = 0.9986]
Q = 1.673e-3
[A = 0.9983]

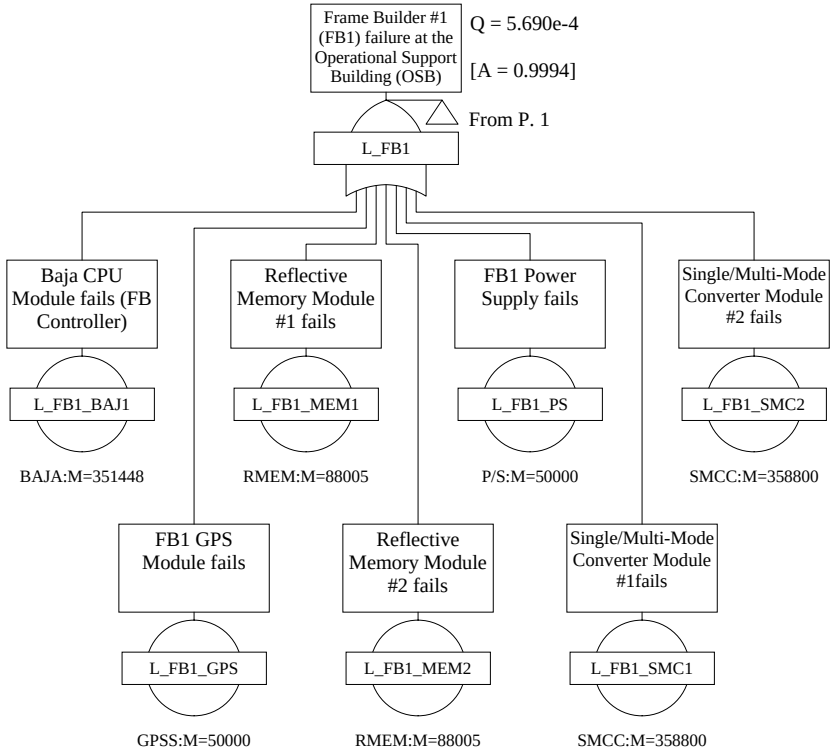

Loss of data acquisition from the LIF1 DCU at the 'X' End Station (L_EA)
Q = 1.038e-3
[A = 0.9990]
From P. 2
L_EA
ADC Module failure
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
L_EA_ADCS
L_EA_BAJA
L_EA_GPS
L_EA_MEM
L_EA_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
ADC Module #1 fails
ADC Module #2 fails
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Single/Multi-Mode Converter Module fails
L_EA_1A
L_EA_2A
L_EA_BIM
L_EA_M162
L_EA_PS
L_EA_SMMC
ICS-B:M=42000
ICS-B:M=42000
BIM:M=100000
MV162:M=190509
P/S:M=50000
SMCC:M=358800

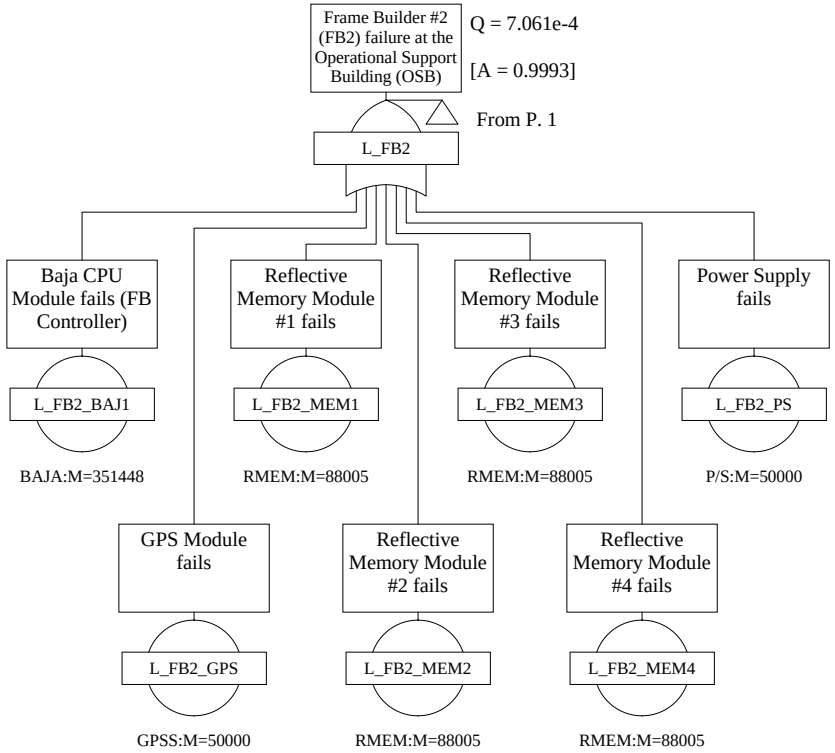

Loss of data acquisition from the LIF1 DCU at the 'X' End Station (L_EB)
Q = 1.038e-3
[A = 0.9990]
From P. 2
L_EB
ADC Module failure
Baja CPU Module fails
GPS Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
L_EB_ADCS
L_EB_BAJA
L_EB_GPS
L_EB_MEM
L_EB_SLOW
BAJA:M=351448
GPSS:M=50000
RMEM:M=88005
TRGGR:M=100000
ADC Module #1 fails
ADC Module #2 fails
Binary Input Module fails
Motorola 162 CPU Module fails
Power Supply fails
Single/Multi-Mode Converter Module fails
L_EB_1A
L_EB_2A
L_EB_BIM
L_EB_M162
L_EB_PS
L_EB_SMMC
ICS-B:M=42000
ICS-B:M=42000
BIM:M=100000
MV162:M=190509
P/S:M=50000
SMCC:M=358800

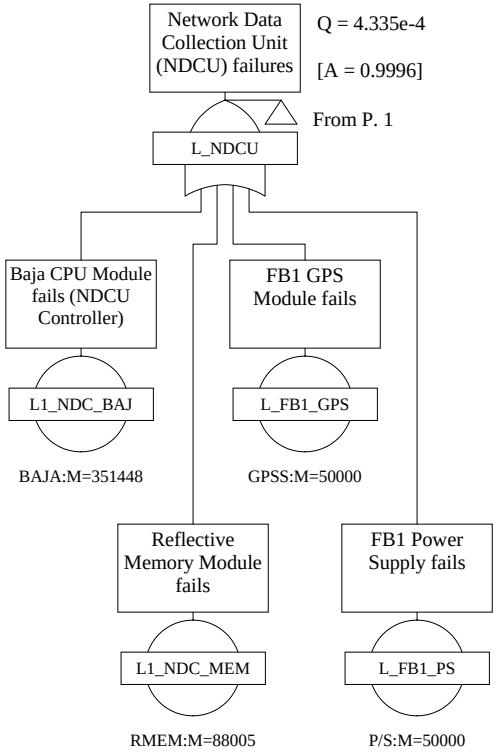

LIF1 'ASC' ADC failure
Q = 9.518e-4
[A = 0.9991]
From P. 13
DCU1_ADC1
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
DCU1_1A
DCU1_3A
DCU1_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
DCU1_2A
DCU1_4A
ICS-B:M=42000
ICS-B:M=42000

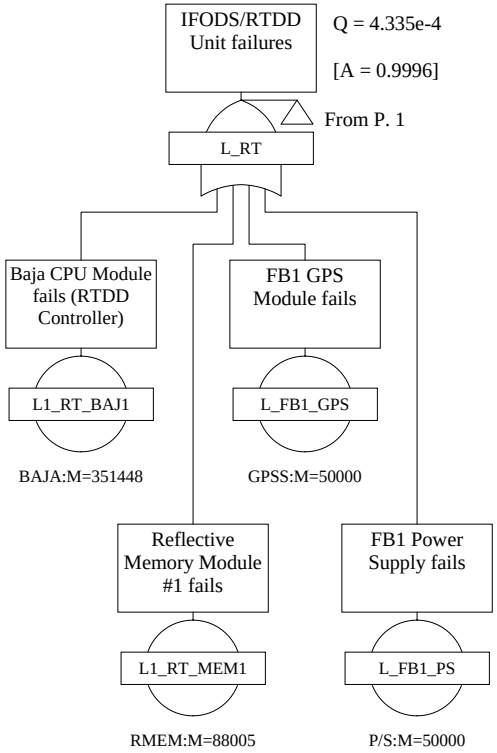

LIF1 'LSC' ADC failure
Q = 7.615e-4
[A = 0.9992]
From P. 14
DCU2_ADCS
ADC Module #1 fails
ADC Module #3 fails
DCU2_1A
DCU2_3A
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
DCU2_2A
DCU2_4A
ICS-B:M=42000
ICS-B:M=42000

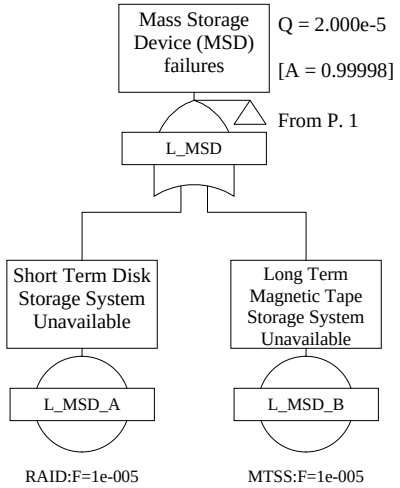

LIF1 'PSL/SUS' ADC failure
Q = 1.142e-3
[A = 0.9989]
From P. 15
DCU3_ADCS
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
DCU3_1A
DCU3_3A
DCU3_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
ADC Module #6 fails
DCU3_2A
DCU3_4A
DCU3_6A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000

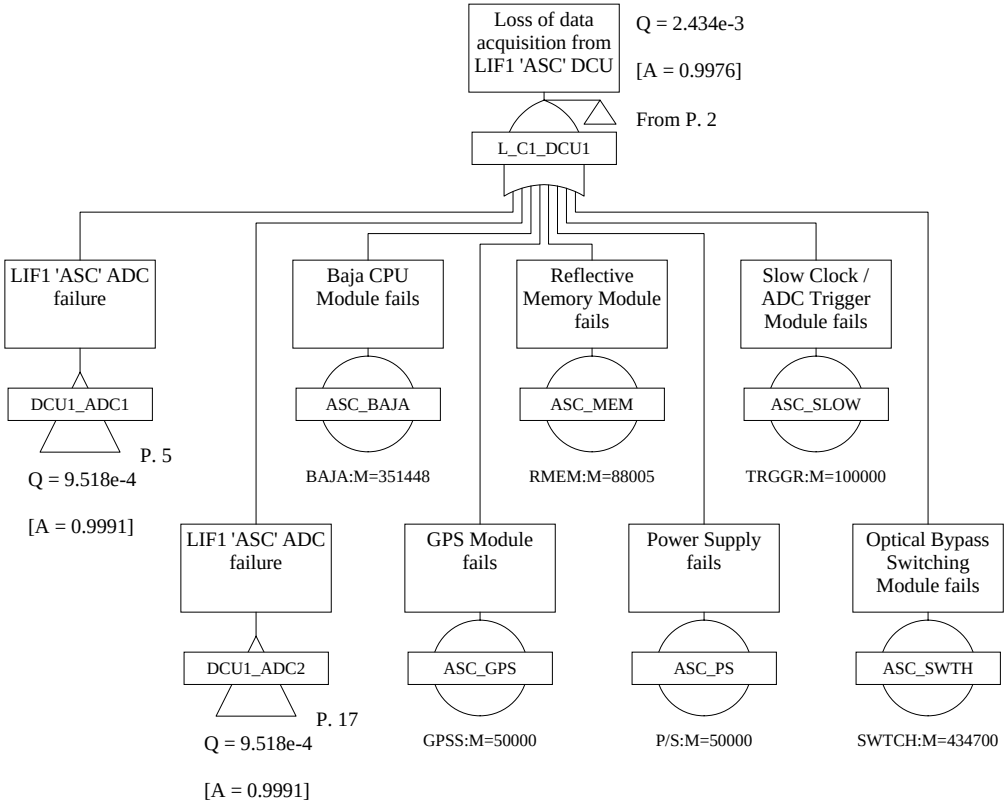

Frame Builder #1 (FB1) failure at the Operational Support Building (OSB)
Q = 5.690e-4
[A = 0.9994]
From P. 1
L_FB1
Baja CPU Module fails (FB Controller)
Reflective Memory Module #1 fails
FB1 Power Supply fails
Single/Multi-Mode Converter Module #2 fails
L_FB1_BAJ1
L_FB1_MEM1
L_FB1_PS
L_FB1_SMC2
BAJA:M=351448
RMEM:M=88005
P/S:M=50000
SMCC:M=358800
FB1 GPS Module fails
Reflective Memory Module #2 fails
Single/Multi-Mode Converter Module #1fails
L_FB1_GPS
L_FB1_MEM2
L_FB1_SMC1
GPSS:M=50000
RMEM:M=88005
SMCC:M=358800

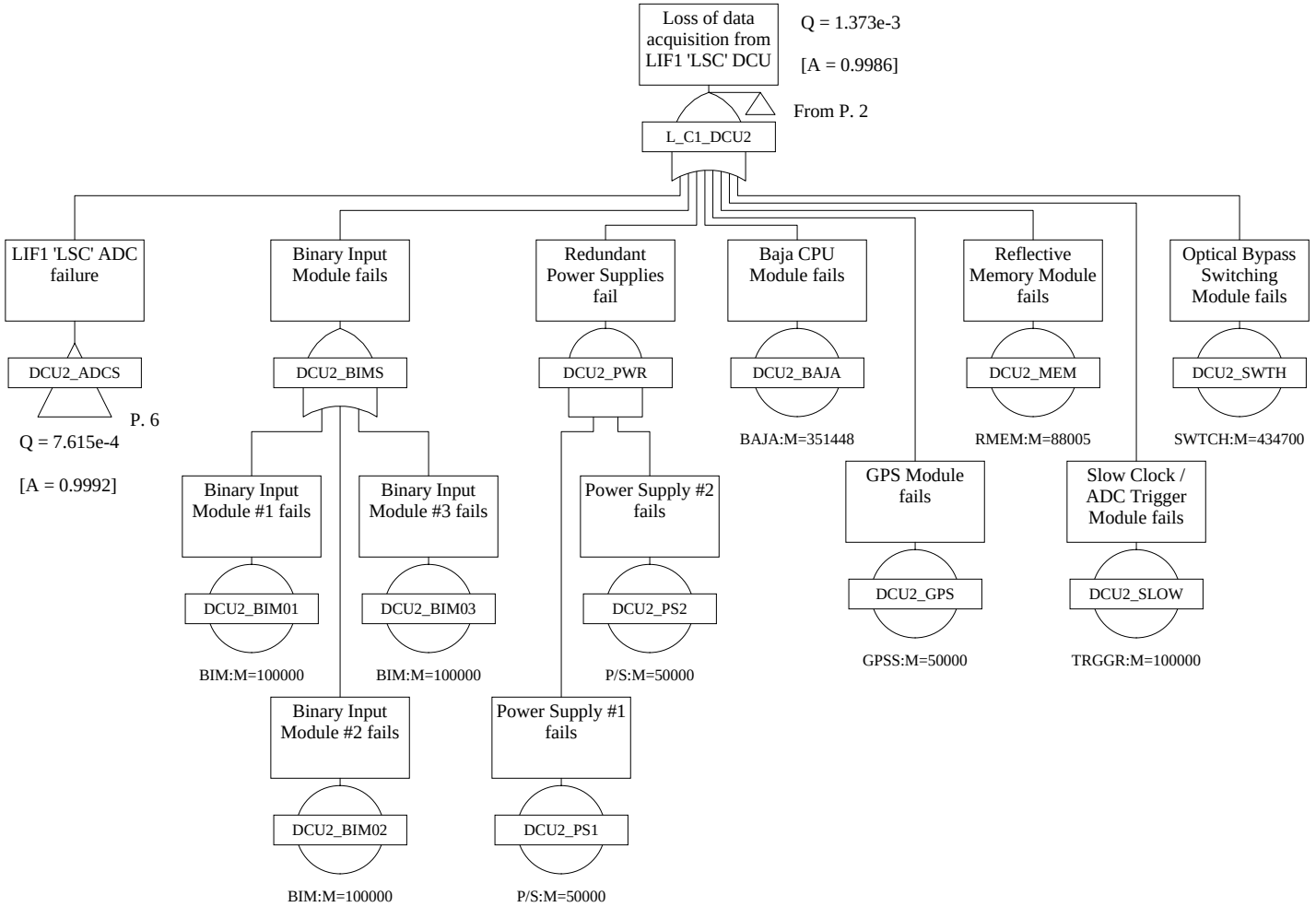

Frame Builder #2 (FB2) failure at the Operational Support Building (OSB)
Q = 7.061e-4
[A = 0.9993]
From P. 1
L_FB2
Baja CPU Module fails (FB Controller)
Reflective Memory Module #1 fails
Reflective Memory Module #3 fails
Power Supply fails
L_FB2_BAJ1
L_FB2_MEM1
L_FB2_MEM3
L_FB2_PS
BAJA:M=351448
RMEM:M=88005
RMEM:M=88005
P/S:M=50000
GPS Module fails
Reflective Memory Module #2 fails
Reflective Memory Module #4 fails
L_FB2_GPS
L_FB2_MEM2
L_FB2_MEM4
GPSS:M=50000
RMEM:M=88005
RMEM:M=88005

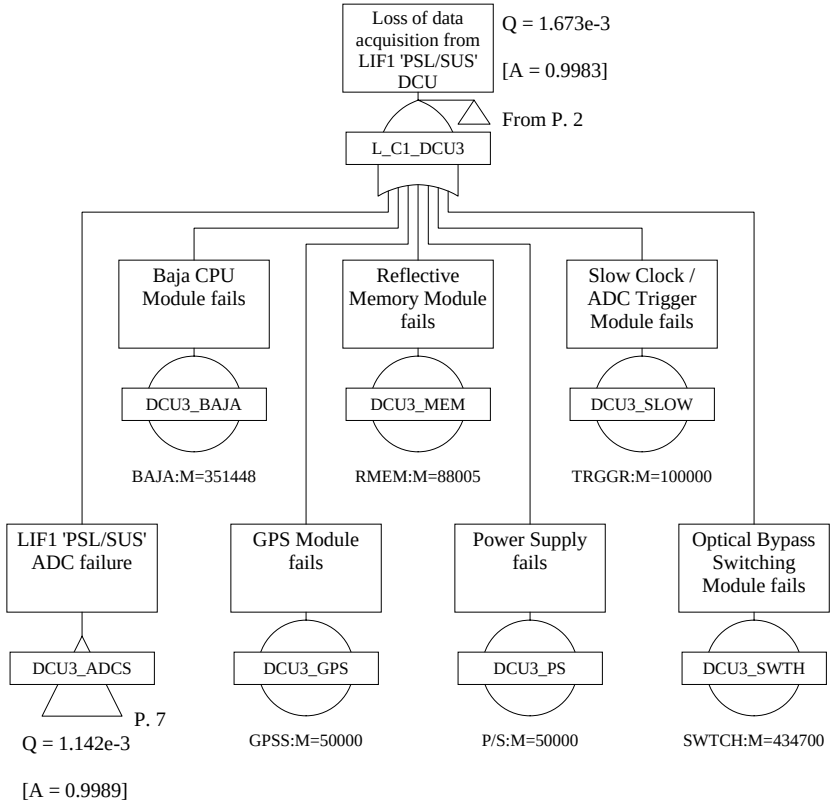

Network Data Collection Unit (NDCU) failures
Q = 4.335e-4
[A = 0.9996]
From P. 1
L_NDCU
Baja CPU Module fails (NDCU Controller)
FB1 GPS Module fails
L1_NDC_BAJ
L_FB1_GPS
BAJA:M=351448
GPSS:M=50000
Reflective Memory Module fails
FB1 Power Supply fails
L1_NDC_MEM
L_FB1_PS
RMEM:M=88005
P/S:M=50000

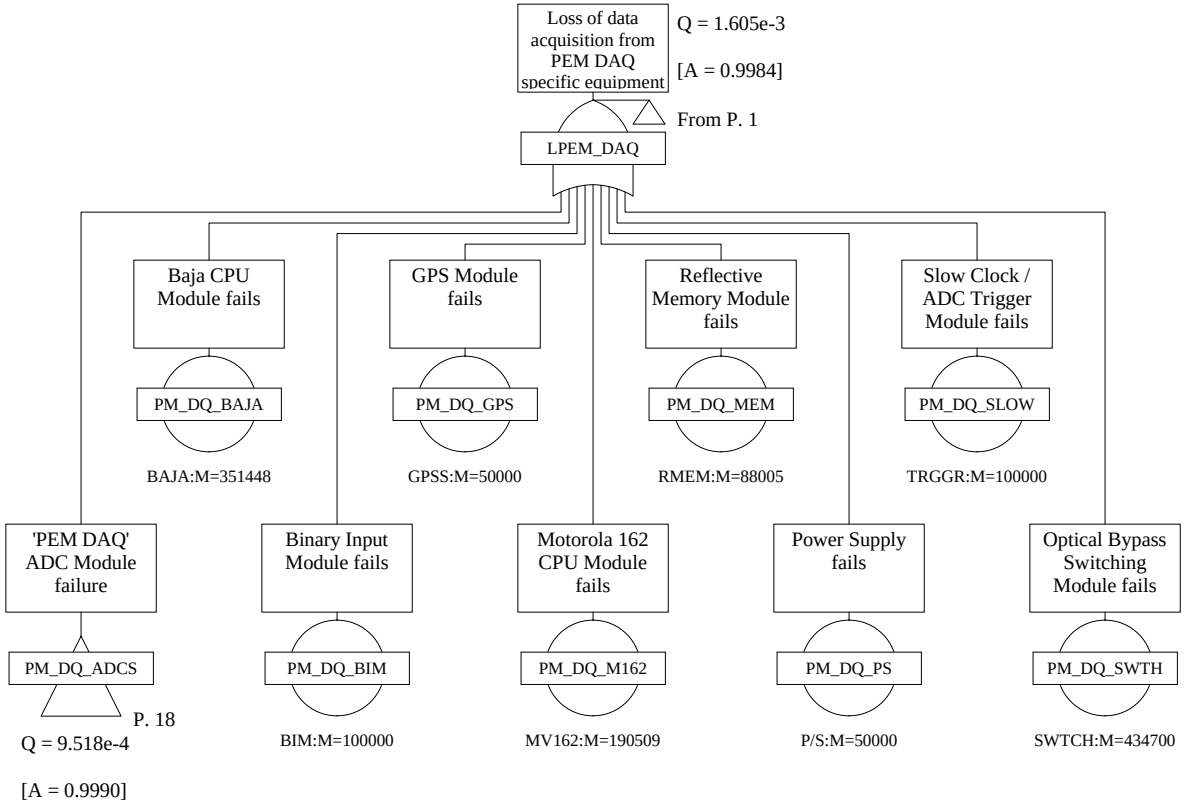

IFODS/RTDD
Unit failures
Q = 4.335e-4
[A = 0.9996]
From P. 1
L_RT
Baja CPU Module
fails (RTDD
Controller)
FB1 GPS
Module fails
L1_RT_BAJ1
L_FB1_GPS
BAJA:M=351448
GPSS:M=50000
Reflective
Memory Module
#1 fails
FB1 Power
Supply fails
L1_RT_MEM1
L_FB1_PS
RMEM:M=88005
P/S:M=50000

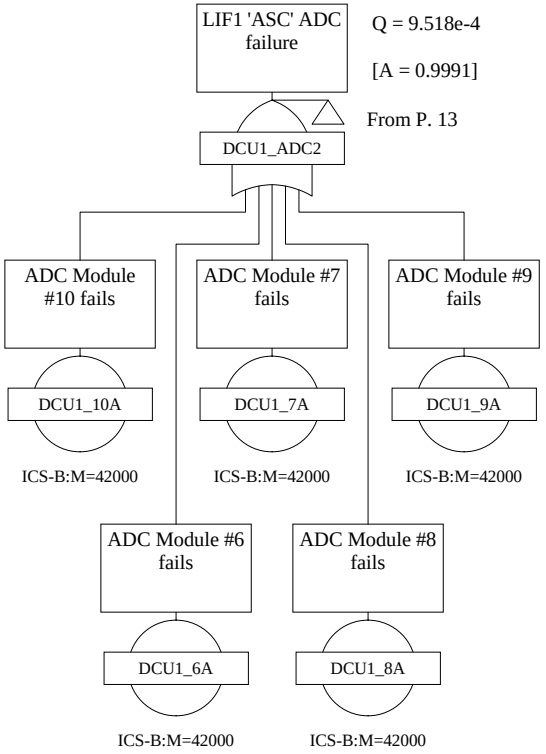

Mass Storage Device (MSD) failures
Q = 2.000e-5
[A = 0.99998]
From P. 1
L_MSD
Short Term Disk Storage System Unavailable
Long Term Magnetic Tape Storage System Unavailable
L_MSD_A
L_MSD_B
RAID:F=1e-005
MTSS:F=1e-005

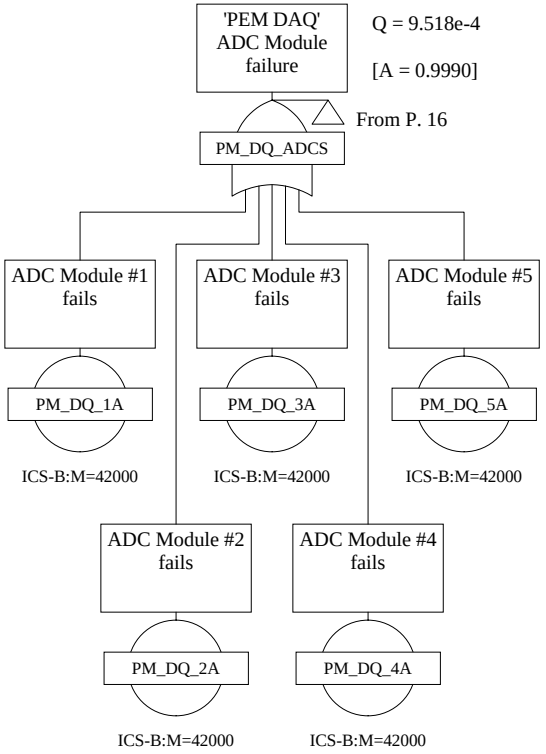

Loss of data acquisition from LIF1 'ASC' DCU
Q = 2.434e-3
[A = 0.9976]
From P. 2
L_C1_DCU1
LIF1 'ASC' ADC failure
DCU1_ADC1
P. 5
Q = 9.518e-4
[A = 0.9991]
Baja CPU Module fails
ASC_BAJA
BAJA:M=351448
Reflective Memory Module fails
ASC_MEM
RMEM:M=88005
Slow Clock / ADC Trigger Module fails
ASC_SLOW
TRGGR:M=100000
LIF1 'ASC' ADC failure
DCU1_ADC2
P. 17
Q = 9.518e-4
[A = 0.9991]
GPS Module fails
ASC_GPS
GPSS:M=50000
Power Supply fails
ASC_PS
P/S:M=50000
Optical Bypass Switching Module fails
ASC_SWTH
SWTCH:M=434700


Loss of data acquisition from LIF1 'LSC' DCU
Q = 1.373e-3
[A = 0.9986]
From P. 2
L_C1_DCU2
LIF1 'LSC' ADC failure
DCU2_ADCS
P. 6
Q = 7.615e-4
[A = 0.9992]
Binary Input Module fails
DCU2_BIMS
Binary Input Module #1 fails
DCU2_BIM01
BIM:M=100000
Binary Input Module #3 fails
DCU2_BIM03
BIM:M=100000
Binary Input Module #2 fails
DCU2_BIM02
BIM:M=100000
Redundant Power Supplies fail
DCU2_PWR
Power Supply #2 fails
DCU2_PS2
P/S:M=50000
Power Supply #1 fails
DCU2_PS1
P/S:M=50000
Baja CPU Module fails
DCU2_BAJA
BAJA:M=351448
GPS Module fails
DCU2_GPS
GPSS:M=50000
Reflective Memory Module fails
DCU2_MEM
RMEM:M=88005
Slow Clock / ADC Trigger Module fails
DCU2_SLOW
TRGGR:M=100000
Optical Bypass Switching Module fails
DCU2_SWTH
SWTCH:M=434700

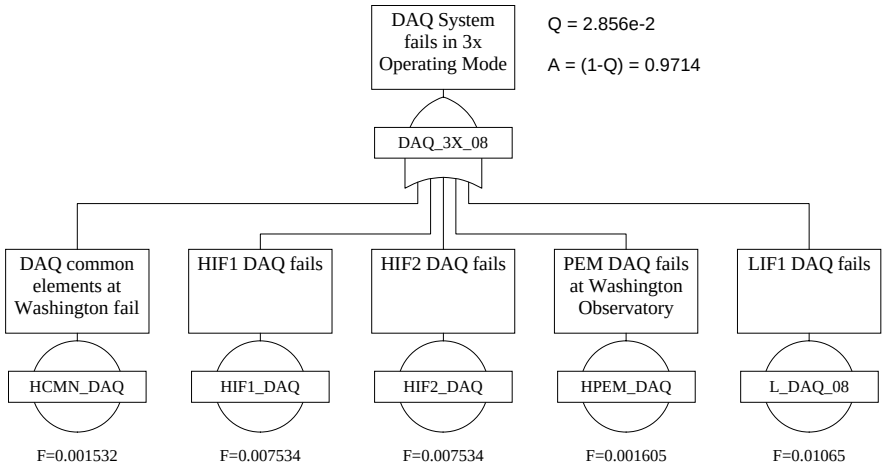

Loss of data acquisition from LIF1 'PSL/SUS' DCU
Q = 1.673e-3
[A = 0.9983]
From P. 2
L_C1_DCU3
Baja CPU Module fails
Reflective Memory Module fails
Slow Clock / ADC Trigger Module fails
DCU3_BAJA
DCU3_MEM
DCU3_SLOW
BAJA:M=351448
RMEM:M=88005
TRGGR:M=100000
LIF1 'PSL/SUS' ADC failure
GPS Module fails
Power Supply fails
Optical Bypass Switching Module fails
DCU3_ADCS
DCU3_GPS
DCU3_PS
DCU3_SWTH
P. 7
Q = 1.142e-3
[A = 0.9989]
GPSS:M=50000
P/S:M=50000
SWTCH:M=434700


Loss of data acquisition from PEM DAQ specific equipment
Q = 1.605e-3
[A = 0.9984]
From P. 1
LPEM_DAQ
Baja CPU Module fails
PM_DQ_BAJA
BAJA:M=351448
GPS Module fails
PM_DQ_GPS
GPSS:M=50000
Reflective Memory Module fails
PM_DQ_MEM
RMEM:M=88005
Slow Clock / ADC Trigger Module fails
PM_DQ_SLOW
TRGGR:M=100000
'PEM DAQ' ADC Module failure
PM_DQ_ADCS
P. 18
Q = 9.518e-4
[A = 0.9990]
Binary Input Module fails
PM_DQ_BIM
BIM:M=100000
Motorola 162 CPU Module fails
PM_DQ_M162
MV162:M=190509
Power Supply fails
PM_DQ_PS
P/S:M=50000
Optical Bypass Switching Module fails
PM_DQ_SWTH
SWTCH:M=434700

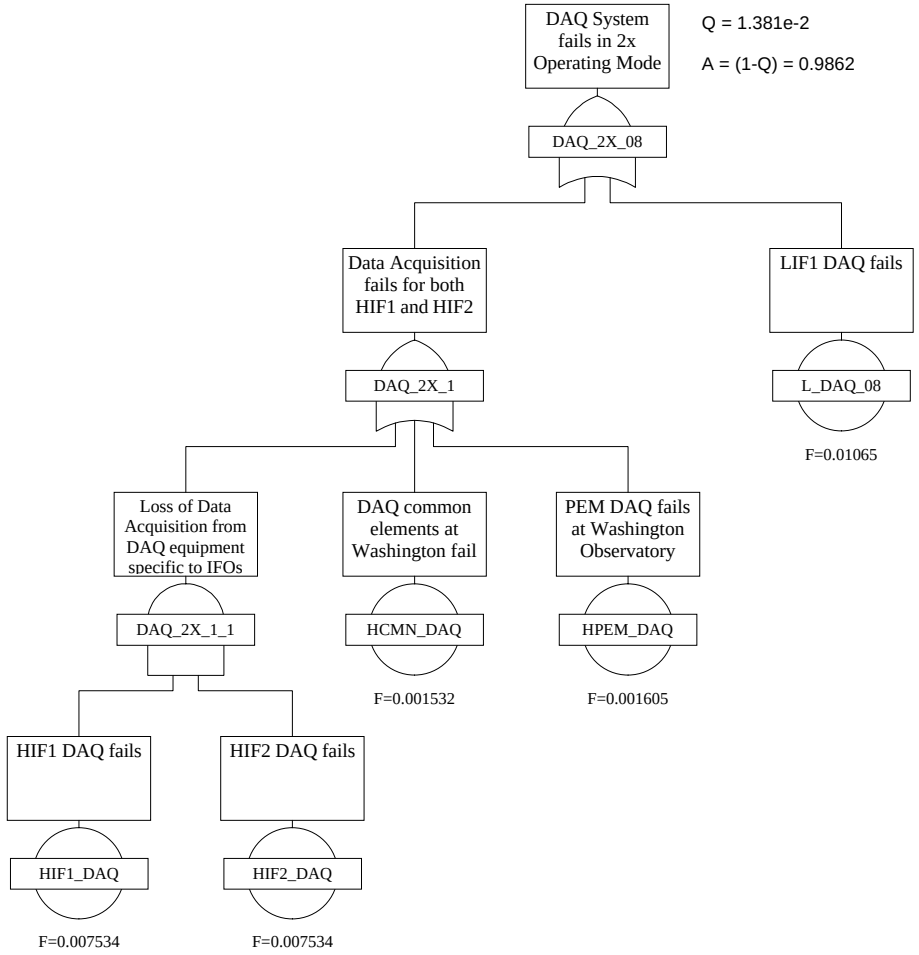

LIF1 'ASC' ADC failure
Q = 9.518e-4
[A = 0.9991]
From P. 13
DCU1_ADC2
ADC Module #10 fails
ADC Module #7 fails
ADC Module #9 fails
DCU1_10A
DCU1_7A
DCU1_9A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #6 fails
ADC Module #8 fails
DCU1_6A
DCU1_8A
ICS-B:M=42000
ICS-B:M=42000


'PEM DAQ' ADC Module failure
Q = 9.518e-4
[A = 0.9990]
From P. 16
PM_DQ_ADCS
ADC Module #1 fails
ADC Module #3 fails
ADC Module #5 fails
PM_DQ_1A
PM_DQ_3A
PM_DQ_5A
ICS-B:M=42000
ICS-B:M=42000
ICS-B:M=42000
ADC Module #2 fails
ADC Module #4 fails
PM_DQ_2A
PM_DQ_4A
ICS-B:M=42000
ICS-B:M=42000

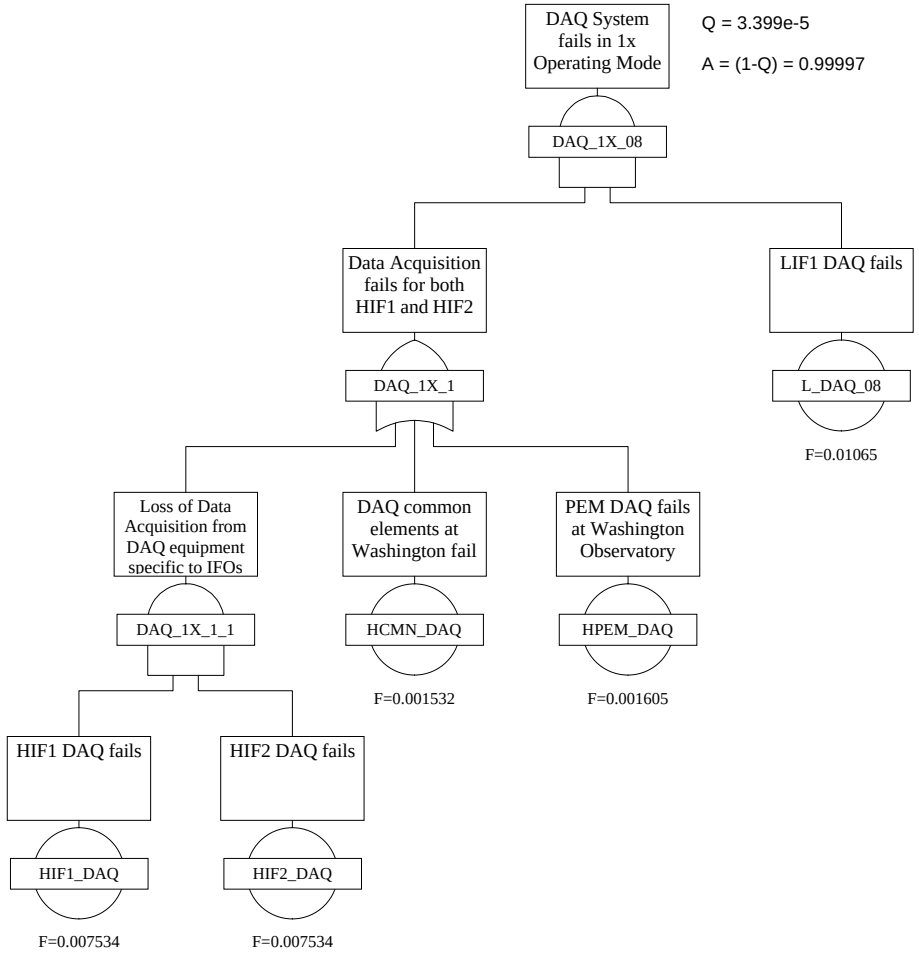
APPENDIX C:
LIGO 3X
DAQ AVAILABILITY PREDICTION


DAQ System fails in 3x Operating Mode
Q = 2.856e-2
A = (1-Q) = 0.9714
DAQ_3X_08
DAQ common elements at Washington fail
HIF1 DAQ fails
HIF2 DAQ fails
PEM DAQ fails at Washington Observatory
LIF1 DAQ fails
HCMN_DAQ
HIF1_DAQ
HIF2_DAQ
HPEM_DAQ
L_DAQ_08
F=0.001532
F=0.007534
F=0.007534
F=0.001605
F=0.01065

APPENDIX D:
LIGO 2X
DAQ AVAILABILITY PREDICTION


DAQ System fails in 2x Operating Mode
Q = 1.381e-2
A = (1-Q) = 0.9862
DAQ_2X_08
Data Acquisition fails for both HIF1 and HIF2
LIF1 DAQ fails
DAQ_2X_1
L_DAQ_08
F=0.01065
Loss of Data Acquisition from DAQ equipment specific to IFOs
DAQ common elements at Washington fail
PEM DAQ fails at Washington Observatory
DAQ_2X_1_1
HCMN_DAQ
HPEM_DAQ
F=0.001532
F=0.001605
HIF1 DAQ fails
HIF2 DAQ fails
HIF1_DAQ
HIF2_DAQ
F=0.007534
F=0.007534

APPENDIX E:
LIGO 1X
DAQ AVAILABILITY PREDICTION


DAQ System fails in 1x Operating Mode
Q = 3.399e-5
A = (1-Q) = 0.99997
DAQ_1X_08
Data Acquisition fails for both HIF1 and HIF2
LIF1 DAQ fails
DAQ_1X_1
L_DAQ_08
F=0.01065
Loss of Data Acquisition from DAQ equipment specific to IFOs
DAQ common elements at Washington fail
PEM DAQ fails at Washington Observatory
DAQ_1X_1_1
HCMN_DAQ
HPEM_DAQ
F=0.001532
F=0.001605
HIF1 DAQ fails
HIF2 DAQ fails
HIF1_DAQ
HIF2_DAQ
F=0.007534
F=0.007534

APPENDIX F: DEMYSTIFYING TAPE RELIABILITY

Strategic Profile

Demystifying Tape Reliability

Our Opinion

Why does there continue to be so much discussion of tape and tape library reliability in the trade press? The not-so-obvious answer is that the tape library industry has discovered the truth; library systems are more reliable than single drives. Unfortunately, that message is always lost in the confusion of jargon and reliability terms. It is time for a new perspective and a definition of reliability consistent with the requirements of today's mission critical application serving environment. The simple reality is that failures happen! No pursuit or variant of *MTBF* terminology will result in a meaningful and useful understanding of how to build mission-critical-capable network applications.

As shown in Figure 1, reliability defines many terms that span data reliability, device (drive or system) reliability, and other systems concerns. Yet, the proof of reliability comes with the company's reputation, warranty, and service policies, not with a phony number and assumptions about utilization, duty cycle, and replacements. We need a new metric and we propose that if you accept that failures happen, then it's not reliability that is of concern. It is *system availability*.

Figure 1

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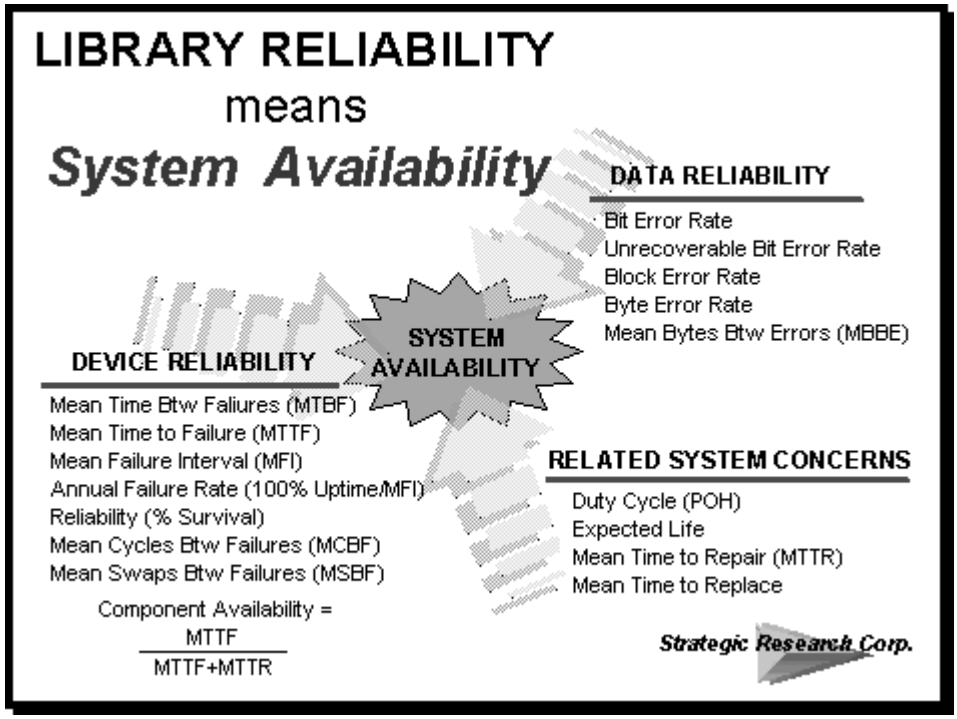
Corporation. Further details on the product reviewed herein are available from the vendor or through the Network Buyer's Guide™ on the Internet at http://www.sresearch.com.

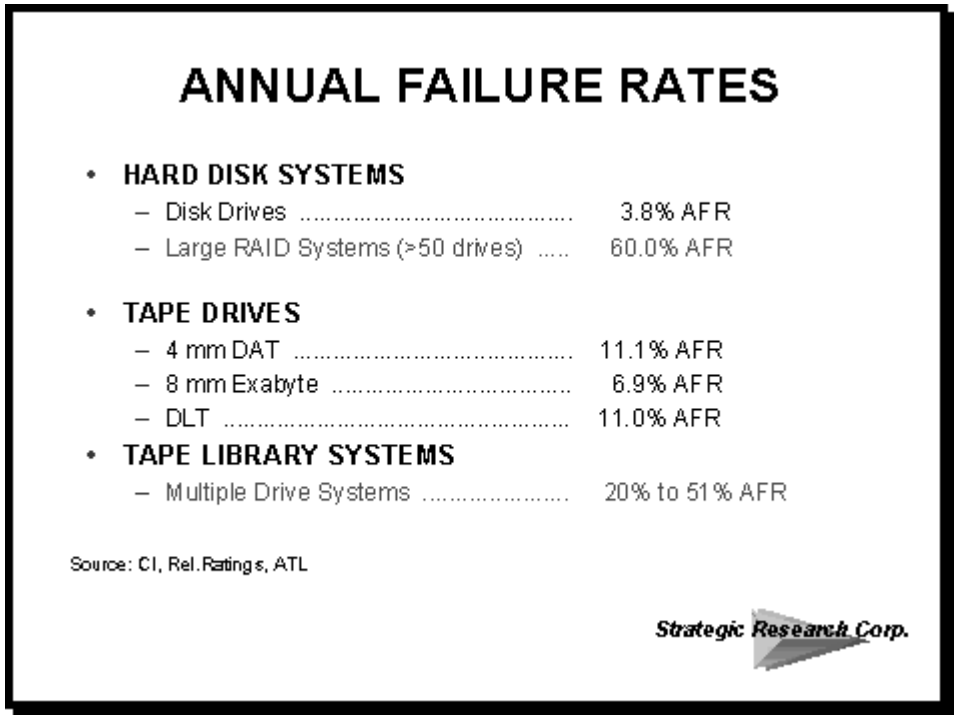


System Availability -- not Reliability!

To further illustrate, consider the overused reliability metric *Mean Time Between Failure*, MTBF. If you used the same methods that the tape library industry uses to calculate MTBF for tape systems and applied it to the human body, you would arrive at 18.2 million hours. The claim that a human body, with replacement, field upgrades, and not counting infant mortalities, has a MTBF of 2,078 years[1], obviously has no relationship to life expectation. What conclusions can you draw from a term like this? How do you even select a "reliable body", using these misleading methods?

The lesson becomes clear by looking at the *Annual Failure Rate*, AFR[2], for disk drives. Leaving the definitions aside, let's look at what AFR tells us. Keep in mind that failures happen! In Figure 2, disk drives are compared to tape drives as well as disk and tape systems. Even with MTBFs of several hundred thousand hours, disk drives fail annually. For disk drives, an AFR of 3.8% is equivalent to saying a single disk drive has a probability of not failing in a given year of 96%.

Figure 2



Faliures Happen!

High-end tape drives are good, but still not as good as disk. These failure probabilities compound when building an array or a system, utilizing multiple drives. A 50 drive disk array experiences an average of 3 drive failures per year. (In comparison, a 1000 drive array sees disk failures weekly!) Two important lessons leap out of this data. RAID does not stop failures. We all accept RAID as the highest reliability storage architecture available. However, RAID is a system solution designed to provide high availability and high data integrity through fault tolerance, not MTBF or AFR. These are completely different concepts! Failures still occur and high availability system architectures are required to prevent downtime, protect data, and insure continued performance. In the disk world, RAID arrays, not JBOD[3], are the solution for reliability. In the tape arena, it is libraries with multiple drives, RAID tape arrays, and multiple libraries with the capability to fail over to available spares that provide equivalent service. The solution is not higher MTBFs.

The Solution

The second key lesson is based on the experience of the tape library industry and its customers. A well designed library with multiple drives will achieve a lower failure rate than just independent single drives, because the library presents a consistent and controlled environment to the drives. Thus, the real-world AFR for a tape library system is lower than for a combination of single drives. This is very important to understand.

The solution to the dilemma of reliability definition hides in the process used for product selection. In purchasing network equipment, we all go through a very similar selection process. It consists of three eliminators and seven selectors.

ELIMINATORS	SELECTORS
Reliability	Performance
Compatibility	Service & Support
Price (within a window)	Availability
	Scaleability
	Manageability
	Flexibility
	Price (Absolute/Cost of Ownership)

Operational Reliability

Product selection begins with an elimination process:
If a product is not reliable, then I will not consider it. If it is not compatible with my computing platforms or if the price is out of range, I will not consider it.

The notion of "reliable" is relatively vague at this point and dependent on experience and references. Do you really shop for the best MTBF? Probably not. It is more likely you evaluate and select products based on the list of selectors.
It's our collective experience that products fail and do not install with ease. That is why "service and support" are always ranked at the top of everyone's list of product selectors. Below service are the four "abilities", availability, scaleability, manageability, and flexibility. Once we've boiled these down, absolute price becomes important.

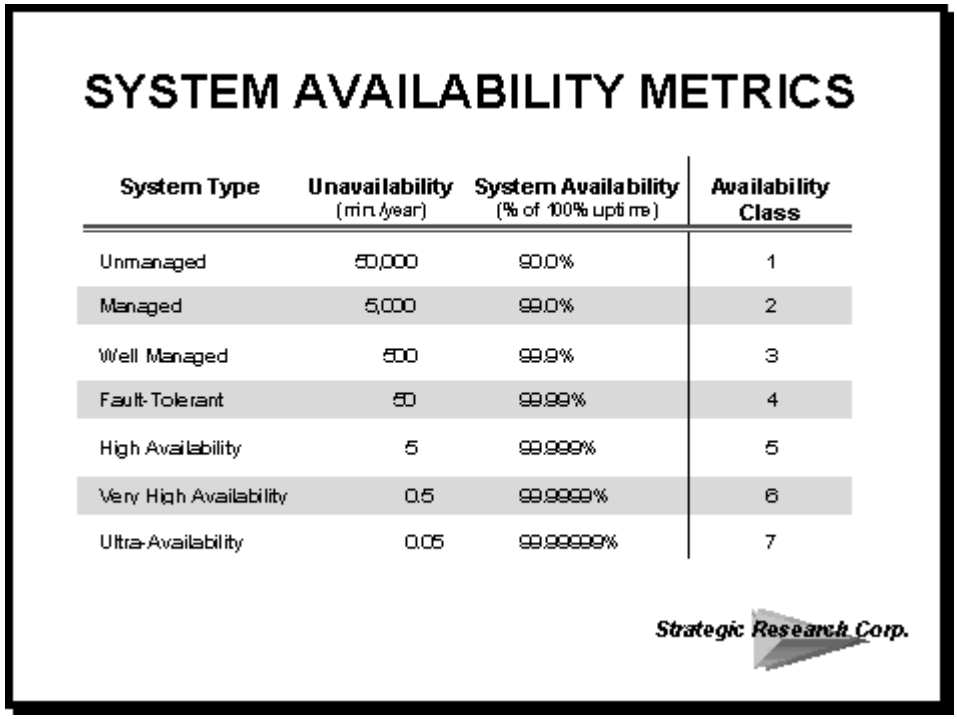
Architectures Define Availability not MTBFs

Put in context, service/support and availability define ***operational reliability*** **as what happens when a failure occurs**. As an administrator, do not look for absolute reliability numbers; they are meaningless. Instead, look for relationships with high levels of service, extended warranties, and then build architectures that keep your systems available.

System availability is defined in the network as the probability that a system is available at a given instant. The system availability term expresses the expected percentage of time a system is available as a percent of total possible uptime. Using this method, networks can be rated on their *unavailability* and categorized into a hierarchy of *availability classes*. Figure 3 presents the standard definitions for network availability which range from "unmanaged" with 50,000 minutes of downtime per year to "ultra-available" with 0.05 minutes of downtime per year.

Figure 3

Availability Criteria



By applying these same principals to disk and tape products the whole discussion of reliability comes into focus. When all tape products are arranged based on their system availability, a hierarchy is formed that corresponds to network system availability.

In late 1996, the RAID Advisory Board, RAB, published a definition of how to implement various levels of availability for RAID systems. Three classes of availability were identified, *fault resistant, fault tolerant, and disaster tolerant.*

We are proposing the same definition set for tape using the categories of *fault resistant* and *fault tolerant* so that we communicate independent of drive technology. Figure 4 presents the architecture. Each level in the availability hierarchy is related to the system availability class defined in Figure 3.

Figure 4

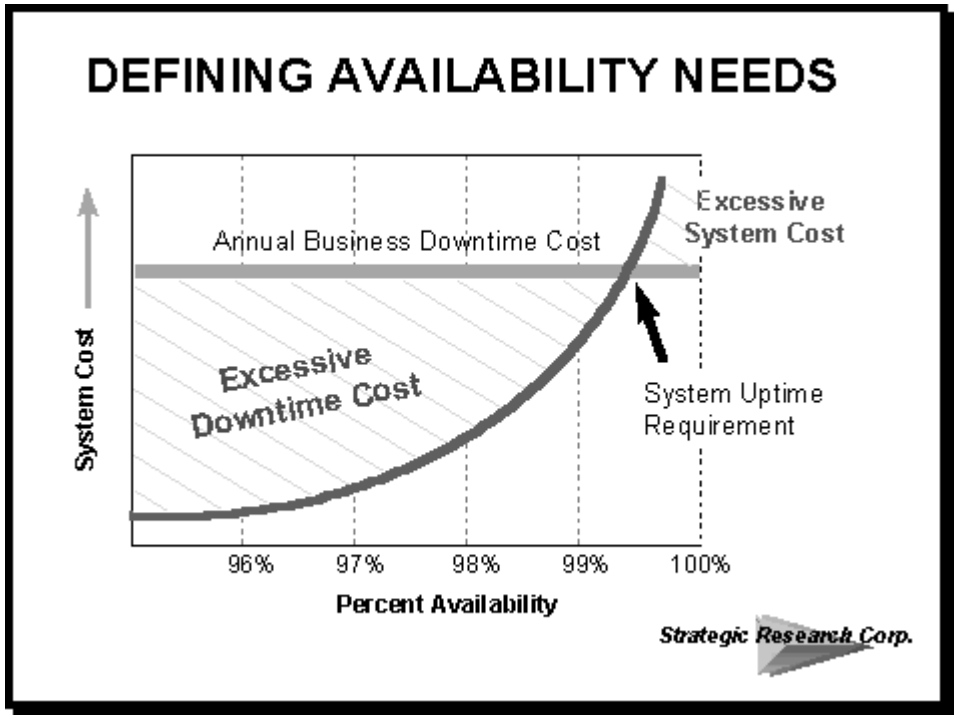
What Should I Buy?

Single drive-based systems are *failure sensitive* and need to be recognized as such, regardless of their "reliability". When (not if) a failure occurs, the entire system is down. In contrast, the first *failure resistant* categories use multiple drives. If one drive is down, then the process can fail-over to an alternate drive. Operations continue even if at a reduced rate. Multiple-drive systems based on libraries or RAID tape arrays are also failure resistant, but operate at a higher level of availability because of their inherent fail-over capability. The next level in the hierarchy is configurations using multiple drives in multiple libraries and RAID tape arrays built into libraries. Redundancy creates a degree of *failure tolerance* and we can truly talk about high availability tape systems. This hierarchy takes into account the reliability experience of the library community. Libraries have higher availability than hordes of single drives and multiple libraries have higher availability than all but specialized "high availability" libraries such as IBM's 3494. Don't forget that good library management software is also essential.

Use the information presented in this paper to resolve what types of tape systems to purchase from an "*operational reliability*" perspective. Our recommendation is to begin with understanding your availability needs. First, measure your downtime costs and decide what degree of system downtime you can tolerate. (If you do not know how, use the downtime calculator on the Network Buyer's Guide at http://www.sresearch.com/java/105308.htm.) Next, determine your uptime requirements by application. Uptime requirements translate to your system availability needs. Use this to determine what class systems you need to install. Figure 5 illustrates the balance point achieved where improved system availability reduces downtime cost without spending too much on equipment. Implement too low a system availability and your downtime costs become excessive.

Figure 5

Recommendation



These same principals apply to tape. Our recommendation is to install a tape system with a system availability corresponding to your downtime requirements. According to the hierarchy presented in Figure 4, tape system availability is scaleable. You can migrate to higher classes through purchase of the right products rather than just throwing more tape drives at the problem. Achieving high availability is more important than "reliability".

IBM's Magstar MP fits the model

By using the "*operational reliability*" approach, the principals of purchasing the proper tape system include looking for a vendor with a commitment to service and support. This is manifested in the length and quality of the warranty, availability of spares, and onsite support. Purchase a configuration that gives you the system availability you need and can be scaled for future expansion. Definitely consider libraries which are superior and have many benefits, including a much lower cost of operations when compared to individual drives. In addition, select robust library management software to operate the library and provide fail-over functionality.

This paper began with the rhetorical question, "What is tape reliability?" In a mission-critical application, the basic premise is that the backup system can not cause a failure, downtime, a system hang, place data at risk, or impact system performance. Traditional reliability thinking does not address the total system availability concern. It takes a superset of approaches and a relationship with a vendor to successfully implement a high availability architecture and achieve what we have called "*operational reliability*".

As an example, IBM has launched this type of an effort with its new *Magstar MP* library systems. *Magstar MP* is the newest implementation of IBM's revolutionary *Magstar* technology. *Magstar MP* utilizes many mainframe-class *Magstar* components in a completely new package targeted at the open-systems network market.

One of the unique facets of the *Magstar MP* program is that IBM has implemented a comprehensive approach to *operational reliability*, not just drive and media reliability. For example, the system is only a library solution, not single drives. IBM recognizes the enhanced system reliability available with libraries, drives, and media that are designed for automation. The libraries are being released as a family, allowing the construction of *scaleable availability* solutions. The administrator can purchase a full range of products from single drive-based libraries, to rack mounted multiple library configurations, all the way to high availability 3494 libraries using *Magstar MP*. So, when the question is asked, "Just how reliable are these drives". IBM answers with, "We issue a 3-year, unconditional warranty and can help you assemble any system availability you need", not with a misleading MTBF number.

Strategic Research Corporation

As we look into the future of applications for tape systems, tape's role continues to expand toward the realm of direct access, requiring higher levels of "*operational reliability*". New tape technologies, designed for automation, high data integrity, high availability, high data accessibility, and rapid time-to-data are needed. IBM's new *Magstar MP* tape libraries with their *Fast-Access Linear Tape Cartridges* are the first systems in the market capable of meeting the HA_{tape}[4] designation. We encourage you to investigate these new tape libraries and evaluate them. We believe that this is a modular and scaleable technology destined to carry you into the future.

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1. Source: Reliability Revealed, John Gniewek & Paul Seger, IBM, 3/95

2. AFR is calculated as (100% of the annual operational time)/(Mean Failure Interval).

3. JBOD = "Just a bunch of Disks", a term describing an array of independent disk volumes.

4. See the Strategic Profile "Backup to the Future".

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